ALEXANDRU IOAN CUZA UNIVERSITY OF IAȘI

FACULTY OF COMPUTER SCIENCE

BACHELOR'S THESIS

Semantic Web API Specification

submitted by

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Term: *July, 2019*

Scientific coordinator
Conf. Dr. Sabin-Corneliu Buraga

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Chapter 1

Introduction

The Web is becoming a large repository of open data, available for rich exploratory querying, machine processing such as generating visualizations, and for combining multiple data sources . The Semantic Web (Web 3.0) has been designed as a WWW extension that allows computing tools to search, combine and process content that is based on the meaning it has for us [17].

Thesis Statement *Can we augment the existing Web API Specifications with Semantic support in order to derive both machine and human readable content in a better, more comprehensive way?*

Thesis Contribution *Added support for Semantic Augmentation of OpenAPI specification within Swagger Editor and Swagger UI tools.*

The thesis is structured as follows. In chapter 1 we provide the introduction. Chapter 2 introduces the concept of Web services, provides an overview of the SOA architectural style, and describes the architecture of Web services along with its identified types, properties and steps involved in offering and consuming it. Chapter 3 describes the concept of Web APIs, how they emerged and what directions they are headed, it exposes several existing standards for defining an API, with particular emphasis on OpenAPI Specification, and provides recommendations regarding the design and documentation of an Web API. Chapter 4 introduces the foundations of Semantic Web technologies: Resource Description Framework (RDF), RDF Schema (RDFS), OWL 2 Web Ontology Language (OWL 2), and SPARQL Protocol and RDF Query Language (SPARQL). Chapter 5 describes the process of augmenting the OpenAPI specification with semantics, it provides an overview of the technologies used for development and the open source projects that we have contributed to in order to achieve this goal, it further proposes a set of extensions that can be used to augment the OpenAPI specification with knowledge, and presents the functionality added to the Swagger Editor and Swagger UI projects. Chapter 6 presents

a case study in order to demonstrate the functionality to the OpenAPI Specification tools that were augmented with Semantic support. In chapter 7 we conclude.

Chapter 2

Web Services

Contents

Introduction

The chapter introduces the concept of Web services. Section 2.1 provides a brief overview of the Service-Oriented Architecture (SOA) architectural style, it also describes the roles and operations involved. Section 2.2 describes the architecture of Web services and provides details regarding the involved technologies. Section 2.3 details the main steps involved in offering and consuming a Web service. Section 2.4 mentions the Web services identified types. Section 2.5 offers information about the main properties of Web services.

2.1 Service-Oriented Architecture (SOA)

The Organization for the Advancement of Structured Information Standards (OASIS) [1] defines SOA as *a paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains*[19].

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[1]https://www.oasis-open.org/

According to The Open Group[2] in [10], *SOA is an architectural style that supports service orientation and is a paradigm for business and IT. This architectural style is for designing systems in terms of services available at an interface and the outcomes of services.*

At this point it is important to highlight the concept of a service. According to [12] a service *is an abstract resource that represents a capability of performing tasks that form a coherent functionality from the point of view of providers entities and requesters entities.* We can say that a service represents a set of activities which have specified outcomes, is self-contained, modular and is a "black box" to consumers of the service.
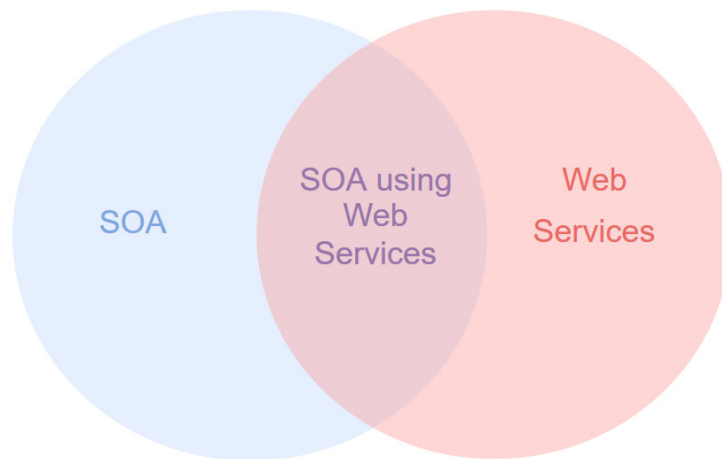
Figure 2.1: Relationship of SOA and Web Services (from [1]).

Web services can be used to implement SOA-based systems, but we need to be aware that this is not the only method. SOA can be implemented using any other service-based technology (e.g. middleware services such as Enterprise Service Bus (ESB), etc.) [1].

Roles

According to [9], we can identify the following roles in a Service-Oriented Architecture:

- **Service consumer**: can be an application, a software module, or another service; it initiates the enquiry of the service in the registry, binds to the service over a transport, andconsumes the functionality provided by the service according to the exposed interface/contract.

- **Service provider**: is a network-addressable entity that accepts and executes requests from consumers; it publishes its services and interface contract to the service registry so that the service consumer can discover and access the service.

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[2]https://www.opengroup.org/

- **Service registry**: is the enabler for service discovery; it contains a repository of available services and allows for the lookup of service provider interfaces to interested service consumers.

Operations

According to [9], the operations identified in a Service-Oriented Architecture are:

- **Publish**: a service description must be published so that it can be discovered and invoked by a service consumer.

- **Find**: a service consumer finds a service by querying the service registry for a service that meets its criteria.

- **Bind** and **invoke**: after retrieving the service description, the service consumer invokes the service according to the information in the service description.

Figure 2.4 provides a visual depiction of the roles and operations previously presented, as well as how these interact with each other.

2.2   Web Service Architecture

According to [3], we can define a Web service as *a software system designed to support interoperable machine-to-machine interaction over a network.*

The architecture of a Web service is comprised from the following elements, according to [3]: concepts, relationships and models.

A concept *is expected to have some correspondence with any realizations of the architecture* (e.g. *message concept identifies a class of object*).

The relationships *denote associations between concepts* (e.g. *a message has a message sender*).

A model is *a coherent subset of the architecture that typically revolves around a particular aspect of the overall architecture.*

- The **Message Oriented Model** *focuses on messages, message structure, message transport and so on − without particular reference as to the reasons for the messages, nor to their significance.*

- The **Service Oriented Model** elaborates *the concept of a service's owner − which has a real world responsibility for the service.*

- The **Resource Oriented Model** refers to the *resources that exist and have owners.*

- The **Policy Model** *focuses on policies that are put in place, or established, by those who have responsibility for the resource.*
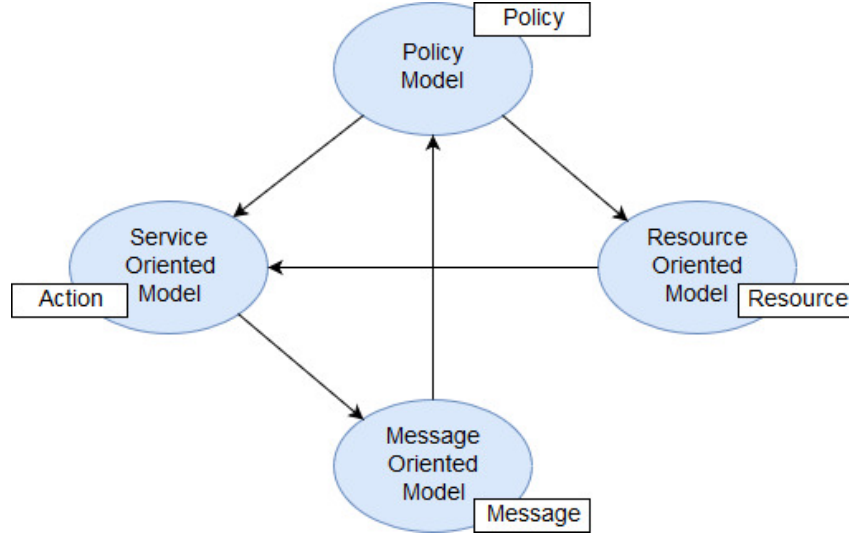
Figure 2.2: Meta Model of the architecture (from [3]).
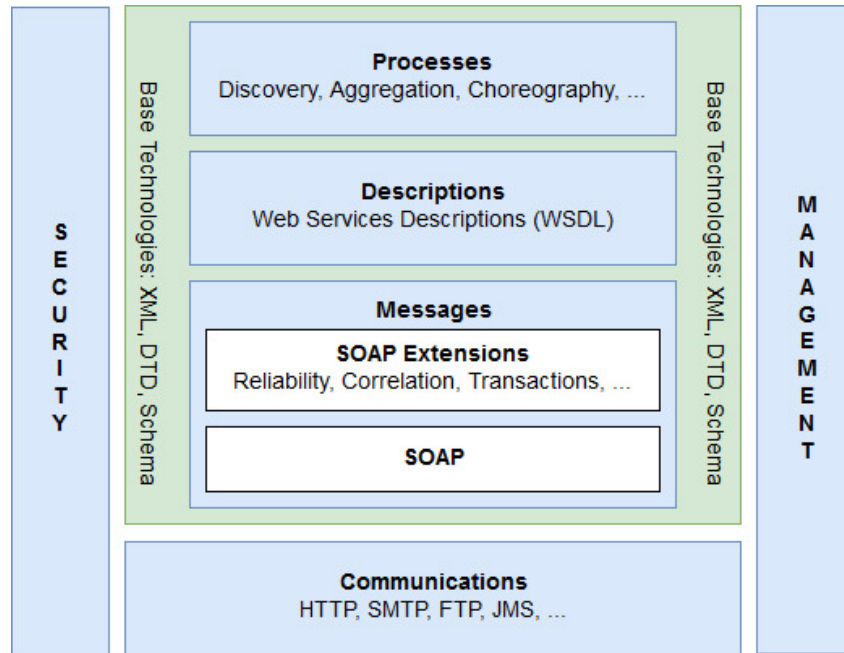
Figure 2.3: Web Services architecture stack (from [3]).

As mentioned in [24], the Web service architecture is based on open technologies such as: eXtensible Markup Language (XML), Simple Object Access Protocol (SOAP), Universal Description, Discovery and Integration (UDDI), and Web Services Description Language (WSDL).

According to [24], the involved *specifications are completely independent of programming language, operating system, and hardware to promote loose coupling between* the service consumer and provider. In the remainder of this section, we will provide a brief characterization of the specifications previously mentioned.

- **Extensible Markup Language (XML)**: is a meta-markup language derived from SGML (Standard Generalized Markup Language) and is a W3C [3] standard. According to [5], XML *describes a class of data objects called XML documents and partially describes the behavior of computer programs which process them.*

- **Communication Protocol — SOAP**: according to [4] SOAP is *a lightweight protocol for exchange of information in a decentralized, distributed environment.* It is an XML based message format. The same message structure is used to send both requests and responses between the client and the Web service. SOAP doesn't specify how a message it's transmitted from the client to the Web service, although the most common scenario is via HTTP.

- **Service Discover — UDDI**: *specifications define a registry service for Web services and for other electronic and non-electronic services. A UDDI registry service is a Web service that manages information about service providers, service implementations, and service metadata* [22].

- **Service Description — WSDL**: addresses the need of describing the communications in a standardized way by *defining an XML grammar for describing network services as collections of communication endpoints capable of exchanging messages* [7].

2.3 Providing and Consuming a Web Service

If a consumer entity does not already know what service it wishes to engage with, then it must discover the appropriate provider entity for that particular task.

As mentioned by Douglas Barry, in [1], the following steps can be identified in providing and consuming a service:

1. A service provider describes its service using WSDL, which will then be published to a services registry.

2. A service consumer searches the services registry to locate a service.

3. Part of the WSDL offered by the service provider is passed to the service consumer. This informs the service consumer about the requests and responses types for the service provider.

4. The service consumer uses the WSDL to invoke the service provider.

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[3]

5. The service provider provides the expected response to the service consumer.

In terms of steps 4 and 5, we observe that the request and subsequent response connections are defined in some way that is understandable to both the service consumer and the service provider.

According to W3C[4] in [3], we can summarize these steps in the following way: both the consumer and provider entities *become known to each other, agree on the semantics of the desired interaction, and exchange messages on behalf of their owners.*
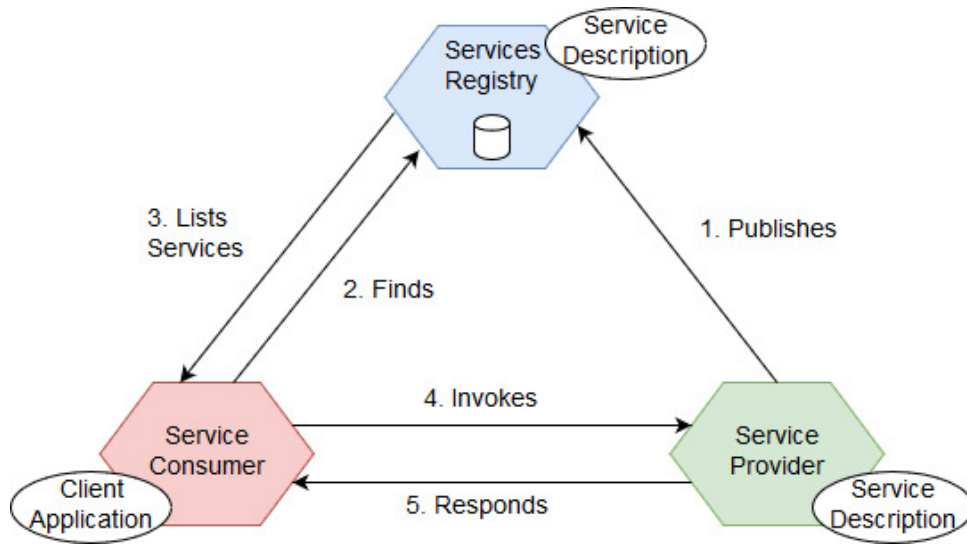
Figure 2.4: Overview of engaging a Web Service(adapted from [9]).

2.4   Types

As mentioned in [1], Web services can be divided into two major categories, namely atomic and compound services.

- An **atomic service** is *a well-defined, self-contained function that does not depend on the context or state of other services. Generally, an atomic service would be seen as fine grained or having a finer granularity.*

- A **composite service** is *an assembly of atomic or other composite services. The ability to assemble services is referred to as composability. Generally, a composite service would be seen as coarse grained or having a larger granularity.*

---

[4]https://www.w3.org/

2.5 Properties

The main properties of a Web service identified by ITSO (part of IBM Global Technical Support[5]) as specified in [9] are:

- **self-contained**: on the client side, no additional software is required.

- **self-describing**: a WSDL file provides all of the necessary information to implement a Web service (as a provider) or to invoke a Web service (as a requester).

- can be **published, located, invoked** across the Web: with the help of standard technologies (for a better understanding see figure 2.4).

- **composable** and **modular**: simple Web services can be aggregated into more complex ones, can be chained together to perform higher-level business functions.

- **language independent** and **interoperable**: the interaction between a service provider and a service consumer is designed to be completely platform and language independent. Because the service provider and the service requester have no idea what platforms or languages the other is using, interoperability is a given.

- **inherently open** and **standards-based**: a large part of the Web service technology has been built using open-source projects, as mentioned in section 2.2.

- **loosely coupled**: the service consumer only needs to know the external behavior of the service, not the details of its implementation.

- **programmatically accessible**

- **dynamic**: dynamic e-business can become a reality using Web services because their description and discovery can be automated (with UDDI and WSDL).

Summary

This chapter examind the open technologies on which Web services are based and how Web services are well suited for implementing a Service-Oriented Architecture. We exposed their defining properties: self-describing and modular applications that expose business logic as services that can be published, discovered, and accessed over the Internet. Web services can be developed as loosely coupled application components using any programming language, any protocol, or any platform.

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[5]https://www.ibm.com/support/home/

Chapter 3

API Specification

Contents

Introduction

This chapter describes the concept of Web API. Section 3.1 provides a brief overview regarding the history of Web APIs, how they emerged and what directions they are headed. Section 3.2 exposes several existing standards that can be used for defining an API, with particular emphasis on OpenAPI Specification. Section 3.3 provides recommendations regarding how an API should be designed, built and documented.

3.1 Definitions, History, and Future Directions

According to Wikipedia[1], an application programming interface (API) is defined as *a set of routines, protocols, and tools for building software applications.*

---

[1] https://en.wikipedia.org/wiki/Application_programming_interface

The conceptual underpinnings of an Application Programming Interface are not a novelty, as Martin Bartlett points out:

The concept of an API pre-dates even the advent of personal computing, let alone the Web, by a very long time! The principal of a well documented set of publicly addressable "entry points" that allow an application to interact with another system has been an essential part of software development since the earliest days of utility data processing. However, the advent of distributed systems, and then the web itself, has seen the importance and utility of these same basic concepts increase dramatically.

—Martin Bartlett, from [18]

There are many different types of APIs: for operating systems, applications, websites, etc. Our main focus will be Web APIs. A Web API is a unique type of interface where the functionality is provided and can be accessed using the Internet and Web-specific protocols.

As for the evolution of Web APIs Specification Standards, and the main actors who have put their mark on this evolution, Kin Lane offers details in [18]. According to him, the pioneer of Web APIs Documentation Standards is the Wordnik [2] organization. In 2011 they created Swagger, a JSON format for describing the Wordnik API, and then built Swagger UI, an automatically generated, interactive documentation for the API. Their main reason for developing Swagger was to keep their documentation up to date. Through this process, they also set the stage for a new way to define and document our APIs.

Later on that year, API management provider Mashery[3] would copy Wordnik's approach, and launch their I/O Docs. Slowly the concept of API design would expand, with tech giants like Google establishing their own approach, which they called Google Discovery. By March 2013, Apiary[4] had launched their own API definition format called API Blueprint. By the end of 2013, we'd see another API definition language emerge, this time from enterprise technology provider Mulesoft[5], called RAML.

According to [16], APIs have reached their breakout moment for three reasons: process maturity, self-service, and technological maturity.

Wendell Santos, editor at ProgrammableWeb[6], has made an analysis of growth in Web APIs since 2015 until 2018. He mentions that the ProgrammableWeb directory passed the 19,000−API mark in January of 2018, with an average of more than 2,000 APIs added per year since 2014.

According to the analysis made by SmartBear[7], in 2019, it seems that the main challenges

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[2]https://developer.wordnik.com
[3]https://www.tibco.com/products/api-management
[4]https://apiary.io/
[5]https://www.mulesoft.com/
[6]https://www.programmableweb.com/
[7]https://smartbear.com/
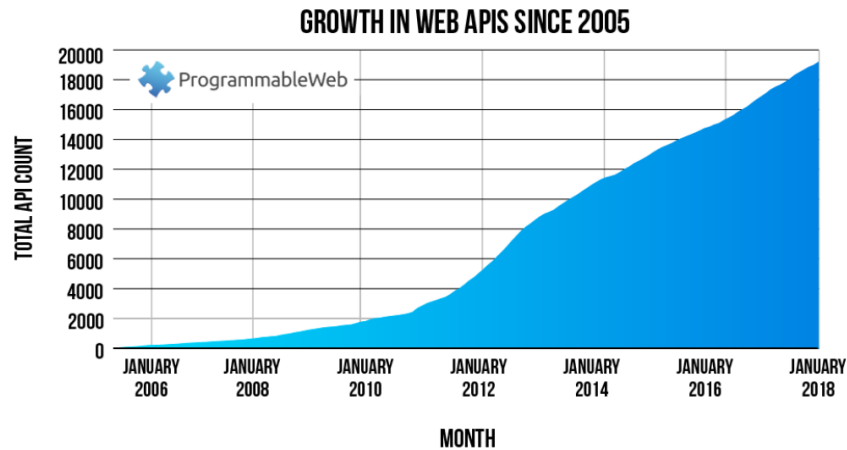
Figure 3.1: The growth over time of the ProgrammableWeb API directory (from https://www.programmableweb.com/).

API teams want to solve in the years to follow are: standardization, versioning, and composability/multi-purpose reuse [27].
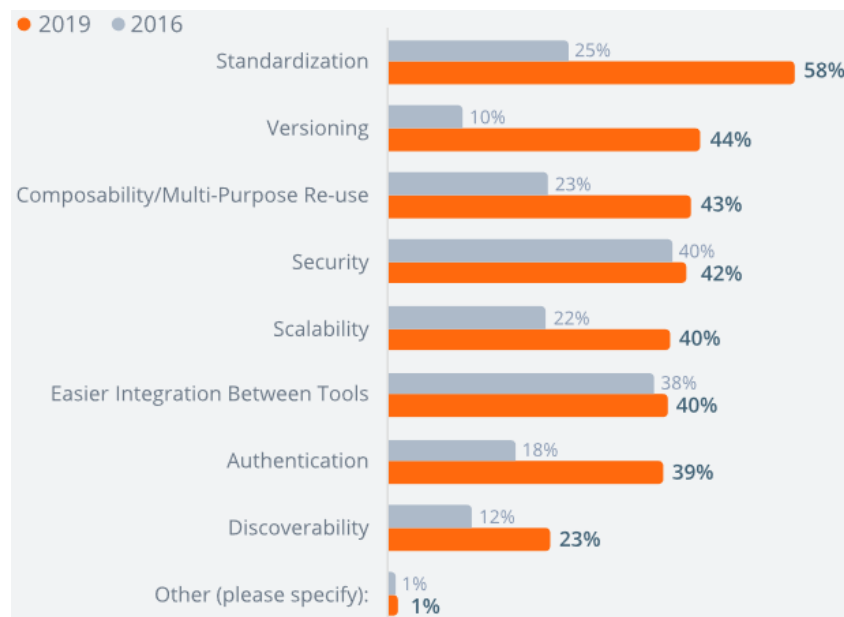
Figure 3.2: The current API challanges providers want to solve (from [27]).

Also, microservices are expected to drive the most API adoption in the years ahead.

The growth of microservice adoption HAS impacted API development. I think the two are intimately intertwined. Constructing microservices from an API-first foundation is a solid strategy, and so an increase in microservices architecture styles will only create a proliferation of APIs.

—Bill Doerrfeld, Editor in Chief, Nordic APIs

In [17], the authors highlighted four directions in which the Web APIs are heading:

- **APIs as the basis of User Interfaces**: nowdays, the functionality is built as a set of APIs, and then the website is created as a client to those APIs.

- **Hypertext State Control**: Web APIs are *moving towards RESTfulness*. However, there is one part of REST *that is not commonly reflected in Web APIs: hypertext as the engine of application state* (HATEOAS). The main benefits of this approach are: reliability, evolution, and reuse.

- **Web API Descriptions**: *machine-readable standard API/interface description is one of the best aspects of the Web Services approach.* However, in the RESTful space, there has been pushback against description languages because, in theory, the Web already has mechanisms for description.

- **Automation**: *the Web is becoming a large repository of open data, available for rich exploratory querying, machine processing such as generating visualizations, and for combining multiple data sources. Some of this open data is being published as Linked Data[8] which builds on the Semantic Web standard RDF. Services have been looking at how to represent service descriptions in RDF while working with the lightweight service description approaches common with Web APIs; and how to deal with APIs that themselves can produce and process linked data.*

3.2 API Specification Standards

We'll detail some of the most used formats for defining an API, with emphasis on OpenAPI Specification.

3.2.1 RESTful API Modeling Language: RAML

RAML[9] is built on broadly-used standards such as YAML and JSON and is a non-proprietary, vendor-neutral open specification. The RAML specification provides mechanisms for defining "practically-RESTful" APIs, creating client/server source code, and comprehensively documenting the APIs for users.

Although designed with RESTful APIs in mind, RAML is capable of describing APIs that do not obey all constraints of REST, hence the description "practically RESTful" as is mentioned in [23]: *because, today in the real world, very few APIs today actually obey all constraints of REST. RAML isn't strict: for now, it focuses on cleanly describing resources, methods, parameters, responses, media types, and other HTTP constructs that form the basis for modern APIs that obey many, though perhaps not all, RESTful constraints.*

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[8]http://linkeddata.org
[9]https://raml.org/

According to [25], RAML is very much a hierarchical style format, supports advanced constructs, decent adoption, human readable format, and high industry backing, which is one of the many reasons it is such an excellent planning tool. In terms of weaknesses, it is mentioned that it lacks code- level tooling, and is still unproven long-term.

3.2.2   API Blueprint

API Blueprint[10] is a documentation oriented API description language. According to [36], an API Blueprint document *is a plain text Markdown document describing a Web API in whole or in part. The document is structured into logical sections. Each section has its distinctive meaning, content and position in the document.*

API Blueprint is focused on collaboration: built to encourage dialogue and collaboration between project stakeholders, developers and customers at any point in the API lifecycle; and open: open sourced under the MIT license.

Kristopher Sandoval, in [25], considers that API Blueprint is perhaps the easiest for newcomers to understand because of the Markdown as its format. It is also important to note that it lacks advanced construct and code level tooling. Because of this, its adoption has been slow when compared to Swagger or RAML.

3.2.3   Web Application Description Language: WADL

According to W3C, in [20], *WADL is designed to provide a machine process-able description of such HTTP-based Web applications.* WADL is the REST equivalent of SOAP's Web Services Description Language (WSDL), which can also be used to describe REST web services.

In [25], WADL is seen as a less appealing alternative solution to those presentend in this section because *is incredibly time consuming to create descriptions with, and the linking methodology leaves much to be desired.*

3.2.4   OpenAPI Specification: OAS

The OpenAPI Specification (previously Swagger) is a community-driven open specification within the OpenAPI Initiative[11], a Linux Foundation Collaborative Project.

As mentioned in [28], the OpenAPI Specification (OAS) defines *a standard, language-agnostic interface to RESTful APIs which allows both humans and computers to discover and understand the capabilities of the service without access to source code, documentation, or through network traffic inspection.*

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[10]https://apiblueprint.org/
[11]https://www.openapis.org/

Of the many API documentation and specification formats, OpenAPI Specification is certainly one of the most popular as we can see in figure 3.3.
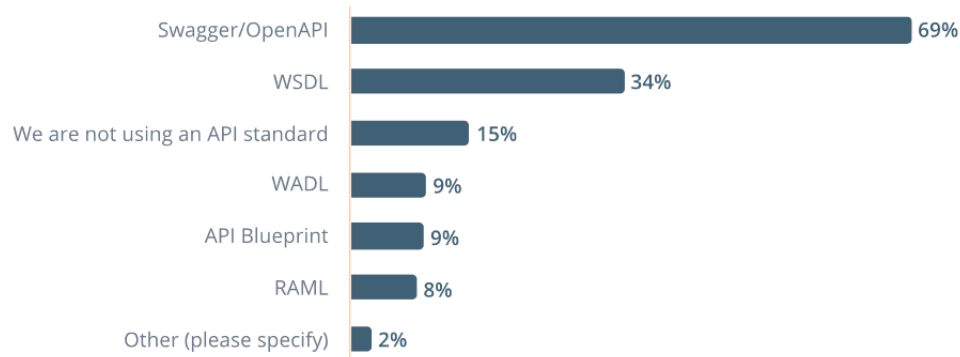
Figure 3.3: Adoption rates of common standards for defining APIs (from [27]).

The main advantages of OpenAPI, according to [25], are: is heavily adopted, has a large community of users and supporters, and greater support for multiple languages. It is important to note, however, that it lacks advanced constructs for metadata.

Keshav Vasudevan, Product Manager at SmartBear, describes in [34] the general outline of an OAS defined API using OAS 3.0:
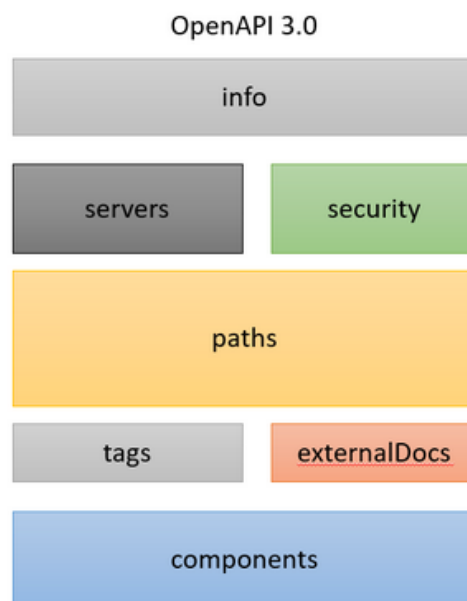
Figure 3.4: Sections in an API contract designed using the OAS 3.0 (from [34]).

- **info**: *contains the metadata associated with the API's contract* (e.g. title, version, and description of the API).

- **servers**: the Server object provides information regarding the location of API servers.

- **security**: *supports various authentication and authorization schemes to mitigate unknown, unregistered users from accessing the API* (e.g. OAuth2, HTTP authentication schemes).

- **paths**: there are four types of parameters you can specify using the OAS 3.0: path parameters, query parameters, header parameters, and cookie parameters.

- **external docs**: *OAS 3.0 allows you to reference external documentation.*

- **tags**: they *allow consumers of the API to better segment and identify what they want use the API for.*

In listing 3.1 we provide an API contract example in yaml format, created using Swagger Editor[12] and OAS 2.0, realised for a project within the Web Technologies[13] course.

Listing 3.1: TREX API OpenAPI Specification.

```
1  swagger: "2.0"
2  info:
3    description: "Trex description"
4    version: "1.0.0"
5    title: "Trex"
6  host: localhost
7  basePath: /trex/api
8  tags:
9  - name: "books"
10   description: "Search for books"
11 schemes:
12 - "http"
13 paths:
14   /books:
15     get:
16       tags:
17       - "books"
18       summary: "Search for books"
19       description: "Search for books"
20       operationId: "getBooks"
21       consumes:
22       - "*/*"
23       produces:
24       - "application/json"
25       parameters:
26         - in: "query"
27           name: "terms"
28           type: string
29           required: true
30           description: "The keywords to search for"
```

---

[12]https://editor.swagger.io/
[13]https://profs.info.uaic.ro/~busaco/teach/courses/web/

```
31          - in: "query"
32            name: "language"
33            type: string
34            description: "The language of the books"
35          - in: "query"
36            name: "minimumRating"
37            type: number
38            description: "The minimum rating of the books"
39          - in: "query"
40            name: "from"
41            type: number
42            description: "The starting year of the books"
43          - in: "query"
44            name: "to"
45            type: number
46            description: "The final year of the books"
47        responses:
48          200:
49            description: "successful operation"
50            schema:
51                $ref: "#/definitions/BooksResponse"
52          400:
53            description: "Invalid status value"
54          405:
55            description: "Invalid input"
56  definitions:
57      Resource:
58          type: "object"
59          properties:
60              type:
61                  type: "string"
62              title:
63                  type: "string"
64              description:
65                  type: "string"
66              authors:
67                  type: "array"
68                  items:
69                      type: "object"
70              image:
71                  type: "string"
72              tags:
73                  type: "array"
74                  items:
75                      type: "object"
76              rating:
77                  type: "number"
```

```
78            date:
79                type: "string"
80            language:
81                type: "string"
82            url:
83                type: "string"
84    BooksResponse:
85        type: "object"
86        properties:
87            totalItems:
88                type: "number"
89            books:
90                type: "array"
91                items:
92                    $ref: "#/definitions/Resource"
93 externalDocs:
94   description: "Find out more about Swagger"
95   url: "http://swagger.io"
```

In [8], in the chapter inspired by Arnaud Lauret's session at the 2016 Platform Summit, there are some important features that are found within OpenAPI:

- **Proper design and approach**: *Any good engineer can tell you that structures don't fail because of the last brick, they fail because of the first. If you start with a shaky foundation, or bad bedrock, you're going to collapse, and the same is true of an API.* There are three methods in which the specification generation is accomplished: Codegen, automatic generation, and manually.

- **Complete documentation and description**: is essential to be able to easily and efficiently describe an API in a simple, well structured document. *SwaggerUI, an element of OpenAPI, is supremely powerful and capable when it comes to generating descriptive documentation.*

- **Rapid testing and iteration**: during development is essential to have the means to actively test and modify API content in an enclosed environment. In this way *endpoints can be tested against any permutation, resource access can be tested in a multitude of environments, and even the API can be tested in interactions with other APIs. The OpenAPI Specification utilizes a declarative resource specification, and as part of this, allows for easy exploration of the API without access to the server code or an understanding of the server implementation. This is all done via that magic implementation called the SwaggerUI. SwaggerUI reads the API description that is stated as part of the OpenAPI Specification, and renders it as a web-page.*

- **Machine and human readability and translation**: *by functioning as a specification which describes the API, the OpenAPI Specification can then derive both machine and human readable content in a better, more complete way.*

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3.3 Best Practices for API Design

According to [16], API publishers should be thinking about what users want from their business assets and how they can provide access to jumpstart the API economy.

Asked about the best technical practices from the Tumblr API[14], Derek Gottfrid, Director of Product at Tumblr, offered this answer: *We want our API to be easy to learn without documentation − the way we lay out our URIs, you should just be able to drop into a command live* [16].

We will present some of the recommendations that should be taken into consideration when designing and building an API, as suggested in [16]:

- **Differentiated API**: the API developer should take into consideration the following questions: Why should a developer use a particular API? How is it different from other APIs that are available on the market? Why should they use it?

  A particular API can be differentiated through any of the following means: providing data that is unique, more comprehensive or accurate than that of competitors, by offering better support, by designing an API that is more reliable or faster than alternatives, or even by offering more data traffic for free.

- **APIs that are easy to try and use**: if the users of a particular API can't make almost immediate progress, they'll go elsewhere, so the key to success is to remove all barriers of entry in using the API.

  There are a few ways to do this. *For private APIs, it is important to demonstrate real value in running a system* (e.g. the API could offer *much more flexible access to content, better overall performance*). *For public APIs, one approach is to offer some level of free access: many developers won't even consider using a particular API if there are only paid options* because *they may not know yet if the API meets their needs.*

- **API understandability**: an example of an intuitively designed API is the Facebook Graph API[15].

  Kin Lane, developer evangelist at Mimeo, gives the following advices: *Don't try to make it too complex. Focus on the core building blocks for an API. Do one thing, do it really well, and bundle it with simple documentation and code samples.*

- **Avoidance of cumbersome approaches**: this is especially important in the area of security. *Many APIs offer custom or complex security schemes that require developers to learn them from scratch.* Instead, the API developers should think about using standardised specifications such as OAuth or other commonly understood security schemes.

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[14]https://www.programmableweb.com/api/tumblr
[15]https://developers.facebook.com/docs/graph-api/

- **Less is more**: the API developer should *start with the absolute minimum amount of functionality, and then expand it slowly over time, as feedback is collected*; the reason for doing this is because the API might evolve in a different direction than what was anticipated.

Apart from these recommendations, particular attention should be paid to the way we document an API. According to [29], *creating and maintaining good documentation that's easy to read, enjoyable to interact with, and sets the consumer up for success can be extremely challenging.*

The fundamental API documentation sections identified by [29] include:

1. Authentication: *most APIs have authentication schemes, and consumers have to authenticate before gaining access to the API* (e.g. Bitly[16]).

2. Error messages: errors must be explained, and also solutions on how to overcome them should be provided (e.g. Mailchimp[17]).

3. Resources: all of the resources an API exposes should be listed; also, it is important to understand how consumers may integrate with them.

4. Terms of use: API limits should be included, with terms and conditions. *Constraints also need to be clearly stated so that consumers understand what API usage and practices are permitted* (e.g. Spotify API[18]).

5. Change log: it is good to have details about updates and versions of an API because this will help consumers know if any changes need to be made for an effective API call (e.g. GitHub API[19]).

Summary

This chapter examined how Web APIs are about delivering valuable, meaningful, scalable and distributed resources across the World Wide Web. It also explored the emerging formats that use JSON, Markdown, and YAML to define an API, providing a simple, machine readable blueprint, that API providers and consumers can use a single truth for all API interactions. It explained why OpenAPI Specification provides perhaps one of the strongest foundations upon which one can build an API: not by solely providing tools or approaches, but by providing a proper design approach.

---

[16]https://dev.bitly.com/authentication.html
[17]https://developer.mailchimp.com/documentation/mailchimp/guides/error-glossary/
[18]https://developer.spotify.com/terms/
[19]https://developer.github.com/changes/

Chapter 4

Knowledge Modeling and Representation

Contents

Introduction

The goal of this chapter is to introduce the foundations of Semantic Web technologies. Section 4.1 provides details on how the Semantic Web evolved. Section 4.2 introduces the Resource Description Framework (RDF). Section 4.3 describes RDF Schema, a semantic extension of RDF. Section 4.4 introduces OWL 2, a powerful modeling language for the Semantic Web. Section 4.5 offers a short description of SPARQL, along with query examples.

4.1 Web of Data

From the beginning, the development of Semantic Web technologies has been strongly correlated with the World Wide Web. Not surprisingly, as the WWW designer, Sir Tim

Berners-Lee[1], has also introduced the Semantic Web concept and encouraged further research in this area in [2]. In 2001, Sir Tim Berners-Lee, along with two other researchers, Ora Lassila and James Hendler, wanted to give the world a new Web called the Semantic Web, in which content would be meaningful to software programs (they would have semantics), allowing programs to interact with the Web the same way that people do [33].

The Semantic Web has been designed as a WWW extension that allows computing tools to search, combine and process content that is based on the meaning it has for us. Because we do not yet have access to human-like artificial intelligence, the only way we can achieve this goal is to specify the semantics of Web resources in a format that can be processed by the computer [15].

According to [35], *the Semantic Web is a Web of Data − of dates and titles and part numbers and chemical properties and any other data one might conceive of. The collection of Semantic Web technologies (e.g. RDF, OWL,SPARQL) provides an environment where application can query that data, draw inferences using vocabularies, etc.*

For the Web of Data to become a reality, it is important to have the huge amount of content on the Web available in a standard format. Also, relationships among data should be made available. *This collection of interrelated datasets on the Web can also be referred to as Linked Data* [35]. To achieve and create Linked Data, technologies should be available in a common format (RDF), so that conversions or on-the-fly access to databases can be made easily.

W3C[2] offers a wealth of technologies (e.g. RDF, RDFS, OWL, SPARQL) to get access to the data, on which we will provide more details in the following sections.

4.2   Resource Description Framework (RDF)

The Resource Description Framework (RDF) is a framework for expressing information about resources. Resources can be anything, including documents, people, physical objects, and abstract concepts [26].

Some of the features that make RDF useful are: adds machine-readable information to Web pages, enriches a dataset by linking it to third-party datasets, builds aggregations of data around specific topics, and provides a standards-compliant way for exchanging data between databases [26].

RDF allows us to make assertions or statements about resources in a simple format with the following structure:

<center><subject> <predicate> <object></center>

---

[1]https://en.wikipedia.org/wiki/Tim_Berners-Lee
[2]https://www.w3.org/

Through such a statement, the relationship between two resources is expressed. The two related resources are represented by the **subject** and the **object**, and the nature of the relationship is denoted by the **predicate**. The link is unidirectional (from subject to object) and is called **property**. *Because RDF statements consist of three elements they are called triples* [26].

Table 4.1 offers a set of triple examples in pseudocode regarding the Earth.

Table 4.1: Triple examples in pseudocode regarding Earth.

Subject	Property	Object
Earth	is a	Planet
Earth	has age	4.5 billion years
Ioana	lives on	Earth
Solar System	includes	Earth

The triples can also be viewed as a graph in which the subjects and objects are represented as nodes, while the predicates form the arcs. Figure 4.1 shows the graph resulting from the triples mentioned in table 4.1.
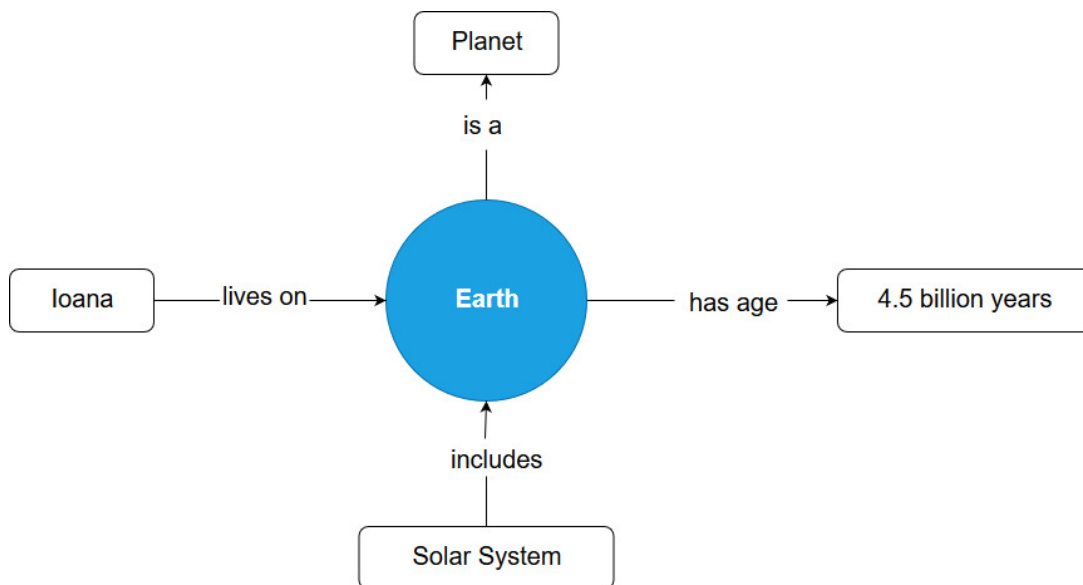
Figure 4.1: The RDF Graph of the Earth example.

While this ways of representing information about resources is easy to read for humans, it is clearly not suitable for processing it in computer systems. To translate this information into a format that can be processed by machines, there exist a number of different serialization formats for writing down RDF graphs: Turtle family of RDF languages, JSON-LD, RDFa, RDF/XML etc. What is important to remember is that different ways of rewriting the same graph lead to the same triplets, so they are logically equivalent.

The graph from figure 4.1 is represented in Turtle syntax in listing 4.1. Protégé[3] was used to define the Earth ontology.

Listing 4.1: Example using turtle syntax generated using Protégé 5.5.0.

```turtle
1  @prefix : <http://www.semanticweb.org/ami/ontologies/earth-ontology#> .
2  @prefix dbo: <http://dbpedia.org/ontology/> .
3  @prefix dbp: <http://dbpedia.org/property/> .
4  @prefix dbr: <http://dbpedia.org/resource/> .
5  @prefix owl: <http://www.w3.org/2002/07/owl#> .
6  @prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
7  @prefix xml: <http://www.w3.org/XML/1998/namespace> .
8  @prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
9  @prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
10 @base <http://www.semanticweb.org/ami/ontologies/earth-ontology> .
11
12 <http://www.semanticweb.org/ami/ontologies/earth-ontology> rdf:type owl:Ontology
        .
13
14 dbo:meanRadius rdf:type owl:AnnotationProperty .
15 dbp:materials rdf:type owl:AnnotationProperty .
16
17 :hasAge rdf:type owl:ObjectProperty ;
18         rdfs:domain dbo:Agent ;
19         rdfs:range dbr:Planet .
20
21 :includes rdf:type owl:ObjectProperty .
22 :livesOn rdf:type owl:ObjectProperty .
23
24 dbo:Agent rdf:type owl:Class .
25 dbr:Planet rdf:type owl:Class .
26
27 dbr:Earth rdf:type owl:NamedIndividual ,
28                    dbr:Planet ;
29                    dbo:meanRadius 6371 ;
30                    dbp:materials dbr:Aluminium ,
31                                  dbr:Iron ,
32                                  dbr:Magnesium ,
33                                  dbr:Nickel ;
34                  :hasAge "4.5 billion years"@en .
35
36 dbr:Metal rdf:type owl:NamedIndividual .
37 dbr:Planet rdf:type owl:NamedIndividual .
38
39 dbr:Solar_System rdf:type owl:NamedIndividual ;
40                  :includes dbr:Earth .
```

---

[3]https://protege.stanford.edu/

```
41
42   :Ioana rdf:type owl:NamedIndividual ;
43          :livesOn dbr:Earth .
```

4.3   RDF Schema (RDFS)

As we mentioned in the previous section, the *RDF data model provides a way to make statements about resources. But, it does not make any assumptions about what resources stand for.* To solve this problem, *RDF is typically used in combination with vocabularies or other conventions that provide semantic information about these resources* [26].

RDF Schema provides a data-modelling vocabulary for RDF data, [it] is a semantic extension of RDF. It provides mechanisms for describing groups of related resources and the relationships between these resources[...]The RDF Schema class and property system is similar to the type systems of object-oriented programming languages. RDF Schema differs from many such systems in that instead of defining a class in terms of the properties its instances may have, [it] describes properties in terms of the classes of resource to which they apply [6].

Table 4.2 summarizes the main modeling constructs provided by RDF Schema.

Construct	Syntactic form	Description
Class (a class)	C `rdf:type rdfs:Class`	**C** (a resource) is an RDF class
Property (a class)	P `rdf:type rdf:Property`	**P** (a resource) is an RDF property
type (a property)	I `rdf:type` **C**	**I** (a resource) is an instance of **C** (a class)
subClassOf (a property)	C1 `rdfs:subClassOf` **C2**	**C1** (a class) is a subclass of **C2** (a class)
subPropertyOf (a property)	P1 `rdfs:subPropertyOf` **P2**	**P1** (a property) is a sub-property of **P2** (a property)
domain (a property)	P `rdfs:domain` **C**	domain of **P** (a property) is **C** (a class)
range (a property)	P `rdfs:range` **C**	range of **P** (a property) is **C** (a class)

Figure 4.2: RDF Schema Constructs (from [26]).

4.4   OWL 2 Web Ontology Language (OWL 2)

OWL 2 Web Ontology Language (OWL) is a *Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things[...]OWL 2 is a language for expressing ontologies. An ontology is a set of precise descriptive statements about some part of the world (usually referred to as the domain of interest or the subject matter of the ontology)* [14].

According to [14], to precisely describe a domain of interest, it is helpful to come up with a set of terms called vocabulary to eliminate ambiguities that may exist on the terms used in the different data sets. An ontology contains two categories of knowledge:

- **terminological knowledge**: provides the general context (vocabulary together with interrelation information).

- **assertional knowledge**: provides the concrete objects from our domain of interest.

4.5 SPARQL Protocol and RDF Query Language (SPARQL)

SPARQL *is a set of specifications that provide languages and protocols to query and manipulate RDF graph content on the Web or in an RDF store* [11].

The results of SELECT queries consist of mappings from variables to RDF terms. To serialize these results, SPARQL supports four exchange formats: XML, JSON, CSV, and TSV.

SPARQL contains capabilities for querying graph patterns. It also supports aggregation, subqueries, negation, creating values by expressions, extensible value testing, and constraining queries based on RDF graph [13]. Following, listings 4.2 and 4.3 offers some SPARQL query examples on the RDF graph for the Earth example.

Listing 4.2: SPARQL query that finds all persons that live on Earth.

```
1  PREFIX : <http://www.semanticweb.org/ami/ontologies/earth-ontology#>
2  PREFIX dbo: <http://dbpedia.org/ontology/>
3  PREFIX dbp: <http://dbpedia.org/property/>
4  PREFIX dbr: <http://dbpedia.org/resource/>
5  PREFIX owl: <http://www.w3.org/2002/07/owl#>
6  PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
7  PREFIX xml: <http://www.w3.org/XML/1998/namespace>
8  PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
9  PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
10
11 SELECT ?earthling
12 WHERE { ?earthling :livesOn dbr:Earth . }
```

Listing 4.3: SPARQL query that finds all the materials from which Earth is made.

```
1  PREFIX : <http://www.semanticweb.org/ami/ontologies/earth-ontology#>
2  PREFIX dbo: <http://dbpedia.org/ontology/>
3  PREFIX dbp: <http://dbpedia.org/property/>
4  PREFIX dbr: <http://dbpedia.org/resource/>
5  PREFIX owl: <http://www.w3.org/2002/07/owl#>
6  PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
```

```
 7  PREFIX xml: <http://www.w3.org/XML/1998/namespace>
 8  PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
 9  PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
10
11  SELECT ?material
12  WHERE { dbr:Earth dbp:materials ?material . }
```

Summary

This chapter examined the main components of the Semantic Web. It introduced Resource Description Framework (RDF), a framework for describing general relationships between objects of interest. We discussed how RDF is extended with RDF Schema (RDFS), allowing us to add expressive features that go beyond the description of simple data. It also introduced OWL 2, a standard for the modeling of ontologies. Using SPARQL, consumers of the Web of Data can extract possibly complex information (e.g. existing resource, references, and their relationships).

Chapter 5

Augmenting OpenAPI Specification With Knowledge

Contents

Introduction

This chapter describes the process of augmenting the OpenAPI specification with semantics. Section 5.1 provides an overview of the technologies used for development and the open source projects that we have contributed to in order to achieve this goal. Section 5.2 proposes a set of extensions that can be used to augment the OpenAPI specification with knowledge and provides details regarding their intended use. Section 5.3 presents the functionality added to the Swagger Editor project along with the relevant code snippets. Section 5.4 exposes the functionality added to the Swagger UI project along with the relevant code snippets. Section 5.5 discusses future directions that can further improve the process of Web Api Semantic augmentation.

5.1   Technologies

In order to augment the OpenAPI specification with knowledge we have used the following technologies for development:

1. **Node.js**[1]: *is a JavaScript runtime built on Chrome's V8 JavaScript engine.* The version used is 10.15.3.

2. **Npm**[2]: is a package manager for the JavaScript programming language that consists of three distinct components: the website, the CLI , and the registry. The version used is 6.4.1.

3. **React**[3]: *is a JavaScript library for building user interfaces.* Its main features are the following: one-way data binding with props, stateful component Virtual DOM, lifecycle methods (e.g. shouldComponentUpdate, componentDidMount, componentWillUnmount, render, etc.), and JSX, an extension to the JavaScript language syntax.

As for the projects on which we have contributed, they are **Swagger Editor**[4] and **Swagger UI**[5], which were forked from their repositories on GitHub.

According to SmartBear[6] in [30], *The Swagger Editor is an open source editor to design, define and document RESTful APIs in the Swagger Specification.* The Swagger Editor software version augmented with Semantic support is available at: https://github.com/ioanabirsan/swagger-editor/.

Also, SmartBear offers in [31] the following description for Swagger UI: *Swagger UI is a tool that allows anyone to visualize and interact with the API's resources without having any of the implementation logic in place. It's automatically generated from your OpenAPI Specification, with the visual documentation making it easy for back end implementation and client side consumption.* The Swagger UI software version augmented with Semantic support is available at: https://github.com/ioanabirsan/swagger-ui/.

5.2   OpenAPI Extension Support

According to [32], *extensions are custom properties that start with x- (e.g. x-<custom-property-name>). They can be used to describe extra functionality that is not covered by the standard OpenAPI Specification.*

---

[1]https://nodejs.org/en/
[2]https://www.npmjs.com/
[3]https://reactjs.org/
[4]https://swagger.io/tools/swagger-editor/
[5]https://swagger.io/tools/swagger-ui/
[6]https://smartbear.com/

We have added support for the following extentions with the purpose to augment the OpenApi specification with Semantic support: **x-same-as** and **x-rdf-type**. The custom properties have been added both at schema and properties level in the case of OAS3, respectively at definitions and properties level for OAS2. The values supported by both extensions are of type string and represent concepts defined in the Schema.org[7] vocabulary:

- The schemas/definitions-level supported value is equivalent to rdfs:Class;

- The properties-level supported value is equivalent to rdf:Property.

Listings 5.1 and 5.2 provide an example of augmenting the OpenAPI specification with Semantic support using the **x-same-as** extension.

Listing 5.1: Example of expansion of OAS3 with semantics.

```
1  components:
2    schemas:
3      Order:
4        type: object
5        x-same-as: 'http://schema.org/Order'
6        properties:
7          id:
8            type: integer
9            x-same-as: 'http://schema.org/identifier'
10           format: int64
```

Listing 5.2: Example of expansion of OAS2 with semantics.

```
1  definitions:
2    Order:
3      type: object
4      x-same-as: 'http://schema.org/Order'
5      properties:
6        id:
7          type: integer
8          x-same-as: 'http://schema.org/identifier'
9          format: int64
```

5.3 Extending Swagger Editor With Semantic Support

The following features have been added to Swagger Editor:

- Suggestions and autocomplete support for the newly added extensions;

---

[7]http://schema.org/

- Contextual suggestions and autocomplete support for concepts retrieved from *Schema.org*, depending on the location where the extension is used (i.e. at the Schema/Model or Property level);

- Ability to convert and save an OpenAPI definition in Turtle (TTL)[8] format.

The entire implementation that augments Swagger Editor with Semantic support can be consulted at: https://github.com/ioanabirsan/swagger-editor/.

The structure of the Swagger Editor project is as follows:

```
1      ...
2      src
3          plugins
4              ast
5              editor
6                  components
7                  editor-helpers
8                  editor-plugins
9              editor-autosuggest
10             editor-autosuggest-keywords
11             editor-autosuggest-oas3-keywords
12             editor-autosuggest-refs
13             editor-autosuggest-snippets
14             editor-metadata
15             json-schema-validator
16             jump-to-path
17             local-storage
18             performance
19             split-pane-mode
20             validate-base
21             validate-semantic
22         standalone
23             styles
24             topbar
25             topbar-insert
26             topbar-menu-edit-convert
27             topbar-menu-file-import
28     ...
29
```

The relevant modules that can be identified in the src folder within Swagger Editor project are the following: *plugins* and *standalone*. The *plugins* module contains submodules responsible for providing suggestions, support for autocompletions, validations, etc. The *standalone* submodules are primarily responsible for the layout and functionality of the menu bar.

---

[8] https://www.w3.org/TR/turtle/

The support added for the above-mentioned features to Swagger Editor in order to extend it with Semantic support has been included in the following submodules: *editor-helpers*, *editor-autosuggest-keywords*, *editor-autosuggest-oas3-keywords*, and *topbar*.

The rest of the section provides a schematic overview of the work that was carried in order to implement the support for these features in Swagger Editor; we will also present key code snippets that detail the most important parts of the implementation.

Listing 5.3 presents the class responsible for implementing the functionality of extracting the identifier for both classes and properties from Schema.org. The class identifier is further used to provide suggestion and autocomplete support for the proposed extensions at schemas/definitions levels of the OpenAPI Specification, while the property identifier is used for the same purpose at the properties level of the OpenAPI Specification.

The *schema-org-extractor.js* file that contains the SchemaOrgExtractor class was added within the Swagger Editor project in the *editor-helpers* submodule.

Listing 5.3: Code from SchemaOrgExtractor class.

```
1  export default class SchemaOrgExtractor {
2    static getClasses () {
3      let concepts = schemaOrg["@graph"]
4      return concepts.filter(concept => concept["@type"] === "rdfs:Class").map(
        concept => concept["@id"])
5    }
6
7    static getProperties () {
8      let concepts = schemaOrg["@graph"]
9      return concepts.filter(concept => concept["@type"] === "rdf:Property").map(
        concept => concept["@id"])
10   }
11 }
```

Listing 5.4 presents the key business logic added to provide autocomplete support for the **x-same-as** and **x-rdf-type** extensions and their accepted values for OpenAPI specification version 2 (OAS2). SchemaOrgExtractor class methods are called for each extension depending on the level at which it was placed.

The *keyword-map.js* file in which we added this functionality is found within the Swagger Editor project in the *editor-autosuggest-keywords* submodule.

Listing 5.4: Code snippet from keyword-map.js.

```
1  var schemaOrgClasses = SchemaOrgExtractor.getClasses()
2  var schemaOrgProperties = SchemaOrgExtractor.getProperties()
3
4  var properties = {
5    ...
6    "x-same-as": schemaOrgProperties,
7    "x-rdf-type": schemaOrgProperties,
```

```
 8   get properties () {
 9     return {
10       ".": this
11     }
12   }
13 }
14
15
16 var schema = {
17   ...
18   "x-same-as": schemaOrgClasses,
19   "x-rdf-type": schemaOrgClasses,
20   get properties () {
21     return {
22       ".": properties
23     }
24   }
25 }
```

Similarly, listing 5.5 presents the key business logic added to provide autocomplete support for the **x-same-as** and **x-rdf-type** extensions and their accepted values for OpenAPI specification version 3 (OAS3).

The *oas3-objects.js* file in which we added this functionality is found within the Swagger Editor project in the *editor-autosuggest-oas3-keywords* submodule.

Listing 5.5: Code snippet from oas3-objects.js.

```
 1 var schemaOrgClasses = SchemaOrgExtractor.getClasses()
 2 var schemaOrgProperties = SchemaOrgExtractor.getProperties()
 3
 4 export const Properties = {
 5   ...
 6   "x-same-as": schemaOrgProperties,
 7   "x-rdf-type": schemaOrgProperties,
 8   get properties () {
 9     return {
10       ".": this,
11     }
12   }
13 }
14
15 export const Schema = {
16   ...
17   "x-same-as": schemaOrgClasses,
18   "x-rdf-type": schemaOrgClasses,
19   get properties () {
20     return {
```

```
21        ".": Properties,
22      }
23   }
24 }
```

Listing 5.6 presents the class responsible for implementing the functionality of converting and saving the OpenAPI definition from JSON/YAML format to Turtle format.

The *TTL.js* file that contains the code for the TTL class was added within the Swagger Editor project in the *editor-helpers* submodule.

Listing 5.6: Code from TTL class

```
1  import YAML from "@kyleshockey/js-yaml"
2
3  let rdfKeywords = {"x-rdf-type": "rdf:type", "x-same-as": "owl:sameAs"}
4
5  export default class TTL {
6   static convertToTurtle (jsonOrYaml, isOAS3) {
7     // JSON or YAML String -> JS object
8     let jsContent = YAML.safeLoad(jsonOrYaml)
9     let ontologyNamespace = jsContent["info"]["title"] || "swagger-schema"
10    ontologyNamespace = ontologyNamespace.replace(" ", "_")
11    return `${TTL.getOntologyHeader(ontologyNamespace)} \n\n${TTL.jsonToTurtle(
        jsContent, isOAS3)}`
12   }
13
14   static getOntologyHeader (ontologyNamespace) {
15     let header =
16       `@prefix : <http://www.semanticweb.org/ontologies/${ontologyNamespace}/> .\
        n` +
17       "@prefix dc: <http://purl.org/dc/elements/1.1/> .\n" +
18       "@prefix gr: <http://purl.org/goodrelations/v1#> .\n" +
19       "@prefix dbo: <http://dbpedia.org/ontology/> .\n" +
20       "@prefix dbp: <http://dbpedia.org/property/> .\n" +
21       "@prefix dbr: <http://dbpedia.org/resource/> .\n" +
22       "@prefix owl: <http://www.w3.org/2002/07/owl#> .\n" +
23       "@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .\n" +
24       "@prefix xml: <http://www.w3.org/XML/1998/namespace> .\n" +
25       "@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .\n" +
26       "@prefix muto: <http://purl.org/muto/core#> .\n" +
27       "@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .\n" +
28       "@prefix schema: <http://schema.org/> .\n" +
29       "@prefix sioc: <http://rdfs.org/sioc/ns#> .\n" +
30       "@prefix yago: <http://dbpedia.org/class/yago/> .\n" +
31       "@prefix owl2xml: <http://www.w3.org/2006/12/owl2-xml#> .\n" +
32       `@base <http://www.semanticweb.org/ontologies/${ontologyNamespace}/> .`
33
```

```
34      return header
35    }
36
37    static jsonToTurtle (swaggerSchema, isOAS3) {
38      let rdfTriplesInTurtleSyntax = ""
39      let definitions
40
41      if (isOAS3) {
42        definitions = swaggerSchema["components"]["schemas"]
43      } else {
44        definitions = swaggerSchema["definitions"]
45      }
46
47      for (let definitionKey in definitions) {
48        let definition = definitions[definitionKey]
49        for (let rdfKey in rdfKeywords) {
50          if (rdfKey in definition) {
51            let rdfKeyword = rdfKeywords[rdfKey]
52            let rdfTriple = `:${definitionKey} ${rdfKeyword} <${definition[rdfKey]}
      > . \n`
53            rdfTriplesInTurtleSyntax += rdfTriple
54          }
55        }
56
57        let properties = definition["properties"]
58        for (let propertyKey in properties) {
59          let property = properties[propertyKey]
60          for (let rdfKey in rdfKeywords) {
61            if (rdfKey in property) {
62              let rdfKeyword = rdfKeywords[rdfKey]
63              let rdfTriple = `:${propertyKey} ${rdfKeyword} <${property[rdfKey]}>
      . \n`
64              let rdfRangeTriple = `:${propertyKey} rdfs:range :${definitionKey} .
      \n`
65              rdfTriplesInTurtleSyntax += rdfTriple
66              rdfTriplesInTurtleSyntax += rdfRangeTriple
67            }
68          }
69        }
70
71        rdfTriplesInTurtleSyntax += `\n`
72      }
73
74      return rdfTriplesInTurtleSyntax
75    }
76  }
```

In listing 5.7, we have the code snippet that calls the TTL class functionality. The *topbar.jsx* file in which we added this functionality is found within the Swagger Editor project in the *topbar* submodule.

Listing 5.7: Code snippet from topbar.jsx

```
1  saveAsTurtle = () => {
2    let editorContent = this.props.specSelectors.specStr()
3    let fileName = this.getFileName()
4
5    if(this.hasParserErrors()) {
6      // we can't recover from a parser error in save as JSON
7      // because we are always parsing so we can beautify
8      return alert("Save as Turtle is not currently possible because Swagger-Editor
         wasn't able to parse your API definiton.")
9    }
10
11   let isOas3 = this.props.specSelectors.isOAS3()
12   let rdfTriplesInTurtleSyntax = TTL.convertToTurtle(editorContent, isOas3)
13   this.downloadFile(rdfTriplesInTurtleSyntax, `${fileName}.ttl`)
14 }
```

5.4 Extending Swagger UI With Semantic Support

We have added support for the following features to Swagger UI in order to augment it with Semantic support:

- Add Structured Data to the generated OpenAPI definition documentation using Microdata[9];

- Retrieve the existing description on Schema.org for each class and property that has been augmented with semantics using the **x-same-as** and **x-rdf-type** extensions and include it in the generated OpenAPI definition documentation;

- Associate the elements from the OpenAPI definition with concepts from the Schema.org vocabulary based on the usage of the previously defined extensions.

According to [21], *Microdata provides a simple mechanism to label content in a document, so it can be processed as a set of items described by name-value pairs. Microdata can be used to provide machine-parseable information about content that is processed by tools to improve accessibility.*

The entire implementation that augments Swagger UI with Semantic support can be consulted at: https://github.com/ioanabirsan/swagger-ui/.

The structure of the Swagger UI project is as follows:

---

[9]https://developer.mozilla.org/en-US/docs/Web/HTML/Microdata

```
1       ...
2     src
3         core
4             components
5             containers
6             plugins
7             presets
8         img
9         plugins
10        standalone
11        style
12    ...
13
```

The relevant module that can be identified in the src folder within Swagger Editor project is the *core* module. It consists of four submodules: *components*, *containers*, *plugins* and *presets*. The support added for the above-mentioned features to Swagger UI in order to augment it with Semantic support has been incorporated within *components* submodule as it will be presented in the remainder of this section.

In listing 5.8, the code snippets with the added attributes specific to the Microdata model are presented, respectively itemscope, itemtype and itemprop. This functionality was added to Models and ObjectModel classes that are found within the Swagger UI project in the *components* submodule.

Listing 5.8: Code snippet showing added attributes from the Microdata model.
```
1 // from models.jsx
2 const extensionClass = schema.get("x-same-as") || schema.get("x-rdf-type") ||
      null
3 ...
4 <div itemScope itemType={extensionClass} id={ ‘model-${name}‘ } className="model
      -container" key={ ‘models-section-${name}‘ }>
5
6 // from object-model.jsx
7 let extensionProperty = this.getProperty(properties, key)
8 ...
9 <tr style={tableRowStyle} itemProp={extensionProperty} key={key} className={
      isDeprecated && ’deprecated’}>
```

The ObjectModel class is responsible for rendering the models defined in the created API. In the *componentWillMount()* method, a request is made to the URL where the schema.jsonld file resource is found, which contains the definition of the core vocabulary. If this request fails, then a local version of the Schema.org vocabulary is referenced. The *getConceptDescriptionFromSchemaOrg()* method is responsible for extracting the description of the concepts for which the defined extensions (i.e., **x-same-as**, **x-rdf-type**) was used. In the *render()* method, the necessary elements were added to display additional information about the models.

The above mentioned functionality that was added to ObjectModel class is found within the Swagger UI project in the *components* submodule. and is presented in the listing 5.9.

Listing 5.9: Code snippet that contains the core Model rendering logic augmented with semantic constructs.

```
 1  import schemaOrg from './schema-org'
 2  import Parser from 'html-react-parser'
 3
 4  let rdfKeywords = {"x-rdf-type": "rdf:type", "x-same-as": "owl:sameAs"}
 5  ...
 6  export default class ObjectModel extends Component {
 7    ...
 8    constructor (props) {
 9      super(props)
10        this.state = {
11                schemaOrg: schemaOrg
12      }
13    }
14
15    getConceptDescriptionFromSchemaOrg (id) {
16      if (!id) { return null }
17      let concept = this.getConceptFromSchemaOrg(id)
18      if (!concept) {return null}
19
20      return this.getDescription(concept)
21    }
22
23    getConceptFromSchemaOrg (id) {
24      let schemaOrg = this.getSchemaOrg()
25      return schemaOrg['@graph'].find(concept => concept['@id'] === id)
26    }
27
28    getSchemaOrg () {
29      return this.state.schemaOrg
30    }
31
32    getDescription (concept) {
33      return concept['rdfs:comment']
34    }
35
36    getPropertyFromSchemaOrg (properties, propertyName) {
37      for (let [key, value] of properties.entries()) {
38        if (key === propertyName) {
39          for (let [innerKey, innerValue] of value.entries()) {
40            if (innerKey in rdfKeywords) {
41              return innerValue
```

41

```
42            }
43          }
44        }
45      }
46      return null
47    }
48
49    componentWillMount () {
50      fetch('https://schema.org/version/3.7/schema.jsonld')
51        .then(response => response.json())
52        .then(schema => this.setState({schemaOrg: schema}))
53        .catch(() => this.setState({schemaOrg: schemaOrg}))
54    }
55
56    render () {
57      ...
58      let extensionClass = schema.get('x-same-as') || schema.get('x-rdf-type') ||
    null
59      let conceptDescription = this.getConceptDescriptionFromSchemaOrg(
    extensionClass)
60      ...
61      <p>
62        {title}
63        {extensionClass && <a href={extensionClass} target={'_blank'}>&lt;{
    extensionClass}&gt;</a>}
64      </p>
65      <p>
66        <a style={descriptionStyle} target={'_blank'} href={extensionClass}>
67          {conceptDescription}
68        </a>
69      </p>
70
71      return <span className="model">
72      ...
73      let extensionProperty = this.getPropertyFromSchemaOrg(properties, key)
74      let propertyDescription
75      if (this.getConceptDescriptionFromSchemaOrg(extensionProperty)) {
76        propertyDescription = Parser(this.getConceptDescriptionFromSchemaOrg(
    extensionProperty))
77      } else {
78        propertyDescription = this.getConceptDescriptionFromSchemaOrg(
    extensionProperty)
79      }
80      ...
81      <td style={propertyStyle}>
82        <a href={extensionProperty} target="_blank">
83          {extensionProperty && <span>&lt;{extensionProperty}&gt;</span>}
```

```
84        </a>
85      </td>
86      <td style={propertyStyle}>
87        <a style={descriptionStyle} target="_blank" href={extensionProperty}>
88          {propertyDescription}
89        </a>
90      </td>
91      ...
92    }
```

5.5   Future Directions

The augmentation of OpenAPI specification with knowledge defined in Schema.org as it was proposed in this thesis is a foundational step in this direction. Further improvements can be made in this direction.

The OpenAPI specification may be extended to incorporate other ontologies (e.g. DBpedia[10], Disease Ontology[11], Dublin Core[12], etc.).

A step in the improvement process is that once we have the augmented specification, it can be discovered by automated tools.

Another direction of improvement is to publish the resulting ontology to a triplestore (e.g. AllegroGraph[13], Amazon Neptune[14], Stardog[15], etc.) and then to create a mechanism, using SPARQL, that provides API recommendations immersed directly in the Swagger UI tool.

A final direction of improvement would be the creation of a mechanism by which Swagger Editor can self-detect what concepts are defined in the created API and automatically create the associations or provide the user with suggestion from which he can choose the most appropriate one.

Summary

This chapter described the process of extending OpenAPI specification with semantics, along with the semantic support added to the Swagger Editor and Swagger UI open source

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[10]http://dbpedia.org/ontology/
[11]http://www.disease-ontology.org/
[12]http://www.dublincore.org/specifications/dublin-core/
[13]https://franz.com/agraph/allegrograph/
[14]https://aws.amazon.com/neptune/
[15]https://www.stardog.com/

tools. The chapter concluded with remarks regarding future directions the augmentation of OpenAPI specification might have.

Chapter 6

Case study: Taxi Service

In order to demonstrate the functionality to the OpenAPI Specification tools that were augmented with Semantic support, we have created an OpenAPI Definition that represents the functionality provided by a Taxi Service. The OpenAPI definition can be consulted in appendix A.

The OpenApi Taxi Service Definition was created using Swagger Editor and made use of the Semantic support functionality implemented as described in chapter 5, namely to provide suggestions of concepts from Schema.org. Figure 6.1 depicts the case in which the editor offers suggestions of concepts from Schema.org at the Schemas level for the **x-same-as** extension.
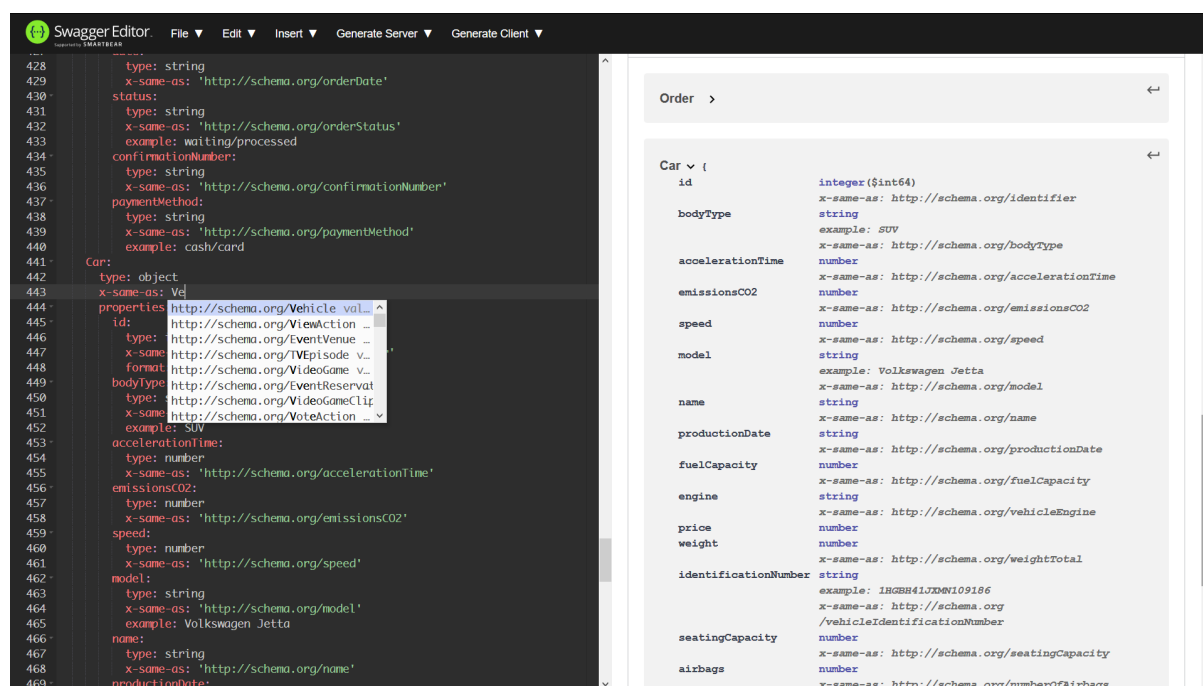

Figure 6.1: Autocomplete support offered by Swagger Editor for x-same-as extension.

During the creation of the Taxi Service OpenAPI Defition we have augmented several elements from it with related concepts from Schema.org:

- **Order** with <http://schema.org/Order>

- **Car** with <http://schema.org/Vehicle>

- **TaxiService** with <http://schema.org/TaxiService>

- **Customer** with <http://schema.org/Person>

We have also made references to related concepts from Schema.org to properties pertaining to the schemas used by the operations defined in the API:

- Order

    - **number** with <http://schema.org/orderNumber>

    - **status** with <http://schema.org/orderStatus>

    - **paymentMethod** with <http://schema.org/paymentMethod>

    - etc.

- Car

    - **bodyType** with <http://schema.org/bodyType>

    - **emissionsCO2** with <http://schema.org/emissionsCO2>

    - **productionDate** with <http://schema.org/productionDate>

    - **seatingCapacity** with <http://schema.org/seatingCapacity>

    - **fuelType** with <http://schema.org/fuelType>

    - etc.

- etc.

Once the creation of the Taxi Service definition has been completed, we can select the **File → Convert and save as Turtle** option, as depicted in figure 6.2.

The contents of the generated file will consist of RDF triples of the form *<subject>* *<predicate>* *<object>*. An excerpt from the result of the Turtle conversion of the Taxi Service OpenAPI definition can be consulted in listing 6.1. The entire result of the conversion to Turtle format can be consulted in Appendix B.
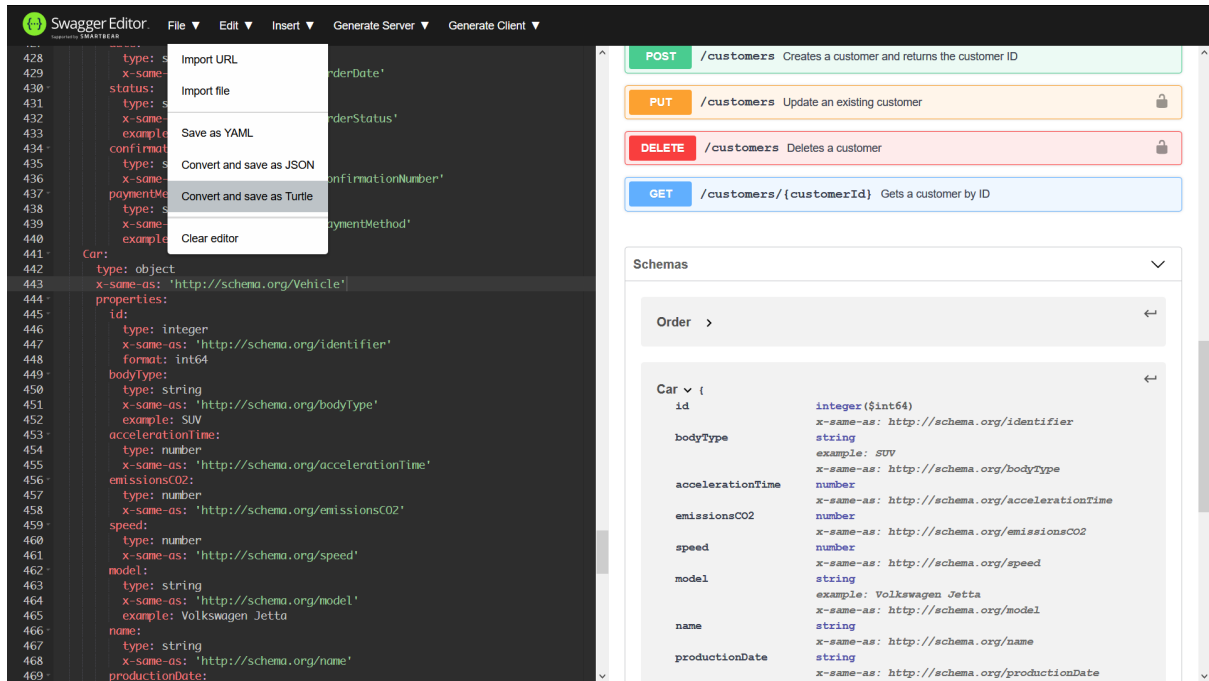
Figure 6.2: **Convert and save as Turtle** option added to Swagger Editor.

Listing 6.1: Taxi Service ontology resulting from knowledge augmentation.

```
 1  @prefix : <http://www.semanticweb.org/ontologies/Taxi_Service/> .
 2  @prefix dc: <http://purl.org/dc/elements/1.1/> .
 3  @prefix gr: <http://purl.org/goodrelations/v1#> .
 4  @prefix dbo: <http://dbpedia.org/ontology/> .
 5  @prefix owl: <http://www.w3.org/2002/07/owl#> .
 6  @prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
 7  @base <http://www.semanticweb.org/ontologies/Taxi_Service/> .
 8  ...
 9
10  :Order owl:sameAs <http://schema.org/Order> .
11  :status owl:sameAs <http://schema.org/orderStatus> .
12  :status rdfs:range :Order .
13  :confirmationNumber owl:sameAs <http://schema.org/confirmationNumber> .
14  :confirmationNumber rdfs:range :Order .
15  :paymentMethod owl:sameAs <http://schema.org/paymentMethod> .
16  :paymentMethod rdfs:range :Order .
17  ...
18
19  :Car owl:sameAs <Vehicle> .
20  :seatingCapacity owl:sameAs <http://schema.org/seatingCapacity> .
21  :seatingCapacity rdfs:range :Car .
22  :airbags owl:sameAs <http://schema.org/numberOfAirbags> .
23  :airbags rdfs:range :Car .
```

47

```
24  :meetsEmissionStandard owl:sameAs <http://schema.org/meetsEmissionStandard> .
25  :meetsEmissionStandard rdfs:range :Car .
26  :fuelType owl:sameAs <http://schema.org/fuelType> .
27  :fuelType rdfs:range :Car .
28  :fuelConsumption owl:sameAs <http://schema.org/fuelConsumption> .
29  :fuelConsumption rdfs:range :Car .
30  ...
31
32  :TaxiService owl:sameAs <http://schema.org/TaxiService> .
33  :hoursAvailable owl:sameAs <http://schema.org/hoursAvailable> .
34  :hoursAvailable rdfs:range :TaxiService .
35  ...
```

Further, we can upload the contents of the Turtle file into WebVOWL[1] to be able to visualize the resulting Taxi Service Ontology. Figure 6.3 provides an interactive visualization of the Taxi Service Ontology.

With the help of the semantic support added to Swagger UI, we can visualize in the Schemas/Models section the references to Schema.org for each concept for which the extensions were used. We can also observe the descriptions retrieved from Schema.org and can access the content on Schema.org for further details for each concept of interest. The descriptions were dynamically retrieved from Schema.org, where available. The previously mentioned functionalities can be observed in figure 6.4.

The Google Structured Data Testing Tool[2] allows us to validate our code to make sure that structured data is understood by search engines when crawling a page. After introducing the content of the HTML document that was augmented with microdata by the Swagger UI tool, the tool detected 4 concepts (i.e. *Order*, *Vehicle*, *TaxiService*, *Person*), as can be observed in figure 6.5.

Figure 6.6 displays all the structured data detected by Google when the TaxiService concept is selected and expanded.

---

[1]http://vowl.visualdataweb.org/webvowl.html
[2]https://search.google.com/structured-data/testing-tool

Figure 6.3: Interactive visualization of the Taxi Service Ontology using WebVOWL.

Figure 6.4: Display of the semantic details in Swagger UI.

Figure 6.5: Structured data detected by Google Structured Data Testing Tool.

Figure 6.6: Structured data for TaxiService item detected by Google Structured Data Testing Tool.

Chapter 7

Conclusions

Thesis Contribution

Added support for Semantic Augmentation of OpenAPI specification within Swagger Editor and Swagger UI tools.

In order to augment OpenAPI specification with Semantic support, we have extended the functionlity of the Swagger Editor and Swagger UI open source tools.

The following features have been added to the *Swagger Editor* tool: the extension of the OpenAPI specification with custom properties: *x-same-as* and *x-rdf-type*, suggestions and autocomplete support for the newly added extensions, contextual suggestions and autocomplete support for concepts retrieved from *Schema.org*, and the ability to convert and save an OpenAPI definition in *Turtle* format.

As for the *Swagger UI* tool, the upcoming features have been added: the incorporation of *Structured Data* in the generated OpenAPI definition documentation using *Microdata*, the retrieval of existing description from *Schema.org* for each element that has been augmented with semantics and its inclusion in the generated OpenAPI definition documentation, and the association of the elements from OpenAPI definition with concepts from *Schema.org vocabulary*.

Future Directions

The thesis provided a foundational layer that enables Semantic support and augmentation of OpenAPI Specification conformant API definitions. The foundational capabilities presented in this thesis can further be extended or improved in the following directions.

The Semantic support currently added by the work in this thesis is limited to using

concepts defined only in the Schema.org vocabulary. The implementation would benefit by enabling the user to incorporate/refer concepts from other ontologies (e.g. DBpedia[1], Disease Ontology[2], Dublin Core[3], etc.).

The next layer of improvement would consist in the addition of a mechanism through which the ontology resulted from the Semantic Augmentation is automatically published in a triplestore (e.g. AllegroGraph[4], Amazon Neptune[5], Stardog[6], etc.); this database will entail itself to provide API recommendations, through the usage of SPARQL queries, immersed directly in the Swagger UI tool. This system can enable API recommendation support based on several similarity criteria.

A final direction of improvement would be the creation of a mechanism by which Swagger Editor can self-detect what concepts are defined in the created API and automatically create the associations or provide the user with suggestion from which he can choose the most appropriate one.

---

[1] http://dbpedia.org/ontology/
[2] http://www.disease-ontology.org/
[3] http://www.dublincore.org/specifications/dublin-core/
[4] https://franz.com/agraph/allegrograph/
[5] https://aws.amazon.com/neptune/
[6] https://www.stardog.com/

Appendix A

Taxi Service OpenAPI Definition

This appendix presents the definition of an Web API that conforms to the OpenAPI Specification. The API models the functionality provided by a Taxi Service and it was developed by the author of the thesis as a case study for demonstrating the Semantic support functionalities that were implemented by the same author in the Swagger Editor and Swagger UI Open Source tools.

Listing A.1: Taxi Service OpenAPI definition using YAML format.

```
 1  openapi: 3.0.0
 2  info:
 3    version: 0.0.0
 4    title: Taxi Service
 5    description: This is a sample server for a taxi service.
 6    termsOfService: 'http://example.com/terms/'
 7  tags:
 8    - name: order
 9      description: Operations about orders
10    - name: car
11      description: Operations about cars
12    - name: taxi service
13      description: Operations about taxi services
14    - name: customer
15      description: Operations about customers
16  paths:
17    /orders:
18      post:
19        tags:
20          - order
21        summary: Creates an order and returns the order ID
22        operationId: createOrder
23        requestBody:
24          required: true
```

```
25          description: A JSON object that contains the order number and item.
26          content:
27            application/json:
28              schema:
29                $ref: '#/components/schemas/Order'
30      responses:
31        '201':
32          description: Created
33          content:
34            application/json:
35              schema:
36                type: object
37                properties:
38                  id:
39                    type: integer
40                    format: int64
41                    description: ID of the created order.
42          links:
43            GetOrderById:
44              operationId: getOrder
45              parameters:
46                orderId: '$response.body#/id'
47              description: >
48                The `id` value returned in the response can be used as the
49                `orderId` parameter in `GET /orders/{orderId}`.
50    put:
51      tags:
52        - order
53      summary: Update an existing order
54      operationId: updateOrder
55      requestBody:
56        required: true
57        description: A JSON object that contains the order number and item.
58        content:
59          application/json:
60            schema:
61              $ref: '#/components/schemas/Order'
62      responses:
63        '400':
64          description: Invalid ID supplied
65        '404':
66          description: Order not found
67        '405':
68          description: Validation exception
69      security:
70        - taxiservice_auth:
71            - 'write:orders'
```

```
72              - 'read:orders'
73        delete:
74          tags:
75            - order
76          summary: Deletes an order
77          operationId: deleteOrder
78          parameters:
79            - name: orderId
80              in: path
81              required: true
82              description: Order id to delete
83              schema:
84                type: integer
85                format: int64
86          responses:
87            '400':
88              description: Invalid ID supplied
89            '404':
90              description: Order not found
91          security:
92            - taxiservice_auth:
93                - 'write:orders'
94                - 'read:orders'
95      '/orders/{orderId}':
96        get:
97          tags:
98            - order
99          summary: Gets an order by ID
100         operationId: getOrderById
101         parameters:
102           - in: path
103             name: orderId
104             required: true
105             schema:
106               type: integer
107               format: int64
108         responses:
109           '200':
110             description: An Order object
111             content:
112               application/json:
113                 schema:
114                   $ref: '#/components/schemas/Order'
115     /cars:
116       post:
117         tags:
118           - car
```

```
119       summary: Creates a car and returns the car ID
120       operationId: createCar
121       requestBody:
122         required: true
123         description: A JSON object that contains the car.
124         content:
125           application/json:
126             schema:
127               $ref: '#/components/schemas/Car'
128       responses:
129         '201':
130           description: Created
131           content:
132             application/json:
133               schema:
134                 type: object
135                 properties:
136                   id:
137                     type: integer
138                     format: int64
139                     description: ID of the created car.
140           links:
141             GetCarById:
142               operationId: getCar
143               parameters:
144                 carId: '$response.body#/id'
145               description: >
146                 The 'id' value returned in the response can be used as the
147                 'carId' parameter in 'GET /cars/{carId}'.
148     put:
149       tags:
150         - car
151       summary: Update an existing car
152       operationId: updateCar
153       requestBody:
154         required: true
155         description: A JSON object that contains the car.
156         content:
157           application/json:
158             schema:
159               $ref: '#/components/schemas/Car'
160       responses:
161         '400':
162           description: Invalid ID supplied
163         '404':
164           description: Car not found
165         '405':
```

```
166              description: Validation exception
167        security:
168          - taxiservice_auth:
169              - 'write:cars'
170              - 'read:cars'
171    delete:
172      tags:
173        - car
174      summary: Deletes a car
175      operationId: deleteCar
176      parameters:
177        - name: carId
178          in: path
179          required: true
180          description: Car id to delete
181          schema:
182            type: integer
183            format: int64
184      responses:
185        '400':
186          description: Invalid ID supplied
187        '404':
188          description: Car not found
189      security:
190        - taxiservice_auth:
191            - 'write:cars'
192            - 'read:cars'
193  '/cars/{carId}':
194    get:
195      tags:
196        - car
197      summary: Gets a car by ID
198      operationId: getCar
199      parameters:
200        - in: path
201          name: carId
202          required: true
203          schema:
204            type: integer
205            format: int64
206      responses:
207        '200':
208          description: A Car object
209          content:
210            application/json:
211              schema:
212                $ref: '#/components/schemas/Car'
```

```
213    /taxiServices:
214      post:
215        tags:
216          - taxi service
217        summary: Creates a taxi service and returns the taxi service ID
218        operationId: createTaxiService
219        requestBody:
220          required: true
221          description: A JSON object that contains the taxi service.
222          content:
223            application/json:
224              schema:
225                $ref: '#/components/schemas/TaxiService'
226        responses:
227          '201':
228            description: Created
229            content:
230              application/json:
231                schema:
232                  type: object
233                  properties:
234                    id:
235                      type: integer
236                      format: int64
237                      description: ID of the created taxi service.
238            links:
239              GetTaxiServiceById:
240                operationId: getTaxiService
241                parameters:
242                  carId: '$response.body#/id'
243                description: >
244                  The 'id' value returned in the response can be used as the
245                  'taxiServiceId' parameter in 'GET /taxis/{taxiServiceId}'.
246      put:
247        tags:
248          - taxi service
249        summary: Update an existing taxi service
250        operationId: updateTaxiService
251        requestBody:
252          required: true
253          description: A JSON object that contains the taxi service.
254          content:
255            application/json:
256              schema:
257                $ref: '#/components/schemas/TaxiService'
258        responses:
259          '400':
```

```yaml
260                  description: Invalid ID supplied
261              '404':
262                  description: TaxiService not found
263              '405':
264                  description: Validation exception
265          security:
266            - taxiservice_auth:
267                - 'write:taxiServices'
268                - 'read:taxiServices'
269      delete:
270        tags:
271          - taxi service
272        summary: Deletes a taxi service
273        operationId: deleteTaxiService
274        parameters:
275          - name: taxiServiceId
276            in: path
277            required: true
278            description: TaxiService id to delete
279            schema:
280              type: integer
281              format: int64
282        responses:
283          '400':
284              description: Invalid ID supplied
285          '404':
286              description: TaxiService not found
287        security:
288          - taxiservice_auth:
289              - 'write:taxiServices'
290              - 'read:taxiServices'
291    '/taxiServices/{taxiServiceId}':
292      get:
293        tags:
294          - taxi service
295        summary: Gets a taxi service by ID
296        operationId: getTaxiService
297        parameters:
298          - in: path
299            name: taxiServiceId
300            required: true
301            schema:
302              type: integer
303              format: int64
304        responses:
305          '200':
306              description: A TaxiService object
```

```
307            content:
308              application/json:
309                schema:
310                  $ref: '#/components/schemas/TaxiService'
311    /customers:
312      post:
313        tags:
314          - customer
315        summary: Creates a customer and returns the customer ID
316        operationId: createDCustomer
317        requestBody:
318          required: true
319          description: A JSON object that contains the customer.
320          content:
321            application/json:
322              schema:
323                $ref: '#/components/schemas/Customer'
324        responses:
325          '201':
326            description: Created
327            content:
328              application/json:
329                schema:
330                  type: object
331                  properties:
332                    id:
333                      type: integer
334                      format: int64
335                      description: ID of the created customer.
336            links:
337              GetCustomerById:
338                operationId: getCustomer
339                parameters:
340                  customerId: '$response.body#/id'
341                description: >
342                  The 'id' value returned in the response can be used as the
343                  'customerId' parameter in 'GET /customers/{customerId}'.
344      put:
345        tags:
346          - customer
347        summary: Update an existing customer
348        operationId: updateCustomer
349        requestBody:
350          required: true
351          description: A JSON object that contains the customer.
352          content:
353            application/json:
```

```
354              schema:
355                  $ref: '#/components/schemas/Customer'
356         responses:
357           '400':
358             description: Invalid ID supplied
359           '404':
360             description: Customer not found
361           '405':
362             description: Validation exception
363         security:
364           - taxiservice_auth:
365               - 'write:customers'
366               - 'read:customers'
367     delete:
368       tags:
369         - customer
370       summary: Deletes a customer
371       operationId: deleteCustomer
372       parameters:
373         - name: customerId
374           in: path
375           required: true
376           description: Customer id to delete
377           schema:
378             type: integer
379             format: int64
380       responses:
381         '400':
382           description: Invalid ID supplied
383         '404':
384           description: Customer not found
385       security:
386         - taxiservice_auth:
387             - 'write:customers'
388             - 'read:customers'
389   '/customers/{customerId}':
390     get:
391       tags:
392         - customer
393       summary: Gets a customer by ID
394       operationId: getCustomer
395       parameters:
396         - in: path
397           name: customerId
398           required: true
399           schema:
400             type: integer
```

```
401          format: int64
402      responses:
403        '200':
404          description: A Customer object
405          content:
406            application/json:
407              schema:
408                $ref: '#/components/schemas/Customer'
409  components:
410    schemas:
411      Order:
412        type: 'object'
413        x-same-as: 'http://schema.org/Order'
414        properties:
415          id:
416            type: 'integer'
417            x-same-as: 'http://schema.org/identifier'
418            format: int64
419          carId:
420            type: 'integer'
421            x-same-as: 'http://schema.org/identifier'
422            format: int64
423          customerId:
424            type: 'integer'
425            x-same-as: 'http://schema.org/identifier'
426            format: int64
427          number:
428            type: 'string'
429            x-same-as: 'http://schema.org/orderNumber'
430            format: int64
431          date:
432            type: 'string'
433            x-same-as: 'http://schema.org/orderDate'
434          status:
435            type: 'string'
436            x-same-as: 'http://schema.org/orderStatus'
437            example: 'waiting/processed'
438          confirmationNumber:
439            type: 'string'
440            x-same-as: 'http://schema.org/confirmationNumber'
441          paymentMethod:
442            type: 'string'
443            x-same-as: 'http://schema.org/paymentMethod'
444            example: 'cash/card'
445      Car:
446        type: object
447        x-same-as: 'http://schema.org/Vehicle'
```

```
448        properties:
449          id:
450            type: 'integer'
451            x-same-as: 'http://schema.org/identifier'
452            format: 'int64'
453          bodyType:
454            type: 'string'
455            x-same-as: 'http://schema.org/bodyType'
456            example: 'SUV'
457          accelerationTime:
458            type: 'number'
459            x-same-as: 'http://schema.org/accelerationTime'
460          emissionsCO2:
461            type: 'number'
462            x-same-as: 'http://schema.org/emissionsCO2'
463          speed:
464            type: 'number'
465            x-same-as: 'http://schema.org/speed'
466          model:
467            type: 'string'
468            x-same-as: 'http://schema.org/model'
469            example: 'Volkswagen Jetta'
470          name:
471            type: 'string'
472            x-same-as: 'http://schema.org/name'
473          productionDate:
474            type: 'string'
475            x-same-as: 'http://schema.org/productionDate'
476          fuelCapacity:
477            type: 'number'
478            x-same-as: 'http://schema.org/fuelCapacity'
479          engine:
480            type: 'string'
481            x-same-as: 'http://schema.org/vehicleEngine'
482          price:
483            type: 'number'
484          weight:
485            type: 'number'
486            x-same-as: 'http://schema.org/weightTotal'
487          identificationNumber:
488            type: 'string'
489            x-same-as: 'http://schema.org/vehicleIdentificationNumber'
490            example: '1HGBH41JXMN109186'
491          seatingCapacity:
492            type: 'number'
493            x-same-as: 'http://schema.org/seatingCapacity'
494          airbags:
```

```yaml
495        type: 'number'
496        x-same-as: 'http://schema.org/numberOfAirbags'
497      meetsEmissionStandard:
498        type: 'string'
499        x-same-as: 'http://schema.org/meetsEmissionStandard'
500      fuelType:
501        type: 'string'
502        x-same-as: 'http://schema.org/fuelType'
503      fuelConsumption:
504        type: 'number'
505        x-same-as: 'http://schema.org/fuelConsumption'
506  TaxiService:
507    type: 'object'
508    x-same-as: 'http://schema.org/TaxiService'
509    properties:
510      id:
511        type: 'integer'
512        x-same-as: 'http://schema.org/identifier'
513        format: int64
514      provider:
515        type: 'string'
516        x-same-as: 'http://schema.org/provider'
517      rating:
518        type: 'number'
519      reviews:
520        type: 'array'
521        items:
522          type: 'string'
523      cars:
524        type: 'array'
525        items:
526          $ref: '#/components/schemas/Car'
527      orders:
528        type: 'array'
529        items:
530          $ref: '#/components/schemas/Order'
531      termsOfService:
532        type: 'string'
533        x-same-as: 'http://schema.org/termsOfService'
534      costPerKm:
535        type: 'number'
536      hoursAvailable:
537        type: 'string'
538        x-same-as: 'http://schema.org/hoursAvailable'
539      phoneNumber:
540        type: 'string'
541  Customer:
```

```
542          type: 'object'
543          x-same-as: 'http://schema.org/Person'
544          properties:
545            id:
546              type: 'integer'
547              x-same-as: 'http://schema.org/identifier'
548              format: int64
549            firstName:
550              type: 'string'
551              x-same-as: 'http://schema.org/name'
552            lastName:
553              type: 'string'
554              x-same-as: 'http://schema.org/name'
555            address:
556              type: 'string'
557              x-same-as: 'http://schema.org/address'
558  externalDocs:
559    description: Find out more about Swagger
560    url: 'http://swagger.io'
```

Appendix B

Taxi Service Ontology

This appendix presents a Taxi Service-related Ontology in Turtle format as a case study for demonstrating the Semantic support functionalities that were added by the author of the thesis in the Swagger Editor and Swagger UI Open Source tools. The Ontology resulted from converting and exporting the Taxi Service OpenAPI Definition presented in appendix A using the functionalities implemented by the author of the thesis in the Swagger Editor tool.

Listing B.1: Taxi Service ontology resulting from knowledge augmentation.

```
1  @prefix : <http://www.semanticweb.org/ontologies/Taxi_Service/> .
2  @prefix dc: <http://purl.org/dc/elements/1.1/> .
3  @prefix gr: <http://purl.org/goodrelations/v1#> .
4  @prefix dbo: <http://dbpedia.org/ontology/> .
5  @prefix dbp: <http://dbpedia.org/property/> .
6  @prefix dbr: <http://dbpedia.org/resource/> .
7  @prefix owl: <http://www.w3.org/2002/07/owl#> .
8  @prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
9  @prefix xml: <http://www.w3.org/XML/1998/namespace> .
10 @prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
11 @prefix muto: <http://purl.org/muto/core#> .
12 @prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
13 @prefix schema: <http://schema.org/> .
14 @prefix sioc: <http://rdfs.org/sioc/ns#> .
15 @prefix yago: <http://dbpedia.org/class/yago/> .
16 @prefix owl2xml: <http://www.w3.org/2006/12/owl2-xml#> .
17 @base <http://www.semanticweb.org/ontologies/Taxi_Service/> .
18
19 :Order owl:sameAs <http://schema.org/Order> .
20 :id owl:sameAs <http://schema.org/identifier> .
21 :id rdfs:range :Order .
22 :carId owl:sameAs <http://schema.org/identifier> .
23 :carId rdfs:range :Order .
```

```
24  :customerId owl:sameAs <http://schema.org/identifier> .
25  :customerId rdfs:range :Order .
26  :number owl:sameAs <http://schema.org/orderNumber> .
27  :number rdfs:range :Order .
28  :date owl:sameAs <http://schema.org/orderDate> .
29  :date rdfs:range :Order .
30  :status owl:sameAs <http://schema.org/orderStatus> .
31  :status rdfs:range :Order .
32  :confirmationNumber owl:sameAs <http://schema.org/confirmationNumber> .
33  :confirmationNumber rdfs:range :Order .
34  :paymentMethod owl:sameAs <http://schema.org/paymentMethod> .
35  :paymentMethod rdfs:range :Order .
36
37  :Car owl:sameAs <Ve> .
38  :id owl:sameAs <http://schema.org/identifier> .
39  :id rdfs:range :Car .
40  :bodyType owl:sameAs <http://schema.org/bodyType> .
41  :bodyType rdfs:range :Car .
42  :accelerationTime owl:sameAs <http://schema.org/accelerationTime> .
43  :accelerationTime rdfs:range :Car .
44  :emissionsCO2 owl:sameAs <http://schema.org/emissionsCO2> .
45  :emissionsCO2 rdfs:range :Car .
46  :speed owl:sameAs <http://schema.org/speed> .
47  :speed rdfs:range :Car .
48  :model owl:sameAs <http://schema.org/model> .
49  :model rdfs:range :Car .
50  :name owl:sameAs <http://schema.org/name> .
51  :name rdfs:range :Car .
52  :productionDate owl:sameAs <http://schema.org/productionDate> .
53  :productionDate rdfs:range :Car .
54  :fuelCapacity owl:sameAs <http://schema.org/fuelCapacity> .
55  :fuelCapacity rdfs:range :Car .
56  :engine owl:sameAs <http://schema.org/vehicleEngine> .
57  :engine rdfs:range :Car .
58  :weight owl:sameAs <http://schema.org/weightTotal> .
59  :weight rdfs:range :Car .
60  :identificationNumber owl:sameAs <http://schema.org/vehicleIdentificationNumber>
        .
61  :identificationNumber rdfs:range :Car .
62  :seatingCapacity owl:sameAs <http://schema.org/seatingCapacity> .
63  :seatingCapacity rdfs:range :Car .
64  :airbags owl:sameAs <http://schema.org/numberOfAirbags> .
65  :airbags rdfs:range :Car .
66  :meetsEmissionStandard owl:sameAs <http://schema.org/meetsEmissionStandard> .
67  :meetsEmissionStandard rdfs:range :Car .
68  :fuelType owl:sameAs <http://schema.org/fuelType> .
69  :fuelType rdfs:range :Car .
```

```
70  :fuelConsumption owl:sameAs <http://schema.org/fuelConsumption> .
71  :fuelConsumption rdfs:range :Car .
72
73  :TaxiService owl:sameAs <http://schema.org/TaxiService> .
74  :id owl:sameAs <http://schema.org/identifier> .
75  :id rdfs:range :TaxiService .
76  :provider owl:sameAs <http://schema.org/provider> .
77  :provider rdfs:range :TaxiService .
78  :termsOfService owl:sameAs <http://schema.org/termsOfService> .
79  :termsOfService rdfs:range :TaxiService .
80  :hoursAvailable owl:sameAs <http://schema.org/hoursAvailable> .
81  :hoursAvailable rdfs:range :TaxiService .
82
83  :Customer owl:sameAs <http://schema.org/Person> .
84  :id owl:sameAs <http://schema.org/identifier> .
85  :id rdfs:range :Customer .
86  :firstName owl:sameAs <name> .
87  :firstName rdfs:range :Customer .
88  :lastName owl:sameAs <http://schema.org/name> .
89  :lastName rdfs:range :Customer .
90  :address owl:sameAs <http://schema.org/address> .
91  :address rdfs:range :Customer .
```

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