

MASTER'S THESIS

CONFIGURABLE SCHEMA-AWARE RDF DATA INPUT FORMS

DÁVID KONKOLY

MAY 2017



ALBERT-LUDWIGS UNIVERSITÄT FREIBURG
DEPARTMENT OF COMPUTER SCIENCE
CHAIR OF DATABASES AND INFORMATION SYSTEMS

Candidate

Dávid Konkoly

Matr. number

3757311

Working period

18. 10. 2016 – 16. 05. 2017

Examiner

Prof. Dr. Georg Lausen

Supervisor

Victor Anthony Arrascue Ayala

Abstract

Ontologies describing biomedical research processes are getting prevalent nowadays. Their utility is that they allow the replacement of textual documentation with structured data. This way the data can be exchanged among research institutes which supports knowledge sharing and collaboration. Nevertheless the creation of RDF data for documentation purposes requires a software application offering some graphical user interface to achieve convenient data input. Usually such applications are complex and require a large amount of code. Furthermore the communication between domain experts and developers, and the specification and documentation of the software is often a tedious task. The goal of the thesis is to overcome this bottleneck of RDF data creation with a software framework which can be programmed on a high-level declarative way that abstracts from the low-level implementation details. With the implemented approach the development of data management applications can be significantly simplified and accelerated, and made possible for researchers even without programming experience.

Kurzfassung

Kurzfassung auf Deutsch

Contents

Abstract	II
Kurzfassung	III
List of Tables	VIII
1 Introduction	1
1.1 RDFBones Project	1
1.2 Goal of the thesis	1
1.3 Thesis outline	2
2 Preliminaries	3
2.1 Semantic Web	3
2.1.1 Resource Description Framework	3
2.1.2 RDF and RDFS Vocabularies	5
2.1.3 OWL	7
2.1.4 SPARQL	9
2.2 Ontologies	12
2.2.1 Ontology for the anatomy of the human body	12
2.2.2 Ontology for Biomedical Investigations (OBI)	13
2.2.3 RDFBones ontology	15
2.3 Web applications	16
2.3.1 Fundamentals	16
2.3.2 VIVO framework	21

3	Problem Statement	26
3.1	Multi level data input	26
3.2	RDFBones use-cases in VIVO	29
3.3	Solution scheme	30
4	Vocabulary for web application domain	32
4.1	Elements of the vocabulary	32
4.1.1	Data definitions	32
4.1.2	Form definition	34
4.2	Use-cases of the <i>RDFBones</i> project	35
4.2.1	Skeletal Inventories	35
4.2.2	Study Design Execution	38
5	Framework functionality	41
5.1	Main software modules and tasks	41
5.1.1	Validation	42
5.1.2	Dependencies and form functionality	44
5.1.3	Graph model generation	46
5.2	Implementation	49
5.2.1	Client side	49
5.2.2	Server side	54
A	Glossary	60
B	Appendix	65
B.1	Something you need in the appendix	65

List of Figures

2.1	RDF graph notation	4
2.2	Class hierarchy of the RDF/RDFS vocabulary	7
2.3	A subset of OWL vocabulary	8
2.4	Scheme of the restrictions	8
2.5	Ontology extension	9
2.6	Example RDF dataset	10
2.7	Ontology structure for the human skeleton	13
2.8	Extending OBI ontology	15
2.9	RDFBones as OBI extension	16
2.10	Client server communication	17
2.11	Static and dynamic web pages	20
2.12	Faux properties on VIVO profile pages	22
2.13	Faux property descriptor RDF dataset	22
2.14	Custom entry form for skeletal subdivision	23
3.1	Ontology and RDF triples for complex entities	27
3.2	Multi level form	27
3.3	Skeletal subdivision graph pattern and form layout	29
3.4	Investigation graph pattern and form layout	29
3.5	Extended RDF graph pattern definition	31
3.6	Framework functionality outline	31
4.1	Complete workflow of data input process	33
4.2	Variable types and their attributes	33

4.3	Triple types	34
4.4	Form definition	35
4.5	Input form for skeletal inventories	36
4.6	Skeletal inventory data triples	37
4.7	Complete data definition	37
4.8	Form layout definition	37
4.9	Input form for study design execution	38
4.10	Instance selector for existing bone segment	39
4.11	Complete data model	39
5.1	More detailed scheme	41
5.2	Processor tasks	42
5.3	Valid and invalid nodes	43
5.4	Valid and invalid graph	43
5.5	Form element order	44
5.6	Skeletal inventory data constraints	45
5.7	Form dependency subgraphs	45
5.8	Form descriptor JSON	47
5.9	Conversion from triples into graph model	47
5.10	Graph decomposition	48
5.11	Form and form element classes	50
5.12	SubForm and sub form adder	51
5.13	Form loading process	55
5.14	UML class diagram for FormConfiguration	55
5.15	UML class diagram for WebappConnector	56
5.16	UML class diagram for VariableDependency	56
5.17	UML class diagram for Graph	58

List of Tables

Introduction

1.1 RDFBones Project

The master thesis is written in the frame of the project called *RDFBones*. The project is conducted by the Biological Anthropology department of the Universitätsklinikum Freiburg, and funded by the Deutsche Forschung Gemeinschaft (DFG). The main idea of the project is to make possible the definition of the rules and steps of particular anthropological investigations in a machine-readable way. This is achieved by the development of a core ontology in Ontology Web Language (OWL), that describes the general scheme of the processes, while custom problems are defined by means of so-called ontology extensions. The extensions are represented by further ontological RDF statements, which has the advantage that a web application for creating RDF data about the execution of the processes, can be programmed in a generic way so that it adapts its interface to the various cases. During the project an open-source web application framework, called VIVO, is adopted and developed.

1.2 Goal of the thesis

Data creation about research processes happens through multiple different web pages, where each page is responsible for a particular subset of the data. The main structure of the individual input forms is characterized by the scheme of the data they create, which is in our case a subset of the core

ontology. While the elements of the pages in turn are defined in the certain extensions of the addressed scheme. The idea of the thesis is develop a web application framework that is capable of generating its interfaces based on a declarative definition of the dataset they supposed to create. To achieve this, a descriptor language is designed which is capable of expressing RDF data models and their mapping to the interface. The utility of the idea is that the developed system can be applied not only for the concise solution of the problems of the *RDFBones* project, but for any kind of domain, where the rules are defined by means of ontology extensions.

1.3 Thesis outline

The second chapter conveys all the background information that is necessary to understand the problem solved by the thesis. The first two subsections handle the RDF data model and the ontologies applied in the project, while the third section is about the basics of the web application technologies and the VIVO framework. The third chapter contains the problem statement and explains briefly the scheme of the proposed solution. The fourth chapter presents the elements of designed descriptor language, and demonstrates how it can be applied to specify two use-cases of the *RDFBones* project. The fifth chapter is dedicated to the discussion of the functionality of the developed software framework. Its first section provides an overview about the main components of the software, while the second gives a deeper insight into the implementation. The last, sixth chapter covers the conclusion and the evaluation of the achieved system, and presents the further potential in the idea.

Chapter 2

Preliminaries

2.1 Semantic Web

2.1.1 Resource Description Framework

The Resource Description Framework (RDF) is a metadata data model used for representing information on the web. The data in RDF is organized into triples, where each triple consists of a subject, predicate and object. The set of RDF triples constitutes a directed graph, which is referred as RDF graph. The nodes of the graph are the subjects and the objects, while the edges are the predicates.

The three most important types of node are the instances, classes and literals. An instance represents concrete a entity like person, institute, but can be an abstract concept. Classes are general concepts, to which the instances can belong, while literals represent data values assigned to instances. The following Listing shows some example triples that illustrates the basics of information representation by means of triples.

Bob	instanceOf	Student	.
Math	instanceOf	Course	.
Bob	attends	Math	.
Bob	avgGrade	1.73	.

Listing 2.1: Information in triples

In the example *Bob* and *Math* are instances, and they represent a concrete

person and a math course of some university. The *Course* and *Student* are classes and the value 1.73 is a literal. The values of the predicates are called properties. There are three main types of it, the one which connects instances to classes (*instanceOf*), one that expresses the relationship between instances (*attends*), and one which assigns a literal value to an instance (*avgGrade*). Important to mention that a literal value cannot be a subjects of a triple.



Figure 2.1: RDF graph notation

Figure 2.1 illustrates the three main types of node in RDF data. In the following this notation will be used on the figures, namely ellipse for the classes, rectangle for the instances and rhombus for the literals.

The provided example gave just an insight into triple based information representation, but the data in Listing 2.1 is not a valid RDF dataset. The instances and classes together are called resources (will be discussed later why), and each of them has to have an Internationalized Resource Identifier (IRI). The IRIs have to be unique, thus if someone wants to represent information in RDF, then it is necessary to choose an own namespace for own IRIs. For example if the chosen namespace is `<http://myDomain.com#>`, then the IRI of the class *Student* may be `<http://myDomain.com#Student>`. The IRIs of the instances in most of the cases are not given manually, but generated by a software, and their names like *Bob* or *Math* are stored in literal values assigned to them.

RDF data does not contain only IRIs from own namespaces, but there are vocabularies that offer a set a built in IRIs. The three most important vocabularies are the RDF, RDF Schema (RDFS), XML Schema (XMLS). RDF and RDFS offer classes and properties, while XMLS contains the datatype IRIs for literal values. Each them of has its own namespace, which are for the sake of readability often abbreviated with prefixes. In such cases the IRIs

are represented with a prefix:suffix syntax, which means the concatenation of the prefix and the suffix. The following Listing shows a valid RDF dataset containing the triples of the example.

```
@prefix rdf:    <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
@prefix rdfs:   <http://www.w3.org/2000/01/rdf-schema#>
@prefix xmls:   <http://www.w3.org/2001/XMLSchema#>
@prefix domain: <http://myDomain.com/#>

domain:1      rdf:type          domain:Student    ;
               rdfs:label       "Bob"^^xmls:string .
domain:2      rdf:type          domain:Course     ;
               rdfs:label       "Math"^^xmls:string .
domain:1      domain:attends    domain:2          ;
               domain:avgGrade  "1.72"^^xmls:float .
```

Listing 2.2: RDF data in N3 serialization format

The ";" in N3 is used to divide predicate-object pairs that constitute a triple with the same subject. With this approach the subject do not have to be written as many times as many triples it participates in. The property *rdf:type* expresses the *instanceOf* relationship, while *rdfs:label* is the most widely used property to assign names to instances. By the literals it can be seen that they are surrounded with quotation marks and extended with the type notation from the XMLS vocabulary.

2.1.2 RDF and RDFS Vocabularies

In the previous section the RDF and RDFS vocabularies were already mentioned, but this section provides much more detailed information about their usage and utility. RDF and RDFS offers classes and properties that allows to express the rules of the RDF data. First of all it has to be defined, what IRIs represent classes and what properties. For this purpose there are two classes the *rdfs:Class* and *rdf:Property*. To define own properties and classes, just like by the instances the *rdf:type* property have to be used.

```
domain:Student      rdf:type          rdfs:Class .
```


domain: Course	rdf:type	rdfs:Class .
----------------	----------	--------------

Listing 2.3: Class definition

In this way it is defined that in our dataset the instances will represent students and courses. The definition in the case of the properties is a bit more complex, because it has to be defined too, what type of subjects and objects they can connect. For this definition there are two properties in RDFS, the *rdfs:domain* and the *rdfs:range* respectively.

domain: attends	rdf:type	rdf:Property ;
	rdfs:domain	domain: Student ;
	rdfs:range	domain: Course .
domain: avgGrade	rdf:type	rdf:Property .
	rdfs:domain	domain: Student .
	rdfs:range	xmls: float .

Listing 2.4: Property definition I.

Further really important concept in data modeling is the subclass relationship. This is expressed in RDFS with the the *rdfs:subClassOf* property. The informal definition of the subclass concept, is that if class B is a subclass of class A, then every instance of class B is an instance of class A as well. The definition is that every student is person can be done in the following way:

domain: Person	rdf:type	rdfs:Class .
domain: Student	rdfs:subClassOf	domain: Person .

Listing 2.5: Sub class definition

The previous three Listing contained the RDF triples for the definition of an own vocabulary. The vocabulary is called as well ontology and its purpose is to define the scheme of the data. Nevertheless the properties for label, type, domain and range, and the classes for class and property are supposed to be defined like the ones in the example ontology. The RDF and RDFS vocabulary have this definition too, and it is depicted in Figure 2.2.

The root of any RDF dataset is the class *rdfs:Resource*. *rdfs:Resource* is class because it is the instance of the *rdfs:Class*. *rdfs:Class* is a class

in our project.



Figure 2.3: A subset of OWL vocabulary



Figure 2.4: Scheme of the restrictions

On the left side the scheme of the value restriction, and on the left side the scheme of the qualified cardinality restriction is depicted. The triples with multiple predicates on the figure show the possible properties that can be applied for that triple. Important by both cases that the central restriction instance (rectangle) is not an RDF resource but a blank node. Blank nodes are such RDF nodes that does not have a IRI. Later in this section example will be provided regarding their definition.

The idea is that the restriction node encompasses the triples that describing a certain rule of the domain. The class on which the restriction is applied, is the subclass of the restriction blank node, while the property is connected to it with the *owl:onProperty* property. By the value restriction the *owl:someValuesFrom*/*owl:allValuesFrom* properties define the instances of *ClassA* can constitute a triple with property *Property1* at least with one instance/and only with instances of *ClassB*. The qualified cardinality restriction asserts how many instances have to present at least/exactly/at most

with the given classes and property. In that case the second class is assigned to the restriction node with the *owl:onClass* property.



Figure 2.5: Ontology extension

In order to illustrate the utility of restrictions, the ontology from the previous section was extended with three subclasses (Figure 2.5). The abbreviation *CS* stands for computer science. The following two restriction asserts that a computer science student is allowed to attend only computer science courses, and has to take at least two key courses.

```

domain:CS_Student rdfs:subClassOf [
  rdf:type          owl:Restriction ;
  owl:onProperty   domain:attends ;
  owl:allValuesFrom domain:CS_Course .
]

domain:CS_Student rdfs:subClassOf [
  rdf:type          owl:Restriction ;
  owl:onProperty   domain:attends ;
  owl:onClass      domain:KeyCourse;
  owl:minQualifiedCardinality "2"^^xmls:nonnegativeInteger .
]

```

Listing 2.7: Blank nodes in N3

2.1.4 SPARQL

RDF data is stored most commonly in triplestores. A triplestore is software for storage and retrieval of RDF triples. The retrieval, like by any other kind

of database, happens via queries, that are formulated in a particular query language. The query language for RDF is called SPARQL.

A basic SPARQL query consists of two main parts. Firstly of a triple pattern, which differs only from a RDF dataset that it contains variables. The variables are denoted with a question mark in the triple pattern. Secondly of a set of variables that the query has to return. Listing 2.8 shows an example query to demonstrate the syntax. After the *SELECT* keyword there is the variable to return and after the *WHERE* keyword inside the parenthesis there is the triple pattern.

```
SELECT ?student
WHERE {
  ?student    rdf:type    domain:Student .
}
```

Listing 2.8: SPARQL Query I.

It can be seen that the namespace abbreviation with prefixes works the same way like in RDF documents. If the query is executed on the dataset from Figure 2.6, then it returns the *domain:1* and *domain:3* instances for the variable *?student*.



Figure 2.6: Example RDF dataset

Furthermore the triple pattern can consists of multiple triples as well, like in the following query:

```
SELECT ?student ?label
WHERE {
  ?student    rdf:type    domain:Student .
  ?student    rdfs:label  ?label .
}
```

```
}

```

Listing 2.9: SPARQL Query II.

Executed on the same dataset, this query returns only the instance *domain:1*, because *domain:3* does not have a label, thus there is no matching RDF node for variable *?label*. This means that the triples in a triple pattern are in *AND* relationship. But there is the keyword *OPTIONAL*, that allows the definition of sub triple patterns, which are not required in the RDF dataset. So if the triple with the label variable is in the *OPTIONAL* sub pattern, then the query II. returns *domain:3* instance as well, so that the variable for the label will be empty.

```
OPTIONAL { ?student rdfs:label ?label . }
```

Listing 2.10: Optional sub triple pattern.

Moreover its is possible to define filters on the variables. The most commonly used are the regular expression filter on literals.

```
FILTER regex(?label , "^Bo ")
```

Listing 2.11: Regex filter in SPARQL

Finally it is possible in SPARQL to query blank nodes, the same way with variables. The following query then queries the ontology and returns at least how many key course must be attended by a computer science student.

```
SELECT ?minKeyCourses
WHERE {
  domain:CS_Student rdfs:subClassOf ?restriction .
  ?restriction      rdf:type          owl:Restriction .
  ?restriction      owl:onProperty   domain:attends .
  ?restriction      owl:onClass      domain:KeyCourse .
  ?restriction      owl:minQualifiedCardinality ?minKeyCourses .
}
```

Listing 2.12: SPARQL Query III.

2.2 Ontologies

Ontologies are used to describe types, relationships and properties of objects of a certain domain. It is a common practice to use existing ontologies rather than developing them by ourselves. The main reason for this lies in the fact that the ontology development is a time consuming and tedious process. Two ontologies are taken in the project, one for the human anatomy and one for biomedical investigations. In order to connect these two, during the project our own ontology (called as well *RDFBones*) is developed too. Firstly the two applied ontologies will be discussed and lastly the *RDFBones* ontology.

2.2.1 Ontology for the anatomy of the human body

The ontology modeling the human body is called *Foundational Model of Anatomy* (FMA). FMA is a fundamental knowledge source for all biomedical domains, and it provides a declarative definition of concepts and relationships of the human body for knowledge-based applications. It contains more than 70 000 classes, and 168 different relationships [6]. All kind of anatomical entities are represented in FMA, like molecules, cells, tissues, muscles and of course bones. In our project we use only the skeletal system related subset of the FMA. The taken elements are the following classes (and its subclasses) and properties:

- Classes

Subdivision of skeletal system - fma:85544

Bone Organ – fma:5018

- Properties

fma:systemic_part_of

fma:regional_part_of

fma:constitutional_part_of

The class *Bone Organ* is the superclass of all bones in the human skeleton. Each bone belongs to a subclass of the class *Subdivision of skeletal system*. Moreover there are such skeletal subdivisions which are part of another skeletal subdivision. In both cases the relationship is expressed by

the property *fma:systemic_part_of*. To define which bone organ belongs to which skeletal subdivision, FMA contains *owl:someValuesFrom* restrictions (Listing 2.13).

```
fma:BoneOrganX  rdfs:subClassOf [
  rdf:type          owl:Restriction ;
  owl:onProperty   fma:systemic_part_of ;
  owl:someValuesFrom fma:SkeletalSubdivisionY .
]
```

Listing 2.13: Rules of the skeletal system defined in OWL

These restrictions mean that a bone organ instance cannot stand on its own, but it has to be a systemic part of an appropriate skeletal subdivision instance. Figure 2.7 shows the main structure of the applied subset of FMA by depicting the restrictions with red arrows, and the subclass relationships with dashed arrows.



Figure 2.7: Ontology structure for the human skeleton

Finally, the advantage of using the FMA ontology is that, if in the future further elements of the human body have to be addressed by the research processes, i.e. muscles, then these classes can be easily integrated to the currently applied subset.

2.2.2 Ontology for Biomedical Investigations (OBI)

The aim of the OBI ontology, is to provide formal representation of the biomedical investigations in order to standardize the processes among different research communities. It is a result of a collaborative effort of several working groups, and it is continuously evolving as new research methods are

being developed. Its main function is to provide a vocabulary that allows the definition of the rules regarding how biological and medical investigations have to be performed. OBI reuses terms from the *Basic Formal Ontology* (bfo), from the *Information Artifact Ontology* (iao) and from the *Open Biological and Biomedical Ontologies* (obo) [1]. The most important classes and properties adopted by the *RDFBones* project are the following ones:

- Classes

Investigation - obo:0000015

Process - bfo:0000015

Entity - bfo:0000001

Information Content Entity - iao:0000030

- Properties

has part - bfo:00000051

has specified input - obi:00000293

has specified output - obi:00000299

Above these classes several other classes have been taken, but they are sufficient to discuss the essence of ontological definition of investigations. The idea of *RDFBones* project is to define custom investigations by defining subclasses of the above mentioned classes, and restriction on the properties, the same way like FMA describes the human skeleton. These further ontological statements are called extensions. The following image illustrates an example ontology extension for an investigation (the notation is the same like on Figure 2.7, just the restrictions are defined on the OBI properties).

It can be seen that the investigation contains two processes (*has part* predicate), and each process has various inputs and an output. In our case input entities are segments of bone organs but they could be any kind of material. During a particular process the input entities are studied, and the result of the study is an information content entity instance, which represents some measurement value. The provided scheme is just an illustrative example and the modeling of an investigation in reality is more complex and involves more OBI classes. They will be discussed in a bit more detail in Chapter 4.



Figure 2.8: Extending OBI ontology

The conclusion is that with these classes and properties, OBI offers a powerful vocabulary for defining custom investigations. The advantage of such ontological description is that everything is stored by means of RDF triples, and therefore it is possible to develop software applications which generates user interfaces based on the results of SPARQL queries performed on the extensions. From this follows that these formal definitions can be considered as software specification as well.

2.2.3 RDFS ontology

RDFS ontology is an extension of the OBI ontology. It has its own namespace (the empty string a valid prefix too):

```
PREFIX : <http://w3id.org/rdfbones/core#>
```

Listing 2.14: RDFS ontology namespace

Figure 2.9 shows the four most important classes (blue ones) as subclasses of further OBI classes using the above defined prefix. On the left, there is class *:SkeletalInventory*, whose purpose is to incorporate the set of existing bones in a skeletal collection. The *Completeness2States* and *Completeness2StatesLabel* classes are used to represent if a bone segment is complete or just partly present. The *:SegmentOfSkeletalElement* is the subclass of *bfo:0000020*, which is the subclass of the previously mentioned *Entity* class. With this class for bone segments, *RDFS* makes possible the definition of custom segments of particular bone organs, in order to allow more fine grained modeling of the research activity. It is again a sort of ontology ex-

tension, thus the definition has to be done by means of custom subclasses and restrictions. The property that expresses the relationship between bone organs and bone segments is the *fma:regional_part_of*. Also this is the property that connects the RDFS bones and thus the OBI to the FMA.



Figure 2.9: RDFS bones as OBI extension

2.3 Web applications

Nowadays web applications are prevalent since they have the advantage against desktop application that they do not have to be installed on local computer, and can be accessed from web browser and thus can be used anywhere from the world. Like by the ontologies, the development of a web application is a complex process, and therefore an existing open-source framework called VIVO has been applied in the project. VIVO is an appropriate choice, because it has been developed particularly for browsing and editing RDF data. The designed software of the thesis is an extension of the VIVO framework. In order to provide the necessary information required to understand the problem and the solution of the thesis, this section covers some fundamental web application technologies and the main functionality and capabilities of VIVO framework.

2.3.1 Fundamentals

Client-server architecture

Web applications consist of two main units. The first is client, which the user interacts with, and the second is the server, which is an other application that serves the request coming from the client. The client and server programs

are running normally on different machines, and they communicate through Hypertext Transfer Protocol (HTTP). The main mechanism is that client, which is a web browser application, sends an HTTP request through the web, and the server is found based on the URI of the HTTP request. Upon the content of the request the server returns a document written in Hypertext Markup Language (HTML). The HTML document contains the definition of the elements of the interface and it is interpreted by the web browser.



Figure 2.10: Client server communication

An HTML document consists of different elements like buttons, tables input fields. Each element is represented by so-called tags. The HTML has a hierarchical structure, and each element is the child of the tag *html*. On listing 2.15 it can be seen that each tag has a opening and closing element.

```
<html>
  <div class = "welcome"> Welcome on the web application </div>
  <a href="http://webapp.com/page1"> Page 1 </a>
</html>
```

Listing 2.15: Example HTML document

The tag, like the *html* in the example can contain further tags, and have normally at least one parameter (i.e *class* and *href*). The tag *div* is the most general element of web pages, while the *a* tag defines link, where the *href* parameter is defines the URI of the HTTP request they initiate. The request of the example link arrives to the same server, and the task of the application is to process the request URI and return the HTML document for the new page.

Data driven web applications

Most of the web applications nowadays incorporate databases. Databases are used to store large amount data in an organized way. Databases are always come along with a database management system (DBMS) that allows to create, edit, delete and retrieve data in the database. So DBMS is software that acts as an interface between the web application and the data. In the following, the database and DBMS together will be referred simply as database.

By web applications using databases the most important point, that web pages are not statically defined in HTML files, but generated by the application dynamically using a particular dataset. The process of loading of a web pages showing any data, starts with the execution of a query. This means the web application sends a query to the database and gets a desired data. The result of a query in terms of the web application is conventionally a list of data objects. The term object is used generally, and refers to a data type that organizes its values by keys. The elements of the output list represent the rows of the query result table, and the fields of the object in turn the rows respectively.

To define how the web page has to be generated from the dataset a so-called template file are used. The template file is basically an HTML document, that is extended with some additional syntax. The elements defined in this syntax can be interpreted by the template engine. There a lot of template engines and languages, but in the following I provide an illustrative example in *Freemarker* template language, that is used within the VIVO framework.

```
<#list students as student>
  <tr>
    <td>${student.name}</td>
    <td> <@linkButton "grades" ${student.id} /> </td>
  </tr>
</#list>
```

Listing 2.16: Template file example

Important that the data that is passed to the template engine has a name,

by which it is referred in the template file. In the example query result is stored in a variable *students*, where each student object has two keys, the *name* and *id*. The tag *#list* represent a loop, that iterates through the input list. The content withing the *#list* tag appear as many times in the resulting HTML, as many elements the input list have. The variables withing normal HTML tags are accessed with *\${..}*.

Other useful feature of templates that it allows the definition of macro, which acts like subroutines in programming. In the example the macro *linkButton* takes two input parameter and generates the *<a/>* tag with a certain image. This make the development more convenient and clear.

```
<#macro linkButton urlMapping id>
  <a href="webapp.com/${urlMapping}?id=${id}">
    
  </a>
</#macro>
```

Listing 2.17: Macro definition

In the macro definition it can be seen that the url of the link contains the parameter *id*, which is an additional information in the HTTP request. The idea is that the request is handled by such a server routine that substitutes the value of the parameter into a query, in order to get data about individuals. Then the returned page may contain additional link for further data entries. This is the fundamental method how web pages are used to discover data from databases.

Interactive web pages

The previous section showed the principles of how data can be browsed by means of web pages and links. In such static cases the HTML document was assembled completely by the server, and the links initiated the loading of whole new pages. Nevertheless it is often more efficient and leads to better user experience if the new content is added dynamically to the currently opened web page. Such functionality can be achieved with JavaScript (JS), which is a scripting language run by the web browser. The most fundamental features of JS, that it is capable of storing data in variables and can add,

edit or remove HTML elements of the pages.



Figure 2.11: Static and dynamic web pages

Figure 2.11 illustrates the difference between static and dynamic web pages, where the blue rectangle stand for the client side. The idea of dynamic web pages in data driven web applications, that if new content has to be shown on the page, then not an HTTP request is sent to the server, but a JS routine is called. JS code is defined in the HTML document within the `<script/>` tag. The routines are assigned to HTML elements by their id-s in the following way:

```
<html>
  <div id = "button"> Show content </div>
  <div id = "content"></div>
  <script>
    ...
    $("#button").click(function(){
      $("#content").text(data)
    })
    ...
  </script>
</html>
```

Listing 2.18: JavaScript routine assigned to an HTML element

This simple JS code illustrates how it is possible to load new content to the HTML element. In the example the *append* function sets the text of the div with id *button*. The *data* is a JS variable holding some text. The value variable can be either initialized by the server by the page assembly, or by AJAX calls. AJAX is an acronym for *Asynchronous JavaScript and XML*. The AJAX is technology that allows JS to load data from the server

asynchronously, which means that the request is initiated through JS routine, and response arrives as well to JS routine. The data by AJAX is mostly in JSON format. JSON stands for *JavaScript Object Notation*, which is a standard data format. A JSON object consists of a set of key-value pairs, where the value can be any data, arrays or even further objects.

```
{ key1 : "data",  
  key2 : [ "value1", "value2" ],  
  key3 : { key : "value" } }
```

Listing 2.19: JSON object example

2.3.2 VIVO framework

VIVO maintains two basic types of page. The first is for displaying, and the second is for creating and editing RDF data. The former will be referred to as profile page, because it shows the data related to one individual RDF instance, and the latter will be referred to as entry form. Although the scope of the thesis is only the data input, the profile pages will be covered as well briefly in the first part, because the entry forms are dependent on them to some extent and they are relevant regarding the future work. The second part provides a simplified explanation of how the RDF data input works originally in VIVO, which is necessary to understand the utility of the idea proposed by the thesis.

Profile pages

The task of the profile pages in VIVO is to display all instances and literals that constitute a triple with the instance, whose page has been called. These neighbor RDF nodes are shown on the pages grouped by property, and properties are organized into tabs. Further grouping possibility is offered by the so-called faux properties. By means of faux property definition, it can be achieved that the instances on the profile pages are grouped by their type.

Figure 2.12 shows the layout of a VIVO profile page of a skeletal inventory, where in the skeletal subdivision property group the two faux properties (*skull* and *vertebral column*) can be seen. The instances (blue



Figure 2.12: Faux properties on VIVO profile pages

entries) are both connected to the skeletal inventory instance with the *rdfbones:hasSkeletalSubDivision* property, but as there two faux properties are defined for the classes "*fma:5018 -Skull-*" and for "*fma:13478 -Vertebral Column-*", they appear in distinct property fields. The peculiarity of VIVO that these interface related issues are not defined in template files of server routines, but in RDF configuration triples. Figure 2.13 a simplified dataset of the faux property description for the skull. The notation in the rectangle denotes the label of the instance, because its IRI is not relevant at this point. By the profile page generation only the triples regarding range class and the base property are considered, the value for the custom entry form is for the data input.



Figure 2.13: Faux property descriptor RDF dataset

On Figure 2.12 next to the property field, a button with a + sign can be seen, which is link to a data entry form page. From each property field the request arrives to the same handler routine on the server. These requests have always three parameters (VIVO uses in its parameter names URI instead of IRI, which is an abbreviation for Unified Resource Identifier, but it

does not make a difference):

- *subjectUri* - IRI of the instance to whom the profile page belongs
- *predicateUri* - is the IRI of the property (can be a faux property)
- *rangeUri* - IRI of the range class of the property

Custom entry forms

By default VIVO redirects the user to such an entry form where only one instance or literal can be added with the type defined in the *rangeUri* parameter. However it is possible to so-called entry custom forms for more complex datasets.



Figure 2.14: Custom entry form for skeletal subdivision

Figure 2.14 shows the layout of an HTML form with three fields, where the user can enter specific values for a new skeletal subdivision. After the data entry, if the submit button is clicked an HTTP request is sent to the server. This is a same type of request like by the link explained in the previous section, just the values of the parameters are set by the user.

The idea of custom entry forms in VIVO, that they allow the definition only of HTML input form layout and the dataset definition, and developer does not have to care about how the values from the form are substituted into the RDF data and how the new instances are generated. For the definition two files have to be created, a *Freemarker* template file (with .ftl extension) for the form definition, and a Java class that contains in its fields the reference to the template file and the RDF data definitions. The name of the Java class is stored in the faux property definition (Figure 2.13), and thus VIVO

can find it based on the *predicateUri* parameter of the custom entry form HTTP request. The template file definition is simple due to the *Freemarker* macros provided in VIVO. Each type of input field has a distinct macro and have two input parameters, the parameter name and the title.

```
<form>
  <@title "Add skeletal subdivision">
  <@labelField "label" "Label">
  <@textField "desc" "Description">
  <@booleanField "complete" "Complete">
  <@submitButton>
</form>
```

Listing 2.20: subdivision.ftl

The class has to extends the class *EditConfigurationGenerator* class, thus its fields are given. The variable *templateFile* must hold the name of the template file.

```
this.templateFile = "subdivision.ftl"
```

Listing 2.21: Form definition in Java

The next fundamental variable of the generator class is the *triplesToCreate*, which contains the RDF triples to be created after the submission.

```
this.triplesToCreate = "
  ?subjectUri    rdfbones:hasSkeletalSubdivision    ?subDivision.
  ?subDivision    rdf:type                            ?rangeUri .
  ?subDivision    rdfs:label                          ?label^^xmls:string.
  ?subDivision    domain:description                 ?desc^^xmls:string .
  ?subDivision    domain:complete                    ?complete^^xmls:boolean . "
```

Listing 2.22: RDF Triples to create

It can be seen that there are variables like in SPARQL, defined with question mark. These must be the same as the variable defined in the template for the input fields. Moreover there are three basic types of variables defined by the following three lists:

```
this.urisOnForm = {};  
this.literalsOnForm = {"label", "desc", "complete"};  
this.newInstances = {"subDivision"};
```

Listing 2.23: Variable type definition

There are no URIs (IRIs) on the form, but there are three literals. The variable *subDivision* has to get new unused IRI, and the *subjectUri* and *rangeUri* values are coming from the initial request. These section gave an insight into how it is possible to define data input processes in a declarative way within the VIVO framework.

Chapter 3

Problem Statement

The first section discusses the problem general way by addressing the challenges of the implementation both for the client and the server side in case of more elaborate data input processes. The second section in turn refers to the use-cases of the *RDFBones* project and to the limitations of VIVO framework. Finally, the third part introduces the main elements the descriptor logic and gives an insight into the functionality of the developed system.

3.1 Multi level data input

In the previous chapter it has been discussed how can we implement simple data input forms within the VIVO framework. The simplicity of the illustrated problem lied in that the number of instances which were created through the process was constant, in particular one, and only a set of literal attributes were set by the user through HTML input elements. Nevertheless there are more complex entities consisting of several sub parts, where these sub parts are represented in the ontology with further classes. Consequently the RDF dataset for such entities incorporates multiple instances organized into a tree structure. Figure 3.1 shows an example ontology and an RDF dataset. The classes (ellipses) without notation are subclasses of the three main classes and their names are not relevant.

Such dataset poses the requirement for the input form, that the user has to be offered such interface elements which enable to add the components and subcomponents step by step. Adding a component means in terms of



Figure 3.1: Ontology and RDF triples for complex entities

the form that a new sub form appears which contains further input fields for the component instance.

Figure 3.2: Multi level form

Figure 3.2 shows the layout of the form for multi level data. The additional element compared to the static HTML form is the field with an button for adding the sub forms. The dotted rectangle stands for the container element that encompasses the added sub forms. The form data contains the same way the key value pairs for the main form element, but it has an additional array field that contains the data objects of the sub forms. The sub form data object works the same way, if the have sub forms then they

contains further arrays. To realize such functionality, JavaScript routine is required on the form, that adds the sub form elements to the container, and generates the appropriate form data upon the user actions.

Listing 3.1 shows the JSON object generated during by form from Figure 3.2, where the objects are surrounded with ("{}"), while the arrays with ("[]"). After the submission the server has to process this object by iterating through the arrays of them, and generate the appropriate RDF triples.

```
{ type : "eq:elementA",  
  label : "Element_4391",  
  components : [  
    { type : "eq:componentA1",  
      label : "Component_8531",  
      subComponents : [ { ... } ],  
    }, {  
      ...  
    }  
  ]  
}
```

Listing 3.1: Multi level form data in JSON

Further challenge is that the options of the type selector on the sub forms, are dependent on the selected type of the parent form (the form which the sub form has been added from). This means that the client has to load asynchronously the values, by sending AJAX request containing the selected type value to server. The task of the server is to perform the query that retrieves the classes defined through restrictions in the ontology. The goal of this functionality is firstly to ensure that only such data is created that conforms to the rules defined in the ontology, secondly the interface is much more usable if not all the components are listed, just the ones that are belong to the selected element. Moreover in this way the validation on the server side after submission can be omitted.

Finally, really important part of the problem is the editing of the existing data. To allow the application has to restore the state of the form, in which it has been submitted by the data creation. In the previous chapter we have seen that it is currently solved by defining SPARQL queries that retrieves the form variables. But since the form data is not just a set of key value-pairs

but a multi level data object, this approach is not sufficient. An algorithm is required that generates the multi level JSON object from the existing triples iteratively. Furthermore after the arrival of the existing data to the client, an other routine has to reset the state of the form with the appropriate sub forms and certain selector options as well.

3.2 RDBFones use-cases in VIVO

During the project two use-cases and their solutions are discussed. We have seen in the previous chapter is the data input process definition for various cases happens through the data definition of RDF triples with variable (graph pattern) and the the form layout. Figure 3.3 and Figure 3.4 illustrate the graph pattern and the multi level form layout of the two most important cases. The yellow rectangles denotes the main nodes of the dataset, which were characterized solely by literals in the static case.

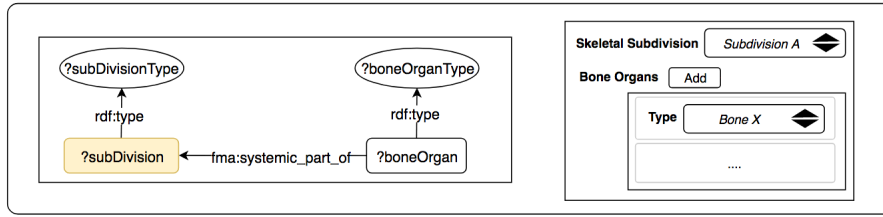


Figure 3.3: Skeletal subdivision graph pattern and form layout

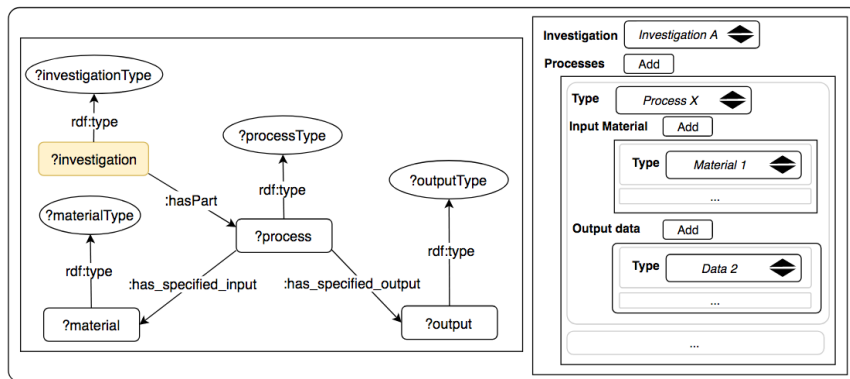


Figure 3.4: Investigation graph pattern and form layout

The problem is that it would be necessary to define custom JavaScript routines for each cases, which adds the sub forms and handles the dependency between the particular selector fields. Moreover since VIVO cannot process the multi level JSON object coming from the client after the submission based on this single triple pattern in string, for each individual Java routines have to be written that creates the data, as well as for the retrieval. Furthermore the individual variables in the triple pattern do not appear only once in the result dataset, thus their value cannot be defined with SPARQL a single queries.

3.3 Solution scheme

In VIVO the data input problems were solved by means of assigning values to a set of fields of a certain Java class, based on which the generic algorithm creates and retrieves the data. The task of the thesis is to design a vocabulary, that allows the expression of multi level cases. The vocabulary is a set of Java classes, whose instances serve as the definition of the problems. Descriptor objects are processed and further Java and JSON objects are generated based on the Java and JavaScript libraries can manage the functionality.

In the triple pattern definition the most fundamental improvement is that it is not stored as a string but as a set of different types of triple. The three main types of triple are the *Triple*, the *MultiTriple* and *RestrictionTriple*. The *Triple* has the same role as a triple in the string in VIVO. The *MultiTriple* allows the expression of the hierarchy in the graph pattern, which presents on the form as well. With the *MultiTriple* it is possible to prepare the submission handler routine that a set of variables are not appear as single values in the form data, within further objects in an array. While the *RestrictionTriple* is used to express dependencies between classes in the graph pattern. This definition is used to generate the SPARQL queries that return the options of the dependent variables. Figure 3.5 depicts the extended graph pattern definition, where the restriction triple are depicted with red arrow, and the multi triple with double line arrow.

For the form layout definition the two main classes are the *Form* and *FormElement*. There are subclasses of the *FormElement* class, which rep-

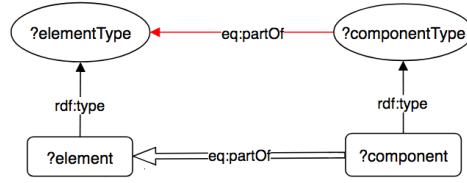


Figure 3.5: Extended RDF graph pattern definition

resent the different input fields. The form element that defines the multi level case is represented by the *SubformAdder* class, which incorporates the elements of the sub form naturally. The hierarchical Java object set is converted into JSON object, based on which the JavaScript library is able to operate.

Figure 3.6 functionality depicts the scheme of the functionality. The most important improvement wrt. to VIVO that there is processor that is capable of inferring some addition descriptor data object from the original descriptor objects. Such as SPARQL queries for the data dependencies and data retrieval.

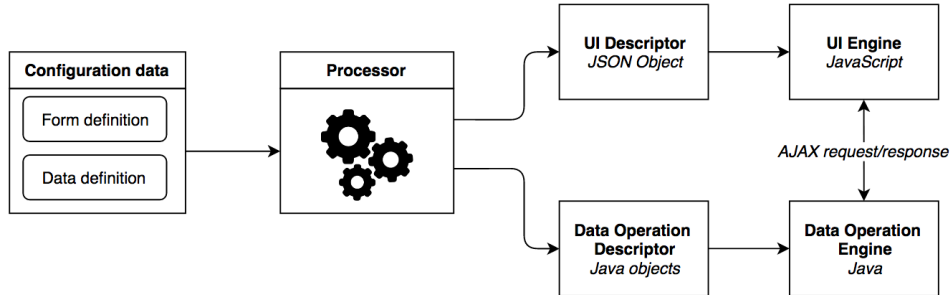


Figure 3.6: Framework functionality outline

Chapter 4

Vocabulary for web application domain

4.1 Elements of the vocabulary

4.1.1 Data definitions

To understand the necessity of certain elements of the vocabulary, further details of web the applications have to be explained. In VIVO, the display of the existing and the creation of the new data happens in individual pages. The display is done by so-called profile pages, that show the information about one particular instance. As it was in section ??, the information is grouped by predicates, and each predicate field contains a link that can call the data input pages. The link contains three parameters, *subjectUri*, *predicateUri* and the *rangeUri*. The *subjectUri* hold the value of the instance on whose profile the link is, the *predicateUri* is for the predicate, with which the new dataset is connected to the subject, and the *rangeUri* is an optional paramater.

Figure 4.4 shows the workflow of a data entry process. On the right profile page of a skeletal inventory can be seen, which lists the added skeletal elements. The profile page is configured that the *rangeUri* parameter holds in the links the URI of the classes of skull and vertebral column respectively. These parameters have to be considered by the form loading because they influences the options of the first selector which let the user add the skele-

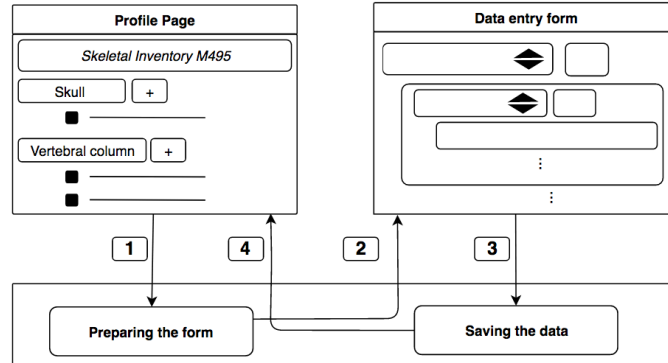


Figure 4.1: Complete workflow of data input process

tal sub sub division. So therefore it necessary to introduce a flag into the vocabulary that sign if a variable is coming with the HTTP request for the form loading, or with the JSON object after the submission.

Figure 4.3 shows all the nodes types and their attributes. Above the *mainInput* boolean flag, there is the variable name, which is required, and the constant value in case. There are three types of variable, the class, resource and literal. The literal variable itself denotes a string value and it has several subclasses for the other primitive types.

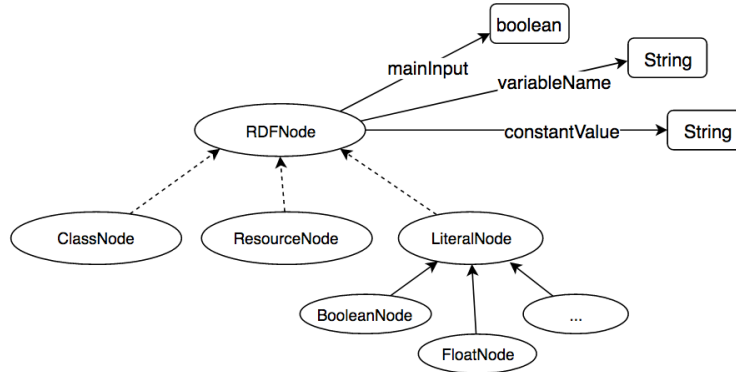


Figure 4.2: Variable types and their attributes

The other, more important is the modeling of the triples in the dataset. The vocabulary for triples has the purpose to express different constraint on the data scheme as well. Above the class *Triple* and *MultiTriple*, which were addressed in the end of the last chapter, there are two types of re-

striction triples. One for the classes and one for the instances. As we have seen in the description of the OWL ontologies, there are different types of restrictions can be defined. For this reason it should be possible to allow the definition of which restriction is used by the ontology, upon the entry form should operate. This can be expressed by the three boolean, types of the *classRestrictionTriple*. Moreover the greedy boolean flag means that the SPARQL query that queries the ontology has to return not only the result class but their superclasses too. Finally the instance restriction triples as the name indicates, expresses constraints between instances on the form. The examples in the next section will make the usage of the vocabulary more clear.

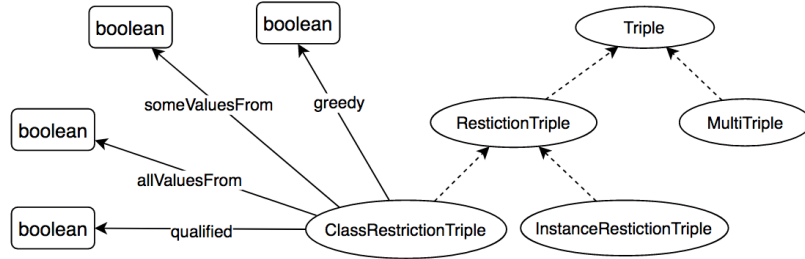


Figure 4.3: Triple types

4.1.2 Form definition

The class *Form* acts like a container for the form elements. There are two main types of form elements, the literal field and the selector. The literal field do not have further subclasses because its type, is defined through the type of the variable it represents. It would be a sort of over definition. This is the simplest case where the form adopts to the data model.

The selector can refer both instances and classes. If it represent an instance, so it let the selection of an existing instance, then it is possible to define an *InstanceViewer*. This feature allows to define a table with several columns. The utility is that the application can show more information about an instance than only the label in the selector field. Each column has a title and a number, and they refer to as well *RDFNodes*, whose values they show in the entries.

The class *SubformAdder* is the subclass of the selector, and has a relationship to the form with the predicate sub form. With this connection it is possible to define the sub form as new form instance. Moreover it has boolean flag, that allow to define a button add all should appear on, which adds all the possible subforms. This feature is useful be the skeletal subdivisions that contains much bones.

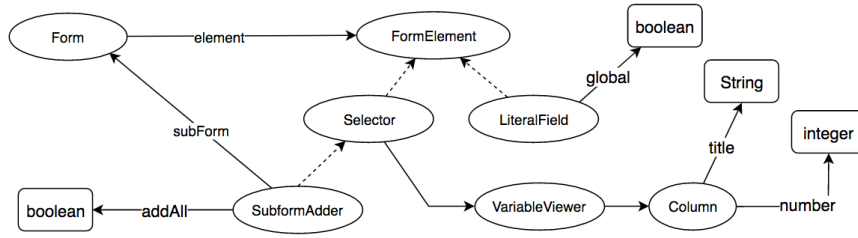


Figure 4.4: Form definition

4.2 Use-cases of the *RDFBones* project

The aim of this section is to show how it is possible to solve different problems with designed vocabulary. It covers the two main tasks of the project, the skeletal inventories and the study design execution. These two examples are sufficient to show the utility of the particular elements in the vocabulary and exemplify how their assembly can lead to a compact definition of complex web application problems.

4.2.1 Skeletal Inventories

Skeletal inventories were already addressed in section ???. Their goal is to define what kind of skeletal elements are present. In this part the creation of the primary skeletal inventories are discussed in more detail. This use-case addresses some additional challenges of the software, that were not mentioned yet. The explanation starts with the illustration of the implemented interface, to show what problem the high level logic has to define. As it was mentioned in figure 4.4, the entry forms can have inputs, which in this case the input is the class URI of the skeletal subdivision that has to be added with it sub subdivisions and bone organs. Therefore the first element of the

entry form is the selector of the sub subdivision.

Skull

Skeletal Regions **Viscerocranium**

Viscerocranium

BoneOrgans **Left temporal bone**

Left temporal bone **complete**

Neurocranium

BoneOrgans **Right parietal bone**

Right parietal bone **partly present**

Figure 4.5: Input form for skeletal inventories

Next to the selector the buttons *Add* and *Add all* can be seen, that let the user add the sub forms. Figure 4.5 shows the layout, when two sub sudvision were added, to each of them, a bone organ. The bone organ selector works exactly the same as the sub sudvision selector, but the selector for the completeness state is simple selector, without a sub form.

Figure 4.5 shows the triple scheme representing the skeletal inventories, where the nodes are representing variables. All the rectangle are representing instances. All of them will be newly created instead of the subjectUri, which comes as a main input, and the arrows with double line depicts the multi triples. Important to note that between the variable *boneOrgan* and *boneSegment* there is only a single triple (*fma:regional_part_of*) because in this use-case is simplified version and only entire bone segments will be added.

Above the instances to be created the classes have to be represented in the model too, because they can be the subjects of the class restriction triples. Figure Figure 4.7 is depicts the complete data model of the problem.

For the better readability the predicates are not denoted, but their value can be found in figure Figure 4.6. Each instance (rectangles) is connected to the class variable (ellipses). The red dotted arrows indicates restriction statements. The large three rectangles, that encompass set of triples are the graph, which are connecting to each other by means of multi triples. This is

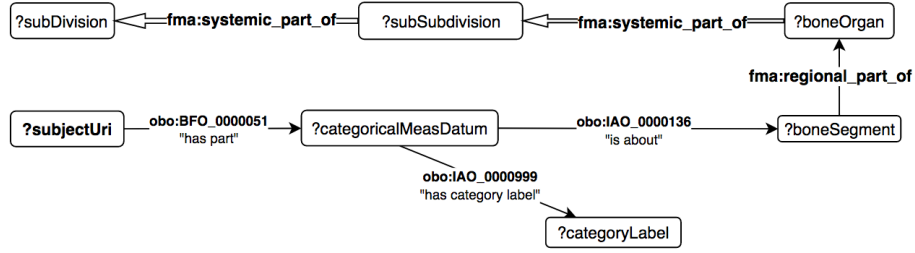


Figure 4.6: Skeletal inventory data triples

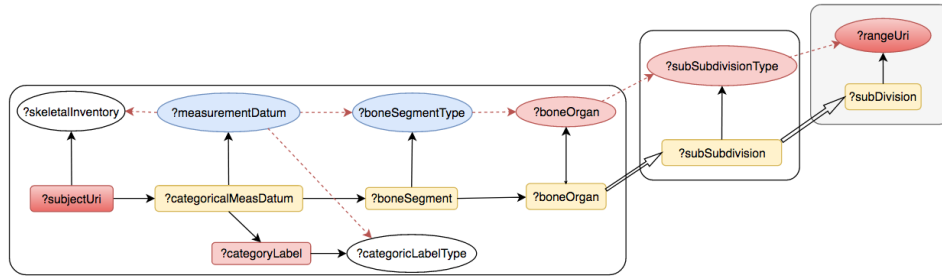


Figure 4.7: Complete data definition

the structure which is followed by the form as well.

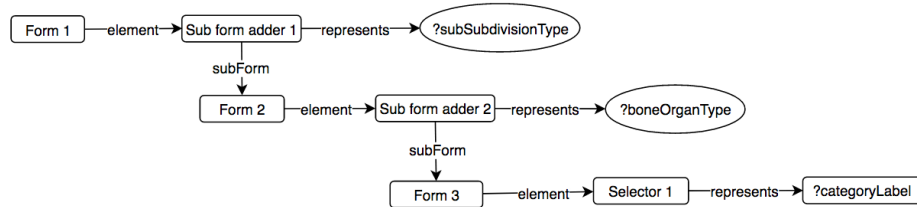


Figure 4.8: Form layout definition

Above the auxiliary rectangles for the graph, the nodes are colored to indicate their role in the process. The information that the colors hold is not defined in the vocabulary but it can be inferred from the whole data and form model. The first rule is that the main input nodes (*subjectUri* and *rangeUri*) are denoted with red, while the variables appear on the interface are light red. Based on that information it is already possible to determine to which instances it is required to assign an unused URI. Those instances are denoted with yellow. Furthermore, there are two classes in the data model that do not

appear on the interface, but their values can be evaluated through SPARQL queries. These are denoted with blue. And the classes with without color, do not appear on the final dataset, but they indicates constraint on the existing instances. Finally Figure 4.8 display the configuration data describing the form structure.

4.2.2 Study Design Execution

The entry form for study design execution has as well the hierarchical layout like the one for skeletal inventories, but there are additionally two elements on the main form. The first is the selector from skeletal inventories. It plays a role by the selection of the bone organs as input for the assays. To each assay a set bone segment types is defined in the extensions, that can be can be assigned to them as input. These bone on this form are not created newly but existing ones are selected, that were already added in the frame of the skeletal inventory data input. However there can be a large amount bone segments stored in the system, and thus the search is facilitated by showing only the ones that belong to the preselected skeletal inventory. The second is a global label field, whose value will be the label of all newly created instances.

Study Design Execution

Skeletal Inventory: Dry Bone Skeletal Inventory

Label: M-342

Assays: Assay.Glabella [Add] [Add all]

Assay.Glabella

Bone Segment: [Select]

Measurement Type: SexScore.Glabella [Add]

SexScore.Glabella

Indifferent [Close]

[Submit] [Cancel]

Figure 4.9: Input form for study design execution

Moreover the bone segment selector is not just a HTML selector input field, but a floating window implemented by JavaScript that allows the convenient browsing (Figure 4.10). It has two advantage with respect to

the conventional selector. Firstly it allows to display additional information about the instances above their labels, like their types or longer descriptions. Secondly it does not loads the form layout with additional subform for the selected instances, which by large amount assays and measurement datums is an important aspect.

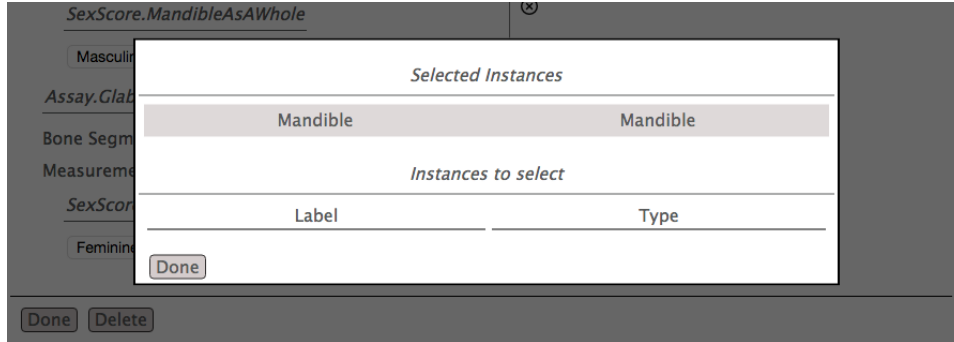


Figure 4.10: Instance selector for existing bone segment

On Figure 4.10 can be seen that there are two sections, one for the selected instances, and one for the instances to select.

The complete data structure of the form can be seen on the following image.



Figure 4.11: Complete data model

- Validation - cyclic graph - multiple dependencies
- subgraph subform dependencies

- Descriptor for data and processing

Chapter 5

Framework functionality

The aim of this chapter is to present the main mechanisms of the implemented software framework, which is capable of operating on high-level configuration data. Section 5.1 contains a more abstract description of the functionality, while section 5.2 goes into the implementation details both of the server and client side programming, including how the framework can be integrated into the applied web application. In both sections the explanation refers to the examples discussed in the previous chapter.

5.1 Main software modules and tasks

In Figure ?? we have seen the main work flow and components of the framework. Figure 5.1 is in turn a more detailed depiction of the software modules and processes of the application.

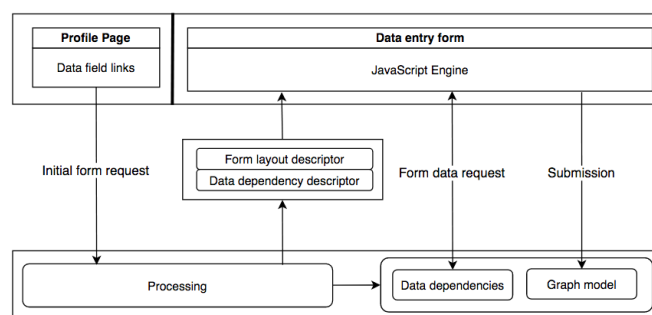


Figure 5.1: More detailed scheme

This section is divided into three subsections. First is the part (section 5.1.1) discusses the processing of the configuration data and generation of the functionality descriptor objects for the client and the server. The second part (section 5.1.2) is about the client functionality including the asynchronous communication with the server. Finally the third (section 5.1.3) part covers the process after the submission, namely how the RDF data is generated based on the data coming from the client, as well as how the existing data is retrieved from the triples store.

5.1.1 Validation

The processor algorithm has four main tasks to solve. The validation of the configuration data, generation of the form descriptor JSON object, and the Java object for data dependencies and for the graph model.



Figure 5.2: Processor tasks

The input of the algorithm is the set of triples describing the data model with its constraints, and form model, which refers to the nodes in the triple set. The first task to do is the validation because the descriptors are not supposed to be generated based on incorrect configuration data. The validator process has three scope of the checking, the nodes, the graph and the form.

Figure 5.3 depicts an example data model and illustrates the cases of valid and invalid nodes (Figure ?? contains the meaning of the shapes and colors). The explanation starts with the discussion of the form input nodes. Node 2 is valid because it is possible to generate a SPARQL query that retrieves the possible values of it. The query contains one triple which ask the subclasses of the constant class. Furthermore node 4 is valid as well, because there is path to it from a valid class node, therefore for there is again a SPARQL query for its values. However the variable 3 is not valid, because it does not contribute to any triple in path with valid input node or constant. Here it is important to note that the path cannot come from the

instance to the class, just the other way around. So the path $2 \rightarrow 1 \rightarrow 4$ counts in the processor routine, but $2 \rightarrow 5 \rightarrow 6 \rightarrow 3$ does not.



Figure 5.3: Valid and invalid nodes

The next task regarding the nodes is to check if each has a value by the RDF triple creation. The instances coming from the interface are automatically valid, because their URI is an input value. But the ones that have to be generated newly and get as value a new unused URI from the triple store, must contribute to triple as subject, where the predicate is *rdf:type* and the object is a valid class. For this reason the node 5 is valid, since its type class is valid, but node 6 is not. Moreover node 7 is not valid as well, since it does not have any type class defined in the data model. Finally regarding the literals the validation is the simplest, either they appear on the form or have constant value, otherwise they are invalid.



Figure 5.4: Valid and invalid graph

Above the nodes important itself the whole graph built by the triples have to be investigated. In the previous chapter the triple type *MultiTriple* were introduced. The rule regarding this type of triple that it divides the graph into subgraphs, and the subgraphs can connect to each other only be these triples. Figure 5.4 illustrates the valid and invalid graph arrangements.

The reason is that only to this type of scheme can the JSON object of the created by the data input process be mapped.

5.1.2 Dependencies and form functionality

The set of triples describing the data model builds a graph where the various input nodes are connected to each other. Further task of the processor algorithm to determine the subgraphs that define the SPARQL queries for the node appear on the form. The elements on the form has a specified order, and the rule that have to be considered during the processing, is that a variable can be dependent only of the main input variables or such variables that are before it on the form. The reason is that the dependency is practically SPARQL query with one output and with one or more inputs, and input node have to available by the execution of the query.



Figure 5.5: Form element order

Figure 5.5 shows the simplified form layout of the skeletal inventories and emphasizes the order of the elements with the number. The idea is that values of the selector for the node *subSubdivision* can be only dependent on the main input nodes because it is the first node. The *boneOrgan* in turn can be dependent on the *subSubDivision* too because its value has to be set before the options of the subform is loaded, thus it can be substituted into a SPARQL query.

Figure 5.6 depicts the scheme of the data constraints of the skeletal inventory, based on which the dependency retriever algorithm can be exemplified. As it was mentioned the task is to get one or more path from the variable of to an other node whose value is available for it. As the form's first element refers to the node *subDivision* its dependency has to be evaluted first. Since the node *subSubDivision* contributes to two restriction triples in the data



Figure 5.6: Skeletal inventory data constraints

scheme it is necessary to check the both paths. Since this node cannot be dependent on any other form node, it is dependent on the two main input nodes (*subjectUri* and *rangeUri*). While the by dependency for the node *boneOrgan* the *rangeUri* does not count, since the algorithm terminates already by the *subSubdivision* variable. Figure 5.7 shows the results subgraphs of the algorithm, where the output is depicted with green and the inputs with red and light red respectively.



Figure 5.7: Form dependency subgraphs

This result of the processor concerns both the descriptor of the client, and the server. On the server the dependencies are stored a classes that have the necessary fields, for the inputs and output and for the triples. Then these initialized dependency descriptor class objects are stored in a data map, where the key is the variable name of the output node. This map is a field of the form configuration class, thus if the client asks for the appropriate form variable through AJAX these SPARQL query assemble by the triples for can be executed with the incoming values.

For the client the dependency description is just the an assignment of an array, which contains the input node of the dependency, to the form node. In the case of the *subSubdivision* it is an empty array, because it is not dependent on any form element, but for example the *boneOrgan* in the use-case for the study design execution the is dependent from the *assayType* and the skeletal inventory. The task of the form by loading new sub form is

to check this array and get the variables required values from the form. This mechanism will be discussed in more detail in section ??.

Above the dependency the descriptor the JavaScript framework obtains the descriptor data file for the form elements upon which it can generate the form. The mechanism of the form description retrieval a quite simple because it is practically the conversion of a Java object into a JSON object. The fields of the Java object appear in the JSON objects as key. In

```
public JSONObject getDescriptor() {  
    JSONObject object = new JSONObject();  
    object.put("title", this.title)  
    ...  
    return object;  
}
```

Listing 5.1: Java to JSON

Where the *this.title* has contains the value for the title of the form object in the descriptor Java object. The same way if the Java class has list field, like the form has list of form elements, then `getDescriptor()` routines of each element is called and inserted into a JSON array. Moreover if the form element is sub form adder then it has a field *subForm*. This comes as well of course into the descriptor, and this is the way how the multi level JSON is created.

```
object.put("subForm", this.subForm.getDescriptor());
```

Listing 5.2: Subform descriptor

Figure 5.8 illustrates the generated JSON object for a form with the data dependencies too. The task of the JavaScript routine to interpret this configuration data and generate the form and subform upon user action.

5.1.3 Graph model generation

The previous section outlined how the set of Java objects are converted into the form decriptor JSON object, and into Java objects describing the variable dependencies for the AJAX requests. Further task of the framework

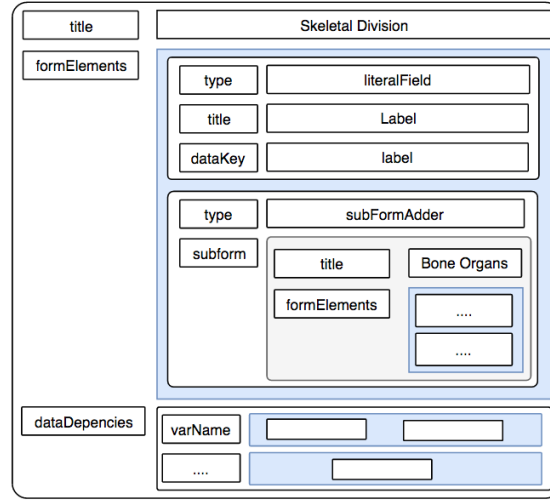


Figure 5.8: Form descriptor JSON

is to receive the submitted multi level JSON object coming from the client and generate the appropriate set of RDF triples. So in order to prepare the server for the reception of the form data, the same object structure have to be generated, which is coming from the form. We have seen in the previous chapters, that the form data object has the same scheme as the form has, and form follows the scheme defined by the multi triples in the triple set. Therefore the task of the last part of the processor algorithm is to decompose the set of triples by multi triples into graphs. The graph structure is represented in the server by a Java class called *Graph*.



Figure 5.9: Conversion from triples into graph model

The decomposition starts by the initial RDF node, which defines the main graph. The class *Graph* has a `Map<String, Graph>` field where the subgraphs are stored. The keys of the map are equivalent to the keys of

the keys of the arrays in the incoming JSON object. The other keys of the JSON are the variables of the corresponding graph. The following code snippet shows the basics of the RDF data generation from multi level JSON object.

```
saveData(JSONObject formData){
    this.save(formData);
    for(String keys : this.subGraphs.keys()){
        JSONArray array = formData.get(key);
        Graph subGraph = this.subGraphs.get(key);
        subGraph.saveArray(array)
    }
}
```

Listing 5.3: Subform descriptor

The save routine creates the RDF triples of the graph based on the data fields of the JSON object. The a loop iterates through the subgraphs of the graph and gets the arrays with the same key from the JSON and passes it to the corresponding subgraphs, that perform the same algorithm as many times, as many elements of the input array have. This is the way how the multi dimensional JSON is processed by the same structure of graph model on the server.

FiguregraphProcess illustrates the process of the JSON-RDF conversion by means of graph model. The advantage of this graph model that it can be applied the same way for the data retrieval, where the graph performs the SPARQL queries based on its triples, and generates the arrays of objects from the result table.



Figure 5.10: Graph decomposition

5.2 Implementation

The description of the implementation starts with the client side because it is more independent from the other parts, and it is sufficient to understand properly the functionality of the server. While in the last subsection it is discussed how can the developed framework be integrated into the VIVO web application.

5.2.1 Client side

This subsection presents the basics of the JavaScript implementation that realizes the dynamic form generation and event handling based on JSON form configuration data. The first part covers the creation of a form itself, and how the data is set to form data object, while the second part is about how the form enables multi dimensional data input by means of sub form adders.

Form loading

In contrast to Java, JavaScript codes are not necessarily built up in an object-oriented manner. On pages where the elements are statically defined in HTML, it is sufficient to assign event handler routines to them. However in our case none of the elements of the page is coded into HTML, but everything is dynamic and thus added by JavaScript. In the implementation JavaScript classes are applied, whose input is the descriptor object, based on which they generate the corresponding data input fields, and handles the data entered through them by the user. In this section the functionality of the two main classes, the *Form* and *Formelement* is discussed.

Figure 5.11 illustrates the structure of the two main classes. The most fundamental difference between these JavaScript classes to Java classes, that they do not contain only fields and routines (or methods) but UI elements as well. The UI elements can represent an HTML tag, and can be added or removed any time by the routines. Each class of the implemented JavaScript library has a defined set of UI elements.

The form generation process starts with the initialization of a *Form* object, where the constructor (like in Java) gets the descriptor JSON object coming from the server. As it was described in the previous chapter



Figure 5.11: Form and form element classes

the descriptor contains a list of the form element descriptor objects. The *loadFormElements()* routine iterates through on this array, and initiates the form element objects.

```

var formData = new Object()
for(var i = 0, i < formElements.length; i++){
  switch(formElements[i].type){
    case "stringField":
      var element = new StringField(formElements[i], formData)
      break;
    case "selector" : ...
  }
  this.elements.append(element.container)
}

```

Listing 5.4: Form generation based on configuration data

Each form element type is represented as subclass of the *formElement* class. They all have a container UI field, that contains their title and input field HTML element. This container field is added to the *elements* field of the *Form* object.

Listing 5.5 show a small cut from the code of the *StringField*, which is the subclass of the *FormElement* class. The field *inputField* is the HTML `<input/>` tag, and if its value changes then the *editHandler* routine is called. The *editHandler* is the function that realizes the dynamic form data creation, by setting the value of the input field into the form data object with the key

defined in its the descriptor. The key is stored in the *dataKey* field of the descriptor, which is the variable name of the RDFNode the input element represents.

```
class StringField extends FormElement{
  constructor(descriptor , formData){
    super(descriptor , formData)
    this.inputField = $("<input/>").type("text").change(this.
      editHandler)
    ...
  }
  editHandler(){
    this.formData[this.descriptor.dataKey]=this.inputField.val()
  }
}
```

Listing 5.5: Form element

This is the basic mechanism of how object-oriented JavaScript can be employed to generate forms, and put the entered values in to JSON object based on configuration data.

Sub forms

The previous section explained how the form algorithm creates the JSON object of the form data. This section extends the explanation of how it is possible to add the multi level data by sub form adders. To this two new JavaScript class functionality is outline, the *SubFormAdder* and the *SubForm*. The former is the subclass of the *FormElement* and the latter of the *Form* class.

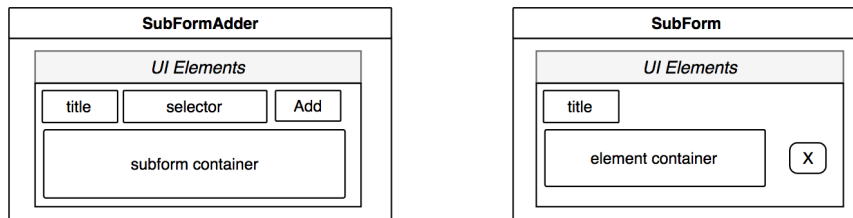


Figure 5.12: SubForm and sub form adder

Figure ?? depicts the UI elements of the two classes. The routines and fields are inherited from the parent classes. The class *SubFormAdder* has a button, which lets the user add new sub forms, which are appended into the sub form container. The class *SubForm* has additionally to the parent class a delete button for the cases if the user wants to delete the added dataset.

Listing 5.10 shows the relevant part of the code in the class *SubFormAdder*. The essence of the class is that the constructor initiates an array (with "") in the form data object, to which the sub form data object will be added dynamically upon the click events. So if the user clicks the add button, then new object is initialized (*subFormDataObject*), which will be the data object of the sub form. Important to note that this object will contain value of the selected option of the sub form adder with the key defined in the *dataKey* field of the descriptor. After the initialization of the object, it is pushed to the array, and the new *SubFormAdder* instance is created, whose container is appended to the sub form container of the sub form adder.

```
class SubformAdder {  
  
    constructor(descriptor , formData){  
        this.addButton = $("<div/>").text("Add").click(this.add)  
        this.subFormDescriptor = this.descriptor.subForm  
        this.formData[this.descriptor.predicate] = []  
    }  
  
    add() {  
        var subformDataObject = new Object()  
        subformDataObject[this.descriptor.dataKey] = this.selector.  
            val()  
        this.formData[this.descriptor.predicate].push(  
            subformDataObject)  
        this.subFormContainer.append(  
            new SubForm(this , this.subFormDescriptor ,  
                subformDataObject).container)  
    }  
}
```

Listing 5.6: Sub form adder routine

The class *SubForm* works almost the same way as its parent, but with

the difference that it checks if there is such selector among its elements, whose data has to be loaded dynamically through AJAX, because its value is dependent on one or more previously set elements of the form.

5.2.2 Server side

This section covers the functionality of the server. On the client side the implemented JavaScript classes were just included into the form template file, but the framework integration to the server is a more complicated issue, therefore the first subsection is dedicated to it. Furthermore the implementation of the form data calls with the variable dependency calls are discussed here, as well as the routines how the graph model can save, edit and retrieve the or subsets of the form data.

VIVO integration

As it was mention in the previous chapter the process of the form loading start with the profile pages of VIVO. In VIVO the entry form loading is initiated by the property fields. Normally the programming in VIVO happens through so called generator classes. The task of the generator classes is to define the dataset that have to be created in the form, and reference the Freemarker template file for entry form.

```
<someProperty> vivo:customEntryFormAnnot  
                "rdfbones.DrawingAConclusionGenerator.java"
```

Listing 5.7: Custom entry form definition in VIVO

The approach implemented in the frame does not replace this structure, but makes it simpler. In our cases we use as well generator classes, but the definition of the data happens through the initialization of an instance of the class *FormConfiguration* instance (listing ??).

Figure 5.13 shows the process of loading an entry form in VIVO. The first step is to find the generator class based on the value of the *predicateUri* parameter of the initial request. If the class has been found the processor algorithm is executed, and the necessary JSON and Java object are generated. Afterwards the server saves the form configuration object its cache with a key, which is called in VIVO *editKey*. The box in the middle of the image shows, that the response web page includes the JS library (simplified notation *framework.js*), and the value of the *edit*. This is the value will be sent in each AJAX request to the server, and based on this the can the server

find the form configuration instance that returns the JSON object for the client.



Figure 5.13: Form loading process

Figure 5.14 show the UML class diagram *FormConfiguration* class. The fields of the classes were already discussed in the previous chapter, but here it is important to note that each AJAX request is server by the method *serveRequest()*, where both the input and the output is JSON object.



Figure 5.14: UML class diagram for FormConfiguration

Listing 5.11 shows the main scheme of *serveRequest()* routine. Each request coming from the client has the key *task*, which defines what data JSON object has to be served for the client.

```
SONObject serveRequest (JSONObject requestData) {
    switch (requestData.get("task")) {
        case "formSubmission": ... break;
```

```

    case "formDescriptor": ... break;
    case "editData":      ... break;
    case "deleteAll":    ... break;
  }
}

```

Listing 5.8: AJAX request server routine

Finally a really important part of the integration is the access to the used triple store. For this purpose an interface, called *WebappConnector* is defined. It defines the functions that allows the querying and manipulation of the triples.



Figure 5.15: UML class diagram for WebappConnector

Form data loading

Important part of the framework functionality is the loading of the dependent data to the forms. This is defined through the keyword *formData* in the task parameter. Moreover it has parameter, the *variableToGet*. Based on this variable, the form configuration finds the variable dependency instance and passes the incoming JSON object to its method *getData()*.



Figure 5.16: UML class diagram for VariableDependency

```

JSONObject serveRequest(JSONObject requestData){
switch (requestData.get("task")) {
...
case "formData":
return this.dependencies.get(requestData.get("varToGet")).
getData(requestData)
...
}

```

Listing 5.9: Loading form data from FormConfiguration

We have seen that the dependency is set of triples, which build a graph. This graph can be built by class restriction triples, which constitutes to the generated SPARQL query not with one triple but with three triples.

```

SELECT ?outputVar ?label
WHERE {
?inputVar      rdfs:subClassOf      ?restriction .
?restriction   owl:onProperty      fma:systemic_part_of .
?restriction   owl:someValuesFrom  ?outputVar .
?outputVar     rdfs:label           ?label .
FILTER (?inputVar = fma:5058)
}

```

Listing 5.10: SPARQL query generated by class restriction triple

Saving, editing and retrieval of RDF Data

```

JSONObject serveRequest(JSONObject requestData){
switch (requestData.get("task")) {
...
case "saveData":
return this.mainGraph.saveData(requestData.get("formData"))
case "retrievedData":
return this.mainGraph.getData(requestData.get("startUri"))
case "editData":
return this.graphMap.get(requestData.get("varToEdit"))
.editData(requestData)
...
}

```



Figure 5.17: UML class diagram for Graph

Listing 5.11: Loading form data from FormConfiguration

Appendix A

Glossary

Just comment `\input{AppendixA-Glossary.tex}` in `Masterthesis.tex` if you don't need it!

Symbols

\$ US. dollars.

A

A Meaning of A.

B

C

D

E

F

G

H

I

J

M

N

P

Q

R

S

T

U

V

W

X

Appendix B

Appendix

B.1 Something you need in the appendix

Just comment `\input{AppendixB.tex}` in `Masterthesis.tex` if you don't need it!

Erklaerung

Hiermit erkläre ich, dass ich diese Abschlussarbeit selbständig verfasst habe, keine anderen als die angegebenen Quellen/Hilfsmittel verwendet habe und alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten Schriften entnommen wurden, als solche kenntlich gemacht habe. Darüber hinaus erkläre ich, dass diese Abschlussarbeit nicht, auch nicht auszugsweise, bereits für eine andere Prüfung angefertigt wurde.

Ort, Datum

Unterschrift

Bibliography

- [1] Anita Bandrowski, Ryan Brinkman, Mathias Brochhausen, Matthew H. Brush, Bill Bug, Marcus C. Chibucos, Kevin Clancy, Mélanie Courtot, Dirk Derom, Michel Dumontier, Liju Fan, Jennifer Fostel, Gilberto Fragoso, Frank Gibson, Alejandra Gonzalez-Beltran, Melissa A. Haendel, Yongqun He, Mervi Heiskanen, Tina Hernandez-Boussard, Mark Jensen, Yu Lin, Allyson L. Lister, Phillip Lord, James Malone, Elisabetta Manduchi, Monnie McGee, Norman Morrison, James A. Overton, Helen Parkinson, Bjoern Peters, Philippe Rocca-Serra, Alan Ruttenberg, Susanna-Assunta Sansone, Richard H. Scheuermann, Daniel Schober, Barry Smith, Larisa N. Soldatova, Christian J. Stoeckert, Jr., Chris F. Taylor, Carlo Torniai, Jessica A. Turner, Randi Vita, Patricia L. Whetzel, and Jie Zheng. The ontology for biomedical investigations. *PLOS ONE*, 11, 11 2015.
- [2] Dan Brickley and Ramanathan Guha. RDF vocabulary description language 1.0: RDF schema. W3C recommendation, W3C, February 2004. <http://www.w3.org/TR/2004/REC-rdf-schema-20040210/>.
- [3] Mike Dean and Guus Schreiber. OWL web ontology language reference. W3C recommendation, W3C, February 2004. <http://www.w3.org/TR/2004/REC-owl-ref-20040210/>.
- [4] Felix Engel, Stefan Schlager, and Ursula Witwer-Backofen. An infrastructure for digital standardisation in physical anthropology. 11, 04 2016.

- [5] Markus Lanthaler, David Wood, and Richard Cyganiak. RDF 1.1 concepts and abstract syntax. W3C recommendation, W3C, February 2014. <http://www.w3.org/TR/2014/REC-rdf11-concepts-20140225/>.
- [6] Cornelius Rosse and José L.V. Mejino Jr. A reference ontology for biomedical informatics: the foundational model of anatomy. *Journal of Biomedical Informatics*, 36(6):478 – 500, 2003. Unified Medical Language System.