

IN3060/4060 – Semantic Technologies – Spring 2019

Lecture 3: Jena – A Java Library for RDF

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UNIVERSITY OF
OSLO

DNV GL Summer Project 2019



- Summer internship with DNV GL, Høvik
- Interdisciplinary team of 8 MSc students
- Deadline 15 February
- Topics: Big Data, Machine Learning, Artificial Intelligence, Natural Language Processing and **Ontologies**.

<https://careers-dnvgl.icims.com/jobs/11797/dnv-gl-summer-project-2019/job>

Today's Plan

- 1 Repetition: RDF
- 2 Jena: Basic Datastructures
- 3 Jena: Inspecting Models
- 4 Jena: I/O
- 5 Example
- 6 Jena: ModelFactory and ModelMaker
- 7 Jena: Combining Models

Outline

- 1 Repetition: RDF
- 2 Jena: Basic Datastructures
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Reminder: RDF triples

- The W3C representation of knowledge in the Semantic Web is RDF (Resource Description Framework)
- In RDF, all knowledge is represented by *triples*
- A triple consists of *subject*, *predicate*, and *object*
- For instance: `geo:germany rdf:type geo:Country .`
- These *qnames* are abbreviations for URIs:
`rdf: ≡ http://www.w3.org/1999/02/22-rdf-syntax-ns#`
`geo: ≡ http://geo.example.com/#`
- Expanded:
`<http://geo.example.com/#germany>`
`<http://www.w3.org/1999/02/22-rdf-syntax-ns#type>`
`<http://geo.example.com/#Country> .`

By the way: Are URIs case sensitive?

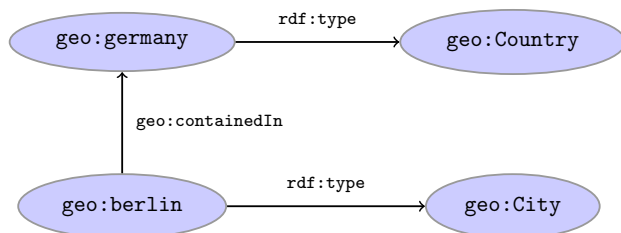
- And does the port matter, e.g. :80 in an HTTP URI?
- How about HTTP vs HTTPS?
- *Actually* RDF 1.1 uses IRIs, RFC 3987
- RDF 1.1 says
Two IRIs are equal if and only if they are equivalent under Simple String Comparison according to section 5.1 of [RFC3987]. Further normalization MUST NOT be performed when comparing IRIs for equality.
- RFC 3987 says that “Simple String Comparison” is what you get comparing character-by-character. Like `String.equals()`.
- So: yes, case-sensitive.

Reminder: RDF graphs

Sets of RDF triples are often represented as directed graphs:

Berlin is a City in Germany, which is a country

```
geo:germany rdf:type geo:Country .
geo:berlin  rdf:type geo:City .
geo:berlin  geo:containedIn geo:germany .
```

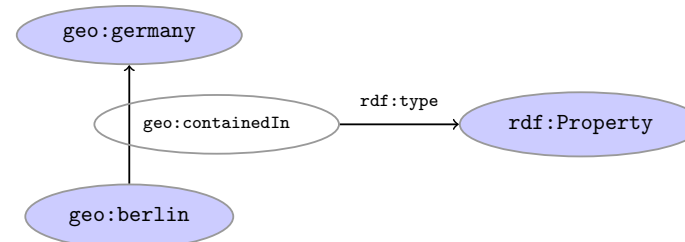


Reminder: RDF graphs (cont.)

Graph representation not always a perfect fit.

Berlin is contained in Germany, and containment is a property

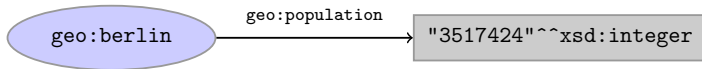
```
geo:berlin geo:containedIn geo:germany .
geo:containedIn rdf:type rdf:Property .
```



Usually speak about *RDF graphs* anyway

Reminder: RDF Literals

- *objects* of triples can also be *literals*
 - I.e. nodes in an RDF graph can be *resources* or *literals*
 - Subjects and predicates of triples can *not* be literals
- Literals
 - have a *type*, given by a URI
 - `geo:berlin geo:population "3517424"^^xsd:integer .`
 - In Turtle, if the type is not given explicitly, it is `xsd:string`
 - `geo:berlin geo:name "Berlin" .` is the same as `geo:berlin geo:name "Berlin"^^xsd:string .`
 - there can be a *language tag*, then the type is `rdf:langString`
 - `geo:germany geo:name "Deutschland"@de .`
 - `geo:germany geo:name "Germany"@en .`
- Usually represented with rectangles:

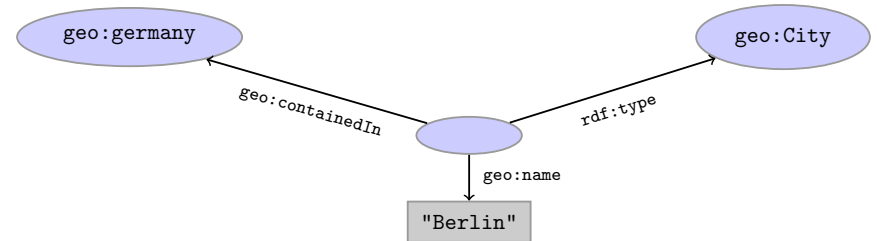


Reminder: RDF Blank Nodes

Blank nodes are like resources without a URI

There is a city in Germany called Berlin

```
_:x rdf:type geo:City .
_:x geo:containedIn geo:germany .
_:x geo:name "Berlin" .
```



Question

How many triples are represented here?

```
:norway :hasCapital [a :Place,:City; :name "Oslo", "Oslo"] ;
           :hasCapital [a :Place,:City; :name "Oslo", "Oslo"] ;
```

Answer: 8. Two different blank nodes, `_:1`, `_:2`, but only one name each.

```
:norway :hasCapital _:1 .           :norway :hasCapital _:2 .
_:1 a :Place .                       _:2 a :Place .
_:1 a :City .                         _:2 a :City .
_:1 :name "Oslo" .                    _:2 :name "Oslo" .
```

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Vital Statistics

- An open source Java framework for building Semantic Web applications.



<http://jena.apache.org/>

- Grown out of work with the HP Labs Semantic Web Programme
- Now Apache Software Foundation
- includes:
 - An RDF API
 - Reading and writing RDF in RDF/XML, N3 and N-Triples
 - An interface to reasoning services
 - An OWL API
 - In-memory and persistent storage
 - A SPARQL query engine

Information About Jena

- *Public interface* of Jena has over 700 classes and interfaces in ca. 35 packages
- Can do useful things knowing only a small part of them!
- The Jena Tutorials: <http://jena.apache.org/tutorials/>
- The API Javadocs:
 - <http://jena.apache.org/documentation/javadoc/>
- And more:
 - <http://jena.apache.org/documentation/>
- In case of doubt: RTFM



Data Representations: URIs

- Start by investigating how different RDF concepts are represented in Jena.
- URIs are simply represented as strings:


```
String germanyURI="http://geo.example.com/#germany"
```
- Some methods interpret QNames (geo:germany) but most don't.
- Probably a good idea to put namespaces in separate strings:

```
String geoNS="http://geo.example.com/#";
String germanyURI=geoNS+"germany";
String berlinURI =geoNS+"berlin";
```

Data Representation: Resources

- Most of the basic RDF representations covered by classes in


```
org.apache.jena.rdf.model
```
- Resources are represented by


```
Resource
```
- Has a method


```
String getURI()
```
- But wait... Resource is an interface. How do you create an instance?
- There is a class ResourceFactory with method


```
static Resource createResource(String uriref)
```
- Beware: this is not usually what you want!



Data Representation: Models

- A `org.apache.jena.rdf.model.Model` represents a set of RDF statements (triples).
- In Jena, Resources and Statements are linked to the Models they are part of.
- Models also have the responsibility for *creating* Resources, etc.
- Need to create a Model first.
- Also an interface! (Can this be on purpose?)
- Easiest way: `org.apache.jena.rdf.model.ModelFactory`

```
Model model = ModelFactory.createDefaultModel();
```
- Other ways: with database storage, with reasoning, etc.
- Also deals with reading & writing various formats



Data Representation: Resources, 2nd try

- Given a model...


```
Model model = ModelFactory.createDefaultModel();
```
- ...and a URI...


```
String berlinURI = geoNS + "berlin";
```
- ...we can use it to create a Resource:


```
Resource berlin = model.createResource(berlinURI);
```
- We can ask the Resource for the Model:


```
berlin.getModel()...
```
- For a fresh blank node:


```
Resource blank = model.createResource();
```

Data Representation: Properties

- Reminder: predicates are simply resources
- Jena defines a separate interface `Property`
- Subinterface of `Resource`
- Doesn't add anything important to `Resource`, but
 - a `Property` cannot be a blank node nor a literal
- To create a `Property` object:


```
Property name = model.createProperty(geoNS+"name");
```

Data Representation: Literals

- Jena defines a `Literal` interface for all kinds of literals.
- To create a literal with default type:


```
Literal b = model.createLiteral("Berlin");
```
- To create a literal with language tag:


```
Literal d = model.createLiteral("Germany","en");
```
- To create a literal with a specific type:


```
String type = "http://www.w3.org/2001/XMLSchema#byte";
Literal n = model.createTypedLiteral("42",type);
```
- Or, with a `org.apache.jena.datatypes.RDFDatatype`:


```
import org.apache.jena.datatypes.xsd.XSDDatatype;

RDFDatatype type = XSDDatatype.XSDbyte;
Literal n = model.createTypedLiteral("42",type);
```

Data Representation: Statements

- To construct a Statement, you need

 $\langle s, p, o \rangle$

- A subject, which is a Resource
- A predicate, which is a Property
- An object, which can be a Resource or a Literal

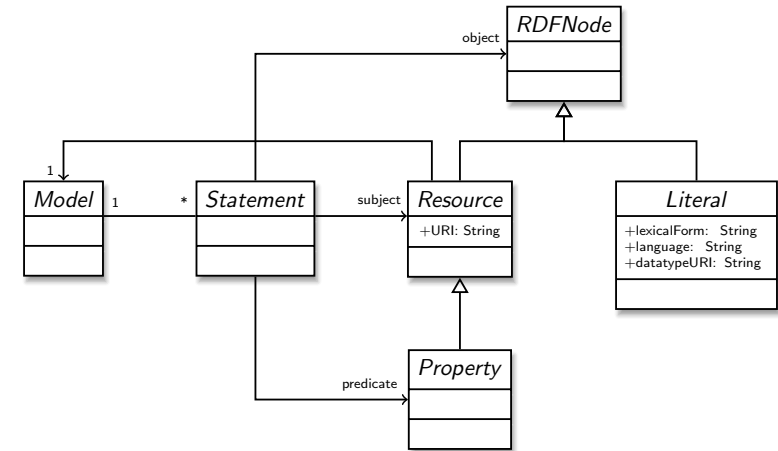
- Again, use the methods in Model:

```
Resource berlin = model.createResource(geoNS+"berlin");
Property name = model.createProperty(geoNS+"name");
Literal b = model.createLiteral("Berlin");
Statement stmt = model.createStatement(berlin,name,b);
```

- Not yet asserted in the model.
- To add this statement to the model:

```
model.add(stmt);
```

Overview



Convenience Methods in Resource

- Can directly add statements to the model.
- Given some properties and resources...

```
Property name = model.createProperty(geoNS+"name");
Property cont = model.createProperty(geoNS+"containedIn");
Property pop = model.createProperty(geoNS+"population");
```

```
Resource berlin = model.createResource(geoNS+"berlin");
Resource germany = model.createResource(geoNS+"germany");
```

- ... we can write:

```
berlin.addProperty(cont, germany);
berlin.addProperty(name, "Berlin");
germany.addProperty(name, "Tyskland", "no");
berlin.addLiteral(pop, 3517424);
```

- Directly adds statements to model!
- Converts Java datatypes to RDF literals.

Models and Graphs, Statements and Triples

- In Jena, they have both *triples* and *statements*!?
- There are also both *graphs* and *models*!?
- Jena is a *framework*!
 - unified view for differing implementations of data storage and processing
- High-level interface
 - API: application programming interface
 - Convenient to use
 - Interfaces Resource, Statement, Model
- Low-level interface
 - SPI: service provider interface
 - Easy to implement
 - Classes Node, Triple, Graph
- We will be concerned only with the API!

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Retrieving Information from a Model

- We've seen how to add statements to a Model
- Two ways to retrieve information:
 - Via Resources
 - Via the Model
- Navigation through resources delegates to model, but sometimes more convenient



Retrieving Information from a Resource

- Resource has methods to retrieve statements having the resource as subject.
- To find all statements about berlin


```
Iterator<Statement> it = berlin.listProperties();
```
- to print them all out:


```
while (it.hasNext()) {
    System.out.println(it.next());
}
```
- to find all statements with a particular predicate:


```
Property name = model.createProperty(geoNS+"name");
Iterator<Statement> it = berlin.listProperties(name);
```

Retrieving Information from a Resource (cont.)

- To get *some* statement, without iterating:


```
Property pop = model.createProperty(geoNS+"population");
berlin.getProperty(pop)
```
- B.t.w., to access the object of a statement as a Java type:


```
int n = berlin.getProperty(pop).getInt();
```
- See also methods
 - getRequiredProperty
 - hasProperty,
 - hasLiteral,

Retrieving information from a Model

- To get *all* statements from a Model:

```
Iterator<Statement> sit = model.listStatements();
```

- To get all resources that are subject of some statement:

```
Iterator<Resource> rit = model.listSubjects();
```

- To get all resources with a statement for a given predicate:

```
Iterator<Resource> rit = model.listResourcesWithProperty(name);
```

- ... with a given value for a property:

```
Iterator<Resource> rit = model.listResourcesWithProperty(cont, germany);
```

Simple Pattern Matching

- To get all statements that have

- a given subject and object,
- a given object,
- a given predicate and subject,
- or any other combination...



- ... use

```
Iterator<Statement> sit = model.listStatements(subj, pred, obj);
```

- where subj, pred, obj can be null to match any value ("wildcard")

- e.g. to print everything contained in Germany:

```
Iterator<Statement> sit = model.listStatements(null, cont, germany);
while (sit.hasNext()) {
    System.out.println(sit.next().getSubject());
}
```

Complex Pattern Matching

- W3C has defined the SPARQL language
- SPARQL Protocol And RDF Query Language
- The Semantic Web equivalent of SQL
- Jena Models can process SPARQL queries
- A much more powerful way of retrieving data from a Model
 - Match patterns of triples
 - Filter on literal values
 - ...
- More about this next week!

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Reading RDF

- Model contains several `read(...)` methods for reading RDF.
- `read` does not create a new Model object.
 - First create a model, then add statements with `read`.
 - Can call `read` several times to accumulate information.
- Available formats: RDF/XML, N-triples, Turtle, RDF/Json, TriG, ...
 - Get format from HTML content type, then file name extension
 - Variants with `format (lang)` parameter exist
- Can read from `InputStream` or `Reader`, or directly from a URL.
- Some `read` variants take a "base URI".
 - Used to interpret relative URIs in the document.
 - Usually not needed: absolute URIs are a better idea.
- Example: Load Martin Giese's FOAF file from the 'net':


```
Model model = ModelFactory.createDefaultModel();
model.read("http://heim.ifi.uio.no/martingi/foaf");
```

Writing RDF

- Model contains several `write(...)` methods for writing RDF.
- Available formats: RDF/XML, N-triples, Turtle, RDF/Json, TriG, ...
 - Format defaults to RDF/XML
 - Variants with `format (lang)` parameter exist
- Can write to `OutputStream` or `Writer`.
- Some `write` variants take a "base URI".
 - Used to make some URIs relative in the output.
 - Absolute URIs are a better idea.
- Example: write model to a file:


```
try {
    model.write(new FileOutputStream("output.rdf"));
} catch (IOException e) {
    // handle exception
}
```

Prefix Mappings

- Jena writes files with namespace @PREFIX definitions
- Mostly for human readability
- Models preserve namespace @PREFIXes from files read
- Model has super-interface `PrefixMapping`
- `PrefixMapping` contains methods to
 - manage a set of namespace prefixes:
 - `setNsPrefix(String prefix, String uri)`
 - `getNsPrefixURI(String prefix)`
 - `getNsURIPrefix(String uri)`
 - ...
 - Convert between URIs and QNames:
 - `expandPrefix(String prefixed)`
 - `shortForm(String uri)`
 - ...

Question

What's the difference in effect between this code snippet:

```
norway=model.getResource("http://...");
name=model.getProperty("http://...");
model.createStatement(norway,name,"Norway");
```

and this:

```
norway=model.getResource("http://...");
name=model.getProperty("http://...");
norway.addProperty(name,"Norway");
```

Answer: they create the same statement,
but only the second snippet adds it to the model.

Outline

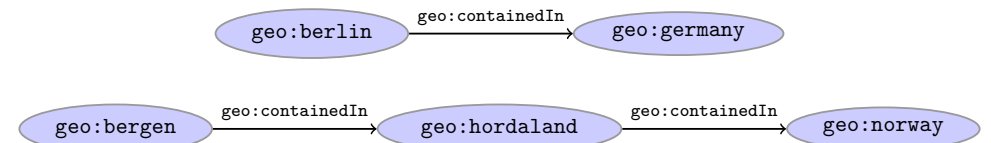
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A Containment Example

Given an RDF/XML file with information about containment of places in the following form:

Geographic containments

```
geo:berlin geo:containedIn geo:germany .
geo:bergen geo:containedIn geo:hordaland .
geo:hordaland geo:containedIn geo:norway .
...
```

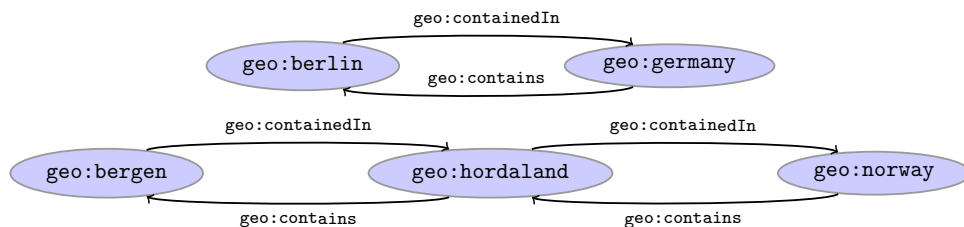


A Containment Example (cont.)

Add inverse statements using property `geo:contains`:

Inverted Containment Statements

```
geo:germany geo:contains geo:berlin .
geo:hordaland geo:contains geo:bergen .
geo:norway geo:contains geo:hordaland .
...
```



Solution: Creating the Model, Reading the File

```
import java.io.*;
import java.util.*;
import org.apache.jena.rdf.model.*;

public class Containment {

    public static String GEO_NS = "http://geo.example.com/#";

    public static void main(String[] args) throws IOException {
        Model model = ModelFactory.createDefaultModel();
        model.read(new FileInputStream("places.rdf"), null);

        Property containedIn = model.getProperty(GEO_NS+"containedIn");
        Property contains = model.getProperty(GEO_NS+"contains");
    }
}
```

Solution: Adding Statements, Writing a File

```

Iterator<Statement> it =
    model.listStatements((Resource)null, containedIn, (Resource)null);
while ( it.hasNext() ) {
    Statement st = it.next();
    model.add((Resource)st.getObject(), contains, st.getSubject());
}

model.write(new FileOutputStream("output.rdf"));
} // main()
} // class Containmentment

```

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57 Varieties of Models

- Until now: “default” models:

```
ModelFactory.createDefaultModel();
```

- A simple collection of statements stored in memory
 - Large datasets require lots of RAM
 - Not persistent, need to read/write to files manually
- Models created by ModelFactory differ in
 - backing storage (Memory, files, RDB)
 - inferencing
 - automatically add triples that are consequences of others
 - more on this in lecture 6 and later!
 - reification style
 - resources representing statements
 - won't go into this



ModelMaker

- Jena likes to store models in groups, identified by names.
- ModelMaker organizes collections of *named* models.
- To create one that handles models stored in memory:


```
ModelMaker mm = ModelFactory.createMemModelMaker();
```
- ... in a collection of file system files:


```
ModelMaker mm = ModelFactory.createFileModelMaker("/path/to/files");
```
- ... a relational database:


```
IDBConnection conn = new DBConnection(DB_URL,DB_USER,DB_PASSWD,DB_TYPE);

ModelMaker mm = ModelFactory.createRDBModelMaker(conn);
```
- See book or documentation for examples of creating a DBConnection!

ModelMaker (cont.)

- Given a ModelMaker object, you can...
 - create a new model if none under that name exists:


```
Model model = mm.createModel("CitiesOfNorway");
```
 - open an already existing model:


```
Model model = mm.openModel("CitiesOfNorway");
```
 - (also strict variants which throw an exception in the other case)
 - remove an already existing model from memory:


```
mm.removeModel("CitiesOfNorway");
```
 - check if there is a model with a given name:


```
if (mm.hasModel("CitiesOfNorway")) {...};
```
- All models are stored as tables in one RDB, files in one file system directory, etc.

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Many Models

- Jena can manage many models simultaneously.
- E.g. some in memory, some in databases, etc.
- Different Model objects don't know of each other
- It is however possible to combine models:


```
Model u = model1.union(model2);
Model i = model1.intersection(model2);
Model d = model1.difference(model2);
```
- Models contain set union/intersection/difference of statements in model1/model2.
- These are new *independent* models:
 - adding/removing statements in model1/model2 does not affect u/i/d
 - adding/removing statements in u/i/d does not affect model1/model2
- Typically a fresh memory model holding all data.

Dynamic Unions

- Also possible to create *dynamic* unions:


```
Model u = ModelFactory.createUnion(model1,model2);
```
- Model u contains set union of statements in model1/model2.
- u remains connected to model1 and model2:
 - adding/removing statements in model1/model2 adds/removes them in u
 - adding/removing statements in u adds/removes them in model1
- Union model delegates storage to other models

The Alignment Problem

- We built a database `places.rdf` with
 - Information about resources like
 - `http://geo.example.com/#oslo`
 - `http://geo.example.com/#germany`
 - Expressed in terms like
 - `http://geo.example.com/#City`
 - `http://geo.example.com/#Country`
 - `http://geo.example.com/#containedIn`
- Now we discover `http://dbpedia.org/` with
 - information about resources like
 - `http://dbpedia.org/resource/Oslo`
 - `http://dbpedia.org/resource/Germany`
 - Expressed in terms like
 - `http://dbpedia.org/ontology/PopulatedPlace`
 - `http://dbpedia.org/ontology/Country`
 - `http://dbpedia.org/property/subdivisionName`

The Alignment Problem (cont.)

- We can now construct the union of both information sources
- But the union will not be very useful :-)
- The data is not linked!
 - The same entities are identified by different URIs
 - The same types are identified by different URIs
 - Similar properties are identified by different URIs
- Need some way to “align” the vocabularies
 - Say that `geo:oslo` equals `dbpedia:Oslo`.
 - Say that a `geo:City` is a kind of `dbpedia-owl:PopulatedPlace`.
 - Say that subdivisions are contained in each other.
- You will learn how to do this later in the course...
- ... but to get it right, some theory is needed!

Outlook

- Lecture 4: The SPARQL Query Language
- Lecture 5: Mathematical Foundations
- Lecture 6: Intro to Reasoning
- Lecture 7: Model Semantics
- Lecture 8: Semantics & Reasoning
- Lecture 9–11: OWL
- All this will be explained with examples
- There will be practical exercises
- But there are some theoretical concepts to grasp!

Oblig

- New oblig to be published today, after the lecture.
- Topic: Programming with Jena.
- Small oblig, as the previous one.
- Can use MrOblig for testing.
- Deadline: 23:59 06.02.2019.