

## IN3060/4060 – Semantic Technologies – Spring 2020

### Lecture 3: Jena – A Java Library for RDF

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DEPARTMENT OF  
INFORMATICS



UNIVERSITY OF  
OSLO

## DNV GL Summer Project 2020



- Summer internship with DNV GL, Høvik
- Interdisciplinary team of 8 fourth year MSc students
- Deadline 15 February
- Topics: artificial intelligence, machine learning, big data, IOT, augmented and virtual reality
- Application area in 2020: Wind Energy

<https://careers-dnvgl.icims.com/jobs/13576/dnv-gl-summer-project-2020/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
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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?

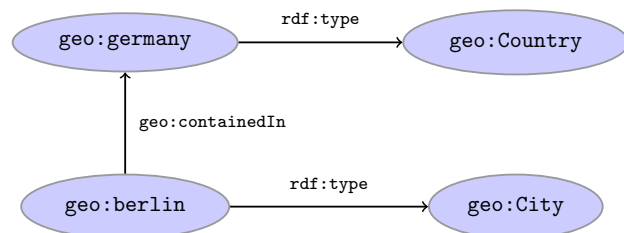
- And does the port matter, e.g. :80 in an HTTP URI?
- How about HTTP vs HTTPS?
- *Actually* RDF 1.1 uses IRIs, RFC 3987
- RDF 1.1 says  
*Two IRIs are equal if and only if they are equivalent under Simple String Comparison according to section 5.1 of [RFC3987]. Further normalization MUST NOT be performed 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 .
```

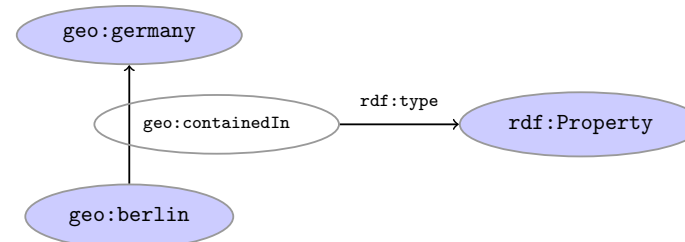


## Reminder: RDF graphs (cont.)

Graph representation not always a perfect fit.

Berlin is contained in Germany, and containment is a property

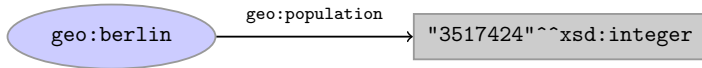
```
geo:berlin geo:containedIn geo:germany .
geo:containedIn rdf:type rdf:Property .
```



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:

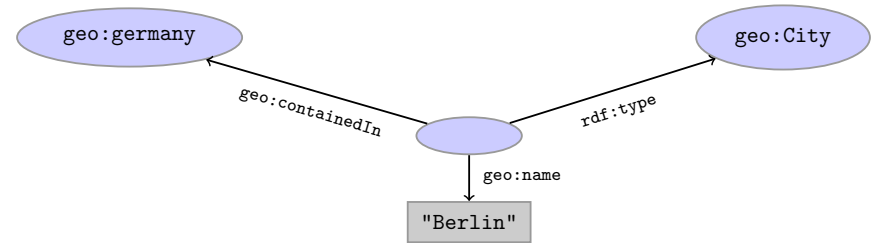


## Reminder: RDF Blank Nodes

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.

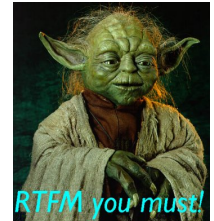
<http://jena.apache.org/>



- 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 800 classes and interfaces in ca. 50 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
  - 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:

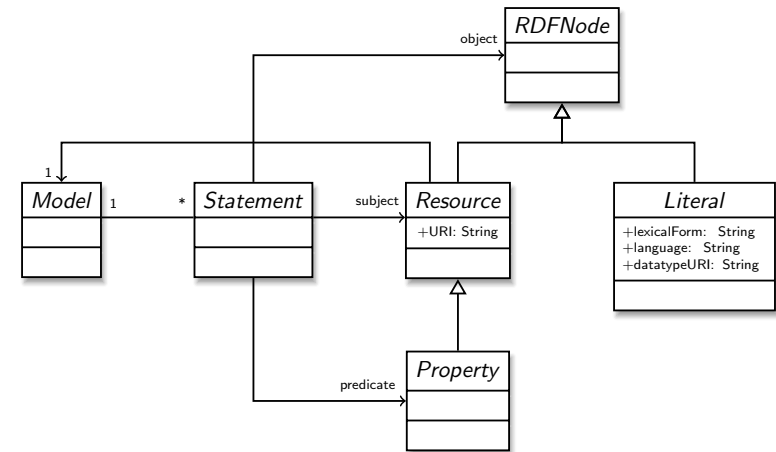
 $\langle s, p, o \rangle$ 

```
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

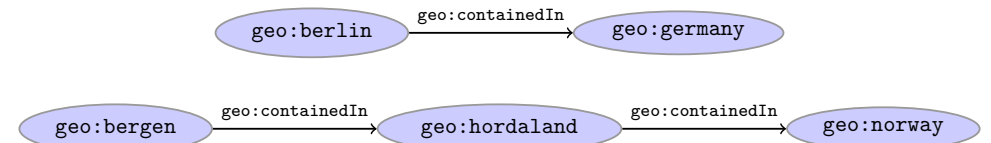
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## A Containment Example

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 .
...
```

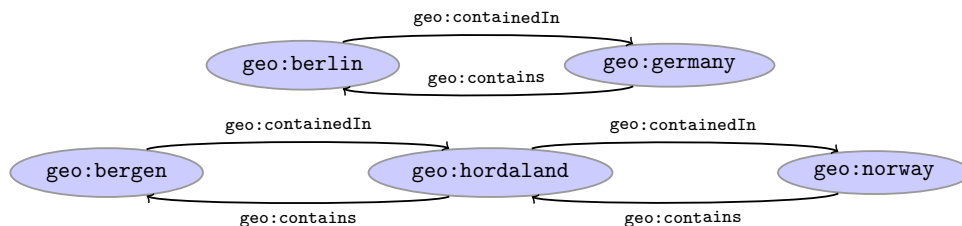


## A Containment Example (cont.)

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, like the previous one.
- Can use MrOblig for testing.
- Deadline: 23:59 07.02.2020.