

IN3060/4060 – Semantic Technologies – Spring 2019

Lecture 4: The SPARQL Query Language

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Today's Plan

- 1 Introduction
- 2 Recap: RDF
- 3 SPARQL by Example
- 4 SPARQL Systematically
- 5 Executing SPARQL Queries in Jena
- 6 Wrap-up

Outline

- 1 Introduction
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SPARQL

- **SPARQL Protocol And RDF Query Language**
- Standard language to query graph data represented as **RDF triples**
- W3C Recommendations
 - **SPARQL 1.0:** W3C Recommendation 15 January 2008
 - **SPARQL 1.1:** W3C Recommendation 21 March 2013
- This lecture is about SPARQL 1.0.
- Documentation:
 - Syntax and semantics of the SPARQL query language for RDF.
<http://www.w3.org/TR/rdf-sparql-query/>

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Recap: RDF triples

- The W3C representation of knowledge in the Semantic Web is RDF (Resource Description Framework)
- RDF talks about *resources* identified by URIs.
- In RDF, all knowledge is represented by *triples* (aka statements or facts)
- A triple consists of *subject*, *predicate*, and *object*
- The *subject* maybe a resource or a blank node
- The *predicate* must be a resource
- The *object* can be a resource, a blank node, or a literal

Recap: RDF Literals

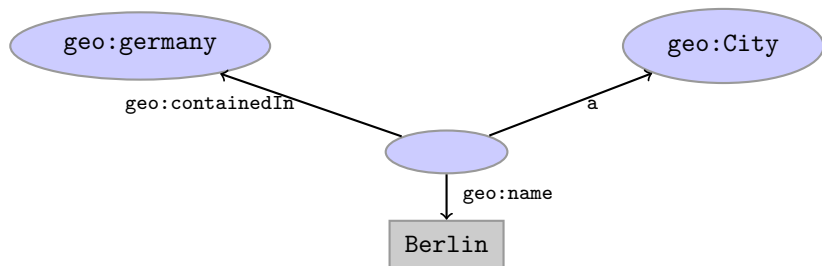
- Can only appear as object in the *object* in the triple.
- Literals can be
 - Plain, without language tag:
`geo:berlin geo:name "Berlin" .`
 - Plain, with language tag:
`geo:germany geo:name "Deutschland"@de .`
`geo:germany geo:name "Germany"@en .`
 - Typed, with a URI indicating the type:
`geo:berlin geo:population "3431700"^^xsd:integer .`

Recap: RDF Blank Nodes

Blank nodes are like resources without a URI

There is a city in Germany called Berlin

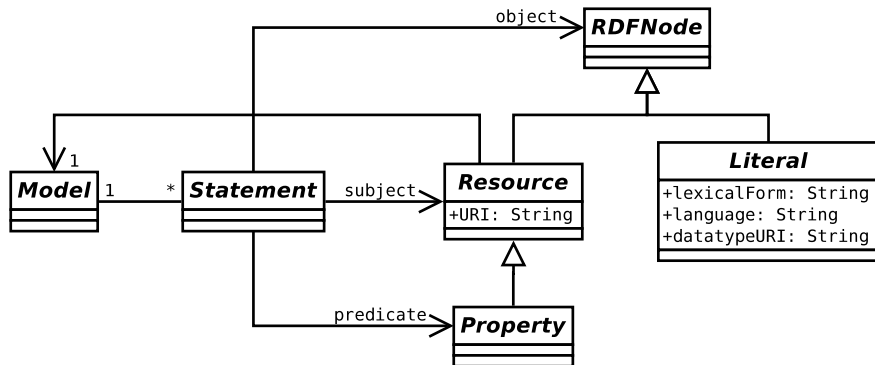
```
_:x a geo:City .  
_:x geo:containedIn geo:germany .  
_:x geo:name "Berlin" .
```



Recap: Jena

- Jena is a Semantic Web programming framework for Java.
- Open source.
- API to extract data from and write to RDF graphs.
- Includes an engine to query RDF graphs through SPARQL.
- Interfaces for main RDF elements Resource, Property, Literal, Statement, Model
- The RDF graphs are represented as an abstract Model.

Recap: Jena



Recap: Vocabularies

- Best Practices: Reuse vocabularies to ease interoperability.
 - People are more familiar with them
 - Can be queried more easily
 - The semantics must be clear, shouldn't twist the meaning too much.
- Good starting point:
 - Linked Open Vocabularies: <http://lov.okfn.org/>
 - Schema.org: <https://schema.org>

Recap: RDF and RDFS Vocabularies

- Prefix `rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>`
- Prefix `rdfs:<http://www.w3.org/2000/01/rdf-schema#>`
- They need to be declared like all others.
- Examples:

```
geo:berlin rdf:type geo:City .  
geo:containedIn a rdf:Property .  
geo:berlin rdfs:label geo:City .
```
- Note that the keyword “a” is an alternative for `rdf:type`.

Recap: Friend Of A Friend

- People, personal information, friends, see <http://www.foaf-project.org/>
- Prefix foaf:<<http://xmlns.com/foaf/0.1/>>
- Important elements:
 - **Person** a person, alive, dead, real, imaginary
 - **name** name of a person (also firstName, familyName)
 - **mbox** mailbox URL of a person
 - **knows** a person knows another
- Examples:

```
<https://w3id.org/scholarlydata/person/ernesto-jimenez-ruiz>
  a foaf:Person ;
  foaf:name "Ernesto Jiménez-Ruiz" ;
  foaf:mbox <mailto:ernestoj@ifi.uio.no> ;
  foaf:knows <http://heim.ifi.uio.no/martingi/foaf#me> .
```

Recap: Dublin Core

- Metadata for documents, see <http://dublincore.org/>.
- Prefix `dc:<http://purl.org/dc/terms/>`
- Important elements:
 - `creator` a document's main author
 - `created` the creation date
 - `title` title of document
 - `description` a natural language description
- Examples:

```
<https://w3id.org/scholarlydata/.../iswc2016/paper/research/res  
  dc:creator
```

```
<https://w3id.org/scholarlydata/person/ernesto-jimenez-ruiz>;  
  dc:created "2016-10-20" ;  
  dc:description "ISWC research paper number 146"@en ;
```

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SPARQL by Example

- SPARQL Protocol And RDF Query Language
- Try it out:

`https://www.w3.org/wiki/SparqlEndpoints`

`DBLP http://dblp.13s.de/d2r/snorql/`

`DBpedia http://dbpedia.org/sparql`

`Lenka http://data.lenka.no/sparql`

`EBI https://www.ebi.ac.uk/rdf/`

Simple Examples

- DBLP contains computer science publications:
`http://dblp.uni-trier.de/`
- Vocabulary of RDF (con)version: `dc:creator`, `dc:title`, `foaf:name`, etc.
- Web service: `http://dblp.l3s.de/d2r/snorql/`
- Endpoint: `http://dblp.l3s.de/d2r/sparql`

People called "Ernesto Jimenez-Ruiz"

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT DISTINCT ?ejr WHERE {
    ?ejr foaf:name "Ernesto Jimenez-Ruiz" .
}
```

Answer:

?ejr
<http://dblp.l3s.de/d2r/resource/authors/Ernesto_Jimenez-Ruiz>

Simple Examples (cont.)

Publications by people called "Ernesto Jimenez-Ruiz"

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
SELECT ?pub WHERE {
    ?ejr foaf:name "Ernesto Jimenez-Ruiz" .
    ?pub dc:creator ?ejr .
}
```

Answer:

?pub
<http://dblp.13s.de/d2r/resource/publications/journals/ijdsn/MartiSMJ12>
<http://dblp.13s.de/d2r/resource/publications/journals/biomedsem/Jimenez-RuizGHL11>
<http://dblp.13s.de/d2r/resource/publications/journals/dke/Jimenez-RuizGHL11>
...

Simple Examples (cont.)

Titles of publications by people called “Ernesto Jimenez-Ruiz”

```
SELECT ?title WHERE {
  ?ejr foaf:name "Ernesto Jimenez-Ruiz" .
  ?pub dc:creator ?ejr .
  ?pub dc:title ?title .
}
```

Answer:

<code>?title</code>
<code>"Localization of Mobile Sensors and Actuators for Intervention in Low-Visibility Conditions ..."</code> <code>^^xsd:string</code>
<code>"Logic-based assessment of the compatibility of UMLS ontology sources."</code> <code>^^xsd:string</code>
<code>"Supporting concurrent ontology development: Framework, algorithms and tool."</code> <code>^^xsd:string</code>
<code>...</code>

Simple Examples (cont.)

Names of people who have published with “Ernesto Jimenez-Ruiz”

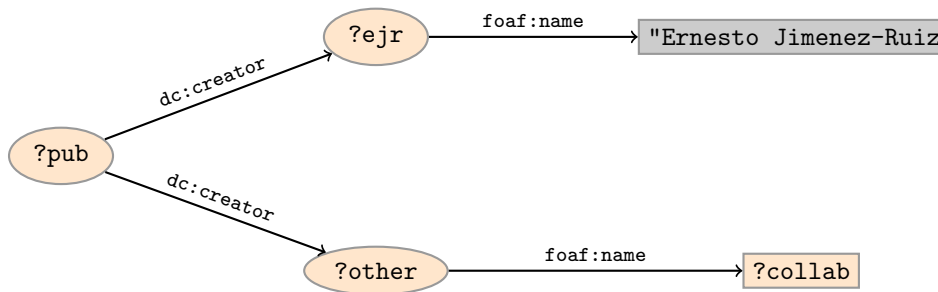
```
SELECT DISTINCT ?collab WHERE {
  ?ejr foaf:name "Ernesto Jimenez-Ruiz" .
  ?pub dc:creator ?ejr .
  ?pub dc:creator ?other .
  ?other foaf:name ?collab.
}
```

Answer:

?collab
"Ernesto Jimenez-Ruiz"
"Jorge Sales"
"Ian Horrocks"
"Bernardo Cuenca Grau"
"Rafael Berlanga Llavori"
...

Graph Patterns

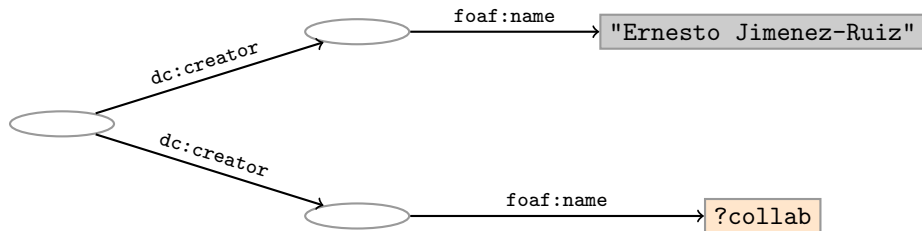
The previous SPARQL query as a graph:



Pattern matching: assign values to variables to make this a sub-graph of the RDF graph!

Graph with blank nodes

Variables not SELECTed can equivalently be blank:



Pattern matching: assign values to variables **and blank nodes** to make this a sub-graph of the RDF graph!

SPARQL Query with blank nodes

Names of people who have published with "Ernesto Jimenez-Ruiz"

```
SELECT DISTINCT ?collab WHERE {  
  _:ejr foaf:name "Ernesto Jimenez-Ruiz" .  
  _:pub dc:creator _:ejr .  
  _:pub dc:creator _:other .  
  _:other foaf:name ?collab.  
}
```

The same with blank node syntax

```
SELECT DISTINCT ?collab WHERE {  
  [ dc:creator [foaf:name "Ernesto Jimenez-Ruiz"] ,  
              [foaf:name ?collab]  
  ]  
}
```

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Components of an SPARQL query

Prologue: prefix definitions **Results form specification:** (1) variable list, (2) type of query (SELECT, ASK, CONSTRUCT, DESCRIBE), (3) remove duplicates (DISTINCT, REDUCED) **Dataset specification** **Query pattern:** graph pattern to be matched **Solution modifiers:** ORDER BY, LIMIT, OFFSET

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
SELECT DISTINCT ?collab
FROM <http://dblp_dataset>
WHERE {
    ?ejr foaf:name "Ernesto Jimenez-Ruiz" .
    ?pub dc:creator ?ejr .
    ?pub dc:creator ?other .
    ?other foaf:name ?collab .
    FILTER (STR(?collab)!="Ernesto Jimenez-Ruiz")
}
```

Types of Queries

SELECT Compute table of bindings for variables

```
SELECT ?a ?b WHERE {  
  [ dc:creator ?a ;  
    dc:creator ?b ]  
}
```

CONSTRUCT Use bindings to construct a new RDF graph

```
CONSTRUCT {  
  ?a foaf:knows ?b .  
} WHERE {  
  [ dc:creator ?a ;  
    dc:creator ?b ]  
}
```

Types of Queries (cont.)

ASK Answer (yes/no) whether there is ≥ 1 match

```
ASK WHERE {  
    ?ejr foaf:name "Ernesto Jimenez-Ruiz" .  
}
```

DESCRIBE Returns and RDF graph with data about matching resources

```
DESCRIBE ?ejr WHERE {  
    ?ejr foaf:name "Ernesto Jimenez-Ruiz" .  
}
```

Solution Sequences and Modifiers

- Permitted to SELECT queries only
- SELECT treats solutions as a sequence (solution sequence)
- Query patterns generate an unordered collection of solutions
- *Sequence modifiers* can modify the solution sequence (not the solution itself):
 - Order
 - Projection
 - Distinct
 - Reduced
 - Offset
 - Limit
- **Applied in this order.**

ORDER BY

- Used to sort the solution sequence in a given way:
- `SELECT ... WHERE ... ORDER BY ...`
- ASC for ascending order (default) and DESC for descending order
- E.g.

```
SELECT ?city ?pop WHERE {  
  ?city geo:containedIn ?country ;  
        geo:population ?pop .  
} ORDER BY ?country ?city DESC(?pop)
```
- Standard defines sorting conventions for literals, URIs, etc.
- Not all “sorting” variables are required to appear in the solution

Projection, DISTINCT, REDUCED

- Projection means that only some variables are part of the solution
 - Done with `SELECT ?x ?y WHERE {?x ?y ?z...}`
- DISTINCT eliminates (all) duplicate solutions:
 - Done with `SELECT DISTINCT ?x ?y WHERE {?x ?y ?z...}`
 - A solution is a duplicate if it assigns the same RDF terms to all variables as another solution.
- REDUCED allows to remove *some* or all duplicate solutions
 - Done with `SELECT REDUCED ?x ?y WHERE {?x ?y ?z...}`
 - Motivation: Can be expensive to find and remove all duplicates
 - Leaves amount of removal to implementation (e.g. consecutive occurrences)
 - Rarely used...

OFFSET and LIMIT

- LIMIT: limits the number of results
- OFFSET: position/index of the first returned result
- Useful for paging through a large set of solutions
- ...but not useful for implementing paging in applications.
- Can compute solutions number 51 to 60
- Done with
SELECT ... WHERE {...} ORDER BY ...
LIMIT 10 OFFSET 50
- LIMIT and OFFSET can be used separately
- OFFSET not meaningful without ORDER BY.

Query patterns

- Different types of *graph patterns* for the query pattern (WHERE clause):
 - Basic Graph Patterns (BGP)
 - Group Graph Patterns
 - Filters or Constraints (FILTER)
 - Optional Graph Patterns (OPTIONAL)
 - Union Graph Patterns (UNION, Matching Alternatives)
 - Graph Graph Patterns (RDF Datasets)

Basic Graph Patterns (BGP)

- A *Basic Graph Pattern* is a set of triple patterns.

- e.g.

```
?ejr foaf:name "Ernesto Jimenez-Ruiz" .  
_:pub dc:creator ?ejr .  
_:pub dc:creator ?other .
```

- Scope of blank node labels is the BGP
- Basically: A match is a function that maps
 - every variable and every blank node in the pattern
 - to a resource, a blank node, or a literal in the RDF graph (an “RDF term”)

Group Graph Patterns

- Group several patterns with { and }.
- A group containing *one* basic graph pattern:


```
{
  _:pub dc:creator ?ejr .
  _:pub dc:creator ?other .
}
```
- Two groups with one basic graph pattern each:


```
{
  { _:pub1 dc:creator ?ejr . }
  { _:pub2 dc:creator ?other . }
}
```
- Note: Same name for two different blank nodes not allowed!
- The scope of a FILTER constraint is the group where the filter appears.

Filters

- Groups may include *constraints* or *filters*
- Reduces matches of surrounding group where filter applies

- E.g.

```
{  
  ?x a dbpedia-owl:Place ;  
      dbpprop:population ?pop .  
  FILTER (?pop > 1000000)  
}
```

- E.g.

```
{  
  ?x a dbpedia-owl:Document ;  
      dbpprop:abstract ?abs .  
  FILTER (lang(?abs) = "no")  
}
```

Filters: Functions and Operators

- Usual binary operators: `||`, `&&`, `=`, `!=`, `<`, `>`, `<=`, `>=`, `+`, `-`, `*`, `/`.
- Usual unary operators: `!`, `+`, `-`.
- Unary tests: `bound(?var)`, `isURI(?var)`, `isBlank(?var)`, `isLiteral(?var)`.
- Accessors: `str(?var)`, `lang(?var)`, `datatype(?var)`
- `regex` is used to match a variable with a regular expression. *Always use with `str(?var)`*. E.g.: `regex(str(?name), "0s")`.

Read the spec for details!

Optional Patterns

- Allows a match to leave some variables *unbound* (e.g. no data was available)
- A *partial* function from variables to RDF terms
- Groups may include *optional parts*

- E.g.

```
{
  ?x a dbpedia-owl:Document ;
    dbpprop:date ?date .
  OPTIONAL {
    ?x dbpprop:abstract ?abs .
    FILTER (lang(?abs) = "no")
  }
}
```

- ?x and ?date bound in every match, ?abs bound if there is a Norwegian abstract
- Groups can contain several optional parts, evaluated separately

Optional Patterns: Negation as Failure

- Testing if a graph pattern is not expressed. . .
- . . . by specifying an OPTIONAL graph pattern that introduces a variable,
- and testing if the variable is not bound.

- E.g.

```
{
  ?x foaf:givenName ?name .
  OPTIONAL {
    ?x dc:date ?date .
    FILTER (!bound(?date))
  }
}
```

- Called **Negation as Failure** in logic programming

Matching Alternatives (UNION)

- A UNION pattern matches if any of some alternatives matches

- E.g.

```
{  
  { ?book dc:creator ?author ;  
    dc:created ?date . }  
  UNION  
  { ?book foaf:maker ?author . }  
  UNION  
  { ?author foaf:made ?book . }  
}
```

Graph Graph Patterns (RDF datasets)

- SPARQL queries are executed against an **RDF dataset**
- An RDF dataset comprises
 - One **default graph** (unnamed) graph.
 - Zero or more **named graphs** identified by an URI
- FROM and FROM NAMED keywords allows to select an RDF dataset by reference
 - The **default graph** will consist of the RDF merge of the graphs referred to in the FROM clauses,
 - FROM NAMED clauses will define the different named graphs.
 - Note that, if there is no FROM clause, but there are FROM NAMED clauses, the default graph will be empty.
- Keyword GRAPH makes the named graphs the **active graph** for pattern matching
 - A specific (named) graph can be used as active graph if its IRI is provided.

Default graph example

Add three RDF datasets to default graph

```
SELECT ?kname ?fname
FROM <http://data.lenka.no/dumps/fylke-geonames.ttl>
FROM <http://data.lenka.no/dumps/kommune-navn.ttl>
FROM <http://.../dumps/kommunesentre-geonames.ttl>
WHERE {
  ?fylke a gd:Fylke ;
         gn:officialName ?fname ;
         gn:childrenFeatures ?kommune .
  ?kommune a gd:Kommune ;
           gn:officialName ?kname ;
  FILTER (langMatches(lang(?fname), 'no'))
  FILTER (langMatches(lang(?kname), 'no'))
}
```

Named graph example 1

Occurrences of Bob in different datasets

```
SELECT ?iri_graph ?bobNick
FROM NAMED <http://example.org/foaf/aliceFoaf>
FROM NAMED <http://example.org/foaf/bobFoaf>
WHERE {
  {
    GRAPH ?iri_graph {
      ?x foaf:mbox <mailto:bob@work.example> .
      ?x foaf:nick ?bobNick .
    }
  }
}
```

Named graph example 2

Take coordinates from one source only

```

SELECT *
FROM <http://data.lenka.no/dumps/kommune-navn.ttl>
FROM <http://data.lenka.no/dumps/kommunesentre-geonames.ttl>
FROM NAMED <http://data.lenka.no/dumps/kommunesentre-geonames.ttl>
FROM NAMED <http://sws.geonames.org/6453350/about.rdf>
WHERE {
  {
    ?feature gn:officialName "Lillehammer"@no .
  } UNION {
    ?feature gn:name "Lillehammer" .
  }
  OPTIONAL {
    GRAPH <http://data.lenka.no/dumps/kommunesentre-geonames.ttl> {
      ?feature pos:lat ?lat ;
        pos:long ?long ;
        owl:sameAs ?other .
    }
  }
  OPTIONAL {
    ?feature gn:population ?pop .
  }
}

```

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SPARQL in Jena

- SPARQL functionality bundled with Jena has separate Javadocs:
`http://jena.apache.org/documentation/javadoc/arq/`
- Main classes in package `org.apache.jena.query`
 - Query a SPARQL query
 - QueryFactory for creating queries in various ways
 - QueryExecution for the execution state of a query
 - QueryExecutionFactory for creating query executions (to get QueryExecution instances)
 - DatasetFactory for creating dataset instances
 - For SELECT queries:
 - QuerySolution, a single solution to the query.
 - ResultSet, all the QuerySolutions (an iterator)
 - ResultSetFormatter, turn a ResultSet into various forms: text, RDF graph (Model, in Jena terminology) or plain XML
 - CONSTRUCT and DESCRIBE return Models, ASK a Java boolean.

Constructing a Query and a QueryExecution

- Query objects are usually constructed by parsing:

```
String qStr =
    "PREFIX foaf: <" + foafNS + ">"
    + "SELECT ?a ?b WHERE {"
    + "  ?a foaf:knows ?b ."
    + "} ORDER BY ?a ?b";
Query q = QueryFactory.create(qStr);
```

- A Query can be used several times, on multiple models
- For each execution, a new QueryExecution is needed
- To produce a QueryExecution for a given Query and Model:

```
QueryExecution qe =
    QueryExecutionFactory.create(q, model);
```

Executing a Query

- `QueryExecution` contains methods to execute different kinds of queries (`SELECT`, `CONSTRUCT`, etc.)
- E.g. for a `SELECT` query:

```
ResultSet res = qe.execSelect();
```
- E.g. for a `CONSTRUCT` query:

```
Model construct_model = qe.execConstruct();
```
- `ResultSet` is a sub-interface of `Iterator<QuerySolution>`
- `QuerySolution` has methods to get list of variables, value of single variables, etc.
- Important to call `close()` on query executions when no longer needed.

Example: SPARQL in Jena

```
String qStr = "SELECT ?a ?b ...";
Query q = QueryFactory.create(qStr);

QueryExecution qe =
    QueryExecutionFactory.create(q, model);

try {
    ResultSet res = qe.execSelect();
    while( res.hasNext()) {
        QuerySolution soln = res.next();
        RDFNode a = soln.get("?a");
        RDFNode b = soln.get("?b");
        System.out.println(""+a+" knows "+b);
    }
} finally {
    qe.close();
}
```


Querying a Model, Dataset or Endpoint

- Querying a model:

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

- Querying a Dataset:

```
String dftGraphURI =
"http://heim.ifi.uio.no/martingi/foaf" ;
List namedGraphURIs = new ArrayList() ;

namedGraphURIs.add("http://richard.cyganiak.de/foaf.rdf");
namedGraphURIs.add("http://danbri.org/foaf.rdf");
Dataset dataset = DatasetFactory.create(dftGraphURI,
namedGraphURIs);
QueryExecutionFactory.create(q, dataset);
```

Querying a Model, Dataset or Endpoint (cont.)

- Jena can also send SPARQL queries to a remote endpoint!
 - Use `sparqlService` in `QueryExecutionFactory`
 - E.g.

```
String endpoint = "http://dblp.13s.de/d2r/sparql";
String qStr = "SELECT ?a ?b ...";
Query q = QueryFactory.create(qStr);

QueryExecution qe =
    QueryExecutionFactory.sparqlService(endpoint,q);

try {
    ResultSet res = qe.execSelect();
    ...
} finally {
    qe.close();
}
```

SPARQL on the 'Net

- Many sites (DBLP, dbpedia, dbtunes, ...) publish *SPARQL endpoints*
- I.e. SPARQL queries can be submitted to a database server that sends back the results
- Uses HTTP to submit URL-encoded queries to server
GET /sparql/?query=... HTTP/1.1
- Actually defined via W3C Web Services, see

<http://www.w3.org/TR/rdf-sparql-protocol/>

- Try it out:

<https://www.w3.org/wiki/SparqlEndpoints>

DBLP <http://dblp.13s.de/d2r/snorql/>

DBpedia <http://dbpedia.org/sparql>

Lenka <http://data.lenka.no/sparql>

EBI <https://www.ebi.ac.uk/rdf/>

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Wrap-up

- SPARQL is a W3C-standardised query language for RDF graphs
- It is built around “graph patterns”
- Comes with a protocol to communicate with “endpoints”
- Can be conveniently used with Jena and tens of other systems.

More to come: SPARQL 1.1

SPARQL 1.1 became W3C Recommendations 21 March 2013.

- Updates (add/delete triples)
- Service Descriptions
- Basic Federated query
- Subqueries.
- Property paths (to shorten common queries)
- Aggregate functions (count, sum, average, . . .)
- Negation, set difference, i.e. something is *not* in a graph
- Entailment regimes

Additional material

An Introduction to SPARQL by Olaf Hartig: <http://www.slideshare.net/olafhartig/an-introduction-to-sparql>

SPARQL Query Language for RDF (SPARQL 1.0 W3C Recommendation): <https://www.w3.org/TR/rdf-sparql-query/>

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](https://careers-dnvgl.icims.com/jobs/11797/dnv-gl-summer-project-2019/job)