UNIVERSITÄT MANNHEIM

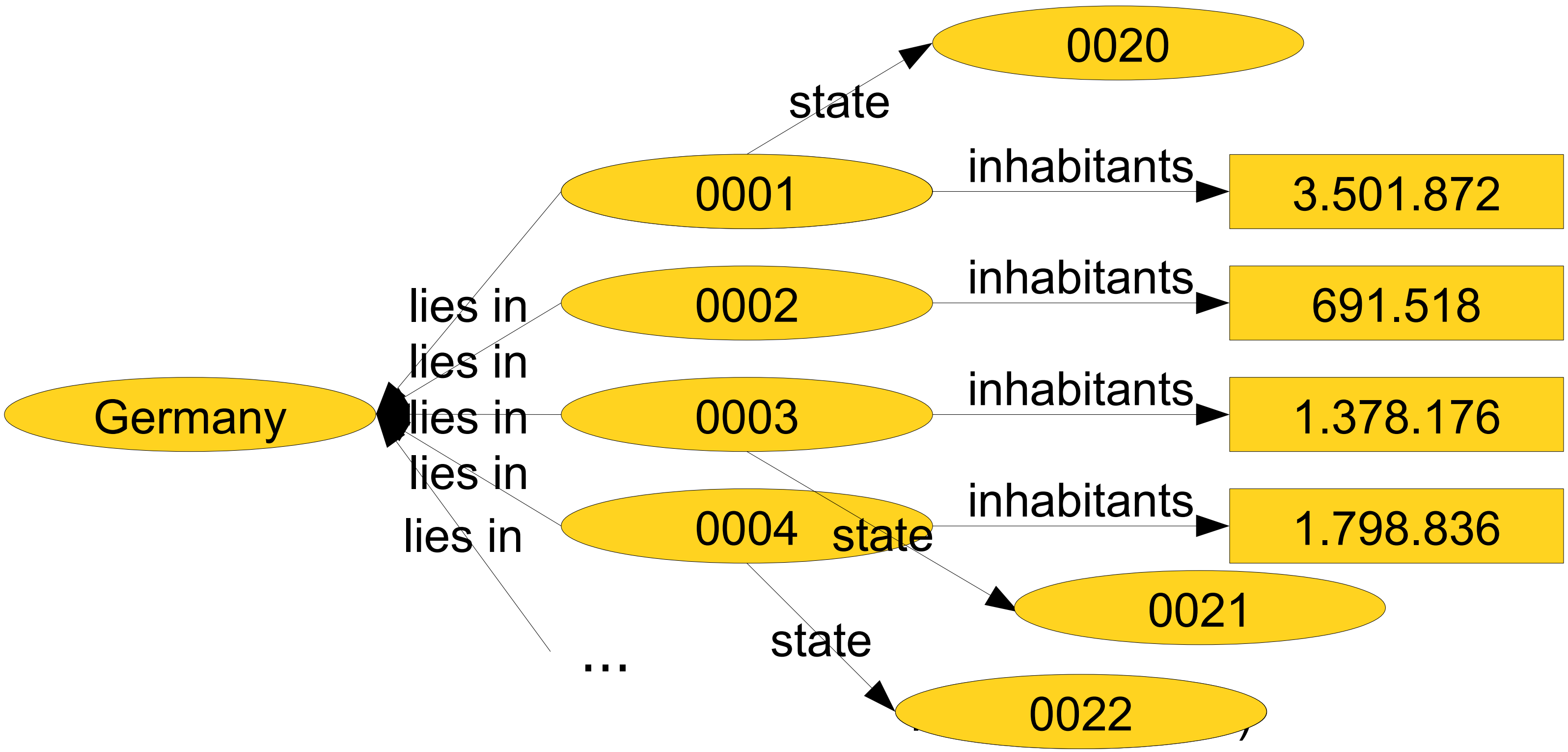
Semantic Web Technologies
SPARQL

Heiko Paulheim

Previously on "Semantic Web Technologies"

- We have got to know
  - The RDF and RDFS languages
  - The Linked Open Data paradigm
- We have accessed Linked Open Data
  - with browsers and via programming frameworks
  - jumping from node to node in the graph
- ...let us have a closer look!

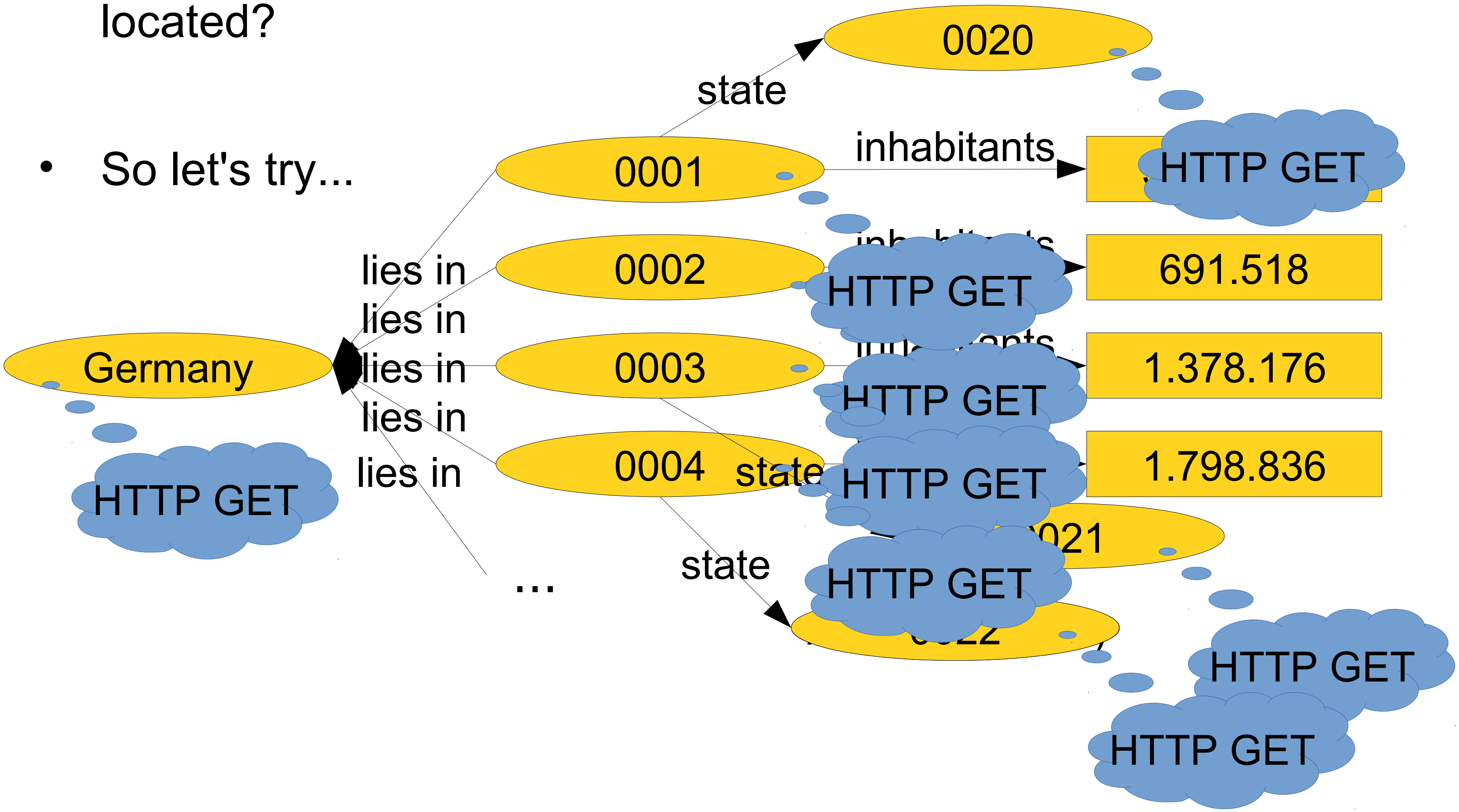
An Example RDF Graph



Question: in which states are the five biggest cities of Germany located?

Information Retrieval on Linked Open Data

- Question: in which states are the five biggest cities of Germany located?
- So let's try...



Information Retrieval on Linked Open Data

- Observations
  - Navigation across derefencable URIs ultimately leads to a goal
  - But it is tedious
  - A lot of useless data is potentially retrieved

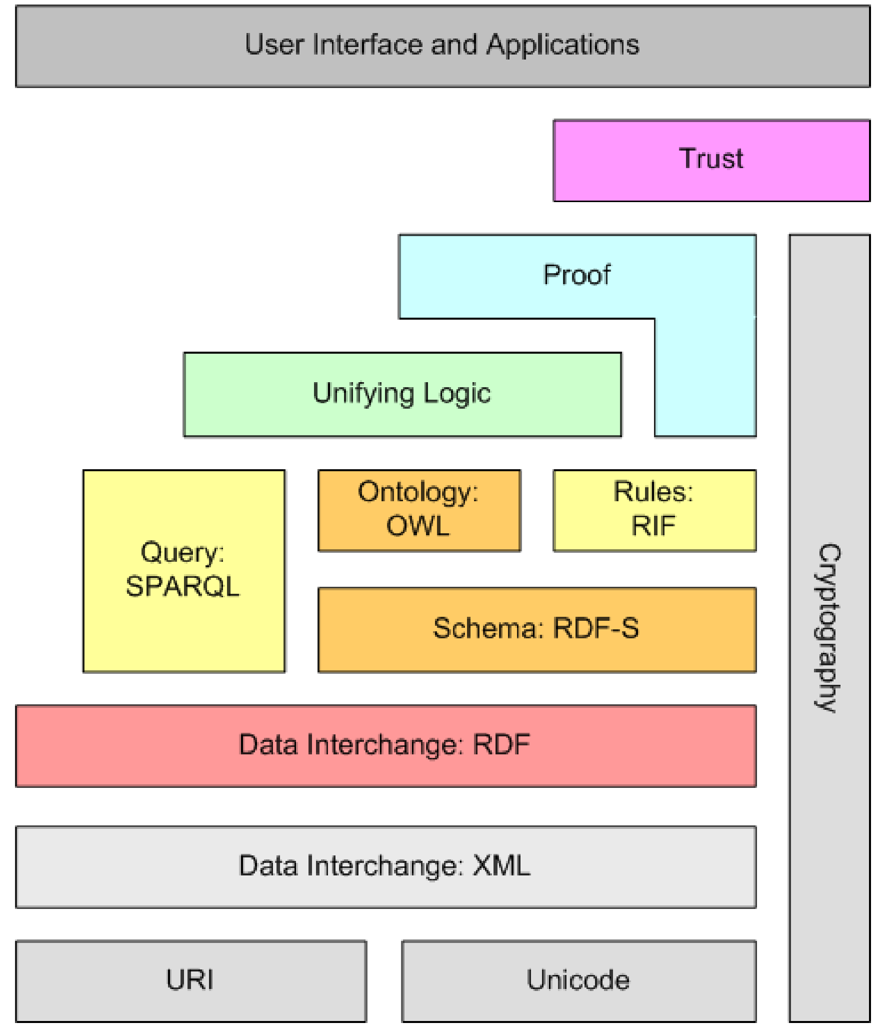
- Different information needs
  - Good for simple factual questions
  - Less efficient for more complex questions

Semantic Web – Architecture

here be dragons...

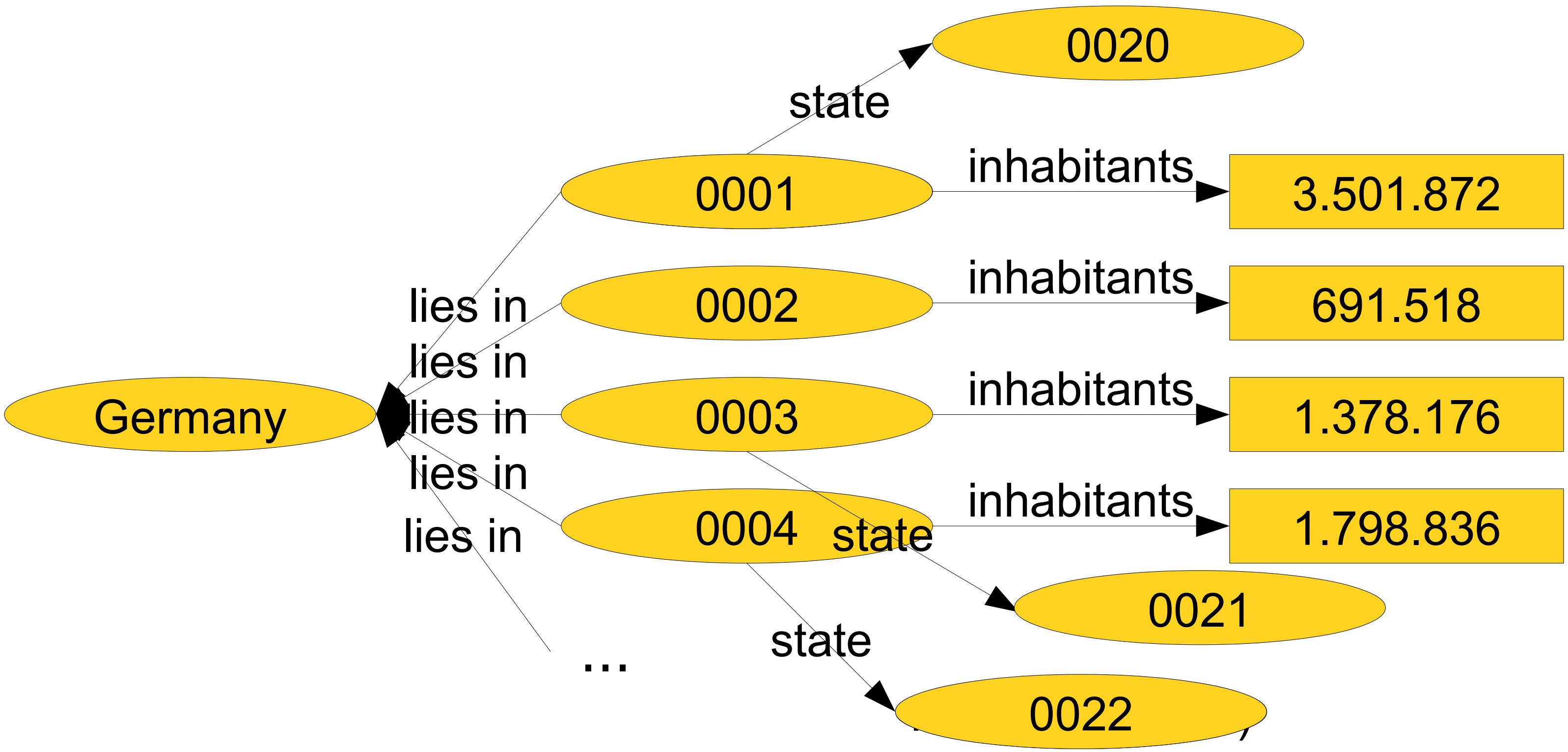
Semantic Web
Technologies
(This lecture)

Technical
Foundations



Berners-Lee (2009): *Semantic Web and Linked Data*
http://www.w3.org/2009/Talks/0120-campus-party-tbl/

What Would We Like to Have?



Question: in which states are the five biggest cities of Germany located?

Wanted: A Query Language for the Semantic Web

- ...just like SQL is for relational databases

```
SELECT  name, birthdate FROM customers
WHERE   id = '00423789'
```

id	name	birthdate
00183283	Stephen Smith	23.08.1975
00423782	Julia Meyer	05.09.1982
00789534	Sam Shepherd	31.03.1953
00423789	Herbert King	02.04.1960
...	...	...

Wanted: A Query Language for the Semantic Web

- SPARQL: "SPARQL Query Language for RDF"
  - a recursive acronym
- A W3C Standard since 2008
- Allows for querying RDF graphs

Hello SPARQL!

- Example:

```
SELECT ?child
WHERE { :Stephen :fatherOf ?child }
```

Expressions with ? denote variables

SPARQL Basics

- Basic structure:

```
SELECT <list of variables>
WHERE { <pattern> }
```

- Variables denoted with ?

- Prefixes as in RDF/N3:

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?person ?name
WHERE { ?person foaf:name ?name }
```

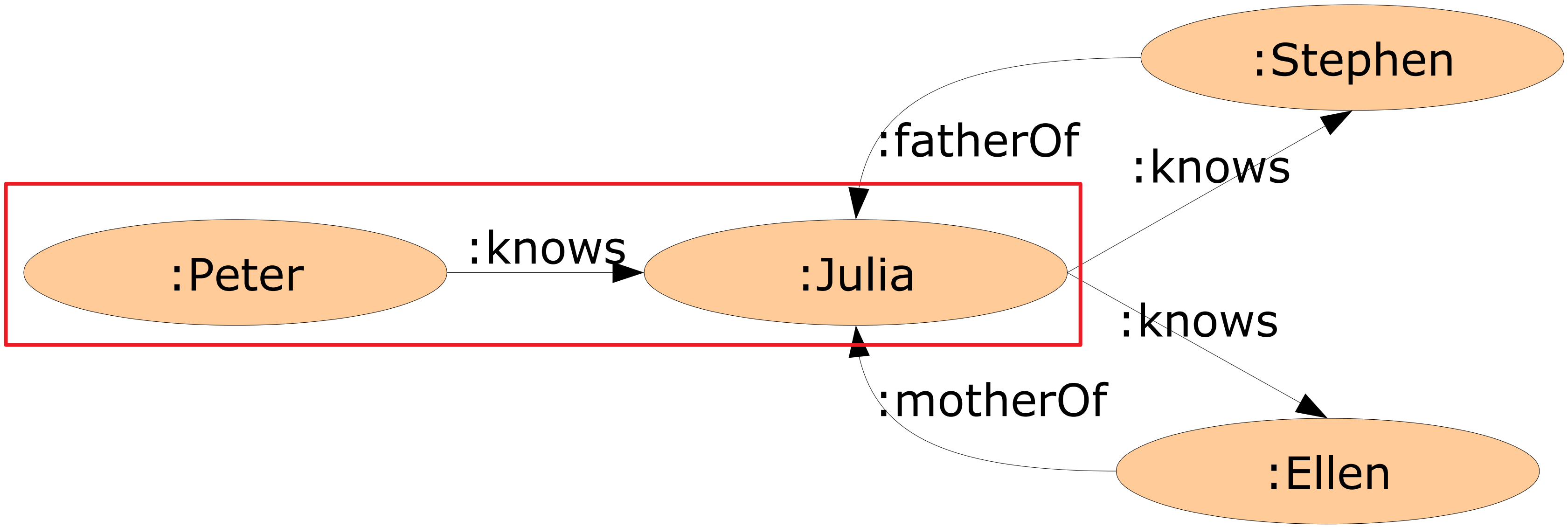
SPARQL Basics

- The <pattern> in the WHERE clause is like N3
  - with variables

- {?p foaf:name ?n }
- {?p foaf:name ?n; foaf:homepage ?hp }
- {?p foaf:knows ?p1, ?p2 }

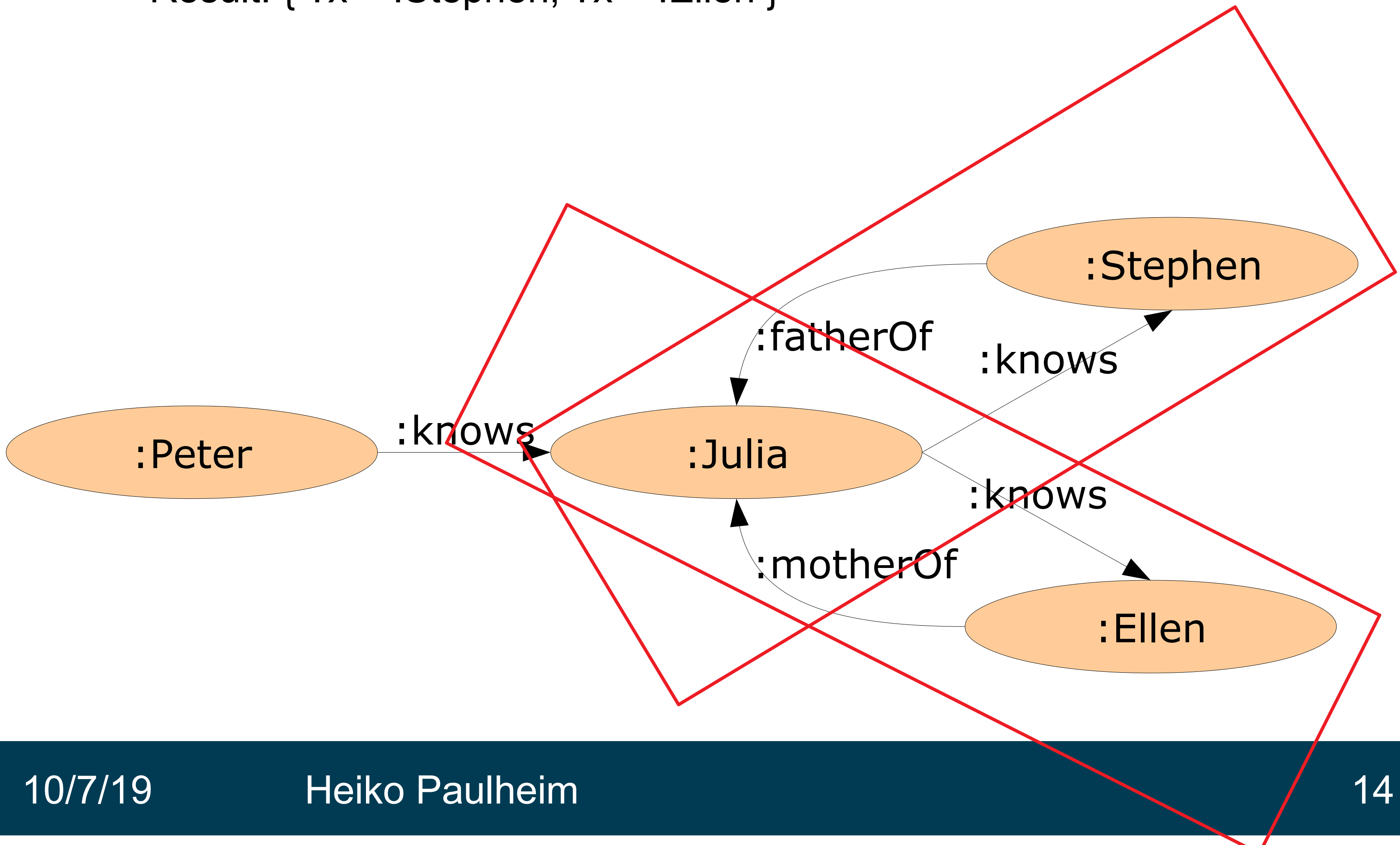
SPARQL Basics: Graph Pattern Matching

- Pattern: ?x :knows :Julia .
  - Result: { ?x = :Peter }



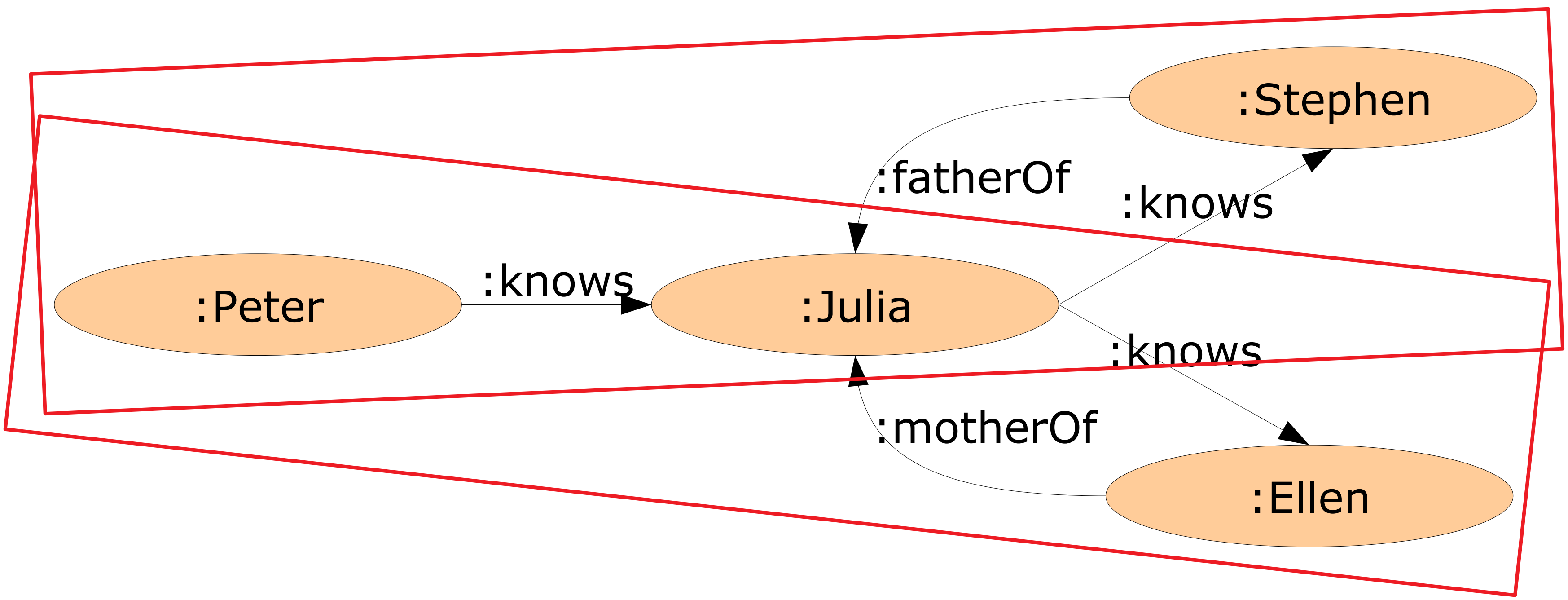
SPARQL Basics: Graph Pattern Matching

- Pattern: :Julia :knows ?x .
  - Result: { ?x = :Stephen, ?x = :Ellen }



SPARQL Basics: Graph Pattern Matching

- Pattern: :Peter :knows ?x . ?x knows ?y .
  - Result: { (?x = :Julia, ?y = :Stephen) ; (?x = :Julia, ?y = :Ellen)}



SPARQL: Pattern Matching on RDF Graphs

- A person who has a daughter and a son:

  { ?p :hasDaughter ?d ; :hasSon ?s . }

- A person knowing two persons who know each other

  { ?p :knows ?p1 , ?p2 . ?p1 :knows ?p2 . }

- A person who has two children:

  { ?p :hasChild ?c1, ?c2 . }

SPARQL: Pattern Matching on RDF Graphs

- ~~A person who has two children:~~

  ~~{ ?p :hasChild ?c1, ?c2 . }~~

- ResultSet:
  - ?p=:Stephen, ?c1=:Julia, ?c2=:Julia

Observation: different variables are not necessarily bound to different resources!

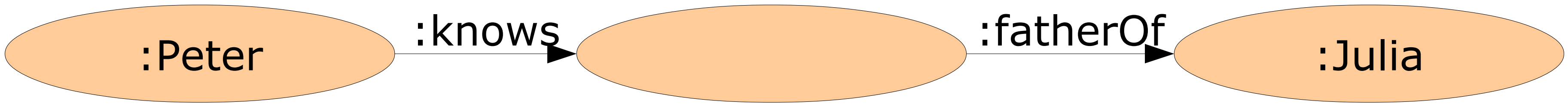
SPARQL: Blank Nodes

- WHERE clause: an RDF graph with variables

```
SELECT ?person1 ?person2 ?otherPerson
WHERE { ?person1 :knows ?otherPerson .
        ?otherPerson :fatherOf ?person2 . }
```

- Result:
  - ?person1 = :Peter, ?person2 = :Julia; ?otherPerson = _:x1

- Note: Blank Node IDs are only unique within one result set!



SPARQL: Matching Literals

- Strings

```
{ ?country :name "Germany" . }
```

- Watch out for language tags!

```
{ ?country :name "Germany"@en . }
```

→ The Strings `"Germany"` and `"Germany"@en` are different!

- Numbers:

```
{ ?person :age "42"^^xsd:int .}
```

Short hand notation:

```
{ ?person :age 42 . }
```

SPARQL: Filters

- Used for further restricting results

```
{?person :age ?age . FILTER(?age < 42) }
```

- Operators for comparisons:

```
=        !=      <      >      <=      >=
```

- Logical operations:

```
&&       ||      !
```

SPARQL: Filters

- Persons with younger siblings

```
{ ?p1 :siblingOf ?p2 .
  ?p1 :age ?a1 .
  ?p2 :age ?a2 .
  FILTER(?a2 < ?a1)}
```

- Persons that have both younger and older siblings

```
{ ?p1 :siblingOf ?p2,p3 .
  ?p1 :age ?a1 .
  ?p2 :age ?a2 .
  ?p3 :age ?a3 .
  FILTER(?a2 < ?a1 && ?a3 > ?a1)}
```

Question: why do we get different persons for p2 and p3?

SPARQL: Filters

- Second try: a person with two children

  `{ ?p :hasChild ?c1, ?c2 . FILTER( ?c1 != ?c2) }`

- A slight improvement

  → Variables are now bound to different resources

- But: we still have the Non-Unique Naming Assumption

  → i.e., given that
  :Peter :hasChild :Julia .
  :Peter :hasChild :Stefan .

  we still cannot conclude that Peter has two children!

- Furthermore, there is still the Open World Assumption

  → i.e., Peter could also have more children

Filters for Strings

- Searching in Strings: using regular expressions

- People called “Ann”

```
{?person :name ?n . FILTER(regex(?n,"^Ann$")) }
{?person :name ?n . FILTER(regex(?n,"Ann")) }
```

→ the second variant would also find, e.g., “Mary-Ann”

- `str`: URIs and Literals as strings
- allows for, e.g., searching for literals across languages

```
{?country :name ?n . FILTER(str(?n) = "Tyskland") }
```

Further Built-In Features

- Querying the type of a resource
  - `isURI`
  - `isBLANK`
  - `isLITERAL`
- Querying for the data type and language tags of literals
  - `DATATYPE(?v)`
  - `LANG(?v)`
- Comparing the language of two literals
  - `langMATCHES(?v1,?v2)`
  - Caution: given `?v1 = "Januar"@DE`, `?v2 = "Jänner"@DE-at`

    `LANG(?v1) = LANG(?v2)` → false

    `langMATCHES(?v1,?v2)` → true

Combining Patterns

- Find the private and work phone number

```
        { ?p :privatePhone ?nr }
UNION   { ?p :workPhone ?nr }
```

- UNION creates a set union

  ?p = :peter, ?nr = 123;
  ?p = :john, ?nr = 234;
  ?p = :john, ?nr = 345;
  ...

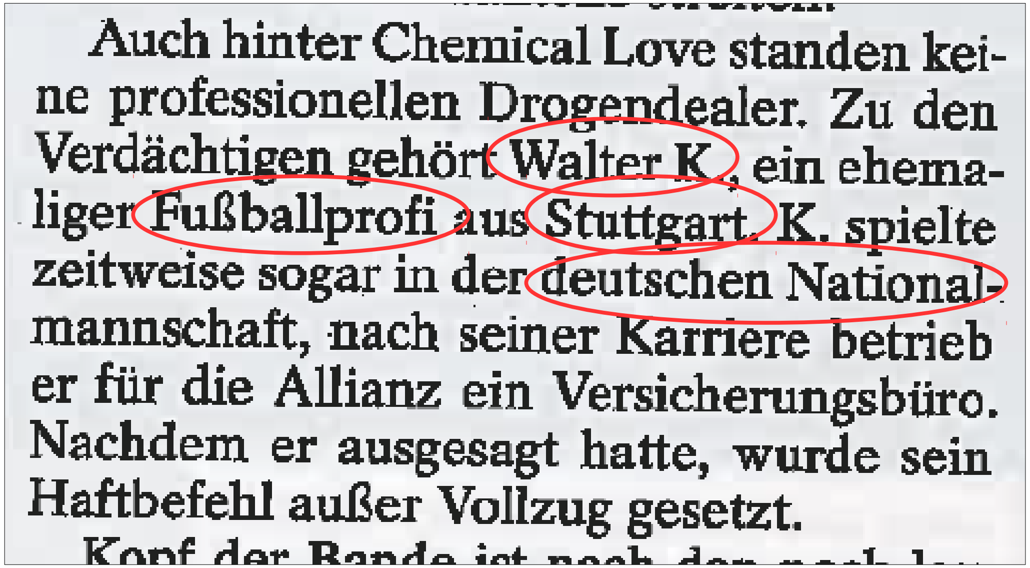
That happens if John has both a private and a work phone

Interlude: A Real-World Example

Auch hinter Chemical Love standen keine professionellen Drogendealer. Zu den Verdächtigen gehört Walter K., ein ehemaliger Fußballprofi aus Stuttgart. K. spielte zeitweise sogar in der deutschen Nationalmannschaft, nach seiner Karriere betrieb er für die Allianz ein Versicherungsbüro. Nachdem er ausgesagt hatte, wurde sein Haftbefehl außer Vollzug gesetzt.

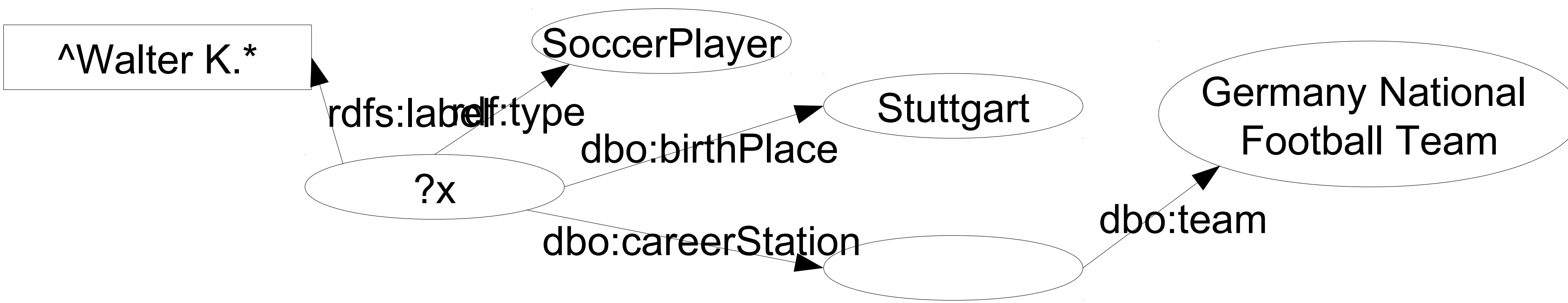
Der SPIEGEL, 27/2016, p. 52

Interlude: A Real-World Example

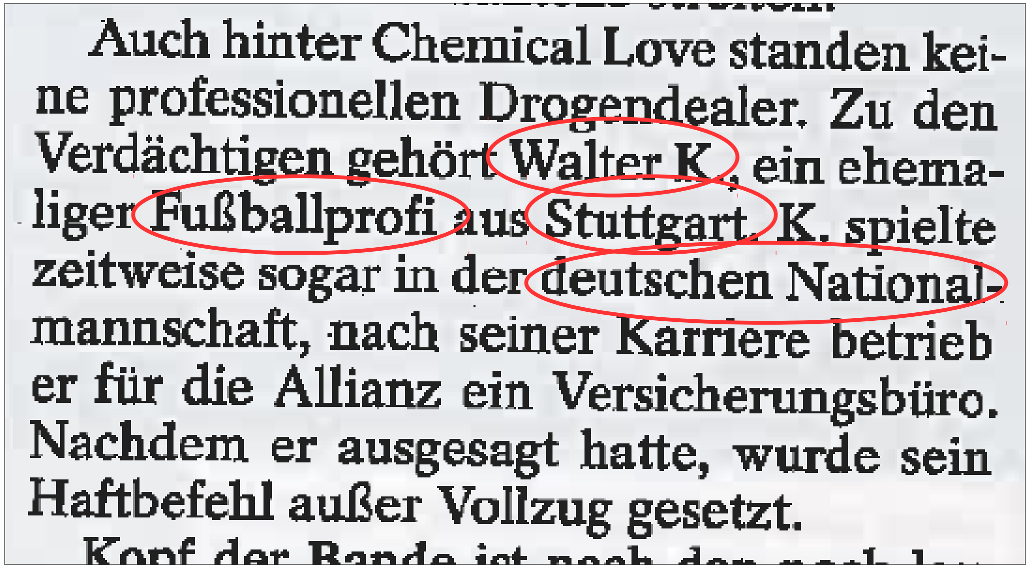


Auch hinter Chemical Love standen keine professionellen Drogendealer. Zu den Verdächtigen gehört Walter K., ein ehemaliger Fußballprofi aus Stuttgart. K. spielte zeitweise sogar in der deutschen Nationalmannschaft, nach seiner Karriere betrieb er für die Allianz ein Versicherungsbüro. Nachdem er ausgesagt hatte, wurde sein Haftbefehl außer Vollzug gesetzt.

Who is this Walter K.?



Interlude: A Real-World Example



Auch hinter Chemical Love standen keine professionellen Drogendealer. Zu den Verdächtigen gehört Walter K., ein ehemaliger Fußballprofi aus Stuttgart. K. spielte zeitweise sogar in der deutschen Nationalmannschaft, nach seiner Karriere betrieb er für die Allianz ein Versicherungsbüro. Nachdem er ausgesagt hatte, wurde sein Haftbefehl außer Vollzug gesetzt.

Who is this Walter K.?

```
SELECT DISTINCT(?x) WHERE {
        ?x dbo:birthPlace dbr:Stuttgart .
        ?x a dbo:SoccerPlayer .
        ?x dbo:careerStation ?s. ?s dbo:team dbr:Germany_national_football_team.
        ?x rdfs:label ?l . FILTER(REGEX(?l,"^Walter K.*"))
}
```

Interlude: A Real-World Example

Auch hinter Chemical Love standen keine professionellen Drogendealer. Zu den Verdächtigen gehört Walter K., ein ehemaliger Fußballprofi aus Stuttgart. K. spielte zeitweise sogar in der deutschen Nationalmannschaft, nach seiner Karriere betrieb er für die Allianz ein Versicherungsbüro. Nachdem er ausgesagt hatte, wurde sein Haftbefehl außer Vollzug gesetzt.

Who is this Walter K.?

We get one result:

<http://dbpedia.org/resource/Walter_Kelsch>

Interlude: A Real-World Example

Dienstag, 03. Mai 2016

Auf schiefe Bahn geraten

Ex-Nationalspieler Kelsch sitzt in U-Haft

Walter Kelsch war ein torgefährlicher Fußballer - sieben Jahre lang spielte er für den VfB Stuttgart, vier Mal trug er das DFB-Trikot. Nun ist der 60-jährige Schwabe mit dem Gesetz in Konflikt geraten.

Teilen Twittern Teilen

Der ehemalige Fußball-Nationalspieler Walter Kelsch sitzt wegen Drogenhandels im Internet in Stuttgart-Stammheim in Untersuchungshaft. Dies bestätigte die Staatsanwaltschaft im niedersächsischen Verden.

Walter Kelsch
(Foto: imago/Pressefoto Baumann)

Insgesamt waren fünf Personen bei einer Razzia am 14. April festgenommen worden. Dabei sei "Deutschlands größter illegaler Webshop für Betäubungsmittel" zerschlagen worden, teilte die Staatsanwaltschaft mit.

Man werfe den Tatverdächtigen vor, "als Gruppierung 'Chemical-Love' über ein vorwiegend deutschsprachiges Dark-Market Forum sowie über einen eigenen Webshop Kokain und diverse synthetische Drogen vertrieben zu haben", hieß es in einer Pressemitteilung. Insgesamt seien 54 kg Amphetamin, etwa 4 kg Heroin, rund 1,3 kg Kokain und etwa 25.000 Ecstasy-Tabletten sichergestellt worden.

Der heute 60-jährige Kelsch hatte von 1977 bis 1984 beim VfB Stuttgart gespielt und in 202 Bundesligaspielen 51 Tore erzielt. 1984 wurde er mit den Schwaben deutscher Meister. In vier Länderspielen erzielte der Offensivspieler drei Tore. Bis 2011 war Kelsch sogar Präsidiumsmitglied bei den Stuttgarter Kickers gewesen.

Quelle: n-tv.de , wne/sid

Optional Patterns

- Find a person's phone number and fax number, **if existing**

```
                   { ?p :phone ?tel }
OPTIONAL           { ?p :fax ?fax }
```

- OPTIONAL also creates unbound variables

  ?p = :peter, ?tel = 123, ?fax = 456;
  ?p = :john, ?tel = 234, ?fax = ;
  ?p = :julia, ?nr = 978; ?fax = 349;
  ...

Unbound variable:
John does not have a fax number (as far as we know)

Unbound Variables

- Variables can remain unbound
- We can test this with BOUND

- Everybody who has a phone or a fax (or both):

```
OPTIONAL {?p :phone ?tel . }
OPTIONAL {?p :fax ?fax . }
FILTER ( BOUND(?tel) || BOUND(?fax) )
```

Negation

- This is a common question w.r.t. SPARQL
- How do I do this:
  - "Find all persons who do not have siblings."

- This is left out of SPARQL intentionally!
- Why?

- Open World Assumption
  - we cannot know!
- For the same reason, there is no `COUNT`
  - at least not in standard SPARQL

Negation – Hacking SPARQL

- However, there is a possibility
  - try with caution!

- Using `OPTIONAL` and `BOUND`
- Find all persons without siblings

```
OPTIONAL {?p :hasSibling ?s . }
FILTER ( !BOUND(?s) )
```

- This works
- However, you should know what you are doing
  - ...and how to interpret the results!

Negation – Hacking SPARQL

- How does that work?
- Results before FILTER:

```
OPTIONAL {?p :hasSibling ?s . }

?p = :peter, ?s = :julia
?p = :julia, ?s = :peter
?p = :mary, ?s =
?p = :paul, ?s =
```

Unbound variables

- Applying the FILTER
  - `FILTER(!BOUND(?s))`

```
?p = :mary, ?s =
?p = :paul, ?s =
```

Sorting and Paging Results

- Sorting: `ORDER BY ?name`
- Limitations: `LIMIT 100`
- Lower Bounds: `OFFSET 200`

- Example: persons 101-200, ordered by name
  - `ORDER BY ?name LIMIT 100 OFFSET 100`

- `LIMIT/OFFSET` without `ORDER BY`:
  - Result orderings are not deterministic
  - There is no default ordering

Sorting and Paging Results

- Application scenarios:
  - Some SPARQL services limit their result set sizes
  - Pre-loading in applications

- Application example:
  - let the user browse cities
  - it is more likely that users want to see the big cities
  - display 100 biggest cities on one page, show more on demand

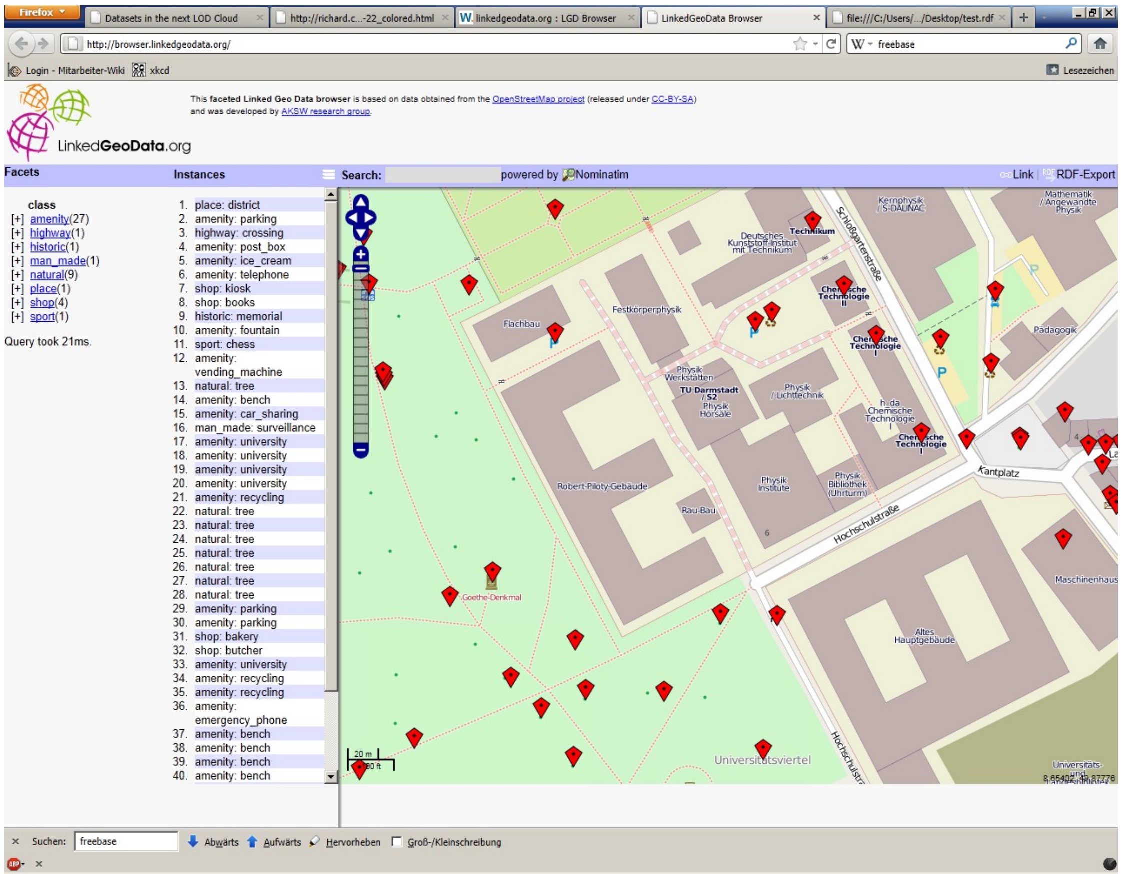
- ```
  SELECT ?city ?population
  WHERE {?city hasPopulation ?population}
  ORDER BY DESC(?population)
  LIMIT 100
  ```
  ```

Filtering Duplicates

- ```
  SELECT DISTINCT ?person
      WHERE { ?person :privatePhone ?nr }
      UNION { ?person :workPhone ?nr }
  ```

- This means: all results with identical variable bindings are filtered

- This does not mean: persons identified by *?person* are actually different

- Why?
  - Non-unique naming assumption
  ```

Custom Built-Ins

- Some SPARQL engines allow special constructs
- also known as *Custom Built-Ins*
- Example: geographic processing
  - Dataset: Linked Geo Data

LinkedGeoData

- A LOD Wrapper for OpenStreetMaps



Custom Built-Ins

- Querying for coordinates
  - simple:
    ```
    WHERE { ?x geo:long ?long; geo:lat ?lat .
    FILTER (?long>8.653 && ?long<8.654 &&
            ?lat>49.878 && ?lat<49.879)}
    ```

- More complex queries
  - all cafés within a 1km radius of a given point
    ```
    WHERE { ?x rdf:type lgdo:Cafe; geo:geometry ?geo .
    FILTER (bif:st_intersects(
            ?geo, bif:st_point(8.653, 49.878), 1))}
    ```

Further Query Types: ASK

- So far, we have only looked at SELECT queries
- ASK allows for yes/no queries:
  - e.g., are there persons with siblings?

```
ASK {?p :hasSibling ?s . }
```

- Often faster than SELECT queries

- The answer is true or false
  - *false* means: there are no matching sub graphs
  - do not misinterpret (Open World Assumption!)

Further Query Types: DESCRIBE

- All properties of a resource

```
DESCRIBE <http://dbpedia.org/resource/Berlin>
```

- Can be combined with a WHERE clause

```
DESCRIBE ?city WHERE { :Peter :livesIn ?city . }
```

- Allows for exploration of a dataset with unknown structure

- Caution: types of results are not standardized, results vary from implementation to implementation!

Further Query Types: CONSTRUCT

- Creates a new RDF graph

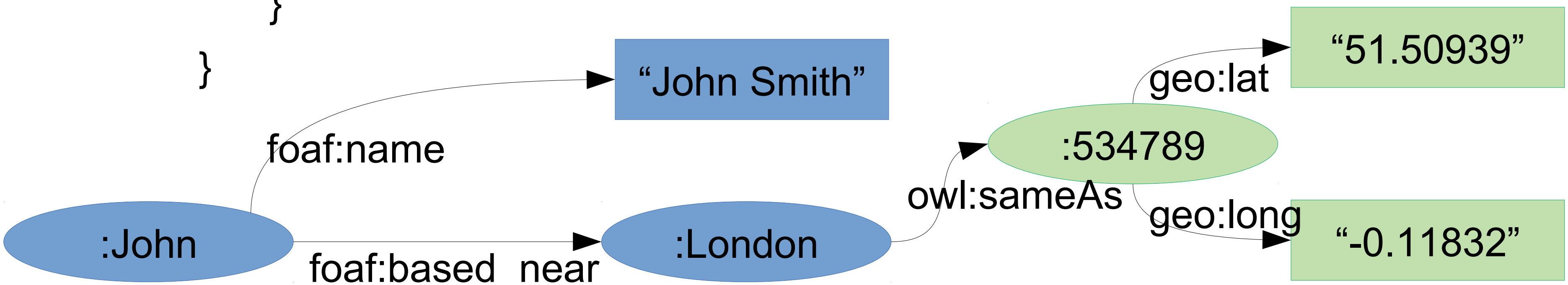
```
CONSTRUCT
{ ?x rdfs:seeAlso
<http://dbpedia.org/resource/Berlin> . } WHERE
{ <http://dbpedia.org/resource/Berlin> ?y ?x .
        FILTER (isURI(?x)) }
```

- CONSTRUCT returns complete RDF graphs
  - e.g., for further processing

Query Federation

- Queries can be answered over *multiple* SPARQL endpoints
- Example

```
SELECT ?name ?lat ?long WHERE {
    ?x a foaf:Person .
    ?x foaf:name ?name .
    ?x foaf:based_near ?city .
    ?city owl:sameAs ?geocity .
    SERVICE <http://linkedcoordinates.org/sparql> {
        ?geocity geo:lat ?lat .
        ?geocity geo:long ?long .
    }
}
```



SPARQL: Wrap-Up

- SPARQL is a query language for the semantic web
- Basic principle: pattern matching on graphs
- SPARQL allows for directed search for information instead of navigating the graph from node to node

- Results follow the semantic principles of RDF!
  - Open World Assumption
  - Non-unique naming assumption

Example: Jena + SPARQL

- Querying models with SPARQL

```
String queryString = "SELECT ?x ...";
Query query = QueryFactory.create(queryString);
QueryExecution qe =
  QueryExecutionFactory.create(query, model);
ResultSet results = qe.execSelect();
while(results.hasNext()) {
  QuerySolution sol = results.next();
  String s = sol.get("x").toString();
  ...
}
```

Recap: Reasoning with Jena

- Given: a schema and some data

```
Model schemaModel = ModelFactory.createDefaultModel();
InputStream IS = new
FileInputStream("data/example_schema.rdf");
schemaModel.read(IS);

Model dataModel = ModelFactory.createDefaultModel();
IS = new FileInputStream("data/example_data.rdf");
dataModel.read(IS);

Model reasoningModel =
  ModelFactory.createRDFSModel(schemaModel, dataModel);
```

- Now, `reasoningModel` contains all derived facts

Example: Jena + SPARQL + Reasoning

- Derived facts can also be queries with SPARQL
- Given the `reasoningModel`

```
Query q = QueryFactory.create(
  "SELECT ?t WHERE
  { <http://example.org/Madrid>
    <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
    ?t .}" );
QueryExecution qexec =
  QueryExecutionFactory.create(q, reasoningModel);
ResultSet rs = qexec.execSelect();
while(rs.hasNext())
  String type = rs.next().get("t");
```

- Here, the query produces two solutions
  - `http://example.org/City`
  - `http://www.w3.org/2000/01/rdf-schema#Resource`

Accessing Public SPARQL Endpoints

- SPARQL Endpoints are an important building block of the Semantic Web tool stack
- Access using Jena:

```
String query = "SELECT ...";
String endpoint = "http://dbpedia.org/sparql";
Query q = QueryFactory.create(strQuery);
QueryExecution qexec =
  QueryExecutionFactory.sparqlService(endpoint, q);
ResultSet RS = qexec.executeSelect();
```

Accessing Public SPARQL Endpoints

- Recap:
  - Jena uses the iterator pattern quite frequently

- Observation:
  - SPARQL ResultSets are also like iterators
  - Data can be retrieved from the server little by little

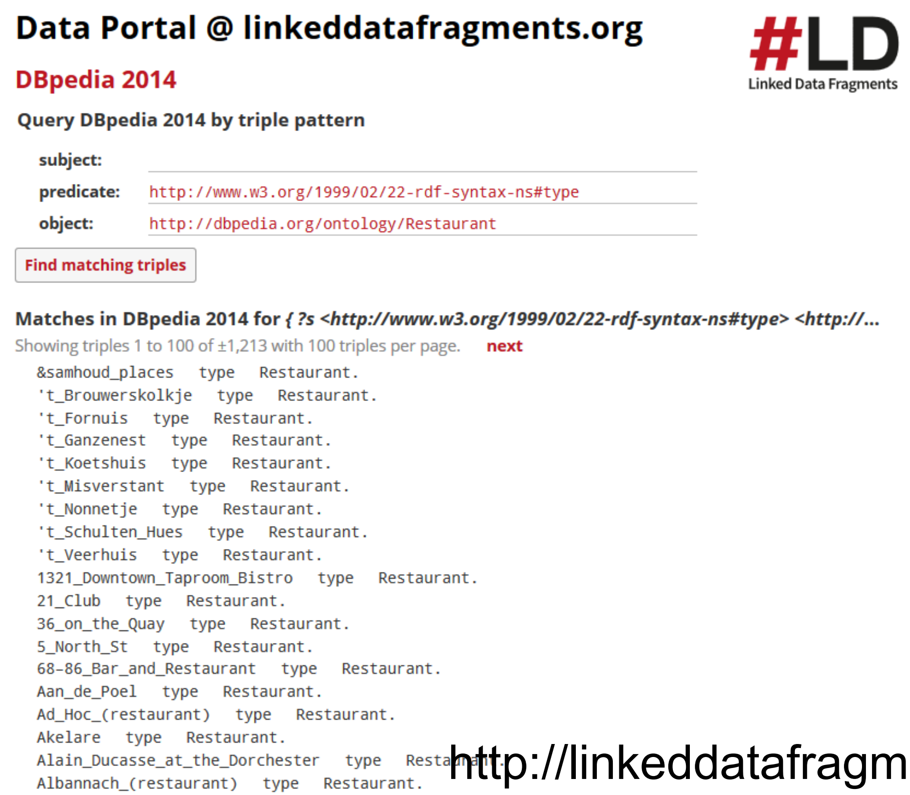
Triple Pattern Fragments

- Observation:
  - Operating SPARQL endpoints is costly
    - Hence, there are often downtimes
  - Accessing data via dumps or derefencing is time consuming
    - See initial experiment
- Triple Pattern Fragments provide a middle ground solution

http://linkeddatafragments.org

Triple Pattern Fragments

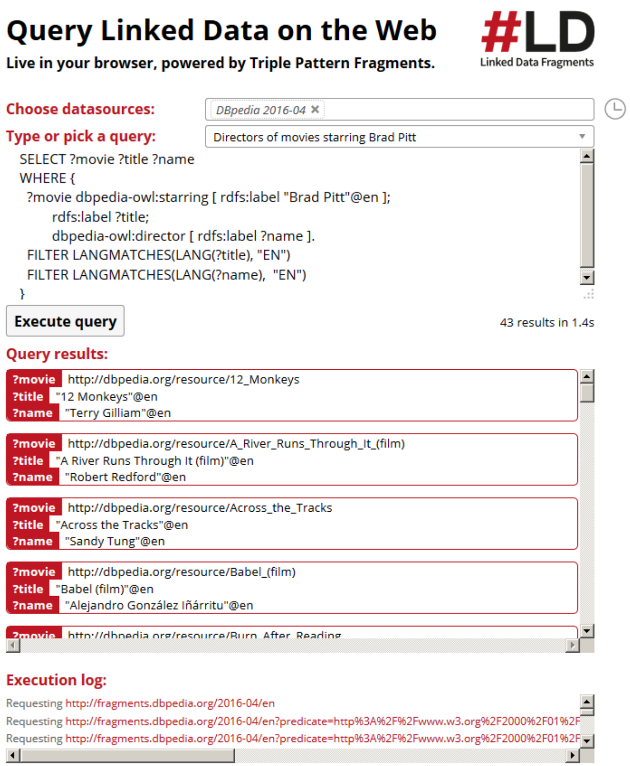
- Only allow simple restrictions
  - i.e., only {?s ?p ?o}
- Provide results in a paged fashion
  - Estimated count
  - Links to further pages



http://linkeddatafragments.org

Triple Pattern Fragments

- Most SPARQL queries can be solved by iteratively retrieving TPFs
  - Successively issuing new *selectors*
  - More targeted, i.e., less calls, than derefencing individual URIs



http://linkeddatafragments.org

Triple Pattern Fragments

- Example: astronauts born in capital countries

```
select ?x ?y ?z where {
  ?x a dbpedia-owl:Astronaut .          +/- 651
  ?x dbpedia-owl:birthPlace ?y .        ±1,137,061
  ?z dbpedia-owl:capital ?y .           ±5,034
  ?z a dbpedia-owl:Country              ±13,779
}
```

- Algorithm:
  - retrieve pattern: ?x a dbpedia-owl:Astronaut . 653
  - for each result ?x: retrieve ?x dbpedia-owl:birthPlace ?y . 1,209
  - for each result ?y: retrieve ?z dbpedia-owl:capital ?y . 637
  - for each result ?z: check ?z a dbpedia-owl:Country .

Triple Pattern Fragments

- Middle ground between
  - setting up a SPARQL server (costly for the server)
  - providing a full RDF dump (costly for the client)
- In our example, a SPARQL query was broken down into ~3k HTTP GET requests
  - Using clever index structures, this might still be faster
  - Results may also be streamed – allows for early stopping

Triple Pattern Fragments vs. SPARQL

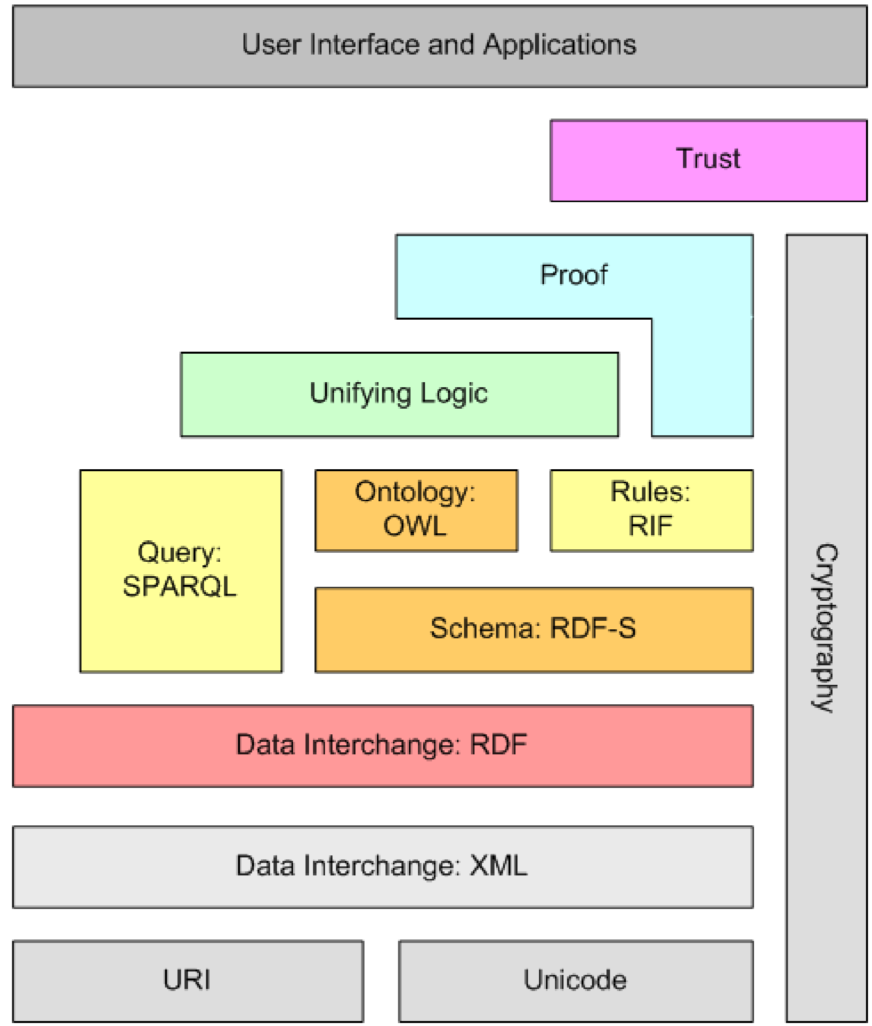
- All SPARQL constructs can be translated to a TPF query plan
- Some are quite fast
  - e.g., typical star-shaped queries
- Some are rather slow
  - e.g., regex queries for labels

Semantic Web – Architecture

here be dragons...

Semantic Web Technologies (This lecture)

Technical Foundations



Berners-Lee (2009): *Semantic Web and Linked Data*
http://www.w3.org/2009/Talks/0120-campus-party-tbl/

Questions?