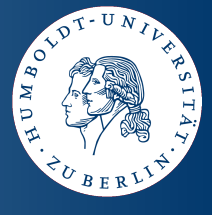

SPARQL - Querying the Web of Data

Seminar WS 2008/2009

RDF and the Web of Data

Olaf Hartig
hartig@informatik.hu-berlin.de


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RDF in General

- Resource Description Framework (RDF)
- A resource is basically everything
  - E.g. persons, places, Web documents, abstract concepts
- Descriptions of resources
  - Attributes and features
  - Relations
- The framework contains:
  - A data model, and
  - Languages and syntaxes

RDF Data Model

- Atoms of knowledge are **triples** (subject, predicate, object)

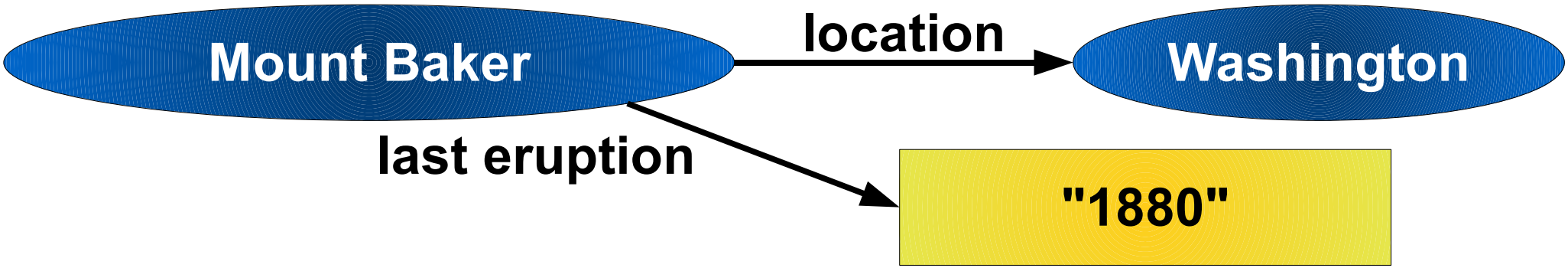
- **Subject**: resources
- **Predicate**: properties
- **Object**: resources or literals

- **Examples**:
  - (Mount Baker , last eruption , "1880")
  - (Mount Baker , location , Washington)

RDF Data Model

- RDF is also a graph model
  - Triples as directed edges
  - Subjects and objects as vertices
  - Edges labeled by predicate

- Example:
  - (Mount Baker , last eruption , "1880")
  - (Mount Baker , location , Washington)



Uniform Resource Identifier (URI)

- Globally unique identifier for resources
- Syntax:
  - URI schema (e.g. http, mailto, urn)
  - Colon character (“:”)
  - Scheme-specific part (often hierarchical)
- Examples:

```
http://dbpedia.org/resource/Mount_Baker
http://www.informatik.hu-berlin.de/~hartig/foaf.rdf#olaf
urn:isbn:0-486-27557-4
```

Uniform Resource Identifier (URI)

- URIs extend the concept of URLs
  - URL of a Web document usually used as its URI
  - Attention: URIs identify not only Web documents
- Example:
  - Me:

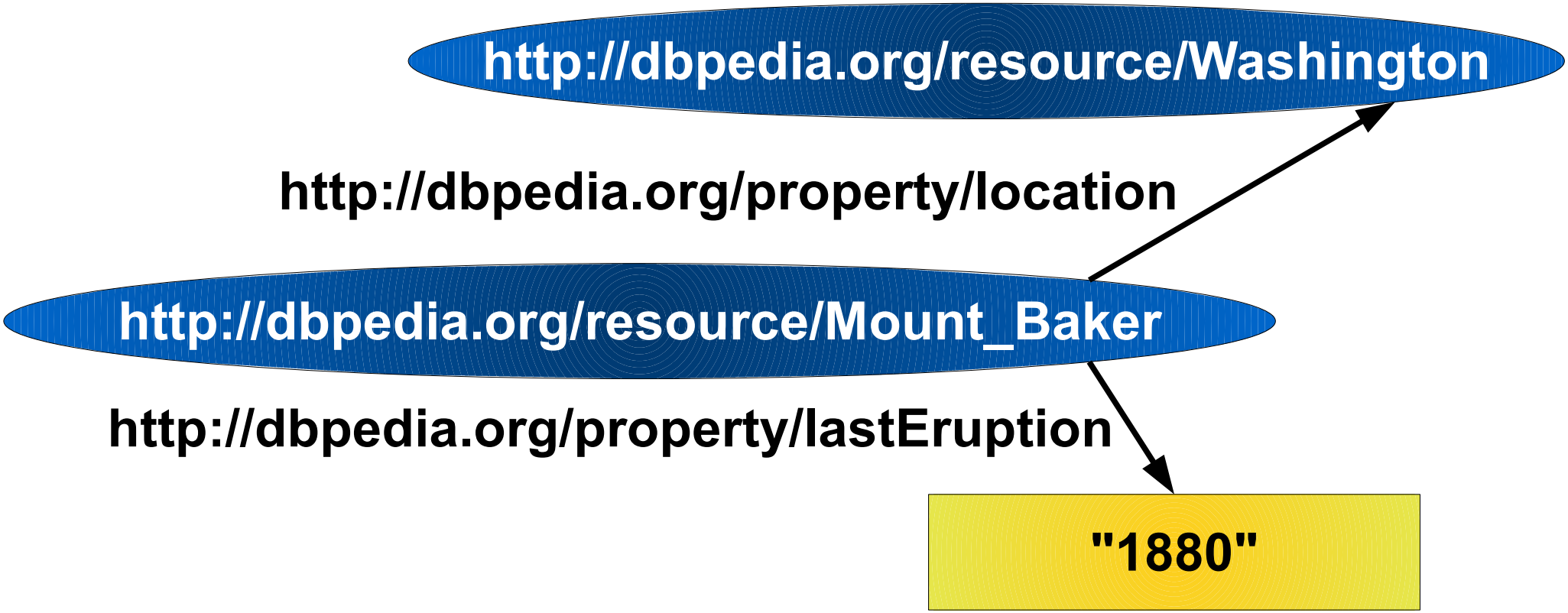
    `http://www.informatik.hu-berlin.de/~hartig/foaf.rdf#olaf`
  - RDF document about me:

    `http://www.informatik.hu-berlin.de/~hartig/foaf.rdf`
  - HTML document about me:

    `http://www.informatik.hu-berlin.de/~hartig/index.html`

Example (revisited)

- (http://dbpedia.org/resource/Mount_Baker, http://dbpedia.org/property/lastEruption, "1880")
- (http://dbpedia.org/resource/Mount_Baker, http://dbpedia.org/property/location, http://dbpedia.org/resource/Washington)



Compact URIs (CURIE)

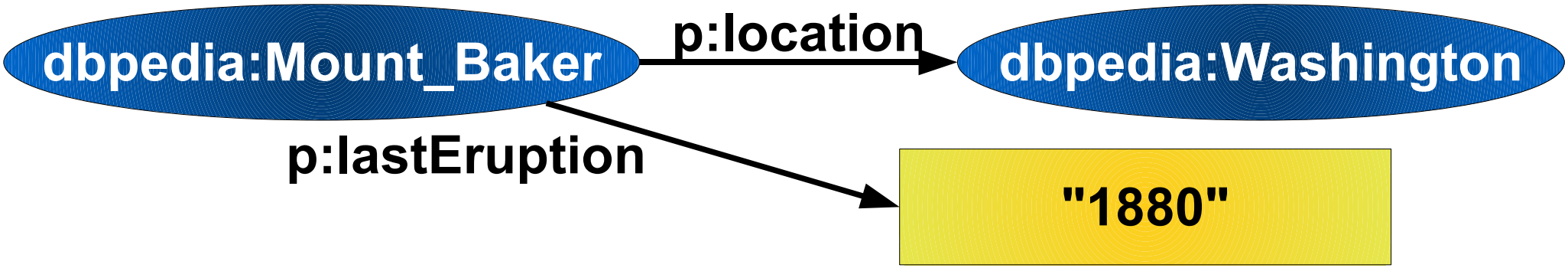
- **Abbreviated Notation for URIs**
- **Syntax:**
  - **Prefix name (references the prefix of the URI)**
  - **Colon character (":")**
  - **Reference part**
- **URI by concatenating the prefix and the reference part**
- **Examples:**
  - `dbpedia:Mount_Baker` **for**

    `http://dbpedia.org/resource/Mount_Baker`
  - `myfoaf:olaf` **for**

    `http://www.informatik.hu-berlin.de/~hartig/foaf.rdf#olaf`

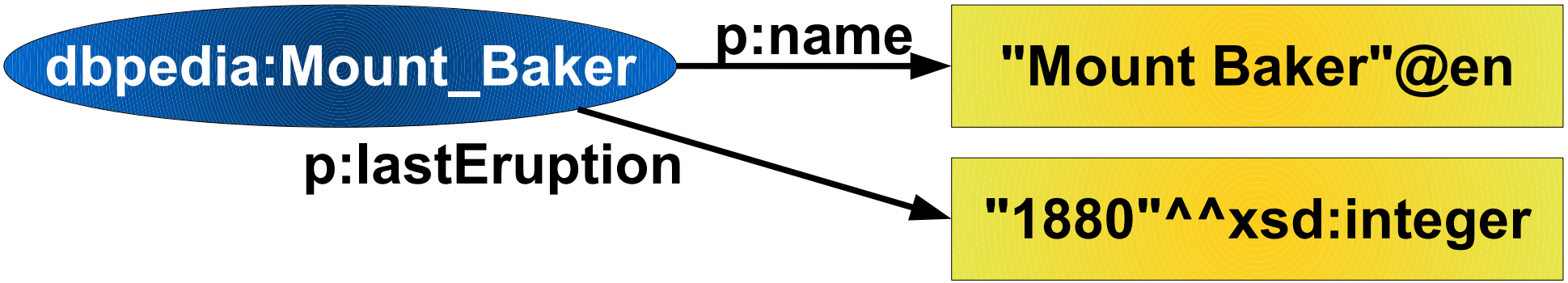
Example with CURIEs

- Using
  - *dbpedia* for prefix *http://dbpedia.org/resource/*
  - *p* for prefix *http://dbpedia.org/property/*
- we have
  - (dbpedia:Mount_Baker, p:lastEruption, "1880")
  - (dbpedia:Mount_Baker, p:location, dbpedia:Washington)



Literals

- Literals may occur in the object position of triples
- Represented by strings
- Literal strings interpreted by datatypes
  - Datatype identified by a URI
  - Common to use the XML Schema datatypes
  - No datatype: interpreted as *xsd:string*
- Untyped literals may have language tags (e.g. @de)



N3 – A Readable Syntax for RDF

- Simple notation to list RDF triples:
  - Triples separated by a period (“.”) character
  - Example:

```
<http://dbpedia.org/resource/Mount_Baker>
        <http://dbpedia.org/property/lastEruption>
                "1880"^^xsd:integer .
<http://dbpedia.org/resource/Mount_Baker>
        <http://dbpedia.org/property/location>
                <http://dbpedia.org/resource/Washington> .
```

N3 – A Readable Syntax for RDF

- N3 allows the use of CURIEs:
  - `@prefix` directive binds a prefix to a namespace URI

```
@prefix dbpedia : <http://dbpedia.org/resource/> .
@prefix p : <http://dbpedia.org/property/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

dbpedia:Mount_Baker p:lastEruption "1880"^^xsd:integer .
dbpedia:Mount_Baker p:location     dbpedia:Washington .

dbpedia:Washington p:borderingstates dbpedia:Oregon .
dbpedia:Washington p:borderingstates dbpedia:Idaho .
```

N3 – A Readable Syntax for RDF

- N3 provides some syntactic sugar:
  - Property lists separated by a semicolon (“;”) character
  - Object lists separated by a comma (“,”) character

```
@prefix dbpedia : <http://dbpedia.org/resource/> .
@prefix p : <http://dbpedia.org/property/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

dbpedia:Mount_Baker p:lastEruption "1880"^^xsd:integer ;
                    p:location     dbpedia:Washington .

dbpedia:Washington p:borderingstates dbpedia:Oregon ,
                                     dbpedia:Idaho .
```

N3 – A Readable Syntax for RDF

- More syntactic sugar:
  - Shortcuts for number literals

```
dbpedia:Mount_Baker p:lastEruption "1880"^^xsd:integer ;
                    geo:lat "48.777222"^^xsd:float ;
                    geo:long "-121.813332"^^xsd:float .
```

Equivalent:

```
dbpedia:Mount_Baker p:lastEruption 1880 ;
                    geo:lat 48.777222 ;
                    geo:long -121.813332 .
```

Classification

- The predefined property *rdf:type* enables classifications
  - Object resource represents a category / class of things
  - Subject resource is an instance of that class

```
@prefix dbpedia: <http://dbpedia.org/resource/> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns>.
@prefix umbel-sc: <http://umbel.org/umbel/sc/> .
@prefix yago:     <http://dbpedia.org/class/yago/>.
@prefix skos:     <http://www.w3.org/2004/02/skos/core#>.
dbpedia:Oregon rdf:type yago:StatesOfTheUnitedStates .
dbpedia:Mount_Baker rdf:type umbel-sc:Mountain .
umbel-sc:Mountain skos:definition "Each instance of ▸
  Mountain is a topographical feature of significantly ▸
  higher elevation ..."@en
```

Classification

- Class membership is not exclusive
  - I.e. instances may have multiple types

```
dbpedia:Mount_Baker rdf:type umbel-sc:Mountain ,
                             umbel-sc:Volcano .
```

- Classes may be instances of other classes!

```
dbpedia:Mount_Baker rdf:type umbel-sc:Mountain .
umbel-sc:Mountain rdf:type umbel-ac:ExistingObjectType .
```

- Syntactical distinction between classes and instances a priori impossible

RDF Schema in General

- RDF Schema enables specification of schema knowledge
  - Definition of the vocabulary used in triples
  - Class hierarchies, property hierarchies
- RDF Schema semantics enable elementary inferences

Predefined Classes

- RDF Schema defines the following classes
  - *rdfs:Resource* – class of all resources
  - *rdfs:Literal* – class of all literals
  - *rdfs:Class* – class of all classes

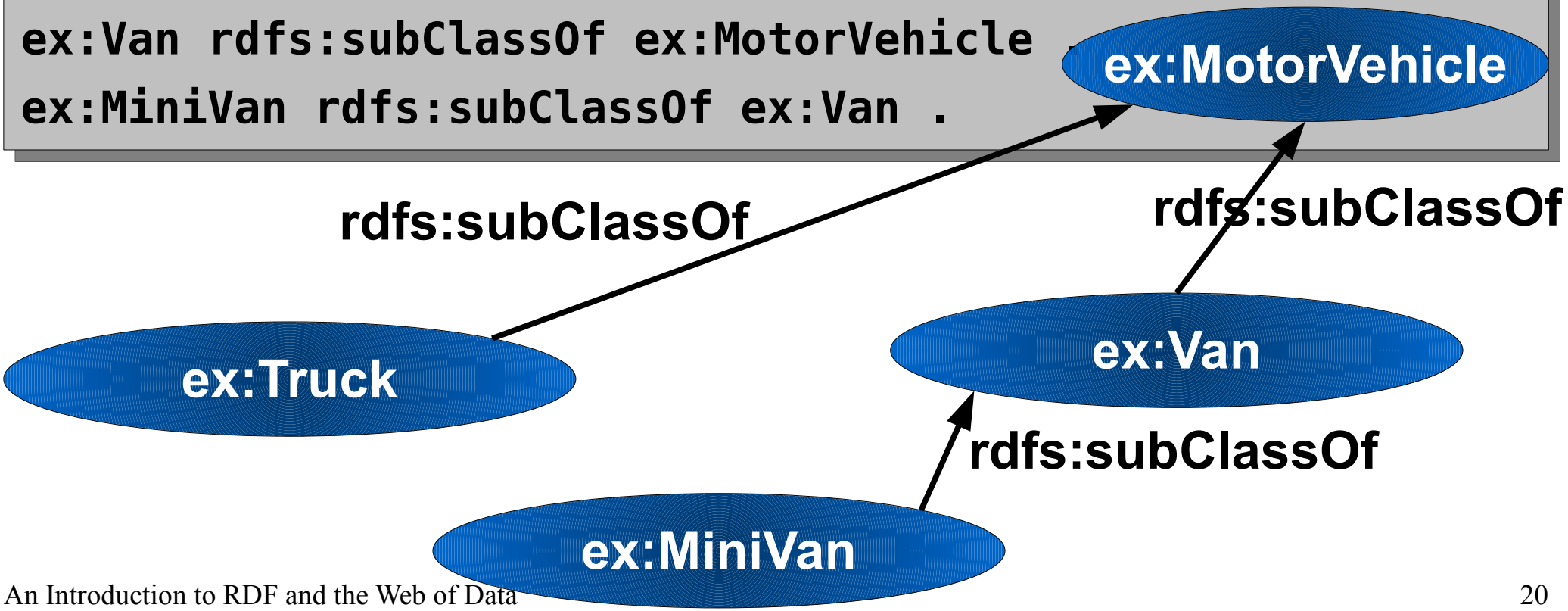
    it holds: (rdfs:Class , rdf:type , rdfs:Class)
  - *rdfs:Datatype* – class of all datatypes
  - *rdf:Property* – class of all properties

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns>.
@prefix rdfs : <http://www.w3.org/2000/01/rdf-schema#> .
@prefix umbel-sc : <http://umbel.org/umbel/sc/> .

umbel-sc:Mountain rdf:type rdfs:Class .
```

Class Hierarchies

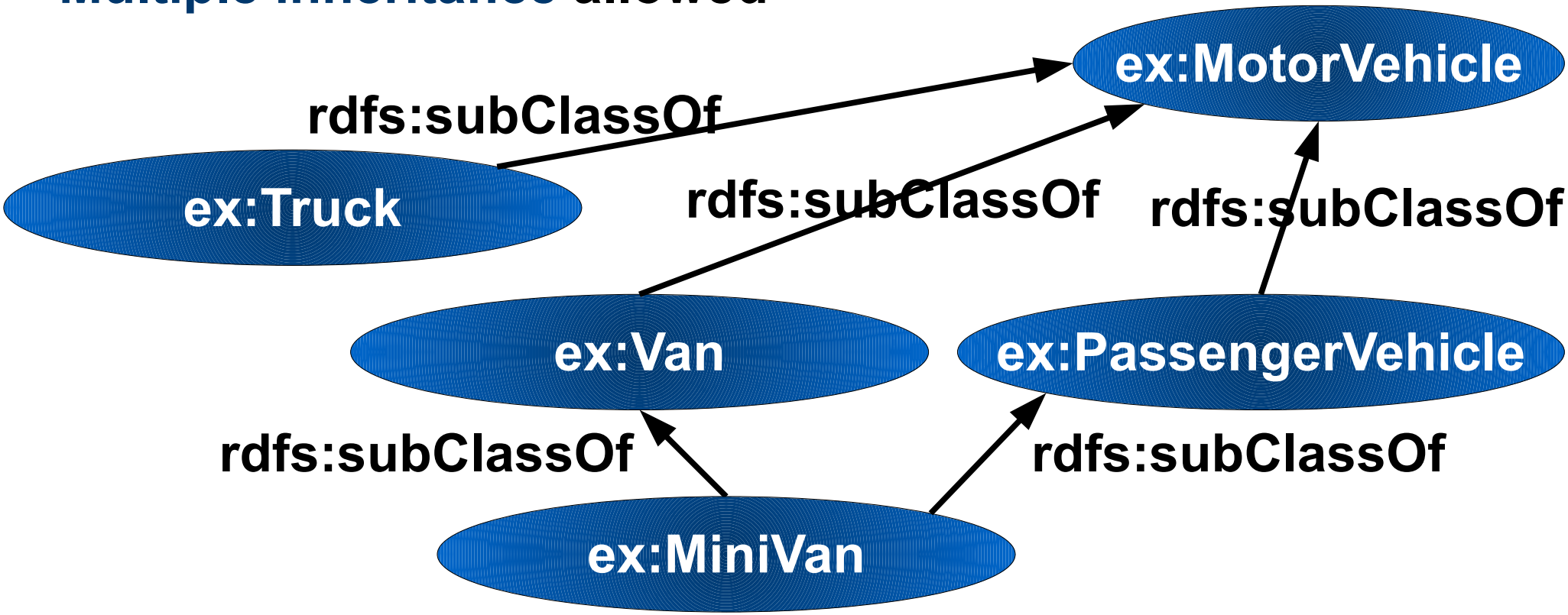
- *rdfs:subClassOf* enables the definition of class hierarchies

```
@prefix rdfs : <http://www.w3.org/2000/01/rdf-schema#> .
@prefix ex : <http://example.org/> .

ex:Truck rdfs:subClassOf ex:MotorVehicle .
ex:Van rdfs:subClassOf ex:MotorVehicle .
ex:MiniVan rdfs:subClassOf ex:Van .
```



Class Hierarchies

- **Multiple inheritance allowed**



- *rdfs:subClassOf* is reflexive – e.g., it holds:

```
ex:Truck rdfs:subClassOf ex:Truck .
```

Class Hierarchies

- *rdfs:subClassOf* is transitive
  - E.g., given

```
ex:Van rdfs:subClassOf ex:MotorVehicle .
ex:MiniVan rdfs:subClassOf ex:Van .
```

  - we can infer

```
ex:MiniVan rdfs:subClassOf ex:MotorVehicle .
```

- Entailment rule:

$$\frac{(A, \text{rdfs:subClassOf}, B) \quad (B, \text{rdfs:subClassOf}, C)}{(A, \text{rdfs:subClassOf}, C)}$$

Class Hierarchies

- Another entailment rule:

$$\frac{(\ a\ ,\ \text{rdf:type}\ ,\ A\ )\qquad (\ A\ ,\ \text{rdfs:subClassOf}\ ,\ B\ )}{(\ a\ ,\ \text{rdf:type}\ ,\ B\ )}$$

- E.g., from

```
ex:Van rdfs:subClassOf ex:MotorVehicle .
ex:MiniVan rdfs:subClassOf ex:Van .
ex:MyRedVWT3 rdf:type ex:MiniVan .
```

- we may infer

```
ex:MyRedVWT3 rdf:type ex:Van .
```

- and (exploiting transitivity)

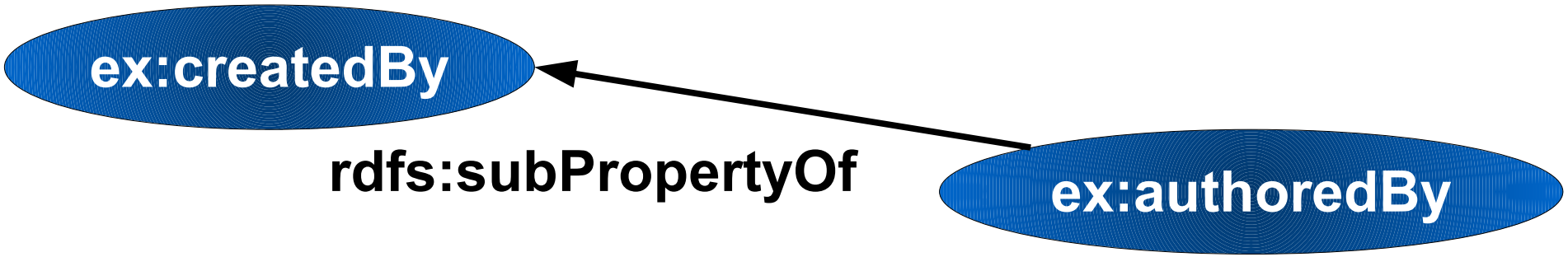
```
ex:MyRedVWT3 rdf:type ex:MotorVehicle .
```

Property Hierarchies

- Properties usually in predicate position
  - Entailment rule:

$$\frac{(\ a\ ,\ p\ ,\ b\ )}{(\ p\ ,\ \text{rdf:type}\ ,\ \text{rdf:Property}\ )}$$

- Properties are first class citizens (in contrast to OOP)
  - Not defined inside classes
  - Own hierarchy (specified by *rdfs:subPropertyOf*)



Property Hierarchies

- **Entailment rule:** $\dfrac{(\,a\,,\,p1\,,\,b\,)\qquad(\,p1\,,\,\text{rdfs:subPropertyOf}\,,\,p2\,)}{(\,a\,,\,p2\,,\,b\,)}$

- **E.g., from**

```
ex:authoredBy rdfs:subPropertyOf ex:createdBy .
dbpedia:The_Lord_of_the_Rings ex:authoredBy
                                  dbpedia:J._R._R._Tolkien .
```

- **we may infer**

```
dbpedia:The_Lord_of_the_Rings ex:createdBy
                                  dbpedia:J._R._R._Tolkien .
```

- ***rdfs:subPropertyOf*** **is reflexive and transitive too**

Property Restrictions

- ***rdfs:domain*** **and** ***rdfs:range*** **specify permitted subjects and objects, respectively**

```
@prefix rdfs : <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xsd  : <http://www.w3.org/2001/XMLSchema#> .
@prefix p  : <http://dbpedia.org/property/> .
@prefix ex : <http://example.org/> .
@prefix foaf : <http://xmlns.com/foaf/0.1/> .

ex:authoredBy rdfs:domain ex:Publication .
ex:createdBy rdfs:range foaf:Person .
p:lastEruption rdfs:range xsd:integer .
```

Property Restrictions

- **Entailment rules:**

$$\frac{(\ p\ ,\ \text{rdfs:domain}\ ,\ A\ ) \qquad (\ a\ ,\ p\ ,\ x\ )}{(\ a\ ,\ \text{rdf:type}\ ,\ A\ )} \qquad \frac{(\ p\ ,\ \text{rdfs:range}\ ,\ A\ ) \qquad (\ x\ ,\ p\ ,\ a\ )}{(\ a\ ,\ \text{rdf:type}\ ,\ A\ )}$$

- **Beware: property restrictions are global and conjunctive**
  - **Let (*p* , rdfs:domain , *A*) and (*p* , rdfs:domain , *B*); for each *a* with (*a* , *p* , *x*) holds (*a* , rdfs:subClassOf , *A*) and (*a* , rdfs:subClassOf , *B*)**
  - **Same holds for *rdfs:range***
  - **Hence, use the most general class**

Property Restrictions

- **Extensional entailment rules:**

$$\frac{(\ p\ ,\ \text{rdfs:domain}\ ,\ A\ )\qquad (\ A\ ,\ \text{rdfs:subClassOf}\ ,\ B\ )}{(\ p\ ,\ \text{rdfs:domain}\ ,\ B\ )}$$

$$\frac{(\ p2\ ,\ \text{rdfs:domain}\ ,\ A\ )\qquad (\ p1\ ,\ \text{rdfs:subPropertyOf}\ ,\ p2\ )}{(\ p1\ ,\ \text{rdfs:domain}\ ,\ A\ )}$$

$$\frac{(\ p\ ,\ \text{rdfs:range}\ ,\ A\ )\qquad (\ A\ ,\ \text{rdfs:subClassOf}\ ,\ B\ )}{(\ p\ ,\ \text{rdfs:range}\ ,\ B\ )}$$

$$\frac{(\ p2\ ,\ \text{rdfs:range}\ ,\ A\ )\qquad (\ p1\ ,\ \text{rdfs:subPropertyOf}\ ,\ p2\ )}{(\ p1\ ,\ \text{rdfs:range}\ ,\ A\ )}$$

Further RDF Schema Properties

- *rdfs:label* – alternative name of a resources
- *rdfs:comment* – comment associated to a resource
- *rdfs:seeAlso* – reference to a resource with more information about the subject
- *rdfs:definedBy* – reference to a resource with a definition of the subject

```
@prefix rdfs : <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf : <http://xmlns.com/foaf/0.1/> .

foaf:Person rdfs:label "Person"@en , "Person"@de ;
            rdfs:comment "Class for persons."@en ;
            rdfs:definedBy <http://xmlns.com/foaf/0.1/> .
```

RDF Schema Summary

- RDF Schema (RDFS) provides elementary means to define
  - vocabularies and
  - a machine-processable meaning of RDF data
- RDF data that uses vocabulary described with RDFS can generically be processed by every RDFS-enabled software.
- Web Ontology Language (OWL)
  - More comprehensive than RDFS
  - Property *owl:sameAs* – both URIs refer to the same thing
- However, vocabulary-specific processing requires vocabulary-specific rules.

Common Vocabularies

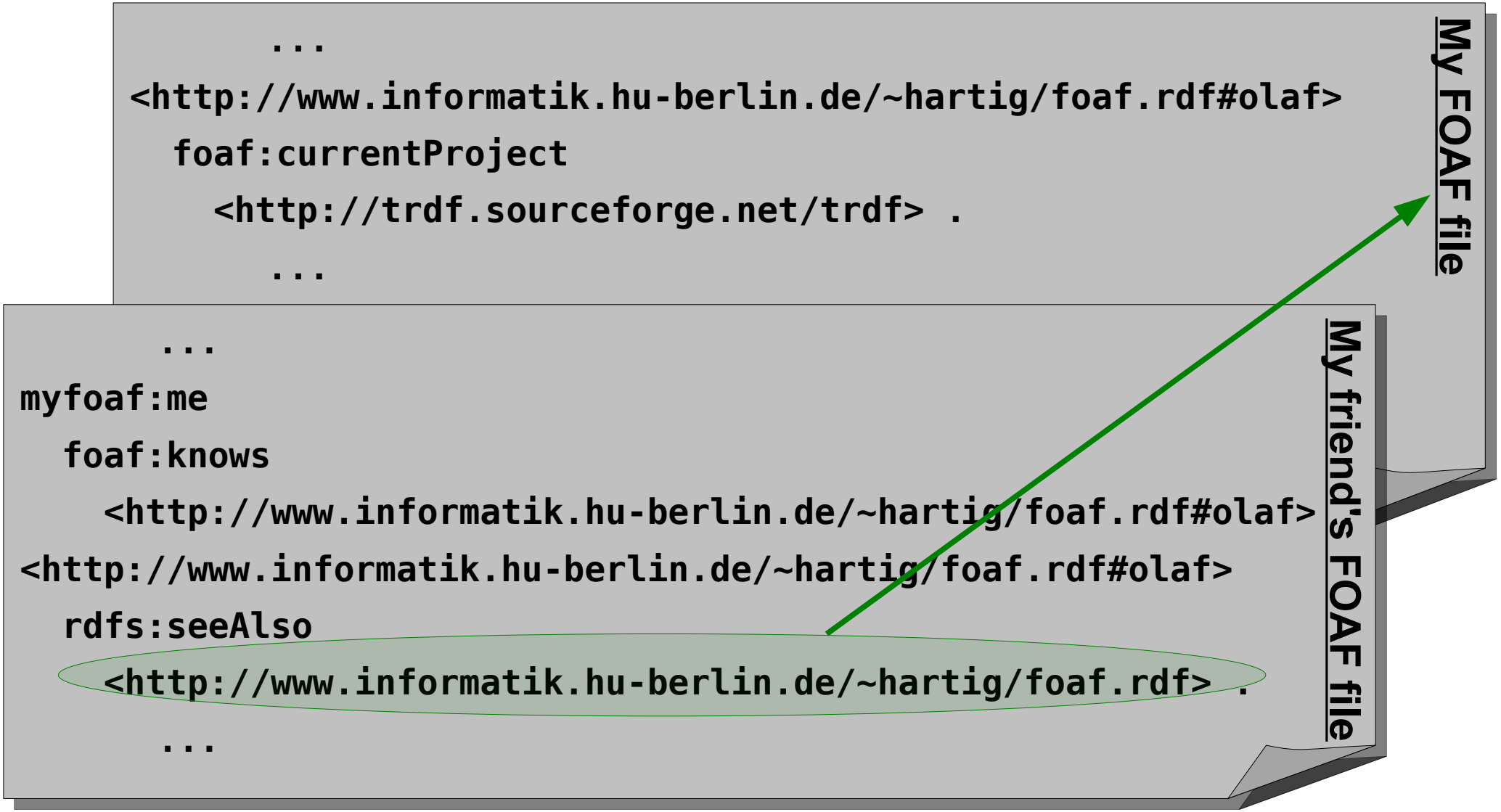
- FOAF (Friend of a Friend)
  - Persons and their main properties (e.g. name, email)
  - *foaf:knows* relation (enables specification of a network)
  - Namespace URI: http://xmlns.com/foaf/0.1/
- DC (Dublic Core)
  - Enables description of created or published resources
  - Namespace URI: http://purl.org/dc/elements/1.1/
- SKOS (Simple Knowledge Organisation Systems)
  - Thesauri, classification schemes, taxonomies, ...
  - Namespace URI: http://www.w3.org/2008/05/skos#

Common Vocabularies

- SIOC (Semantically-Interlinked Online Communities)
  - Content and structure of online community sites
  - Weblogs, mailing lists, newsgroups,
  - Connections between channels and posts
  - Namespace URI: http://rdfs.org/sioc/ns#
- DOAP (Description of a Project)
  - (Software) projects
  - Maintainer, programming language, source repository, ...
  - Namespace URI: http://usefulinc.com/ns/doap#

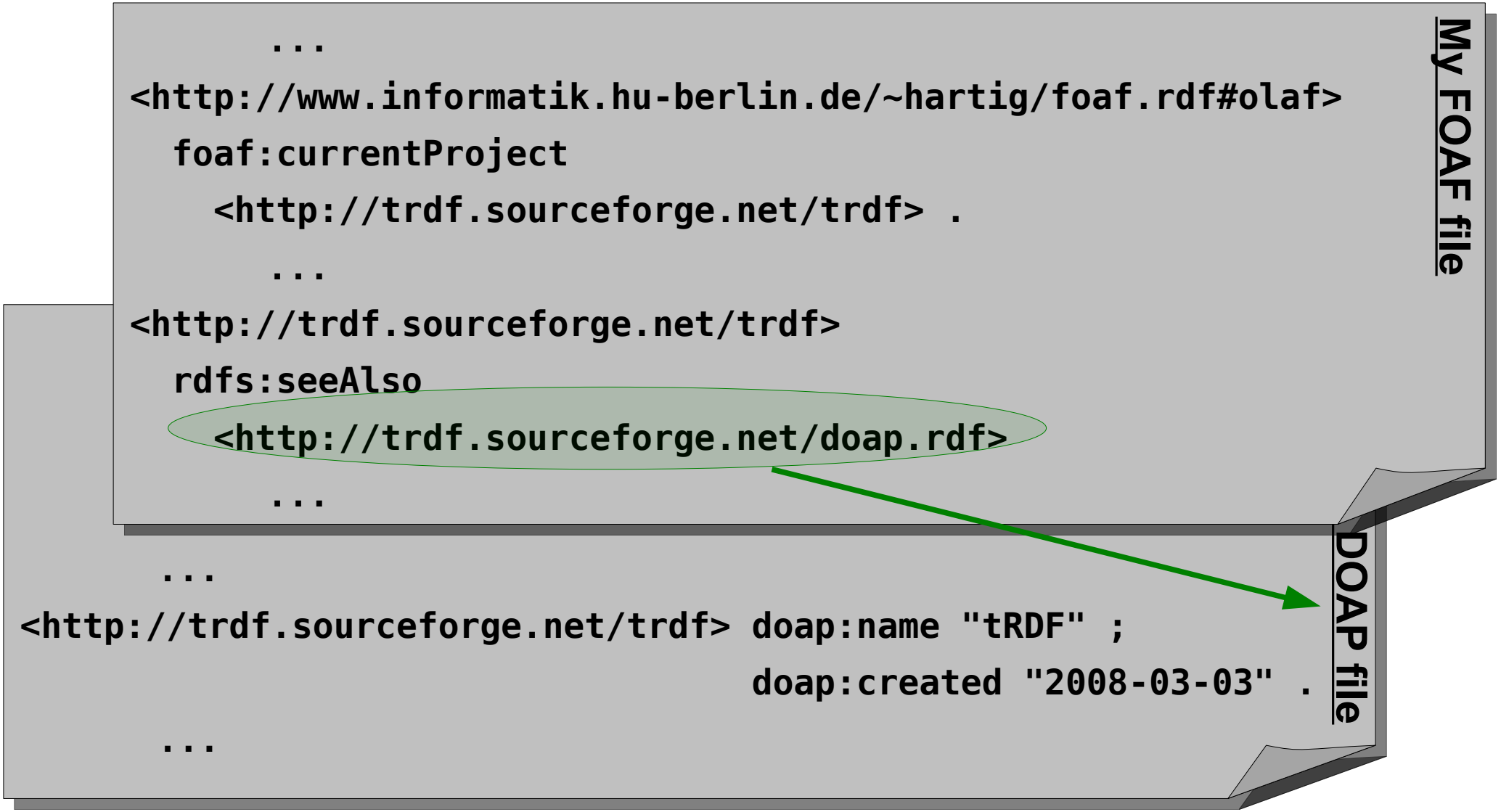
Web of Data

- **Triples may link different data spaces**



Web of Data

- Triples may link different data spaces



Web of Data

- **Linked data principles**[1] **(set of best practices for publishing and deploying data on the Web using RDF):**
  1. **Use URIs as names for things.**
  2. **Use HTTP URIs so that people can look up those names.**
  3. **When someone looks up a URI, provide useful RDF data.**
  4. **Include RDF statements that link to other URIs, so that they can discover related things.**
- **These principles allow a true Web of data**

- **RDF links have a machine-processable semantic (in contrast to links between Web documents)**

[1] **http://www.w3.org/DesignIssues/LinkedData.html**

Web of Data

My FOAF file

```
      ...
<http://www.informatik.hu-berlin.de/~hartig/foaf.rdf#olaf>
  foaf:currentProject
    <http://trdf.sourceforge.net/trdf> .
      ...
```

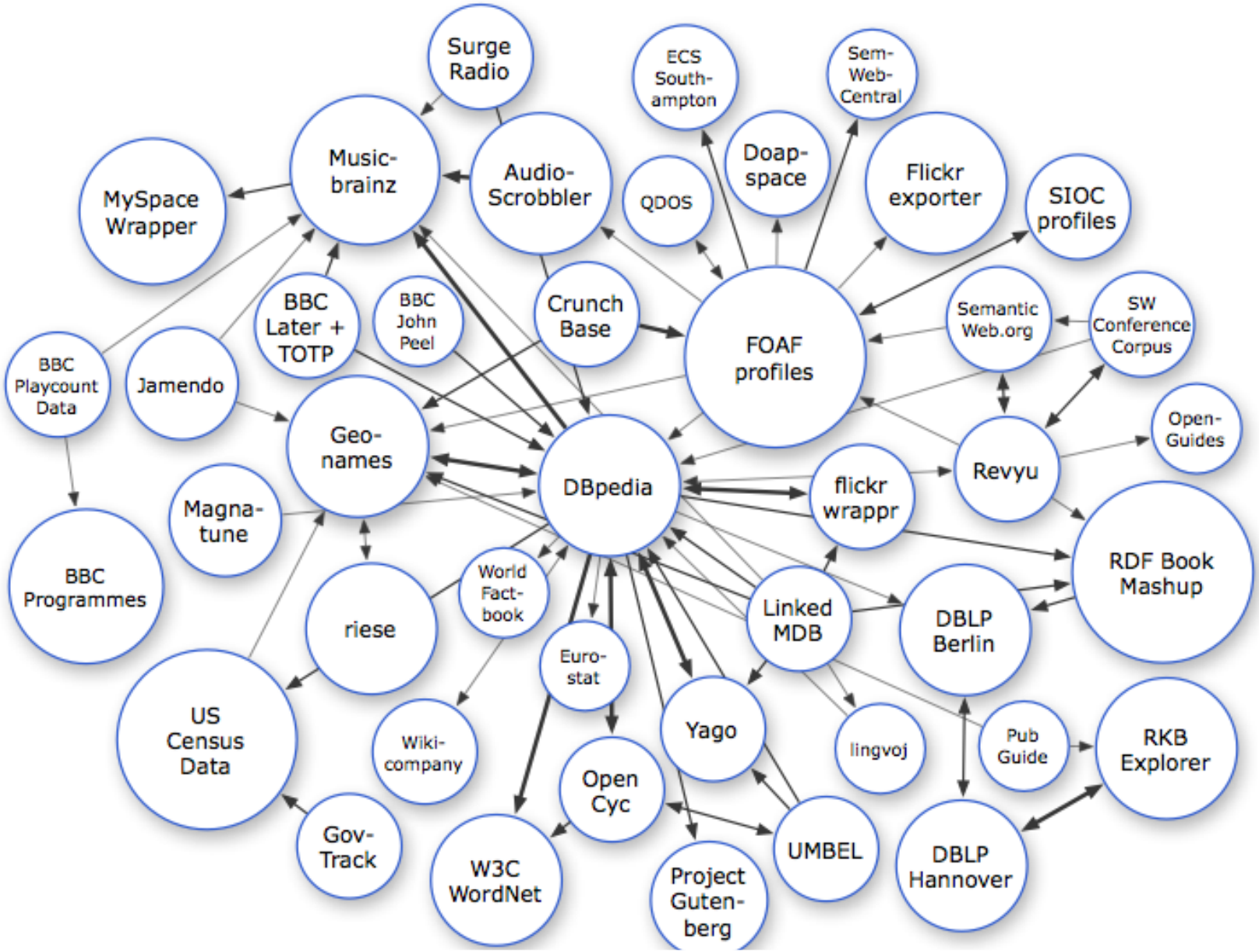
- **HTTP Request: GET http://trdf.sourceforge.net/trdf**
- **Server response:**
  303 See Other – http://trdf.sourceforge.net/doap.rdf
- **2nd Request: GET http://trdf.sourceforge.net/doap.rdf**

Redirection

Project

```
      ...
<http://trdf.sourceforge.net/trdf> doap:name "tRDF" ;
                                   doap:created "2008-03-03" .
      ...
```

Web of Data



By courtesy of the Linking Open Data community project As of September 2008
License: CC-BY-SA
http://esw.w3.org/topic/SweoIG/TaskForces/CommunityProjects/LinkingOpenData

Web of Data

- **Selected open RDF datasets:**

Dataset	Description	Triples
Dbpedia	Structured information extracted from Wikipedia	ca. 117M
U.S.Census	2000 U.S. Census data	ca. 1B
GovTrack	U.S. Congress data	ca. 13M
riese	EuroStat data	ca. 5M (3B)
DBLP	Bibliographic information on major computer science journals and conference proceedings	ca. 28M
MusicBrainz	Data about artists, records, songs etc.	ca. 36M
BBC	Data about BBC Programmes	ca. 2M
CrunchBase	Directory of technology companies, people, and investors	ca. 700K

Open World Assumption

- The absence of a triple is not relevant
- The knowledge:

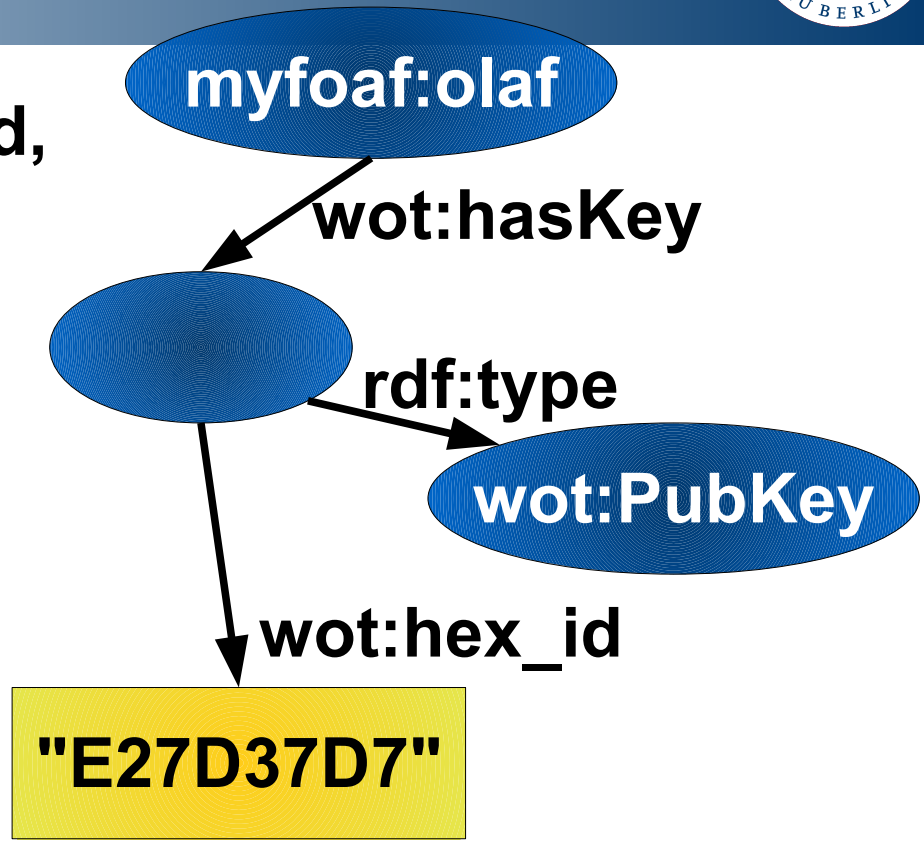
```
@prefix dbpedia : <http://dbpedia.org/resource/> .
@prefix p : <http://dbpedia.org/property/> .

dbpedia:Washington p:borderingstates dbpedia:Oregon .
```

  does not mean Washington has one bordering state!

- If you have no other triples doesn't mean they are not true.

Blank Nodes

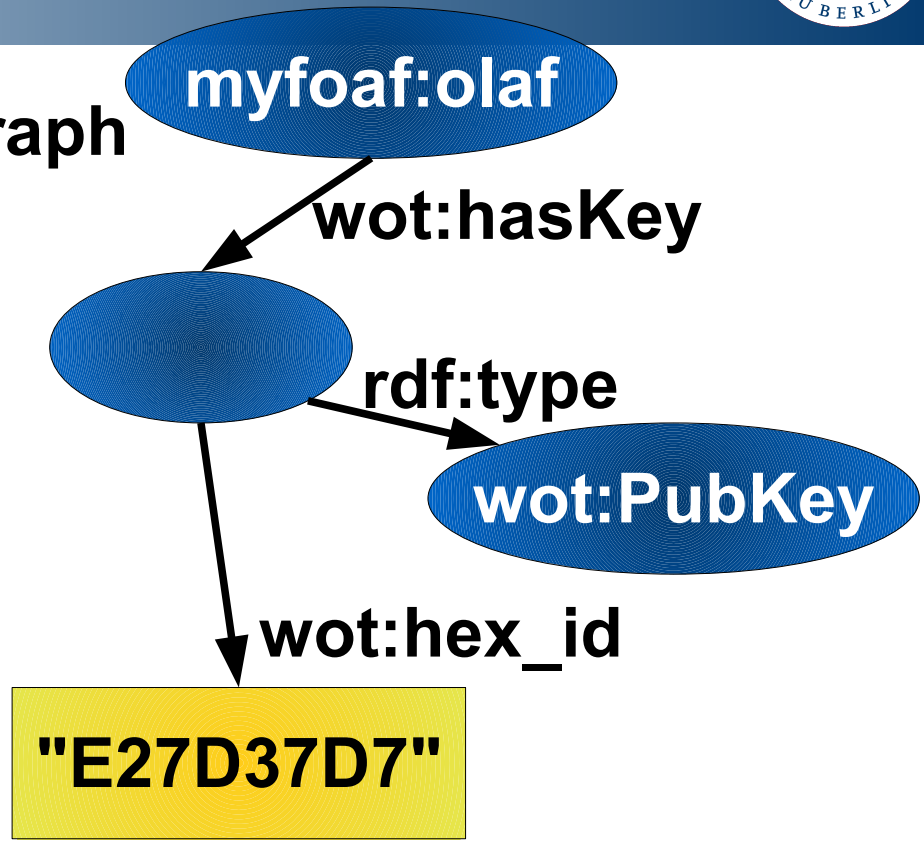
- Blank nodes represent unnamed, anonymous resources
  - Not identified by a URI
- Blank node identifiers
  - Identification of blank nodes in triple serializations
  - Form: *_:xyz*
  - Significant only within a single RDF graph




```
myfoaf:olaf wot:hasKey _:x .
_:x rdf:type   wot:PubKey ;
    wot:hex_id "E27D37D7" .
```

Blank Nodes

- Blank nodes break the global graph
  - Cannot be referenced
  - Not reusable
  - Name your resources (linked data principle)



- Abbreviated syntax in N3:

```
myfoaf:olaf wot:hasKey [ rdf:type   wot:PubKey ;
                         wot:hex_id "E27D37D7" ]
```

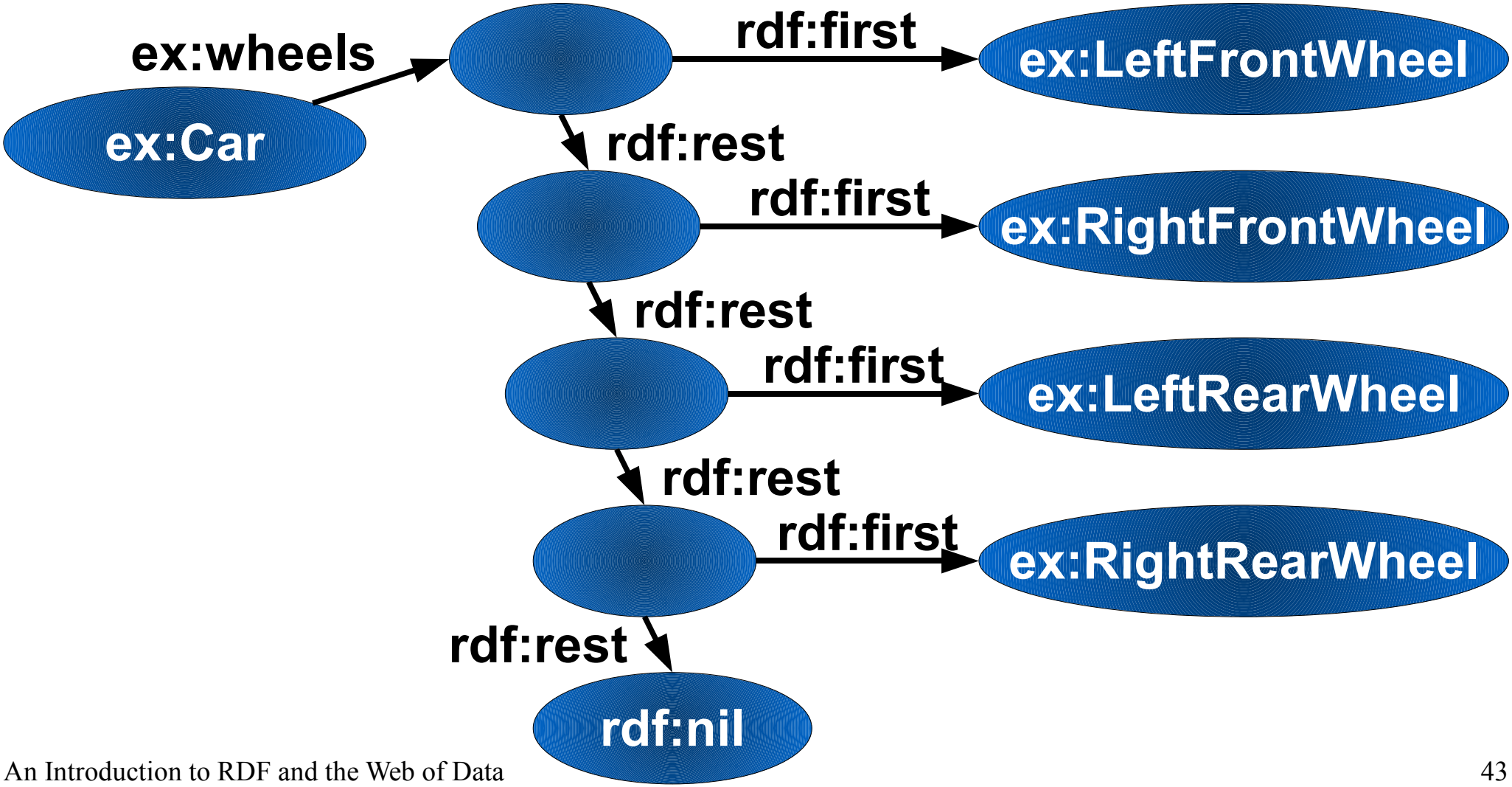
Groups of Things

- Containers are an open group
  - Contain resources or literals, possibly duplicates
  - *rdf:Seq* – ordered list
  - *rdf:Bag* – set (unordered)
  - *rdf:Alt* – for alternatives

```
dbpedia:Mount_Etna ex:eruptions [ rdf:type rdf:Bag ;
                                  rdf:_1 "1669" ;
                                  rdf:_2 "1949" ;
                                  rdf:_3 "1971" ;
                                  rdf:_4 "2001" ] .
```

Groups of Things

- Collections
  - Closed list of resources or literals, possibly duplicates



Groups of Things

- Collections in N3

```
ex:Car ex:wheels _:a ;
_:a rdf:first ex:LeftFrontWheel ; rdf:rest _:b .
_:b rdf:first ex:RightFrontWheel ; rdf:rest _:c .
_:c rdf:first ex:LeftRearWheel ; rdf:rest _:d .
_:d rdf:first ex:RightRearWheel ; rdf:rest rdf:nil .
```

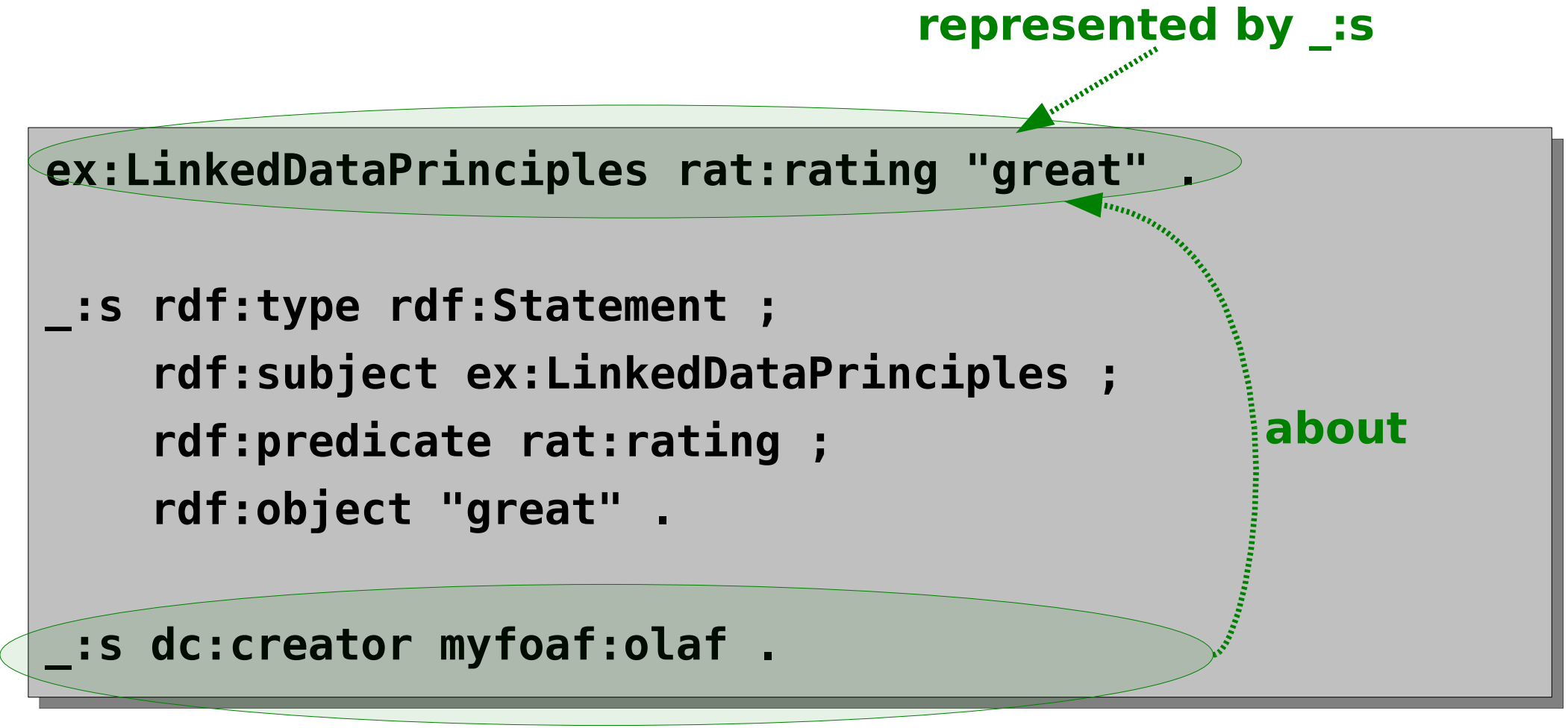
  - Shortcut

```
ex:Car ex:wheels ( ex:LeftFrontWheel ex:RightFrontWheel
                   ex:LeftRearWheel ex:RightRearWheel ) .
```

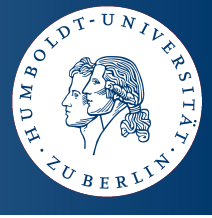
- Generic access with SPARQL impossible

Reification

- Reification allows statements about statements



RDF/XML – An XML syntax for RDF



N3

```
@prefix dbpedia : <http://dbpedia.org/resource/> .
@prefix p : <http://dbpedia.org/property/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

dbpedia:Mount_Baker p:lastEruption "1880"^^xsd:integer .
dbpedia:Mount_Baker p:location     dbpedia:Washington .
```

RDF/XML

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:p="http://dbpedia.org/property/">
 <rdf:Description rdf:about="http://dbpedia.org/resource/Mount_Baker">
   <p:lastEruption ▸
       rdf:datatype="http://www.w3.org/2001/XMLSchema#integer" ▸
       >1880</p:lastEruption>
   <p:location rdf:resource="http://dbpedia.org/resource/Washington"/>
 </rdf:Description>
</rdf:RDF>
```

Further Reading

- W3C RDF Specifications – http://www.w3.org/RDF/
  - RDF Primer
  - RDF: Concepts and Abstract Syntax
  - RDF Vocabulary Description Language 1.0: RDF Schema
  - RDF Semantics
  - RDF/XML Syntax Specification (Revised)
  - RDF Test Cases
- Information about Linked Data – http://linkeddata.org/