RDF and RDF Schema

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Main References

Gómez-Pérez, A.; Fernández-López, M.; Corcho, O. **Ontological Engineering.** *Springer Verlag. 2003*

Capítulo 4: Ontology languages

Brickley D, Guha RV (2004) *RDF Vocabulary Description Language 1.0: RDF Schema*. W3C Recommendation.
http://www.w3.org/TR/PR-rdf-schema
Lassila O, Swick R (1999) *Resource Description Framework (RDF) Model and Syntax Specification*. W3C Recommendation.
http://www.w3.org/TR/REC-rdf-syntax/
Prud'hommeaux E, Seaborne A (2008) *SPARQL Query Language for RDF*. W3C Recommendation.
http://www.w3.org/TR/rdf-sparql-query/

Jena web site: *http://jena.sourceforge.net/*
Jena API: *http://jena.sourceforge.net/tutorial/RDF_API/*
Jena tutorials: *http://www.ibm.com/developerworks/xml/library/j-jena/index.html*
http://www.xml.com/pub/a/2001/05/23/jena.html

SPARQL validator: *http://www.sparql.org/validator.html*
SPARQL implementations: *http://esw.w3.org/topic/SparqlImplementations*
SPARQL tutorials: *http://jena.sourceforge.net/ARQ/Tutorial/*
http://www.w3.org/2004/Talks/17Dec-sparql/intro/all.html
http://www.cs.man.ac.uk/~bparsia/2006/row-tutorial/

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   - 2.2. Reasoning with RDF
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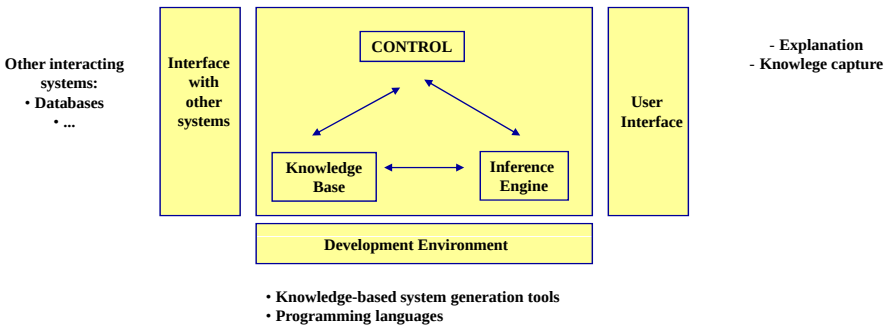
4. RDF(S) management APIs
5. RDF(S) query languages: SPARQL

Common Architecture of a Knowledge-based System



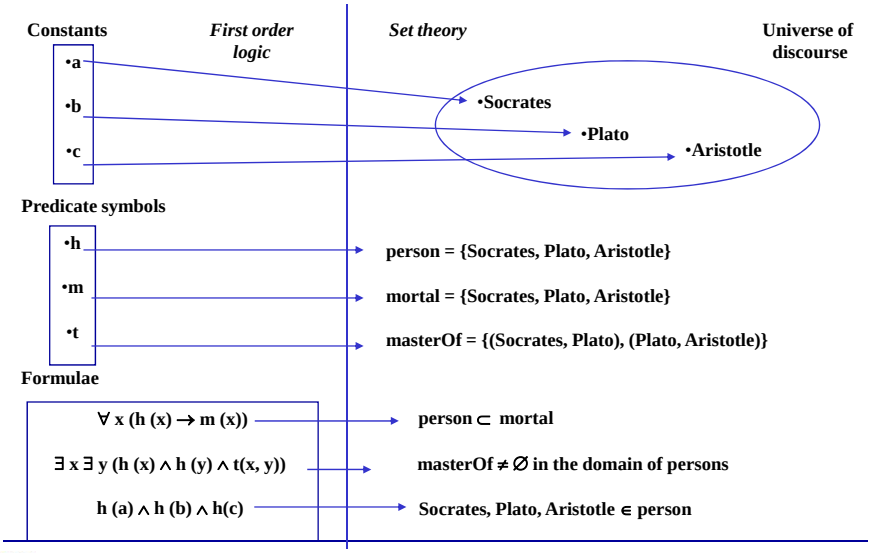
Knowledge Representation Formalisms. A Summary

- **Knowledge representation**
  - To store knowledge so that programs can process it and achieve the verisimilitude of human intelligence
- **Knowledge representation formalisms/techniques**
  - Originated from theories of human information processing.
  - Since knowledge is used to achieve intelligent behavior, the fundamental goal of knowledge representation is to represent knowledge in a manner as to facilitate inferencing i.e. drawing conclusions from knowledge.
  - Some examples are:
    - First order logic
    - Semantic networks and conceptual maps
    - Frames
    - Description logic
    - Production rules
    - Fuzzy logic
    - Bayesian networks
    - Etc.

These are the ones that we will analyse

First order logic. Basic elements

We can establish mappings between logical symbols and domain objects (universe of discourse)



First order logic. Formalisation

- **We have a robot that delivers boxes to offices. We know:**
  - Boxes in room 27 are smaller than those in room 28.
  - All boxes in the same room are of the same size.
  - In a given moment in time, we know:
    - i) Box A is inside room 27 or 28 (we do not know which one).
    - ii) Box B is inside room 27.
    - iii) Box B is not smaller than box A.
  - We want to test whether box A is in room 27.

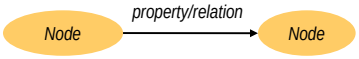
First order logic. Formalisation. Solution

- **We have a robot that delivers boxes to offices. We know:**
  - Boxes in room 27 are smaller than those in room 28.
    $\forall x \forall y (box(x) \wedge inside(x,h27) \wedge box(y) \wedge inside(y,h28) \rightarrow smallerThan(x,y))$
  - All boxes in the same room are of the same size.
    $\forall x \forall y \forall h (box(x) \wedge box(y) \wedge room(h) \wedge room(x,h) \wedge inside(y,h) \rightarrow sameSizeAs(x,y))$
  - In a given moment in time, we know :
    - i) Box A is inside room 27 or 28 (we do not know which one).
      $box(a) \wedge room(h27) \wedge room(h28) \wedge (inside(a,h27) \vee inside(a,h28))$
    - ii) Box B is inside room 27.
      $box(b) \wedge inside(b,h27)$
    - iii) Box B is not smaller than box A.
      $\neg smallerThan(b,a)$
  - We want to test whether box A is in room 27.
    ¿inside(a,h27)?

Semantic Network. Basic elements

- **Nodes**
  - They represent entities or concepts, or values

- **Edges**
  - They represent properties or relations



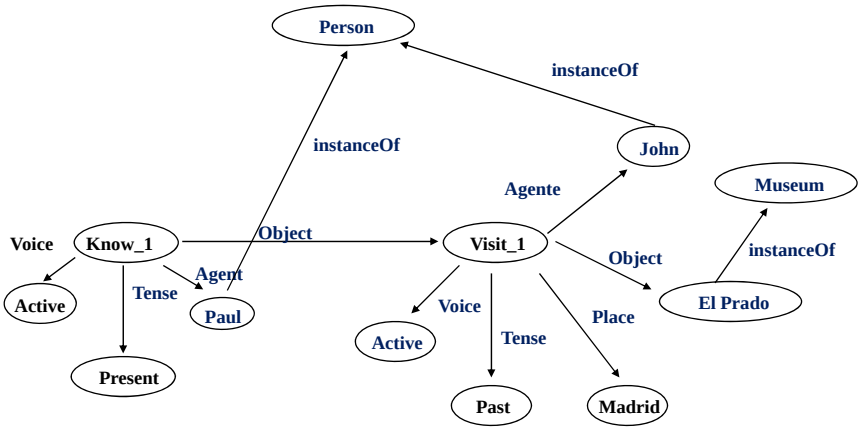
- **The semantics (mapping to the real world) depends on the tags used for nodes and edges**
- **There is no predefined KR vocabulary**
  - Although sometimes there are *structural* edges

Semantic networks. Example

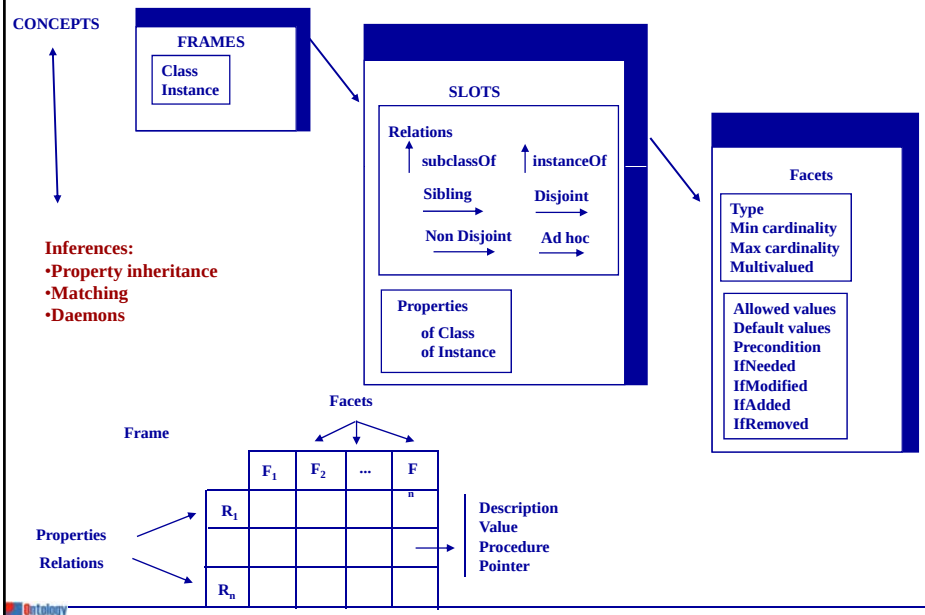
- **Paul and John are persons**
- **El Prado is a museum**
- **Paul knows that John visited El Prado in Madrid**

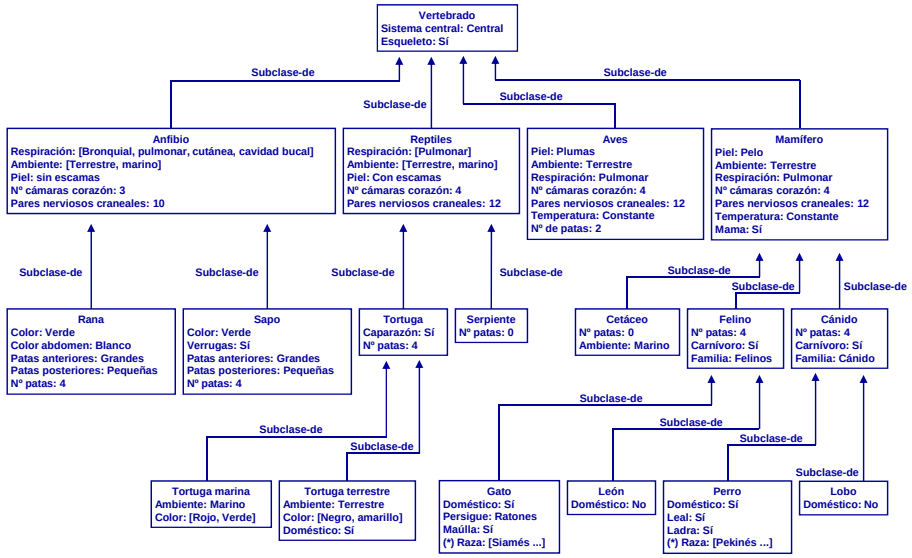
Semantic networks. Example. Solution

- Paul and John are persons
- El Prado is a museum
- Paul knows that John visited El Prado in Madrid



Frames. Basic elements





Frames. Example

- Men and women are persons
- A person can be married to another person
- Nobody can be a man and a woman at the same time
- John, Paul and Michael are men
- Mary and Anne are women
- John is married to Mary
- Paul is married to Anne

Frames. Example

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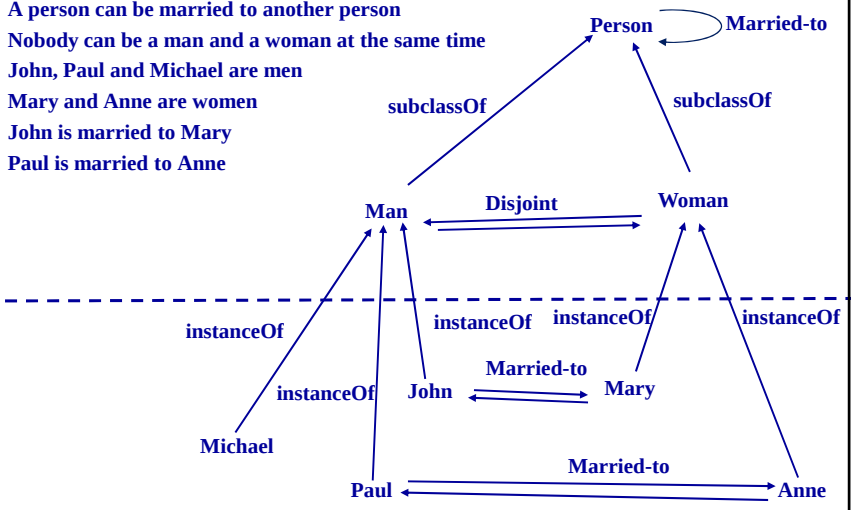
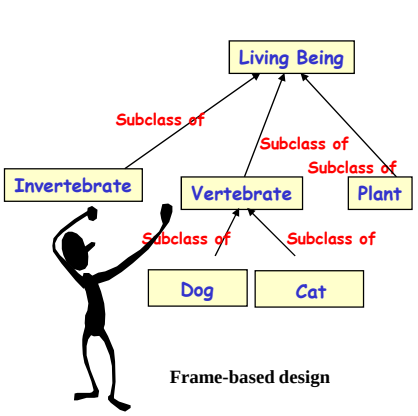
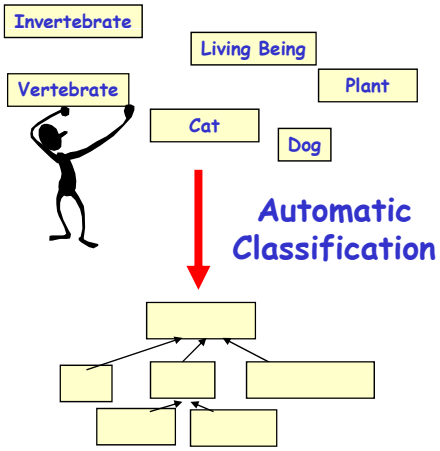


Description Logics. Basic elements

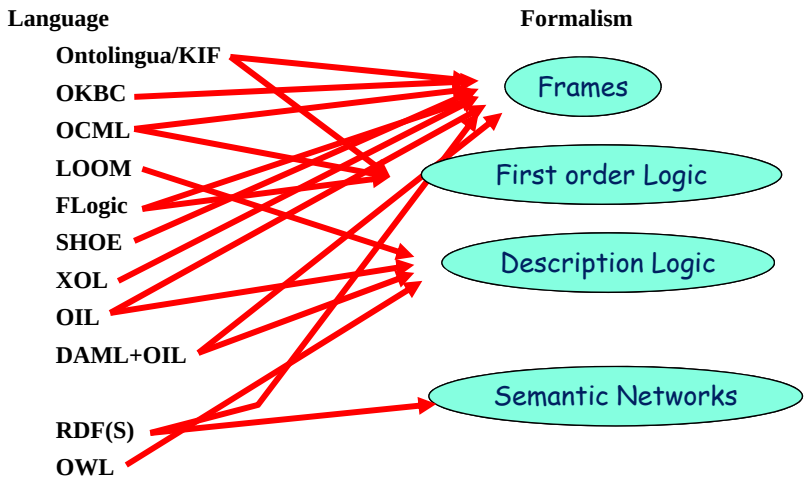
- A subset of first order logic with good reasoning properties
- Automatic classification



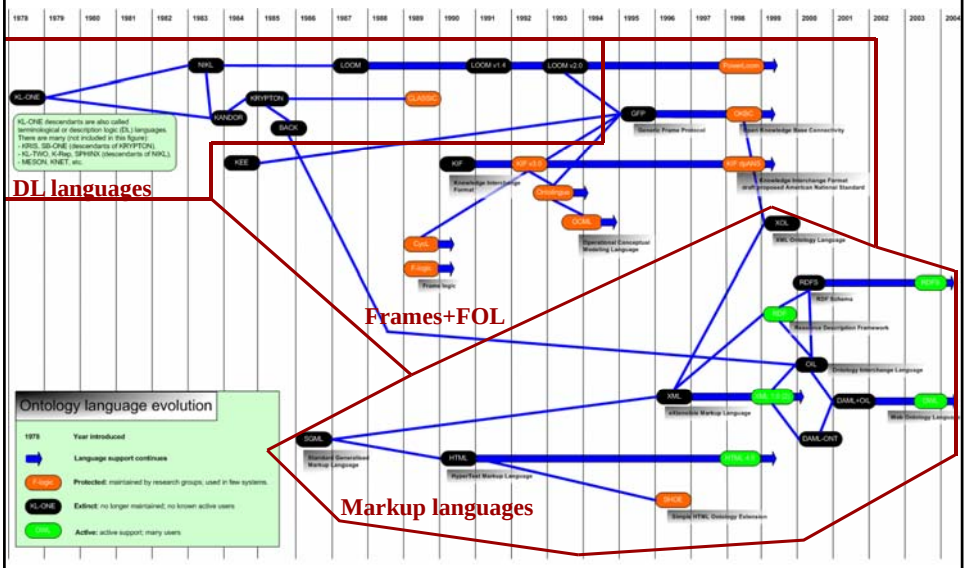
Frame-based design



KR Formalisms



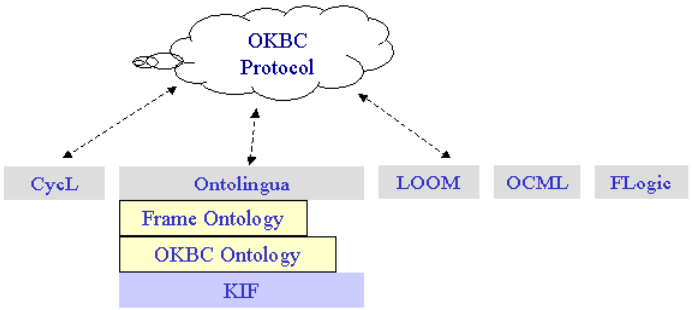
Ontology language evolution



Ontology Languages (I)

Traditional ontology languages

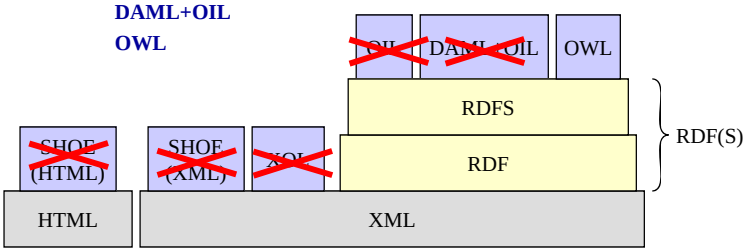
- **Ontolingua/KIF**
- **OKBC**
- **OCML**
- **LOOM**
- **FLogic**



Ontology Languages (II)

Ontology markup languages

- **Standards & Recommendations of W3C**
  - **XML**
  - **RDF(S)**
- **Ontology specification languages**
  - **SHOE**
  - **OIL**
  - **DAML+OIL**
  - **OWL**
  - **XOL**



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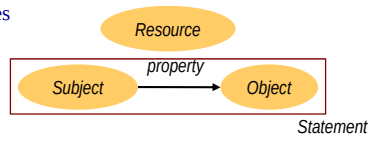
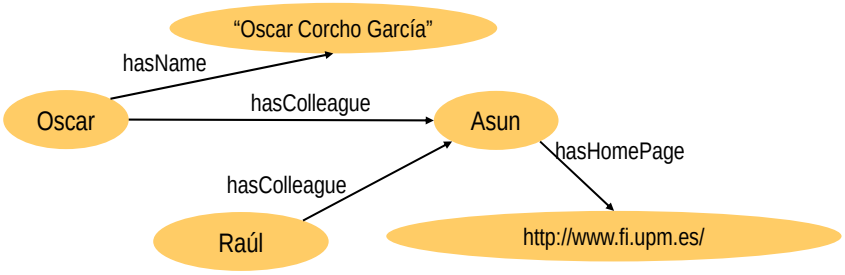
RDF: Resource Description Framework

- **W3C recommendation**
- **RDF is a basic KR language, based on semantic networks**
  - Useful to represent metadata and describe any type of information in a machine-accessible way (aka data model)
  - Resources are described in terms of properties and property values using RDF statements.
  - Statements are represented as triples, consisting of a subject, predicate and object. [S, P, O]



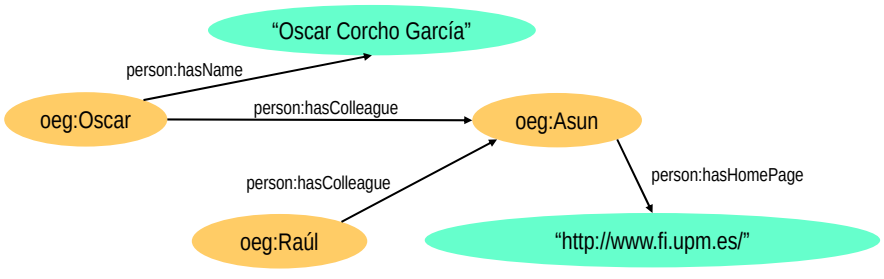


RDF (and other W3C Recommendations) and URIs

- A URI (Unique Resource Identifiers) is a Web identifier
  - e.g. http://www.oeg-upm.net/ontologies/people#Oscar
  - URI ≠ URL
    - If we open a Web browser and point to that URI, the corresponding object will not be necessarily downloaded or shown
    - If URLs work for **locating** uniquely (with no collisions) a Web page/resource, why not using the same approach for **identifying** Web resources?
  - Other valid URIs could be
    - ftp://www.oeg-upm.net/ontologies/people#Oscar
    - persons://www.oeg-upm.net/ontologies/people#Oscar
    - ...
- URIs allow identifying
  - Individuals: http://www.oeg-upm.net/ontologies/people#Oscar
  - Kinds of things: http://www.ontologies.org/ontologies/people#Person
  - Properties of those things: http://www.ontologies.org/ontologies/people#hasColleague
- **Beware!! This is changing in the context of Linked Data!!**

RDF (and other W3C Recommendations) and URIs

- For practical purposes, especially if handwritten, URIs are shortened using XML namespaces
  - xmlns:oeg="http://www.oeg-upm.net/ontologies/people#"
  - oeg:Oscar is equivalent to http://www.oeg-upm.net/ontologies/people#Oscar



RDF Serialisations

- **Normative**
  - RDF/XML (www.w3.org/TR/rdf-syntax-grammar/)
- **Alternative (for human consumption)**
  - N3 (http://www.w3.org/DesignIssues/Notation3.html)
  - Turtle (http://www.dajobe.org/2004/01/turtle/)
  - TriX (http://www.w3.org/2004/03/trix/)
  - …

Important note: the order of RDF statements in a serialisation does not affect the behaviour of a parser/application

RDF Serialisations. RDF/XML

```
<?xml version="1.0"?>
<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:person="http://www.ontologies.org/ontologies/people#"
  xmlns="http://www.oeg-upm.net/ontologies/people#"
  xml:base="http://www.oeg-upm.net/ontologies/people">

  <rdf:Property rdf:about="http://www.ontologies.org/ontologies/people#hasHomePage"/>
  <rdf:Property rdf:about="http://www.ontologies.org/ontologies/people#hasColleague"/>
  <rdf:Property rdf:about="http://www.ontologies.org/ontologies/people#hasName"/>

  <rdf:Description rdf:about="#Raúl"/>
  <rdf:Description rdf:about="#Asun">
    <person:hasColleague rdf:resource="#Raúl"/>
    <person:hasHomePage>http://www.fi.upm.es</person:hasHomePage>
  </rdf:Description>
  <rdf:Description rdf:about="#Oscar">
    <person:hasColleague rdf:resource="#Asun"/>
    <person:hasName>Oscar Corcho García</person:hasName>
  </rdf:Description>

</rdf:RDF>
```

RDF Serialisations. N3

```
@base  <http://www.oeg-upm.net/ontologies/people >
@prefix person: <http://www.ontologies.org/ontologies/people#>
:Asun    person:hasColleague :Raúl ;
         person:hasHomePage “http://www.fi.upm.es/”.
:Oscar   person:hasColleague :Asun ;
         person:hasName “Oscar Corcho García”.
```


Exercise

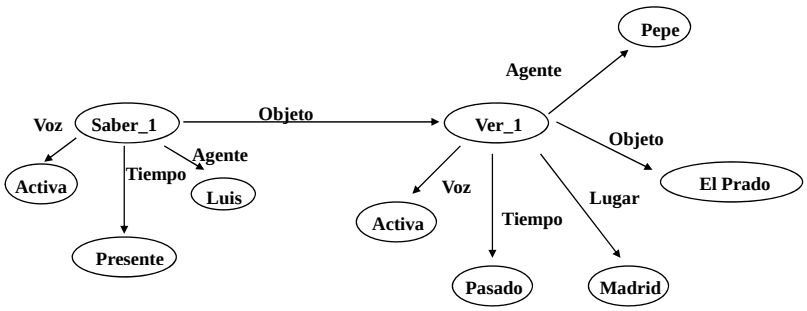
- **Objective**
  - Get used to the different syntaxes of RDF
- **Tasks**
  - Take the text of an RDF file and create its corresponding graph
  - Take an RDF graph and create its corresponding RDF/XML and N3 files

Exercise 1.a. Create a graph from a text file

- Open the file StickyNote_PureRDF.rdf
- Create the corresponding graph from it
- Compare your graph with those of your colleagues

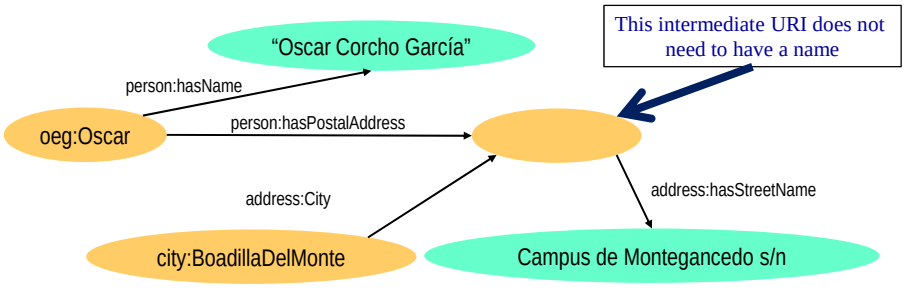
Exercise 1.b. Create RDF/XML and N3 text files from an RDF graph

- Transform the following graph into RDF/XML and N3 syntaxes



Blank nodes: structured property values

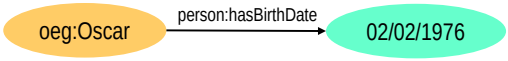
- Most real-world data involves structures that are more complicated than sets of RDF triple statements



- In RDF/XML, it is an <rdf:Description> node with no rdf:about
- In N3, it is an _:oscarAddress

Typed literals

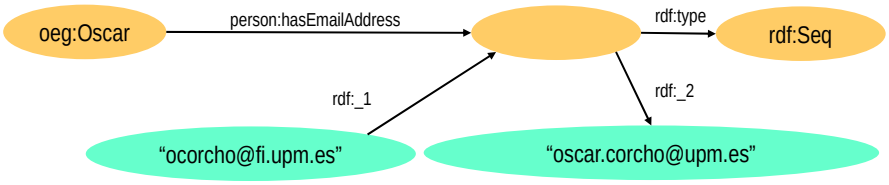
- **So far, all values have been presented as strings**
- **XML Schema datatypes can be used to specify values (objects in some RDF triple statements)**



- **In RDF/XML, this is expressed as:**
  - <rdf:Description rdf:about="#Oscar">
    <person:hasBirthDate
    rdf:datatype="http://www.w3.org/2001/XMLSchema#date">02/02/1976
    </person:hasBirthDate>
    </rdf:Description>
- **In N3, this is expressed as:**
  - oeg:Oscar person:hasBirthDate "02/02/1976"^xsd:date .

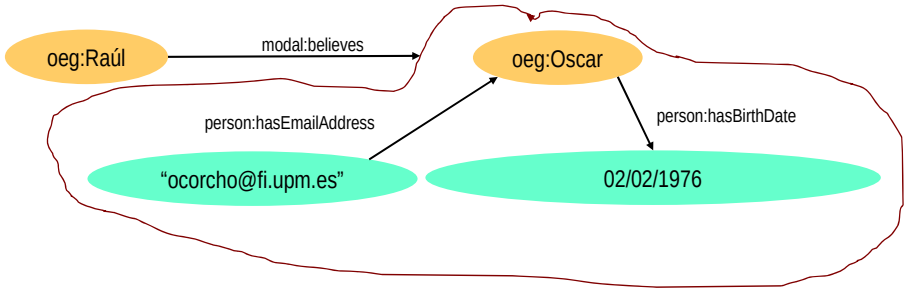
RDF Containers

- **There is often the need to describe groups of things**
  - A book was created by several authors
  - A lesson is taught by several persons
  - etc.
- **RDF provides a container vocabulary**
  - rdf:Bag → A group of resources or literals, possibly including duplicate members, where the order of members is not significant.
  - rdf:Seq → A group of resources or literals, possibly including duplicate members, where the order of members is significant.
  - rdf:Alt → A group of resources or literals that are alternatives (typically for a single value of a property).



RDF Reification

- **RDF statements about other RDF statements**
  - “Raúl believes that Oscar’s birthdate is on Feb 2nd, 1976 and that his e-mail address is ocorcho@fi.upm.es”



- **RDF Reification**
  - Allows expressing beliefs (and other modalities)
  - Allows expressing trust models, digital signatures,etc.
  - Allows expressing metadata about metadata

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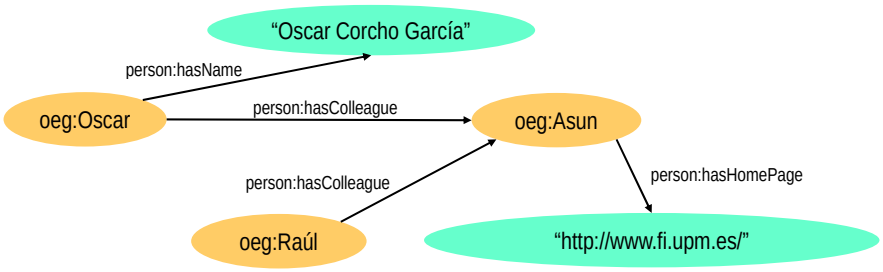
RDF inference. Graph matching techniques

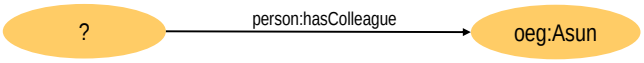
- **RDF inference is based on graph matching techniques**
- **Basically, the RDF inference process consists of the following steps:**
  - Transform an RDF query into a template graph that has to be matched against the RDF graph
    - It contains constant and variable nodes, and constant and variable edges between nodes.
  - Match against the RDF graph, taking into account constant nodes and edges.
  - Provide a solution for variable nodes and edges.

RDF inference. Examples (I)

- **Sample RDF graph**



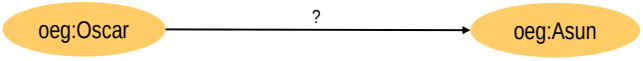
- **Query: "Tell me who are the persons who have Asun as a colleague"**



  - Result: oeg:Oscar and oeg:Raúl

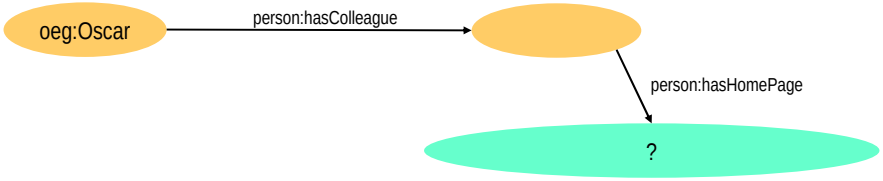
RDF inference. Examples (II)

- **Query: "Tell me which are the relationships between Oscar and Asun"**



  - Result: oeg:hasColleague

- **Query: "Tell me the homepage of Oscar colleagues"**



  - Result: "http://www.fi.upm.es/"

RDF inference. Entailment rules

Rule Name	if E contains	then add
rdf1	uuu aaa yyy .	aaa `rdf:type rdf:Property .`
rdf2	uuu aaa lll . where lll is a well-typed XML literal .	_:nnn `rdf:type rdf:XMLLiteral .` where _:nnn identifies a blank node allocated to lll by rule lg.

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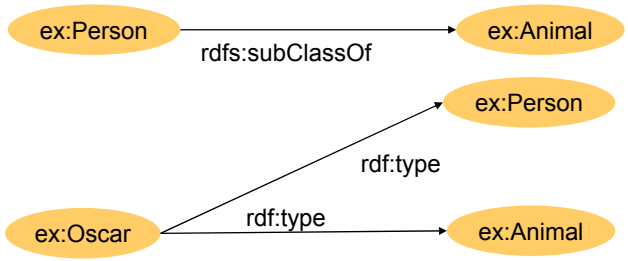
RDFS: RDF Schema

- **W3C Recommendation**
- **RDF Schema extends RDF to enable talking about classes of resources, and the properties to be used with them.**
  - Class definition: rdfs:Class, rdfs:subClassOf
  - Property definition: rdfs:subPropertyOf, rdfs:range, rdfs:domain
  - Other primitives: rdfs:comment, rdfs:label, rdfs:seeAlso, rdfs:isDefinedBy
- **RDFS vocabulary adds constraints on models, e.g.:**
  - ∀x,y,z type(x,y) and subClassOf(y,z) → type(x,z)



RDF(S) = RDF + RDF Schema. RDF/XML syntax

```
<?xml version="1.0"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:person="http://www.ontologies.org/ontologies/people#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns="http://www.oeg-upm.net/ontologies/people#"
   xml:base="http://www.oeg-upm.net/ontologies/people">
  <rdfs:Class rdf:about="http://www.ontologies.org/ontologies/people#Professor">
    <rdfs:subClassOf>
      <rdfs:Class rdf:about="http://www.ontologies.org/ontologies/people#Person"/>
    </rdfs:subClassOf>
   </rdfs:Class>
   <rdfs:Class rdf:about="http://www.ontologies.org/ontologies/people#Lecturer">
    <rdfs:subClassOf rdf:resource="http://www.ontologies.org/ontologies/people#Person"/>
   </rdfs:Class>
   <rdfs:Class rdf:about="http://www.ontologies.org/ontologies/people#PhDStudent">
     <rdfs:subClassOf rdf:resource="http://www.ontologies.org/ontologies/people#Person"/>
   </rdfs:Class>

  …
```

RDF(S) = RDF + RDF Schema. RDF/XML syntax

```
…
 <rdf:Property rdf:about="http://www.ontologies.org/ontologies/people#hasHomePage"/>
 <rdf:Property rdf:about="http://www.ontologies.org/ontologies/people#hasColleague">
  <rdfs:domain rdf:resource=" http://www.ontologies.org/ontologies/people#Person"/>
  <rdfs:range rdf:resource=" http://www.ontologies.org/ontologies/people#Person"/>
 </rdf:Property>
 <rdf:Property rdf:about="http://www.ontologies.org/ontologies/people#hasName">
  <rdfs:domain rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
 </rdf:Property>

 <person:PhDStudent rdf:ID="Raúl"/>
 <person:Professor rdf:ID="Asun">
    <person:hasColleague rdf:resource="#Raúl"/>
    <person:hasHomePage>http://www.fi.upm.es</person:hasHomePage>
 </person:Professor>
 <person:Lecturer rdf:ID="Oscar">
    <person:hasColleague rdf:resource="#Asun"/>
    <person:hasName>Oscar Corcho García</person:hasName>
 </person:Lecturer>
</rdf:RDF>
```


RDF(S) Serialisations. N3

```
@base  <http://www.oeg-upm.net/ontologies/people >
@prefix person: <http://www.ontologies.org/ontologies/people#>
person:hasColleague        a rdf:Property;
                           rdfs:domain person:Person;
                           rdfs:range person:Person.
person:Professor rdfs:subClassOf person:Person.
person:Lecturer rdfs:subClassOf person:Person.
person:PhDStudent rdfs:subClassOf person:Person.
:Asun     a person:Professor;
          person:hasColleague :Raúl ;
          person:hasHomePage "http://www.fi.upm.es/".
:Oscar    a person:Lecturer;
          person:hasColleague :Asun ;
          person:hasName "Oscar Corcho García".
:Raúl     a person:PhDStudent.
```

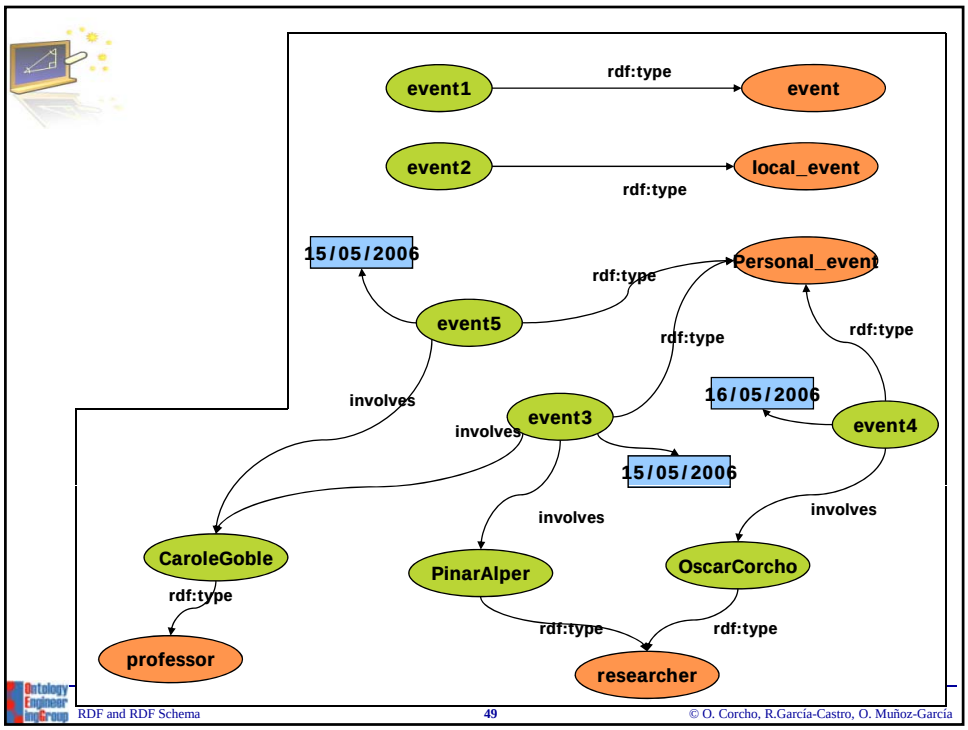
a is equivalent to rdf:type

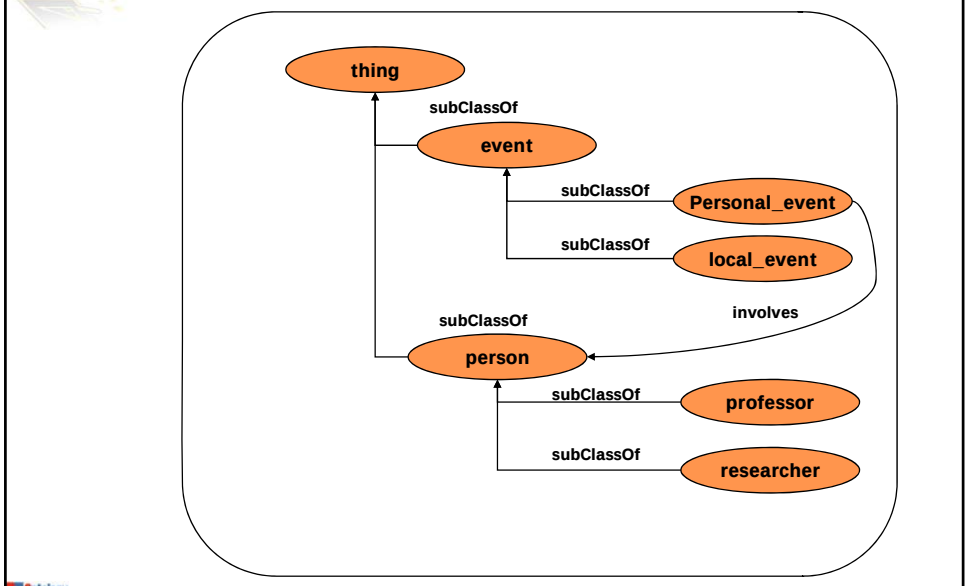
Exercise

- **Objective**
  - **Get used to the different syntaxes of RDF(S)**
- **Tasks**
  - **Take the text of an RDF(S) file and create its corresponding graph**
  - **Take an RDF(S) graph and create its corresponding RDF/XML and N3 files**

Exercise 2.a. Create a graph from a text file

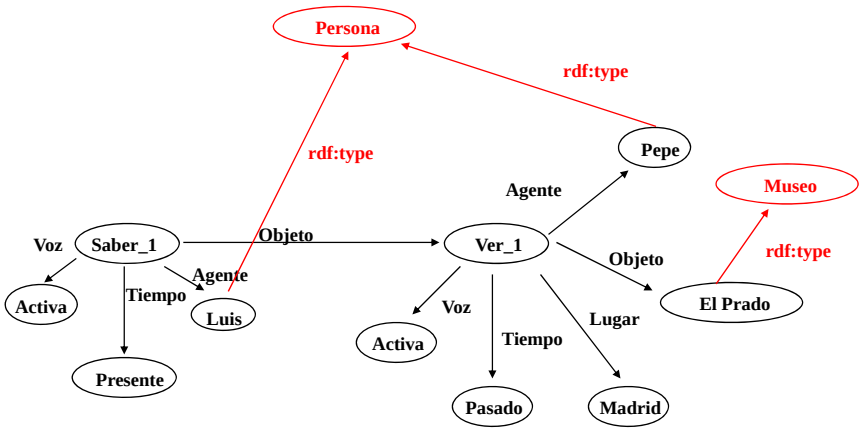
- **Open the files StickyNote.rdf and StickyNote.rdfs**
- **Create the corresponding graph from them**
- **Compare your graph with those of your colleagues**


event1
rdf:type
event
event2
local_event
rdf:type
15/05/2006
Personal_event
rdf:type
event5
rdf:type
rdf:type
involves
16/05/2006
event3
event4
involves
15/05/2006
involves
involves
CaroleGoble
PinarAlper
OscarCorcho
rdf:type
rdf:type
rdf:type
professor
researcher


thing
subClassOf
event
subClassOf
Personal_event
subClassOf
local_event
involves
subClassOf
person
subClassOf
professor
subClassOf
researcher

Exercise 2.b. Create RDF/XML and N3 text files from an RDF(S) graph

- Transform the following graph into RDF/XML and N3 syntaxes



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RDF(S) inference. Entailment rules

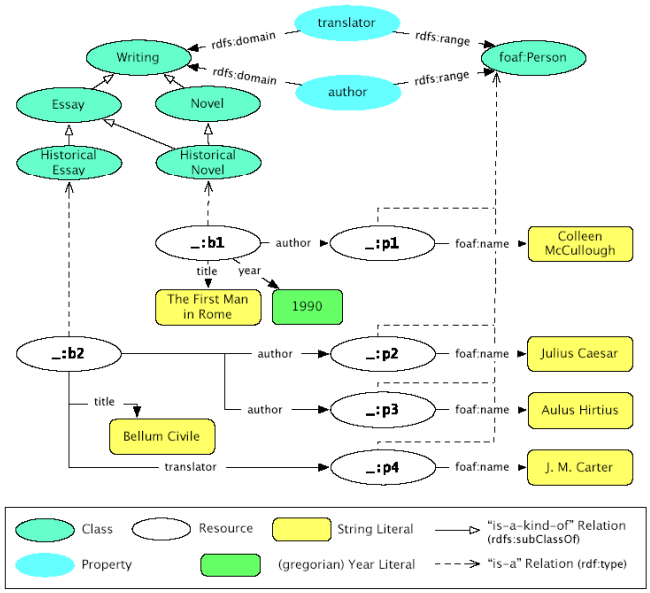
Rule Name	If E contains:	then add:
rdfs1	uuu aaa lll. where lll is a plain literal (with or without a language tag).	_:nnn rdf:type rdfs:Literal . where _:nnn identifies a blank node allocated to lll by rule rule lg.
rdfs2	aaa rdfs:domain xxx . uuu aaa yyy .	uuu rdf:type xxx .
rdfs3	aaa rdfs:range xxx . uuu aaa vvv .	vvv rdf:type xxx .
rdfs4a	uuu aaa xxx .	uuu rdf:type rdfs:Resource .
rdfs4b	uuu aaa vvv.	vvv rdf:type rdfs:Resource .
rdfs5	uuu rdfs:subPropertyOf vvv . vvv rdfs:subPropertyOf xxx .	uuu rdfs:subPropertyOf xxx .
rdfs6	uuu rdf:type rdf:Property .	uuu rdfs:subPropertyOf uuu .
rdfs7	aaa rdfs:subPropertyOf bbb . uuu aaa yyy .	uuu bbb yyy .
rdfs8	uuu rdf:type rdfs:Class .	uuu rdfs:subClassOf rdfs:Resource .
rdfs9	uuu rdfs:subClassOf xxx . vvv rdf:type uuu .	vvv rdf:type xxx .
rdfs10	uuu rdf:type rdfs:Class .	uuu rdfs:subClassOf uuu .
rdfs11	uuu rdfs:subClassOf vvv . vvv rdfs:subClassOf xxx .	uuu rdfs:subClassOf xxx .
rdfs12	uuu rdf:type rdfs:ContainerMembershipProperty .	uuu rdfs:subPropertyOf rdfs:member .
rdfs13	uuu rdf:type rdfs:Datatype .	uuu rdfs:subClassOf rdfs:Literal .

RDF(S) inference. Additional inferences

ext1	uuu rdfs:domain vvv . vvv rdfs:subClassOf zzz .	uuu rdfs:domain zzz .
ext2	uuu rdfs:range vvv . vvv rdfs:subClassOf zzz .	uuu rdfs:range zzz .
ext3	uuu rdfs:domain vvv . www rdfs:subPropertyOf uuu .	www rdfs:domain vvv .
ext4	uuu rdfs:range vvv . www rdfs:subPropertyOf uuu .	www rdfs:range vvv .
ext5	rdf:type rdfs:subPropertyOf www . www rdfs:domain vvv .	rdfs:Resource rdfs:subClassOf vvv .
ext6	rdfs:subClassOf rdfs:subPropertyOf www . www rdfs:domain vvv .	rdfs:Class rdfs:subClassOf vvv .
ext7	rdfs:subPropertyOf rdfs:subPropertyOf www . www rdfs:domain vvv .	rdf:Property rdfs:subClassOf vvv .
ext8	rdfs:subClassOf rdfs:subPropertyOf www . www rdfs:range vvv .	rdfs:Class rdfs:subClassOf vvv .
ext9	rdfs:subPropertyOf rdfs:subPropertyOf www . www rdfs:range vvv .	rdf:Property rdfs:subClassOf vvv .

Exercise

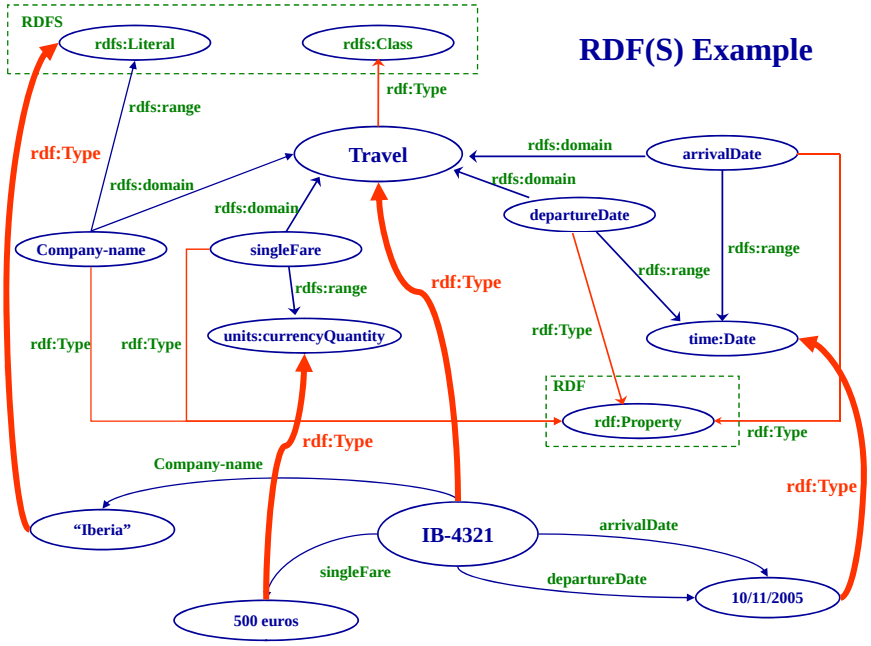
- **Objective**
  - **Understand how to RDF(S) reasoning works**
- **Tasks**
  - **Generate all possible RDF triples that can be inferred from an RDF(S) graph**



Exercise

- **Objective**
  - Understand how to use an RDF(S) development tool to create RDF(S) ontologies
- **Tasks**
  - Create the previous ontologies in an RDF(S) development tool

RDF(S) Example



Exercise

- **Objective**
  - **Understand the features of RDF(S) for implementing ontologies, including its limitations**
- **Tasks**
  - **Take the ontologies previously defined and create their graphs**
    - **First only include the vocabulary from the domain**
    - **Then include references to the RDF and RDFS vocabularies**

Domain description

- **Un lugar puede ser un lugar de interés.**
- **Los lugares de interés pueden ser lugares turísticos o establecimientos, pero no las dos cosas a la vez.**
- **Los lugares turísticos pueden ser palacios, iglesias, ermitas y catedrales.**
- **Los establecimientos pueden ser hoteles, hostales o albergues.**
- **Un lugar está situado en una localidad, la cual a su vez puede ser una villa, un pueblo o una ciudad.**
- **Un lugar de interés tiene una dirección postal que incluye su calle y su número.**
- **Las localidades tienen un número de habitantes.**
- **Las localidades se encuentran situadas en provincias.**

- **Covarrubias es un pueblo con 634 habitantes de la provincia de Burgos.**
- **El restaurante "El Galo" está situado en Covarrubias, en la calle Mayor, número 5.**
- **Una de las iglesias de Covarrubias está en la calle de Santo Tomás.**

Sample resulting ontology