7.2 OWL

- the OWL versions use certain DL semantics:
- Base: $\mathcal{ALC}_{\mathcal{R}^+}$: (i.e., with transitive roles). This logic is called $\mathcal{S}$ (reminiscent to its similarity to the modal logic S).
- roles can be ordered hierarchically (rdfs:subPropertyOf; $\mathcal{H}$).
- OWL Lite: $\mathcal{SHIF}(D)$, Reasoning in EXPTIME.
- OWL DL: $\mathcal{SHOIN}(D)$, decidable.
  Pellet (2007) implements $\mathcal{SHOIQ}(D)$. Decidability is in NEXPTIME (combined complexity wrt. TBox+ABox), but the actual complexity of a given task is constrained by the maximal used cardinality and use of nominals and inverses and behaves like the simpler classes.

  (Ian Horrocks and Ulrike Sattler: A Tableau Decision Procedure for SHOIQ(D); In IJCAI, 2005, pp. 448-453; available via `http://dblp.uni-trier.de`)
- OWL 2.0 towards $\mathcal{SROIQ}(D)$ and more datatypes ...

OWL Notions; OWL-DL vs. RDF/RDFS; Model vs. Graph

- OWL is defined based on (Description Logics) model theory,
- OWL ontologies can be represented by RDF graphs,
- Only *certain* RDF graphs are allowed OWL-DL ontologies: those, where class names, property names, individuals etc. occur in a well-organized way.
- Reasoning works on the (Description Logic) model, the RDF graph is only a means to represent it.
  (recall: RDF/RDFS "reasoning" works on the graph level)

OWL Vocabularies

- An OWL-DL vocabulary $\mathcal{V}$ is a 7-tuple (= a sorted vocabulary) $\mathcal{V} = (\mathcal{V}_{cls}, \mathcal{V}_{objprop}, \mathcal{V}_{dtprop}, \mathcal{V}_{annprop}, \mathcal{V}_{indiv}, \mathcal{V}_{DT}, \mathcal{V}_{lit})$:
- $\mathcal{V}_{cls}$ is the set of URIs denoting class names,
  `<http://.../mondial/10/meta#Country>`
- $\mathcal{V}_{objprop}$ is the set of URIs denoting object property names,
  `<http://.../mondial/10/meta#capital>`
- $\mathcal{V}_{dtprop}$ is the set of URIs denoting datatype property names,
  `<http://.../mondial/10/meta#population>`
- ($\mathcal{V}_{annprop}$ is the set of URIs denoting annotation property names,)
- $\mathcal{V}_{indiv}$ is the set of URIs denoting individuals, `<http://.../mondial/10/countries/D>`
- $\mathcal{V}_{DT}$ is the set of URIs denoting datatype names,
  `<http://www.w3.org/2001/XMLSchema#int>`
- $\mathcal{V}_{lit}$ is the set of literals;
- the builtin notions (=URIs) from RDF, RDFS, OWL namespaces do not belong to the vocabulary of the ontology (they are only used for describing the ontology in RDF).

OWL Interpretations

Since DL is a subset of FOL, the interpretation of an OWL-DL vocabulary can be given as a FOL interpretation

$$\mathcal{I} = (I_{indiv} \cup I_{cls} \cup I_{objprop} \cup I_{dtprop} \cup I_{annprop} \cup I_{DT} \ , \mathcal{U}_{obj} \cup \mathcal{U}_{DT})$$

where I interprets the vocabulary as

- I_{indiv} constant symbols (individuals),
- I_{cls}, I_{DT} unary predicates (classes and datatypes),
- $I_{objprop}$, I_{dtprop}, $I_{annprop}$ binary predicates (properties),

and the universe $\mathcal{U}$ is partitioned into

- an *object domain* $\mathcal{U}_{obj}$
- and a data domain $\mathcal{U}_{DT}$ (of all values of datatypes).

OWL INTERPRETATIONS

The interpretation I is as follows:

I_{indiv}: each individual $a \in \mathcal{V}_{indiv}$ to an object $I(a) \in \mathcal{U}_{obj}$,
(e.g., $I(\texttt{<http://.../mondial/10/countries/D>}) =$ *germany*)

I_{cls}: each class $C \in \mathcal{V}_{cls}$ to a set $I(C) \subseteq \mathcal{U}_{obj}$,
(e.g., *germany* $\in I(\texttt{<http://.../mondial/10/meta\#Country>})$)

I_{DT}: each datatype $D \in \mathcal{V}_{DT}$ to a set $I(D) \subseteq \mathcal{U}_{DT}$,
(e.g., $I(\texttt{<http://www.w3.org/2001/XMLSchema\#int>}) = \{\ldots, -2, -1, 0, 1, 2, \ldots\}$)

$I_{objprop}$: each object property $p \in \mathcal{V}_{objprop}$ to a binary relation $I(p) \subseteq \mathcal{U}_{obj} \times \mathcal{U}_{obj}$,
(e.g., (*germany*, *berlin*) $\in I(\texttt{<http://.../mondial/10/meta\#capital>})$)

I_{dtprop}: each datatype property $p \in \mathcal{V}_{dtprop}$ to a binary relation $I(p) \subseteq \mathcal{U}_{obj} \times \mathcal{U}_D$,
(e.g., (*germany*, $83536115) \in I(\texttt{<http://.../mondial/10/meta\#population>})$)

$I_{annprop}$: each annotation property $p \in \mathcal{V}_{annprop}$ to a binary relation $I(p) \subseteq \mathcal{U} \times \mathcal{U}$.

OWL Class Definitions and Axioms (Overview)

- owl:Class
- The properties of an owl:Class (including owl:Restriction) node describe the properties of that class.
  An owl:Class is required to satisfy the conjunction of all constraints (implicit: intersection) stated about it.
  These characterizations are roughly the same as discussed for DL class definitions:
  - Constructors: owl:unionOf, owl:intersectionOf, owl:complementOf ($\mathcal{ALC}$)
  - Enumeration Constructor: owl:oneOf (enumeration of elements; $\mathcal{O}$)
  - Axioms rdfs:subClassOf, owl:equivalentClass,
  - Axiom owl:disjointWith (also expressible in $\mathcal{ALC}$: C disjoint with D is equivalent to $C \sqsubseteq \neg D$)

OWL Notions (Cont'd)

OWL Restriction Classes (Overview)

- owl:Restriction is a subclass of owl:Class, allowing for specification of a constraint on *one* property.
- one property is restricted by an owl:onProperty specifier and a constraint on this property:
  - ($\mathcal{N}$, $\mathcal{Q}$, $\mathcal{F}$) owl:cardinality, owl:minCardinality or owl:maxCardinality,
  - owl:allValuesFrom ($\forall R.C$), owl:someValuesFrom ($\exists R.C$),
  - owl:hasValue ($\mathcal{O}$),
  - including datatype restrictions for the range (D)
- by defining intersections of owl:Restrictions, classes having multiple such constraints can be specified.

OWL Notions (Cont'd)

OWL Property Axioms (Overview)

- Distinction between owl:ObjectProperty and owl:DatatypeProperty
- from RDFS: rdfs:domain/rdfs:range assertions, rdfs:subPropertyOf
- Axiom owl:equivalentProperty
- Axioms: subclasses of rdf:Property:
  owl:TransitiveProperty, owl:SymmetricProperty, owl:FunctionalProperty, owl:InverseFunctionalProperty (see Slide 310)

OWL Individual Axioms (Overview)

- Individuals are modeled by unary classes
- owl:sameAs, owl:differentFrom, owl:AllDifferent(o_1,...,o_n).

First-Order Logic Equivalents

OWL : $x \in C$	DL Syntax	FOL
C	C	$C(x)$
intersectionOf(C_1, C_2)	$C_1 \sqcap \ldots \sqcap C_n$	$C_1(x) \wedge \ldots \wedge C_n(x)$
unionOf(C_1, C_2)	$C_1 \sqcup \ldots \sqcup C_n$	$C_1(x) \vee \ldots \vee C_n(x)$
complementOf(C_1)	$\neg C_1$	$\neg C_1(x)$
oneOf$(x_1, \ldots, x_n)$	$\{x_1\} \sqcup \ldots \sqcup \{x_n\}$	$x = x_1 \vee \ldots \vee x = x_n$

OWL : $x \in C$, Restriction on P	DL Syntax	FOL
someValuesFrom(C')	$\exists P.C'$	$\exists y : P(x,y) \wedge C'(y)$
allValuesFrom(C')	$\forall P.C'$	$\forall y : P(x,y) \rightarrow C'(y)$
hasValue(y)	$\exists P.\{y\}$	$P(x,y)$
maxCardinality(n)	$\leq n.P$	$\exists^{\leq n} y : P(x,y)$
minCardinality(n)	$\geq n.P$	$\exists^{\geq n} y : P(x,y)$
cardinality(n)	$n.P$	$\exists^{=n} y : P(x,y)$

First-Order Logic Equivalents (Cont'd)

OWL Class Axioms for C	DL Syntax	FOL
rdfs:subClassOf(C_1)	$C \sqsubseteq C_1$	$\forall x : C(x) \rightarrow C_1(x)$
equivalentClass(C_1)	$C \equiv C_1$	$\forall x : C(x) \leftrightarrow C_1(x)$
disjointWith(C_1)	$C \sqsubseteq \neg C_1$	$\forall x : C(x) \rightarrow \neg C_1(x)$

OWL Individual Axioms	DL Syntax	FOL
x_1 sameAs x_2	$\{x_1\} \equiv \{x_2\}$	$x_1 = x_2$
x_1 differentFrom x_2	$\{x_1\} \sqsubseteq \neg\{x_2\}$	$x_1 \neq x_2$
AllDifferent$(x_1, \ldots, x_n)$	$\bigwedge_{i \neq j} \{x_i\} \sqsubseteq \neg\{x_j\}$	$\bigwedge_{i \neq j} x_i \neq x_j$

First-Order Logic Equivalents (Cont'd)

OWL Properties	DL Syntax	FOL
P	P	$P(x, y)$

OWL Property Axioms for P	DL Syntax	FOL
rdfs:range(C)	$\top \sqsubseteq \forall P.C$	$\forall x, y : P(x, y) \rightarrow C(y)$
rdfs:domain(C)	$C \sqsupseteq \exists P.\top$	$\forall x, y : P(x, y) \rightarrow C(x)$
subPropertyOf(P_2)	$P \sqsubseteq P_2$	$\forall x, y : P(x, y) \rightarrow P_2(x, y)$
equivalentProperty(P_2)	$P \equiv P_2$	$\forall x, y : P(x, y) \leftrightarrow P_2(x, y)$
inverseOf(P_2)	$P \equiv P_2^-$	$\forall x, y : P(x, y) \leftrightarrow P_2(y, x)$
TransitiveProperty	$P^+ \equiv P$	$\forall x, y, z : ((P(x, y) \wedge P(y, z)) \rightarrow P(x, z))$
		$\forall x, z : ((\exists y : P(x, y) \wedge P(y, z)) \rightarrow P(x, z))$
FunctionalProperty	$\top \sqsubseteq \leq 1 P.\top$	$\forall x, y_1, y_2 : P(x, y_1) \wedge P(x, y_2) \rightarrow y_1 = y_2$
InverseFunctionalProperty	$\top \sqsubseteq \leq 1 P^-.\top$	$\forall x, y_1, y_2 : P(y_1, x) \wedge P(y_2, x) \rightarrow y_1 = y_2$

Syntactical Representation

- OWL specifications can be represented by graphs: OWL constructs have a straightforward representation as triples in RDF/XML and N3.
- there are several logic-based representations (e.g. *Manchester OWL Syntax*); TERP (which can be used with pellet) is a combination of Turtle and Manchester syntax.
- OWL in RDF/XML format: usage of class, property, and individual names:
  - as @rdf:about when used as identifier of a subject (owl:Class, rdf:Property and their subclasses),
  - as @rdf:resource as the object of a property.
- some constructs need auxiliary structures (collections):
  owl:unionOf, owl:intersectionOf, and owl:oneOf are based on Collections
  - representation in RDF/XML by rdf:parseType="Collection".
  - representation in N3 by (x_1 x_2 $\ldots$ x_n)
  - as RDF lists: rdf:List, rdf:first, rdf:rest

REQUIREMENT

- every entity in an OWL ontology must be explicitly typed (i.e., as a class, an object property, a datatype property, ..., or an instance of some class).
  (for reasons of space this is not always done in the examples; in general, it may lead to incomplete results)

QUERYING OWL DATA

- queries are atomic and conjunctive DL queries against the underlying OWL-DL model.
- this model can still be seen as a graph:
  - many of the edges are those known from the basic RDF graph
  - some edges (and collections) are only there for encoding OWL stuff (describing owl:unionOf, owl:propertyChain etc.) – these should not be queried
- SPARQL-DL is a subset of SPARQL: not every SPARQL query pattern is allowed for use on an OWL ontology
  (but the reasonable ones are, so in practice this is not a problem.)
- the query language SPARQL-DL allows exactly such well-sorted patterns using the notions of OWL.

Some TBox-only Reasoning Examples on Sets

Example: Paradox

```
<?xml version="1.0"?>
<rdf:RDF xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xml:base="foo://bla/">
 <owl:Class rdf:about="Paradox">
  <owl:complementOf rdf:resource="Paradox"/>
 </owl:Class>
</rdf:RDF>
```

[Filename: RDF/paradox.rdf]

- without reasoner:

  jena -t -if paradox.rdf

  Outputs the same RDF facts in N3 without checking consistency.

- with reasoner:

  jena -e -pellet -if paradox.rdf

  reads the RDF file, creates a model (and checks consistency) and in this case reports that it is not consistent.

Union as $A \sqcup B \equiv \neg((\neg A) \sqcap (\neg B))$

```
@prefix : <foo://bla/>.
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
:A rdf:type owl:Class.        :B rdf:type owl:Class.
:Union1 owl:unionOf (:A :B).
:CompA owl:complementOf :A.   :CompB owl:complementOf :B.
:IntersectComps owl:intersectionOf (:CompA :CompB).
:Union2 owl:complementOf :IntersectComps.
:x rdf:type :A.               :x rdf:type :B.
:y rdf:type :CompA. # a negative assertion y not in A would be better -> OWL 2
:y rdf:type :CompB.
```

[Filename: RDF/union.n3]

```
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
prefix : <foo://bla/>
select ?X ?C ?D
from <file:union.n3>
where {{?X rdf:type ?C} UNION {:Union1 owl:equivalentClass ?D}}
```

[Filename: RDF/union.sparql]

Example: Union and Subclass

```
<?xml version="1.0"?>
<rdf:RDF xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:f="foo://bla/"
    xml:base="foo://bla/">
 <owl:Class rdf:about="Person">
  <owl:unionOf rdf:parseType="Collection">
   <owl:Class rdf:about="Male"/>
   <owl:Class rdf:about="Female"/>
  </owl:unionOf>
 </owl:Class>
 <owl:Class rdf:about="EqToPerson">
  <owl:unionOf rdf:parseType="Collection">
   <owl:Class rdf:about="Female"/>
   <owl:Class rdf:about="Male"/>
  </owl:unionOf>
 </owl:Class>
 <f:Person rdf:about="unknownPerson"/>
</rdf:RDF>
```

[Filename: RDF/union-subclass.rdf]

Example (Cont'd)

- print class tree (with jena -e -pellet):

```
owl:Thing
   bla:Person = bla:EqToPerson - (bla:unknownPerson)
      bla:Female
      bla:Male
```

- Male and Female are derived to be subclasses of Person.
- Person and EqToPerson are equivalent classes.
- unknownPerson is a member of Person and EqToPerson.

```
prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <foo://bla/>
select ?SC ?C ?T ?CC ?CD
from <file:union-subclass.rdf>
where {{?SC rdfs:subClassOf ?C} UNION
       {:unknownPerson rdf:type ?T} UNION
       {?CC owl:equivalentClass ?CD}}
```

[Filename: RDF/union-subclass.sparql]

Exercise

Consider

```
<owl:Class rdf:about="C1">
 <owl:intersectionOf rdf:parseType="Collection">
  <owl:Class rdf:about="A"/>
  <owl:Class rdf:about="B"/>
 </owl:intersectionOf>
</owl:Class>
```

and

```
<owl:Class rdf:about="C2">
 <rdfs:subClassOf rdf:resource="A"/>
 <rdfs:subClassOf rdf:resource="B"/>
</owl:Class>
```

- give mathematical characterizations of both cases.
- discuss whether both fragments are equivalent or not.

Discussion

- Two classes are *equivalent* (wrt. the knowledge base) if they have the same interpretation in every *model* of the KB.
- C_1 is characterized to be the intersection of classes A and B.
- for C_2, it is asserted that C_2 is a subset of A and that it is a subset of B.
- Thus there can be some c that is in A, B, C_1, but not in C_2.
- Thus, C_1 and C_2 are not equivalent.

Discussion: Formal Notation

The DL equivalent to the knowledge base (TBox) is

$$\mathcal{T} = \{C_1 \equiv (A \sqcap B)\ , \quad C_2 \sqsubseteq A\ , \quad C_2 \sqsubseteq B\}$$

The First-Order Logic equivalent is

$$\mathcal{KB} = \{\forall x : A(x) \land B(x) \leftrightarrow C_1(x)\ , \quad \forall x : C_2(x) \rightarrow A(x) \land B(x)\}$$

Thus, $\mathcal{KB} \models \forall x : C_2(x) \rightarrow A(x) \land B(x)$.

Or, in DL: $\mathcal{T} \models C_2 \sqsubseteq C_1$.

On the other hand, $\mathcal{M} = (\mathcal{D}, \mathcal{I})$ with $\mathcal{D} = \{c\}$ and

$$\mathcal{I}(A) = \{c\},\ \ \mathcal{I}(B) = \{c\},\ \ \mathcal{I}(C_1) = \{c\},\ \ \mathcal{I}(C_2) = \emptyset$$

is a model of $\mathcal{KB}$ (wrt. first-order logic) and $\mathcal{T}$ (wrt. DL) that shows that C_1 and C_2 are not equivalent.

Subclasses of Properties

Triple syntax: *some property* rdf:type *a specific type of property*

According to their ranges

- owl:ObjectProperty – subclass of rdf:Property; object-valued (i.e. rdfs:range must be an Object class)
- owl:DatatypeProperty – subclass of rdf:Property; datatype-valued (i.e. its rdfs:range must be an rdfs:Datatype)

⇒ OWL ontologies require each property to be typed in such a way!
(for reasons of space sometimes omitted in examples)

According to their Cardinality

- specifying n:1 or 1:n cardinality:
owl:FunctionalProperty, owl:InverseFunctionalProperty

⇒ useful for deriving that objects must be different from each other.

According to their Properties

- owl:TransitiveProperty, owl:SymmetricProperty see later ...

Functional Cardinality Specification

property rdf:type owl:FunctionalProperty

- not a constraint, but
- if such a property results in two things ... these things are inferred to be the same.

```
@prefix : <foo://bla/names#>.
@prefix family: <foo://bla/persons/>.
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix owl: <http://www.w3.org/2002/07/owl#>.
  :world :has_pope family:josephratzinger .
  :world :has_pope [ :name "Benedikt XVI" ] .
  :has_pope rdf:type owl:FunctionalProperty.
```

[Filename: RDF/popes.n3]

```
prefix : <foo://bla/names#>
prefix family: <foo://bla/persons/>
select ?N  from <file:popes.n3>
where { family:josephratzinger :name ?N }
```

[Filename: RDF/pope.sparql]

owl:Restriction – Example

- owl:Restriction for $\exists p.C$ and $\forall p.C$.   (cf. earlier examples)

```
<?xml version="1.0"?>
<rdf:RDF xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:f="foo://bla/"
    xml:base="foo://bla/">
 <owl:Class rdf:about="Parent">
  <owl:intersectionOf rdf:parseType="Collection">
   <owl:Class rdf:about="Person"/>
   <owl:Restriction>
    <owl:onProperty rdf:resource="hasChild"/>
    <owl:minCardinality>1</owl:minCardinality>
   </owl:Restriction>
  </owl:intersectionOf>
 </owl:Class>
 <f:Person rdf:about="john">
   <f:hasChild><f:Person rdf:about="alice"/></f:hasChild>
 </f:Person>
</rdf:RDF>
```

[Filename: RDF/restriction.rdf]

```
prefix : <foo://bla/>
select ?C
from <file:restriction.rdf>
where {:john a ?C}
```

[Filename: RDF/restriction.sparql]

Restrictions Only as Blank Nodes

Consider the following (bad) specification:

```
:badIdea a owl:Restriction; owl:onProperty :hasChild; owl:minCardinality 1.
```

This is not allowed in OWL-DL.

Correct specification:

```
:badIdea owl:equivalentClass
 [a owl:Restriction; owl:onProperty :hasChild; owl:minCardinality 1].
```

Why? ... there are many reasons, for one of them see next slide.

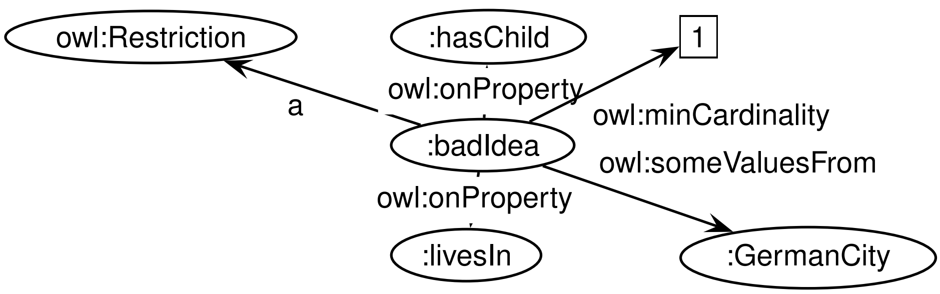
Restrictions Only as Blank Nodes (Cont'd)

A class with two such specifications:

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo://bla/>.
:badIdea a owl:Restriction; owl:onProperty :hasChild; owl:minCardinality 1 .
:badIdea a owl:Restriction; owl:onProperty :livesIn; owl:someValuesFrom :GermanCity.
```

[Filename: RDF/badIdea.n3]

- call jena -t -pellet -if badIdea.n3:



The two restriction specifications are messed up.

Restrictions Only as Blank Nodes (Cont'd)

- Thus specify each Restriction specification with a separate blank node:

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo://bla/>.
:TwoRestrictions owl:equivalentClass
 [ owl:intersectionOf
   ( [ a owl:Restriction; owl:onProperty :hasChild; owl:minCardinality 1]
     [ a owl:Restriction; owl:onProperty :livesIn; owl:someValuesFrom :GermanCity] ) ].
```

[Filename: RDF/twoRestrictions.n3]

The DL equivalent: TwoRestrictions $\equiv (\exists$ hasChild.$\top) \sqcap (\exists$ livesIn.GermanCity)

Another reason:

```
:AnotherBadDesignExample a owl:Restriction;
   owl:onProperty :hasChild; owl:minCardinality 1;
   rdfs:subClassOf :Person.
```

... mixes the *definition* of the Restriction with an assertive axiom: ABDE $\equiv \exists \geq 1$ hasChild.$\top \wedge$ ABDE $\sqsubseteq$ Person

Multiple Restrictions on a Property

- "All persons that have at least two children, and one of them is male"

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix : <foo://bla/>.
### Test: multiple restrictions: the someValuesFrom-condition is then ignored
:HasTwoChildrenOneMale owl:intersectionOf (:Person
   [ a owl:Restriction; owl:onProperty :hasChild;
     owl:someValuesFrom :Male; owl:minCardinality 2]).
:name a owl:FunctionalProperty.
:Male rdfs:subClassOf :Person; owl:disjointWith :Female.
:Female rdfs:subClassOf :Person.
:kate a :Female; :name "Kate"; :hasChild :john.
:john a :Male; :name "John";
  :hasChild [a :Female; :name "Alice"], [a :Male; :name "Bob"].
:sue a :Female; :name "Sue";
  :hasChild [a :Female; :name "Anne"], [a :Female; :name "Barbara"].
```

[Filename: RDF/restriction-double.n3]

```
prefix : <foo://bla/>
select ?X
from <file:restriction-double.n3>
where {?X a :HasTwoChildrenOneMale}
```

[Filename: RDF/restriction-double.sparql]

- The the someValuesFrom-condition is ignored in this case (Result: John and Sue).
- Solution: intersection of restrictions

Multiple Restrictions on a Property

- "All persons that have at least two children, and one of them is male"

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix : <foo://bla/>.
:HasTwoChildrenOneMale owl:equivalentClass
 [ owl:intersectionOf (:Person
   [ a owl:Restriction; owl:onProperty :hasChild; owl:someValuesFrom :Male]
   [ a owl:Restriction; owl:onProperty :hasChild; owl:minCardinality 2] ) ].
:name a owl:FunctionalProperty.
:Male rdfs:subClassOf :Person; owl:disjointWith :Female.
:Female rdfs:subClassOf :Person.
:kate a :Female; :name "Kate"; :hasChild :john.
:john a :Male; :name "John";
  :hasChild [a :Female; :name "Alice"], [a :Male; :name "Bob"].
:sue a :Female; :name "Sue";
  :hasChild [a :Female; :name "Anne"], [a :Female; :name "Barbara"].
```

[Filename: RDF/intersect-restrictions.n3]

```
prefix : <foo://bla/>
select ?X
from <file:intersect-restrictions.n3>
where {?X a :HasTwoChildrenOneMale}
```

[Filename: RDF/intersect-restrictions.sparql]

- Note: this is different from Qualified Range Restrictions such as "All persons that have at least two male children" – see Slide 370.

Use of a Derived Class

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix : <foo://bla/names#>.
:kate :name "Kate"; :child :john.
:john :name "John"; :child :alice.
:alice :name "Alice".
:Parent a owl:Class; owl:equivalentClass
 [ a owl:Restriction; owl:onProperty :child; owl:minCardinality 1].
:Grandparent owl:equivalentClass
 [a owl:Restriction; owl:onProperty :child; owl:someValuesFrom :Parent].
```

[Filename: RDF/grandparent.n3]

```
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
prefix : <foo://bla/names#>
select ?A ?B
from <file:grandparent.n3>
where {{?A a :Parent} UNION
       {?B a :Grandparent} UNION
       {:Grandparent rdfs:subClassOf :Parent}}
```

[Filename: RDF/grandparent.sparql]

Non-Existence of Property Fillers

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo://bla/names#>.
:kate a :Person; :name "Kate"; :hasChild :john.
:john a :Person; :name "John"; :hasChild :alice, :bob.
:alice a :Person; :name "Alice".
:bob a :Person; :name "Bob".
:name a owl:FunctionalProperty.
:ChildlessA owl:intersectionOf (:Person
  [ a owl:Restriction; owl:onProperty :hasChild; owl:maxCardinality 0]).
:ChildlessB owl:intersectionOf (:Person
  [ a owl:Restriction; owl:onProperty :hasChild; owl:allValuesFrom owl:Nothing]).
:ParentA owl:intersectionOf (:Person [owl:complementOf :ChildlessA]).
:ParentB owl:intersectionOf (:Person
  [ a owl:Restriction; owl:onProperty :hasChild; owl:minCardinality 1]).
```

[Filename: RDF/childless.n3]

```
prefix : <foo://bla/names#>
select ?X ?Y
from <file:childless.n3>
where {{?X a :ChildlessA}
       union {?Y a :ParentA}}
```

[Filename: RDF/childless.sparql]

- export class tree: ChildlessA and ChildlessB are equivalent,
- note: due to the Open World Assumption, both classes are empty.
- Persons where no children are known are neither in ChildlessA or in Parent!

Inverse Properties

- *owl:ObjectProperty* owl:inverseOf *owl:ObjectProperty*
- owl:DatatypeProperties cannot have an inverse
  (this would define properties of objects, cf. next slide)

```
@prefix : <foo://bla/names#> .
@prefix family: <foo://bla/persons/> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
  family:john :child family:alice, family:bob.
  family:john :parent family:kate .
  :descendant rdf:type owl:TransitiveProperty.
  :child rdfs:subPropertyOf :descendant.
  :child owl:inverseOf :parent.
```

[Filename: RDF/inverse.n3]

```
prefix : <foo://bla/names#>
select ?X ?Y
from <file:inverse.n3>
where {?X :descendant ?Y}
```

[Filename: RDF/inverse.sparql]

No Inverses of owl:DatatypeProperties!

- an owl:DatatypeProperty must not have an inverse:
- ":john :age 35" would imply "35 :ageOf :john" which would mean that a literal has a property, which is not allowed.

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix : <foo://bla/names#> .
# :john :name "John"; :age 35; :child [:name "Alice"], [:name "Bob"; :age 8].
:age a owl:DatatypeProperty.
:child a rdf:Property.
:childOf owl:inverseOf :child.
:ageOf owl:inverseOf :age.
```

[Filename: RDF/inverseDTProp.n3]

```
jena -e -pellet -if inverseDTProp.n3
WARN [main] (OWLLoader.java:352) - Unsupported axiom:
Ignoring inverseOf axiom between foo://bla/names#ageOf (ObjectProperty)
  and foo://bla/names#age (DatatypeProperty)
```


Specification of Inverse Functional Properties

- Mathematics: a mapping m is inverse-functional if the inverse of m is functional: $x\ p\ y$ is inverse-functional, if for every y, there is at most one x such that xpy holds.
- Example:
  - hasCarCode is functional: every country has one car code,
  - hasCarCode is also inverse functional: every car code uniquely identifies a country.
- OWL:
  `:m-inverse owl:inverseOf :m .`
  `:m-inverse a owl:FunctionalProperty .`
  not allowed for e.g. `mon:carCode a owl:DatatypeProperty`:

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo:bla#>.
:carCode a owl:DatatypeProperty; rdfs:domain :Country;
  owl:inverseOf :isCarCodeOf.
# :Germany :carCode "D".
```

[Filename: RDF/noinverse.n3]

- the statement is rejected.

OWL:INVERSEFUNCTIONALPROPERTY

- such cases are described with owl:InverseFunctionalProperty
- a property P is an owl:InverseFunctionalProperty if $\forall x, y_1, y_2 : P(y_1, x) \wedge P(y_2, x) \rightarrow y_1 = y_2$ holds

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo:bla#>.
:carCode rdfs:domain :Country; a owl:DatatypeProperty;
  a owl:FunctionalProperty; a owl:InverseFunctionalProperty.
:name a owl:DatatypeProperty; a owl:FunctionalProperty.
:Germany :carCode "D"; :name "Germany".
:DominicanRepublic :carCode "D"; :name "Dominican Republic".
```

[Filename: RDF/invfunctional.n3]

- the fragment is detected to be inconsistent.

OWL:HASKEY (OWL 2)

- description of key attributes $(k_1, \ldots, k_n)$ is a relevant issue in data modeling. Note that InverseFunctionalProperty covers the simple case that $n = 1$.

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo:bla#>.
:name a owl:DatatypeProperty; a owl:FunctionalProperty.
:Country owl:hasKey (:carCode).
:Germany a :Country; :carCode "D"; :name "Germany".
:DominicanRepublic a :Country; :carCode "D"; :name "Dominican Republic".
:Duesseldorf  a :City; :carCode "D"; :name "Duesseldorf".
```

[Filename: RDF/haskey.n3]

- the fragment is inconsistent.

OWL:HASKEY (OWL 2)

- keys can also be used to detect that two resources (e.g. described by different Web sources) are actually the same:

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo:bla#>.
:Person owl:hasKey (:givenName :familyName).
 _:b1 a :Person; :firstName "John"; :familyName "Doe";  :age 32 .
 _:b2 a :Person; :firstName "John"; :familyName "Doe";  :address "Main Street 1" .
```

[Filename: RDF/haskey2.n3]

```
prefix : <foo:bla#>
select ?X ?P ?Y
from <file:haskey2.n3>
where {?X a :Person ; ?P ?Y}
```

[Filename: RDF/haskey2.sparql]

NAMED AND UNNAMED RESOURCES

(from the DL reasoner's perspective)

Named Resources

- resources with explicit global URIs
  <http://www.semwebtech.org/mondial/10/country/D>
  <foo://bla/bob>
- resources with local IDs/named blank nodes
- unnamed blank nodes

Unnamed (implicit) Resources

- things that exist only implicitly:
  John's child in

```
:Parent a owl:Class; owl:equivalentClass
   [ a owl:Restriction; owl:onProperty :child; owl:minCardinality 1].
:john a Parent.
```

- such resources can even have properties (see next slides).

Implicit Resources

- "every person has a father who is a person" and "john is a person".
- the *standard model* is *infinite*:
  john, john's father, john's father's father, ...
- pure RDF graphs are always finite,
- only with OWL axioms, one can specify such infinite models,

⇒ they have only finitely many *locally to path length* n different nodes,

- the reasoner can detect the necessary n ("blocking", cf. Slides 418 ff) and create "typical" different structures.

Aside: "standard model" vs "nonstandard model"

- the term "standard model" is not only "what we understand (in this case)", but is a notion of mathematical theory which –roughly– means "the simplest model of a specification"
- nonstandard models of the above are those where there is a cycle in the ancestors relation.
  (as the length of the cycle is arbitrary, this would not make it easier for the reasoner - there is only the possibility to have an owl:sameAs somewhere)

Implicit Resources

```
@prefix : <foo://bla/names#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
:Person owl:equivalentClass [a owl:Restriction;
  owl:onProperty :father; owl:someValuesFrom :Person].
:bob :name "Bob";  a :Person; :father :john.
:john :name "John";  a :Person.
```

[Filename: RDF/fathers-and-forefathers.n3]

```
prefix : <foo://bla/names#>
prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
select ?X ?F ?C
from <file:fathers-and-forefathers.n3>
where {{ ?X :father ?F } UNION { ?C a :Person }}
```

[Filename: RDF/fathers-and-forefathers.sparql]

- Reasoner: works on the model, including blocking, i.e. *modulo equivalence up to paths of length* n.
- SPARQL (and SWRL) rules: works on the graph – without the unnamed/implicit resorces.

7.3 RDF Graph vs. OWL Model; SPARQL vs. Reasoning

- SPARQL is an RDF (graph) query language
- OWL talks about models.

Consequences (Overview)

⇒ SPARQL queries are answered against the graph of triples

- Some OWL notions are directly represented by triples, such as c a owl:Class.
- Some others are directly supported by special handling in the reasoners, e.g., c rdfs:subClassOf d and c owl:equivalentClass d.
- some others are only “answered” when given explicitly in the RDF input! The results then do not incorporate further results that could be found by reasoning!
- OWL notions in the input are often not contained as triples, but are only translated into DL atoms for the reasoner. (e.g. owl:Restriction definitions)
- Most OWL notions in queries are not “understood” as OWL, but only matched.
- SPARQL answers are only concerned with the graph, not with implicit things that are only known in the model.

NOT REASONED: OWL:FUNCTIONALPROPERTY

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo:bla#>.
:p a owl:ObjectProperty; rdfs:domain :D.
:D owl:equivalentClass [ a owl:Restriction; owl:onProperty :p;
                                            owl:maxCardinality 1 ].
# :x :p :a, :b.    :a owl:differentFrom :b.
```

[Filename:RDF/functional.n3]

```
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <foo:bla#>
select ?P
from <file:functional.n3>
where {{ ?X :p ?Y } UNION {?P a owl:FunctionalProperty }}
```

[Filename:RDF/functional.sparql]

- SPARQL-DL (Sirin, Parsia OWLED 2007) is a proposal that allows certain OWL built-ins to be queried.

NOT ALLOWED: COMPLEX TERMS IN SPARQL QUERIES

- example: all cities that are a capital
- runs both with pellet and jena (Feb. 2013):

```
pellet query -query-file countrycaps.sparql \
       mondial-europe.n3 mondial-meta.n3 countrycaps.n3
```

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <http://www.semwebtech.org/mondial/10/meta#> .
:CountryCapital owl:intersectionOf
  (:City [a owl:Restriction; owl:onProperty :isCapitalOf;
         owl:someValuesFrom :Country]).
```

[Filename: RDF/countrycaps.n3]

```
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <http://www.semwebtech.org/mondial/10/meta#>
select ?N1 ?N2
where {{?X a :CountryCapital; :name ?N1} union
       {?Y a [a owl:Restriction; owl:onProperty :isCapitalOf;
              owl:someValuesFrom :Country]; :name ?N2}}
```

[Filename:RDF/countrycaps.sparql]

- 53 answers, column ?N1 is filled, ?N2 is null.

NOT ALLOWED: COMPLEX TERMS IN SPARQL QUERIES (CONT'D)

- all organizations whose headquarter city is a capital:
- use pellet! jena does not support this (Feb. 2013):

```
pellet query -query-file organizations-query2.sparql \
  mondial-europe.n3 mondial-meta.n3
```

```
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <http://www.semwebtech.org/mondial/10/meta#>
select ?A ?H
where {?X a [ owl:intersectionOf
            (:Organization [a owl:Restriction; owl:onProperty :hasHeadq;
                           owl:someValuesFrom
                             [ a owl:Restriction; owl:onProperty :isCapitalOf;
                               owl:someValuesFrom :Country ] ] ) ];
       :abbrev ?A; :hasHeadq ?C . ?C :name ?H . }
```

[Filename:RDF/organizations-query2.sparql]

- 35 answers.

Answer Sets to Queries as Ad-hoc Concepts

- all organizations whose headquarter city is a capital:

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <http://www.semwebtech.org/mondial/10/meta#> .
:CountryCapital owl:equivalentClass
  [ owl:intersectionOf
    (:City [a owl:Restriction; owl:onProperty :isCapitalOf;
           owl:someValuesFrom :Country])].
<bla:Result>  owl:equivalentClass [ owl:intersectionOf
  (:Organization [a owl:Restriction; owl:onProperty :hasHeadq;
    owl:someValuesFrom :CountryCapital])] .
```

[Filename: RDF/organizations-query.n3]

```
prefix : <http://www.semwebtech.org/mondial/10/meta#>
select ?A ?N
from <file:organizations-query.n3>
from <file:mondial-europe.n3>
from <file:mondial-meta.n3>
where {?X a <bla:Result> . ?X :abbrev ?A . ?X :hasHeadq ?C . ?C :name ?N}
```

[Filename:RDF/organizations-query.sparql]

SPARQL on the Graph

- SPARQL does not return any answer related with nodes (=resources) that are only implicitly known (=non-named resources)

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
prefix : <foo://bla/names#>
:ParentOf12YOChild  owl:equivalentClass [a owl:Restriction;
  owl:onProperty :child; owl:someValuesFrom :12YOPerson].
:12YOPerson owl:equivalentClass [a owl:Restriction;
  owl:onProperty :age; owl:hasValue 12].
[ :name "John"; :age 35;  a :ParentOf12YOChild;
   :child [:name "Alice"; :age 10], [:name "Bob"; :age 8]].
:age rdf:type owl:FunctionalProperty.
# :12YOPerson owl:equivalentClass owl:Nothing.

:TwoChildrenParent  owl:equivalentClass [a owl:Restriction;
  owl:onProperty :child; owl:cardinality 2].
:ThreeChildrenParent  owl:equivalentClass [a owl:Restriction;
  owl:onProperty :child; owl:minCardinality 3].
```

[Filename: RDF/john-three-children-impl.n3]

SPARQL and Non-Named Resources (Cont'd)

- implicit resources exist only on the reasoning level,
- not considered by SPARQL queries:

```
prefix : <foo://bla/names#>
prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
select ?X ?C ?A ?T
from <file:john-three-children-impl.n3>
where {{ ?X :name "John" . ?X a ?C }
       UNION {?X :age ?A} UNION {?T a :12YOPerson}}
```

[Filename: RDF/john-three-children-impl.sparql]

- John is a ThreeChildrenParent,
- no person known who is 12 years old
- adding `:12YOPerson owl:equivalentClass owl:Nothing` makes it inconsistent.
- same applies to owl:hasKey (cf. Slides 324 and 336) and SWRL rules (cf. Slides 421 ff).

OWL:HASKEY AND NON-NAMED RESOURCES

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix : <foo:bla#>.
:XYThing owl:hasKey (:x :y).
:pointTo rdfs:range :XYThing.
:xy10 a :XYThing; :x 10; :y 10; :text "free".
:XYTen owl:intersectionOf
  ([ a owl:Restriction; owl:onProperty :x; owl:hasValue 10]
   [ a owl:Restriction; owl:onProperty :y; owl:hasValue 10]
   [ a owl:Restriction; owl:onProperty :text; owl:hasValue "pointedTo"]).
:foo a [ a owl:Restriction;
         owl:onProperty :pointTo; owl:onClass :XYTen; owl:qualifiedCardinality 1].
  # forces implicit existence of a node (10,10,"pointedTo").
# Make this implicit node named by forcing "another" node pointed to
# from :tenTen without any properties: via hasKey, xyxy = xy10
# :foo :pointTo :xyxy.
```

[Filename: RDF/easykeys-impl.n3]

OWL:HASKEY AND NON-NAMED RESOURCES (CONT'D)

```
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <foo:bla#>
SELECT ?CT ?Y ?T ?SameAsxyxy
FROM <easykeys-impl.n3>
WHERE {{ :foo :pointTo [ :text ?CT ] }
        UNION { ?Y :text ?T }
        UNION { [:text ?T] }
        UNION { :xyxy owl:sameAs ?SameAsxyxy }}
```

[Filename: RDF/easykeys-impl.sparql]

- as long as the relevant node is only implicit (although quite some information about it is known), it is not considered in the answers.

[ASIDE] OWL VS. RDF LISTS

- RDF provides structures for representing lists by triples (cf. Slide 226): rdf:List, rdf:first, rdf:rest.
  These are *distinguished* classes/properties.
- OWL/reasoners have a still unclear relationship with these:
  - use of lists for its internal representation of owl:unionOf, owl:oneOf etc. (that are actually based on collections),
  - do or do not allow the user to query this internal representation,
  - ignore user-defined lists over usual resources.

UNIONOF (ETC) AS TRIPLES: LISTS

- owl:unionOf (x y z), owl:oneOf (x y z) is actually only syntactic sugar for RDF lists.
- The following are equivalent:

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo://bla/>.

:Male a owl:Class.
:Female a owl:Class.

:Person a owl:Class; owl:unionOf (:Male :Female).
:EqToPerson a owl:Class;
  owl:unionOf
  [ a rdf:List; rdf:first :Male;
    rdf:rest [ a rdf:List; rdf:first :Female; rdf:rest rdf:nil]].
:x a :Person.
```
[Filename: RDF/union-list.n3]

- jena -t -if union-list.n3: both in usual N3 notation as owl:unionOf (:Male :Female).

UNIONOF (ETC) AS TRIPLES (CONT'D)

```
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <foo://bla/>
select ?C
from <file:union-list.n3>
where {:Person owl:equivalentClass ?C}
```
[Filename: RDF/union-list.sparql]

- jena -q -pellet -qf union-list.sparql: both are equivalent.

```
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <foo://bla/>
select ?P1 ?P2 ?X ?Q ?R ?S ?T
from <file:union-list.n3>
where {{:Person owl:equivalentClass :EqToPerson} UNION
  {:Person ?P1 ?X . ?X ?Q ?R . OPTIONAL {?R ?S ?T}} UNION
  {:EqToPerson ?P2 ?X . ?X ?Q ?R} . OPTIONAL {?R ?S ?T}}
```
[Filename: RDF/union-list2.sparql]

- both have actually the same list structure
  (pellet2/nov 2008: fails; pellet 2.3/sept 2009: fails)

REASONING OVER LISTS (PITFALLS!)

- rdf:first and rdf:rest are (partially) ignored for reasoning (at least by pellet?); they cannot be used for deriving other properties from it.
- they can even not be used in queries (since pellet2/nov 2008; before it just showed weird behavior)

```
prefix rdf:
<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix : <foo://bla/>
select ?X ?Y ?Z
from <file:union-list.n3>
where {?X a rdf:List; rdf:first ?Y .
       OPTIONAL {?X rdf:rest ?Z}}
```

[Filename: RDF/union-list3.sparql]

- jena-tool with pellet2.3: OK.
- pellet2.3: NullPointerException.

Extension of a class defined by a list

Given an RDF list as below, define an owl:Class :Invited which contains exactly the elements in the list (i.e., in the above sample data, :alice, :bob, :carol, :dave).

```
@prefix : <foo:bla#>.
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
# Problem: when the real rdf namespace is used, rdf:first/rest are ignored
@prefix rdfL: <http://www.w3.org/1999/02/22-rdf-syntax-nsL#>.    # <<<<<<<<<<<<<
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.

:Invited a owl:Class.
:InvitationList rdfs:subClassOf rdfL:List.
:list1 a :InvitationList; rdfL:first :alice;
  rdfL:rest [a rdfL:List; rdfL:first :bob;
    rdfL:rest [a rdfL:List; rdfL:first :carol;
      rdfL:rest [a rdfL:List; rdfL:first :dave; rdfL:rest rdf:nil]]].

# rest of an InvitationList is also an InvitationList
:InvitationList owl:equivalentClass
  [a owl:Restriction;
    owl:onProperty rdfL:rest; owl:allValuesFrom :InvitationList],
  [ a owl:Restriction;
    owl:onProperty rdfL:first; owl:allValuesFrom :Invited].
```

[Filename: RDF/invitation-list.n3]

```
prefix : <foo:bla#>
select ?I
from <file:invitation-list.n3>
where {?I a :Invited}
```

[Filename: RDF/invitation-list.sparql]

7.4 Nominals: The O in SHOIQ

TBox vs. ABox

DL makes a clean separation between TBox and ABox vocabulary:

- TBox: RDFS/OWL vocabulary for information about classes and properties (further partitioned into definitions and axioms),
- ABox: Domain vocabulary and rdf:type.

RDFS/OWL allows to mix everything in a set of triples.

Nominals

- use individuals (that usually occur only in the ABox) in the TBox:
- as individuals :Italy (that are often implemented in the reasoner as unary classes) with *property* owl:hasValue o
  (the class of all things such that {?x *property* o} holds).
- in enumerated classes *class* owl:oneOf ($o_1, \ldots, o_n$)
  (*class* is defined to be the set {$o_1, \ldots, o_n$}).

Difference to Reification

- Reification treats a class (e.g. :Penguin) or a property as an individual (:Penguin a :Species)
  - without reification, only specific RDFS and OWL properties are allowed for classes and properties only
  - reification assigns properties from an application domain to classes and properties.
- useful when talking about metadata notions,
- risk: allows for paradoxes

Using Nominals: Italian Cities

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix mon: <http://www.semwebtech.org/mondial/10/meta#>.
@prefix it: <foo://italian/>.
it:Italy owl:sameAs <http://www.semwebtech.org/mondial/10/countries/I/>.
it:ItalianProvince owl:intersectionOf
  (mon:Province
   [a owl:Restriction; owl:onProperty mon:isProvinceOf;
    owl:hasValue it:Italy]).        # Nominal: an individual in a TBox axiom
it:ItalianCity owl:intersectionOf
  (mon:City
   [a owl:Restriction;
    owl:onProperty mon:belongsTo;
    owl:someValuesFrom it:ItalianProvince]).
```

[Filename: RDF/italiancities.n3]

```
prefix it: <foo://italian/>
select ?X
from <file:mondial-meta.n3>
from <file:mondial-europe.n3>
from <file:italiancities.n3>
where {?X a it:ItalianCity}
```

[Filename: RDF/italiancities.sparql]

An Ontology in OWL

Consider the Italian-English-Ontology from Slide 52.

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix f: <foo://bla/>.
f:Italian rdfs:subClassOf f:Person;
  owl:disjointWith f:English;
  owl:unionOf (f:Lazy f:LatinLover).
f:Lazy owl:disjointWith f:LatinLover.
f:English rdfs:subClassOf f:Person.
f:Gentleman rdfs:subClassOf f:English.
f:Hooligan rdfs:subClassOf f:English.
f:LatinLover rdfs:subClassOf f:Gentleman.
```

[Filename: RDF/italian-english.n3]

Class tree with jena -e:

```
owl:Thing
   bla:Person
      bla:English
         bla:Hooligan
         bla:Gentleman
      bla:Italian = bla:Lazy
owl:Nothing = bla:LatinLover
```

- LatinLover is empty, thus Italian ≡ Lazy.

Italians and Englishmen (Cont'd)

- the conclusions apply to the instance level:

```
@prefix : <foo://bla/>.
:mario a :Italian.
```

[Filename: RDF/mario.n3]

```
prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
prefix : <foo://bla/>
select ?C
from <file:italian-english.n3>
from <file:mario.n3>
where {:mario rdf:type ?C}
```

[Filename: RDF/italian-english.sparql]

AN ONTOLOGY IN OWL

Consider the Italian-Ontology from Slide 53.

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix it: <foo://italian/>.
it:Bolzano owl:sameAs
<http://www.semwebtech.org/mondial/10/countries/I/provinces/TrentinoAltoAdige/cities/Bolzano/>
it:Italian owl:intersectionOf
  (it:Person
   [a owl:Restriction; owl:onProperty it:livesIn;
    owl:someValuesFrom it:ItalianCity]);
  owl:unionOf (it:Lazy it:Mafioso it:LatinLover).
it:Professor rdfs:subClassOf it:Person.
it:Lazy owl:disjointWith it:ItalianProf;
   owl:disjointWith it:Mafioso;
   owl:disjointWith it:LatinLover.
it:Mafioso owl:disjointWith it:ItalianProf;
   owl:disjointWith it:LatinLover.
it:ItalianProf owl:intersectionOf (it:Italian it:Professor).
it:enrico a it:Professor; it:livesIn it:Bolzano.
```

[Filename: RDF/italian-prof.n3]

```
prefix : <foo://italian/>
select ?C
from <file:italian-prof.n3>
from <file:mondial-meta.n3>
from <file:mondial-europe.n3>
from <file:italiancities.n3>
where {:enrico a ?C}
```

[Filename: RDF/italian-prof.sparql]

ENUMERATED CLASSES: ONEOF

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix mon: <http://www.semwebtech.org/mondial/10/meta#>.
<bla:MontanunionMembers> owl:intersectionOf
 (mon:Country
  [owl:oneOf
   (<http://www.semwebtech.org/mondial/10/countries/NL/>
    <http://www.semwebtech.org/mondial/10/countries/B/>
    <http://www.semwebtech.org/mondial/10/countries/L/>
    <http://www.semwebtech.org/mondial/10/countries/F/>
    <http://www.semwebtech.org/mondial/10/countries/I/>
    <http://www.semwebtech.org/mondial/10/countries/D/>)]).
<bla:Result> owl:intersectionOf (mon:Organization
  [a owl:Restriction; owl:onProperty mon:hasMember;
   owl:someValuesFrom <bla:MontanunionMembers>]).
```

[Filename: RDF/montanunion.n3]

```
select ?X
from <file:montanunion.n3>
from <file:mondial-europe.n3>
from <file:mondial-meta.n3>
where {?X a <bla:Result>}
```

[RDF/montanunion.sparql]

- Query: all organizations that share a member with the Montanunion.

oneOf (Example Cont'd)

- previous example: "all organizations that share a member with the Montanunion."
  (DL: $x \in \exists$hasMember.MontanunionMembers)
- "all organizations where *all* members are also members of the Montanunion."
  (DL: $x \in \forall$hasMember.MontanunionMembers)
- The result is empty (although there is e.g. BeNeLux) due to open world: it is not known whether there may exist additional members of e.g. BeNeLux.
- Only if the membership of Benelux is "closed", results can be proven:

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix mon: <http://www.semwebtech.org/mondial/10/meta#>.
<http://www.semwebtech.org/mondial/10/organizations/Benelux/>
 a [a owl:Restriction;
     owl:onProperty mon:hasMember; owl:cardinality 3].
<bla:SubsetOfMU> owl:intersectionOf (mon:Organization
  [a owl:Restriction; owl:onProperty mon:hasMember;
     owl:allValuesFrom <bla:MontanunionMembers>]).
mon:name a owl:FunctionalProperty. # not yet given in th
```

[Filename: RDF/montanunion2.n3]

```
select ?X
from <file:montanunion.n3>
from <file:montanunion2.n3>
from <file:mondial-europe.n3>
from <file:mondial-meta.n3>
where {?X a <bla:SubsetOfMU>}
```

[RDF/montanunion2.sparql]

oneOf (Example Cont'd)

- "all organizations that cover *all* members of the Montanunion."

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix mon: <http://www.semwebtech.org/mondial/10/meta#>.
<bla:EUMembers> owl:equivalentClass  [a owl:Restriction;
    owl:onProperty mon:isMember; owl:hasValue
    <http://www.semwebtech.org/mondial/10/organizations/EU/>].
```

[Filename: RDF/montanunion3.n3]

```
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
select ?X # ?Y ?Z
from <file:montanunion.n3>
from <file:montanunion3.n3>
from <file:mondial-europe.n3>
from <file:mondial-meta.n3>
where {#{?Y a <bla:EUMembers>} UNION {?Z a <bla:MontanunionMembers>} UNION
       {<bla:MontanunionMembers> rdfs:subClassOf ?X}}
```

[RDF/montanunion3.sparql]

ONEOF (EXAMPLE CONT'D)

Previous example:

- only for one organization
- defined a class that contains all members of the organization
- not possible to define a *family of classes* – one class for each organization.
- this would require a *parameterized constructor*:
  "c_{org} is the set of all members of org"
  Second-Order Logic: each organization can be seen as a unary predicate (=set):
  $\forall Org : Org(c) \leftrightarrow$ hasMember(Org, c)
  or in F-Logic syntax: `C isa Org :- Org:organization[hasMember->C]`
  yields e.g.
  $I(eu) = \{germany, france, \ldots\}$,
  $I(nato) = \{usa, canada, germany, \ldots\}$
  Recall that "organization" itself is a predicate:
  $I(organization) = \{eu, nato, \ldots, \}$
  So we have again reification: organizations are both first-order-individuals and classes.

CONVENIENCE CONSTRUCT: OWL:ALLDIFFERENT

- owl:oneOf defines a class as a closed set;
- in owl:oneOf ($x_1, \ldots, x_n$), two items may be the same (open world),

owl:AllDifferent

- Triples of the form :a owl:differentFrom :b state that two individuals are different. For a database with n elements, one needs $(n-1)+(n-2)+\ldots+2+1 = \sum_{i=1..n} i = n \cdot (n+1)/2 = O(n^2)$ such statements.
- The –purely syntactical– convenience construct

  [a owl:AllDifferent; owl:members ($r_1\ r_2 \ldots r_n$)]

  provides a shorthand notation.
  - it is *immediately* translated into the set of all statements $\{r_i$ owl:differentFrom $r_j \mid i \neq j \in 1..n\}$
  - [a owl:AllDifferent; owl:members (...)] is to be understood as a (blank node) that acts as a *specification* that the listed things are different that does not actually exist in the model.

[SYNTAX] OWL:ALLDIFFERENT IN RDF/XML

```
<?xml version="1.0"?>
<rdf:RDF xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:f="foo://bla/"  xml:base="foo://bla/">
 <owl:Class rdf:about="Foo">
  <owl:equivalentClass> <owl:Class>
    <owl:oneOf rdf:parseType="Collection">
     <owl:Thing rdf:about="a"/>  <owl:Thing rdf:about="b"/>
     <owl:Thing rdf:about="c"/>  <owl:Thing rdf:about="d"/>
    </owl:oneOf>
   </owl:Class> </owl:equivalentClass>
 </owl:Class>
 <owl:AllDifferent>  <!-- use like a class, but is only a shorthand -->
    <owl:members rdf:parseType="Collection">
     <owl:Thing rdf:about="a"/>  <owl:Thing rdf:about="b"/>
     <owl:Thing rdf:about="c"/>  <owl:Thing rdf:about="d"/>
    </owl:members>
 </owl:AllDifferent>
 <owl:Thing rdf:about="a"> <owl:sameAs rdf:resource="b"/> </owl:Thing>
</rdf:RDF>
```

[Filename: RDF/alldiff.rdf]

```
prefix : <foo://bla/>
prefix owl:
  <http://www.w3.org/2002/07/owl#>
select ?X ?P ?P2 ?V
from <file:alldiff.rdf>
where {?X a owl:AllDifferent ;
       ?P [?P2 ?V]}
```

[Filename: RDF/alldiffxml.sparql]

- AllDifferent is only intended as a kind of command to the application to add all pairwise “different-from” statements, it does not actually introduce itself as triples:
- querying {?X a owl:AllDifferent} is actually not intended.

[SYNTAX] OWL:ALLDIFFERENT IN N3

Example:

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo://bla/>.
:Foo owl:equivalentClass [ owl:oneOf (:a :b :c :d) ].
# both the following syntaxes are equivalent and correct:
[ a owl:AllDifferent; owl:members (:a :b)].
[] a owl:AllDifferent; owl:members (:c :d).
:a owl:sameAs :b.
# :b owl:sameAs :d.
```

[Filename: RDF/alldiff.n3]

```
prefix : <foo://bla/>
select ?X ?Y
from <file:alldiff.n3>
where {?X a owl:AllDifferent ; ?P [?P2 ?V]}
```

[Filename: RDF/alldiff.sparql]

ONEOF: A TEST

- owl:oneOf defines a “closed set” (use with anonymous class; see below):
- note that in owl:oneOf ($x_1, \ldots, x_n$), two items may be the same (open world),
- optional owl:AllDifferent to guarantee that ($x_1, \ldots, x_n$) are pairwise distinct.

```
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo://bla/>.
:Person owl:equivalentClass [ owl:oneOf (:john :alice :bob) ].
# :john owl:sameAs :alice.  # to show that it is consistent that they are the same
[] a owl:AllDifferent; owl:members (:john :alice :bob).  # to guarantee distinctness
# :name a owl:FunctionalProperty.  # this also guarantees distinctness ;)
:john :name "John".
:alice :name "Alice".
:bob :name "Bob".
:d a :Person.
:d owl:differentFrom :john, :alice.
# :d owl:differentFrom :bob.   ### adding this makes the ontology inconsistent
```

[Filename: RDF/three.n3]

- Who is :d?

oneOf: a Test (cont'd)

Who is :d?

- check the class tree:
  bla:Person - (bla:bob, bla:alice, bla:d, bla:john)

- and ask it:

```
prefix : <foo://bla/>
select ?N
from <file:three.n3>
where {:d :name ?N}
```

  [Filename: RDF/three.sparql]
  The answer is ?N/“Bob”.