

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 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>)

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OWL NOTIONS

- Classes and Properties are nodes in an RDF model, their characteristics are specified by OWL properties.

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 by its subelements.
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 $C \sqsubseteq \neg D$)

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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 an owl:Restriction as subclass of another owl:Restriction, multiple such constraints can be defined.

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OWL NOTIONS (CONT'D)

OWL Property Axioms (Overview)

- atomic constructor: rdf:Property
- 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 238)

OWL Individual Axioms (Overview)

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

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FIRST-ORDER LOGIC EQUIVALENTS

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

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)	$n.P$	$\exists^{=n} y : P(x, y)$

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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, \dots, x_n)	$\bigwedge_{i \neq j} \{x_i\} \sqsubseteq \neg \{x_j\}$	$\bigwedge_{i \neq j} x_i \neq x_j$

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FIRST-ORDER LOGIC EQUIVALENTS (CONT'D)

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

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REPRESENTATION

- most OWL constructs have a straightforward representation in RDF/XML and N3.
- 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 $(x_1 \ x_2 \ \dots \ x_n)$
 - as RDF lists: `rdf:List`, `rdf:first`, `rdf:rest`

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USE OF THE JENA TOOL

- option “-t”: transform
`jena -t -pellet -if rdf-file .`
- option “-q”: query
`jena -q -pellet [-if rdf-input-file] -qf query-file .`
- option “-e”: export the class tree (available only when the pellet reasoner is activated).
Input is an RDF or OWL file:
`jena -e -pellet -if rdf-file.`
- [note: since Jan. 2008, the former [-il RDF/XML] for indicating RDF/XML vs N3 input can be omitted in most cases]

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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 -il RDF/XML -if paradox.rdf`
Outputs the same RDF facts in N3 without checking consistency.
- with reasoner:
`jena -t -inf -r pellet -il RDF/XML -if paradox.rdf`
reads the RDF file, creates a model (and checks consistency) and in this case reports that it is not consistent.

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EXAMPLE: UNION AND SUBCLASS; T-BOX REASONING

```
<?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]

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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]

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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.

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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_1 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 on C_2 .
- Thus, C_1 and C_2 are not equivalent.

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DISCUSSION: FORMAL NOTATION

The DL equivalent to the knowledge base (TBox) is

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

The First-Order Logic equivalent is

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

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

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.

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OWL:RESTRICTION – EXAMPLE

```
<?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>
```

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

[Filename: RDF/restriction.sparql]

[Filename: RDF/restriction.rdf]

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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:

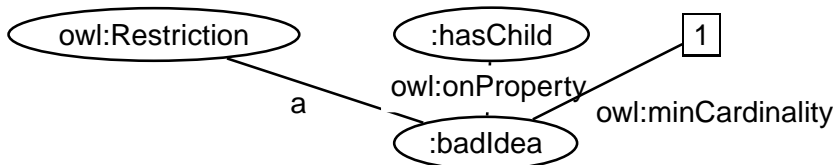
```
:badIdea owl:equivalentClass
  [a owl:Restriction; owl:onProperty :hasChild; owl:minCardinality 1].
```

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

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Restrictions Only as Blank Nodes (Cont'd)

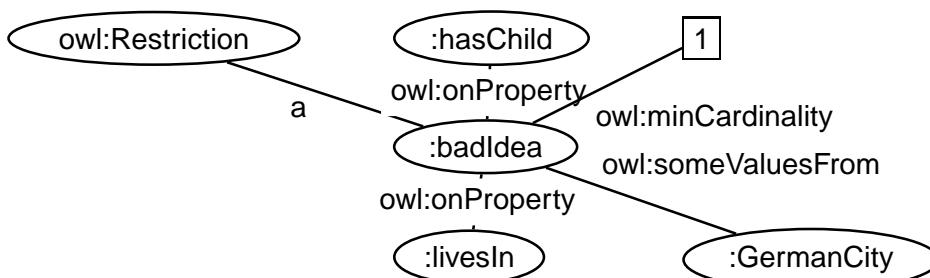
A class with two such specifications:



```
@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.

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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: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: $\text{TwoRestrictions} \equiv (\exists \text{hasChild}.\top) \sqcap (\exists \text{livesIn}.\text{GermanCity})$

Another reason:

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

... mixes the *definition* of the Restriction with an axiom; the meaning is unclear (and the outcome is up to the strategy of the Reasoner). Obviously, the designer intended to specify an intersection, but actually specified an assertive axiom.

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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 cardinality 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"].
```

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

[Filename: RDF/restriction-double.sparql]

[Filename: RDF/restriction-double.n3]

- The cardinality condition is ignored in this case (Result: John and Kate).
- Solution: intersection of restrictions

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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: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"].
```

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

[Filename: RDF/intersect-restrictions.n3]

- Note: this is different from Qualified Range Restrictions such as “All persons that have at least two male children” – see Slide 363.

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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]

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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 1.1
: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>                                     [Filename: RDF/union.sparql]
where {{?X rdf:type ?C} UNION {:Union1 owl:equivalentClass ?D}}

```

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NON-EXISTENCE OF A PROPERTY

```

@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]).

```

```

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

```

[Filename: RDF/childless.n3]

- 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!

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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.

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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 $\{?x \text{ property } o\}$ holds).
- in enumerated classes *class* `owl:oneOf (o1, . . . , on)` (*class* is defined to be the set $\{o_1, \dots, o_n\}$).

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

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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]
```

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AN ONTOLOGY IN OWL

Consider the Italian-English-Ontology from Slide 109.

```
@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:Latin Lover).
f:Lazy owl:disjointWith f:Latin Lover.
f:English rdfs:subClassOf f:Person.
f:Gentleman rdfs:subClassOf f:English.
f:Hooligan rdfs:subClassOf f:English.
f:Latin Lover 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:Latin Lover
```

- Latin Lover is empty, thus Italian \equiv Lazy.

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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]

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AN ONTOLOGY IN OWL

Consider the Italian-Ontology from Slide 110.

```
@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.
```

```
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]

[Filename: RDF/italian-prof.n3]

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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#>.
```

```
mon:Montanunion 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 mon:Montanunion]).
```

```
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.
- Note: with owl:allValuesFrom (all organizations that are subsets of the Montanunion) 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.

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CONVENIENCE CONSTRUCT: OWL:ALLDIFFERENT

- owl:oneOf defines a class as a closed set;
- in owl:oneOf (x_1, \dots, 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 $(n-1) + (n-2) + \dots + 2 + 1 = \sum_{i=1..n} i = n \cdot (n+1)/2 = O(n^2)$ such statements.
- The –purely syntactical– convenience construct

`owl:AllDifferent owl:distinctMembers ($r_1 r_2 \dots r_n$)`

provides a shorthand notation.

- it is *immediately* translated into the set of all statements

$\{r_i \text{ owl:differentFrom } r_j \mid i \neq j \in 1..n\}$

- owl:AllDifferent is a special constant (in RDF/XML used like a class, in N3 used like an individual) that does not actually exist in the model.

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[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:abo
        <owl:Thing rdf:about="c"/> <owl:Thing rdf:abo
      </owl:oneOf>
    </owl:Class> </owl:equivalentClass>
  </owl:Class>
  <owl:AllDifferent> <!-- use like a class, but is only a shorthand -->
    <owl:distinctMembers rdf:parseType="Collection">
      <owl:Thing rdf:about="a"/> <owl:Thing rdf:about="b"/>
      <owl:Thing rdf:about="c"/> <owl:Thing rdf:about="d"/>
    </owl:distinctMembers>
  </owl:AllDifferent>
  <!-- <owl:Thing rdf:about="a"> <owl:sameAs rdf:resource="b"/> </owl:Thing-->
</rdf:RDF>
```

```
prefix : <foo://bla/>
prefix owl:
  <http://www.w3.org/2002/07/owl#>
select ?X ?Y
from <file:alldiff.rdf>
where {{?X a :Foo} UNION
      {?Y a owl:AllDifferent}}
```

[Filename: RDF/alldiffxml.sparql]

[Filename: RDF/alldiff.rdf]

- <owl:AllDifferent> is just syntactical sugar,
- nevertheless, “_b0” is seen as an instance of owl:AllDifferent.

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[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) ].
owl:AllDifferent owl:distinctMembers (:a :b). ## Correct use
  ## owl:AllDifferent owl:distinctMembers MUST ONLY BE USED TOGETHER IN THIS WAY
:DontDoThis owl:equivalentClass
  [ a owl:AllDifferent; owl:distinctMembers (:c :d) ]. ### Wrong Use !
# :a owl:sameAs :b.
:c owl:sameAs :d. ## nevertheless, this is recognized to be inconsistent
```

[Filename: RDF/alldiff.n3]

```
prefix : <foo://bla/>
select ?X ?Y
from <file:alldiff.n3>
where {{?X a :Person} UNION {?Y a :DontDoThis}} [Filename: RDF/alldiff.sparql]
```

- DontDoThis is empty; nevertheless, the owl:distinctMembers is understood.

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ONEOF: A TEST

- owl:oneOf defines a “closed set” (use with anonymous class; see below):
- note that in owl:oneOf (x_1, \dots, x_n), two items may be the same (open world),
- optional owl:AllDifferent to guarantee that (x_1, \dots, 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
# owl:AllDifferent owl:distinctMembers (: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; owl:differentFrom :alice.
# :d owl:differentFrom :bob. ### adding this makes the ontology inconsistent
```

[Filename: RDF/three.n3]

- Who is :d?

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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”.

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ANSWER SETS TO QUERIES AS AD-HOC CONCEPTS

- all organizations whose headquarter city is a capital:

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@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]).
<bla:Result> 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]
```

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HOW TO DEAL WITH OWL:ALLVALUESFROM IN AN OPEN WORLD?

- “forall items” is only applicable if additional items can be excluded (\Rightarrow locally closed predicate/property),
- often, RDF data is generated from a database,
- certain predicates can be closed by defining restriction classes with maxCardinality.

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OWL:ALLVALUESFROM

```

@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix : <foo://bla/names#>.
[ a :Male; a :threeChildrenParent; :name "John";
  :child [a :Female; :name "Alice"], [a :Male; :name "Bob"],
         [a :Female; :name "Carol"]].
[ a :Female; a :twoChildrenParent; :name "Sue";
  :child [a :Female; :name "Anne";], [a :Female; :name "Barbara"]].
:name a owl:FunctionalProperty.
:oneChildParent owl:equivalentClass [a owl:Restriction;
  owl:onProperty :child; owl:cardinality 1].
:twoChildrenParent owl:equivalentClass [a owl:Restriction;
  owl:onProperty :child; owl:cardinality 2].
:threeChildrenParent owl:equivalentClass [a owl:Restriction;
  owl:onProperty :child; owl:cardinality 3].
:onlyFemaleChildrenParent owl:equivalentClass [a owl:Restriction;
  owl:onProperty :child; owl:allValuesFrom :Female].

```

```

prefix : <foo://bla/names#>
select ?N
from <file:allvaluesfrom.n3>
where {?X :name ?N .
       ?X a :onlyFemaleChildrenParent}

```

[Filename: RDF/allvaluesfrom.n3]

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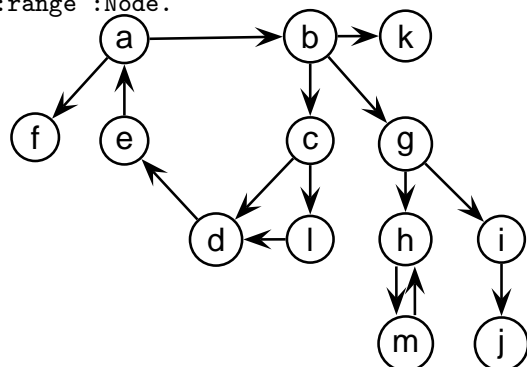
EXAMPLE: WIN-MOVE-GAME IN OWL

```

@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/>.

:Node a owl:Class; owl:equivalentClass
  [ a owl:Class; owl:oneOf (:a :b :c :d :e :f :g :h :i :j :k :l :m)].
:edge a owl:ObjectProperty; rdfs:domain :Node; rdfs:range :Node.
:out a owl:DatatypeProperty.
:a a :Node; :out 2; :edge :b, :f.
:b a :Node; :out 3; :edge :c, :g, :k.
:c a :Node; :out 2; :edge :d, :l.
:d a :Node; :out 1; :edge :e.
:e a :Node; :out 1; :edge :a.
:f a :Node; :out 0.
:g a :Node; :out 2; :edge :i, :h.
:h a :Node; :out 1; :edge :m.
:i a :Node; :out 1; :edge :j.
:j a :Node; :out 0.
:k a :Node; :out 0.
:l a :Node; :out 1; :edge :d.
:m a :Node; :out 1; :edge :h.

```



[Filename: RDF/winmove-graph.n3]

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Win-Move-Game in OWL – the Game Axioms

“If a player cannot move, he loses.”

Which nodes are WinNodes, which one are LoseNodes (i.e., the player who has to move wins/loses)?

- if a player can move to some LoseNode (for the other), he will win.
- if a player can move only to WinNodes (for the other), he will lose.
- recall that there can be nodes that are neither WinNodes nor LoseNodes.

```
@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/>.

:WinNode a owl:Class; owl:intersectionOf ( :Node
  [a owl:Restriction; owl:onProperty :edge; owl:someValuesFrom :LoseNode]).
:LoseNode a owl:Class; owl:intersectionOf ( :Node
  [a owl:Restriction; owl:onProperty :edge; owl:allValuesFrom :WinNode]).
```

[Filename: RDF/winmove-axioms.n3]

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Win-Move-Game in OWL – Closure

```
@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/>.

:DeadEndNode a owl:Class; rdfs:subClassOf :Node;
  owl:equivalentClass [ a owl:Restriction; owl:onProperty :out; owl:hasValue 0 ],
    [ a owl:Restriction; owl:onProperty :edge; owl:cardinality 0 ].
:OneExitNode a owl:Class; rdfs:subClassOf :Node;
  owl:equivalentClass [ a owl:Restriction; owl:onProperty :out; owl:hasValue 1 ],
    [ a owl:Restriction; owl:onProperty :edge; owl:cardinality 1 ].
:TwoExitsNode a owl:Class; rdfs:subClassOf :Node;
  owl:equivalentClass [ a owl:Restriction; owl:onProperty :out; owl:hasValue 2 ],
    [ a owl:Restriction; owl:onProperty :edge; owl:cardinality 2 ].
:ThreeExitsNode a owl:Class; rdfs:subClassOf :Node;
  owl:equivalentClass [ a owl:Restriction; owl:onProperty :out; owl:hasValue 3 ],
    [ a owl:Restriction; owl:onProperty :edge; owl:cardinality 3 ].
```

[Filename: RDF/winmove-closure.n3]

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Win-Move-Game in OWL: DeadEndNodes

Prove that DeadEndNodes are LoseNodes:

- obvious: Player cannot move from there
- exercise: give a formal (Tableau) proof
- The OWL Reasoner does it:

```
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
prefix : <foo://bla/>
select ?X
from <file:winmove-axioms.n3>
from <file:winmove-closure.n3>
where { :DeadEndNode rdfs:subClassOf :LoseNode }
```

[Filename: RDF/deadendnodes.sparql]

The answer contains an (empty) tuple which means “yes”.

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Win-Move-Game in OWL

```
prefix : <foo://bla/>
select ?W ?L ?D
from <file:winmove-graph.n3>
from <file:winmove-axioms.n3>
from <file:winmove-closure.n3>
where { { ?W a :WinNode } UNION
        { ?L a :LoseNode } }
```

[Filename: RDF/winmove.sparql]

Exercise

- Is it possible to characterize DrawNodes in OWL?

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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).

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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]

```
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]
```

- jena -q -qf union-list2.n3: both have the list structure and they are equivalent.

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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.

```
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-list3a.sparql]

```
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 rdf:first ?Y .
      OPTIONAL {?X rdf:rest ?Z}}
```

[Filename: RDF/union-list3b.sparql]

- 3a yields four answers (as expected), 3b only two.
- the (...) list is not recognized to be an `rdf:List` (although it has the `rdf:first` and `rdf:rest` structure).

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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 namespace is changed to the real rdf ns, 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/lists.n3]

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

[Filename: RDF/lists.sparql]

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DATATYPES: HASVALUE WITH LITERAL VALUE

Characterize a class as the set of all things where a given property has a given value:

- all things in Mondial that have the name "Berlin":

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
@prefix mon: <http://www.semwebtech.org/mondial/10/meta#>.
@prefix : <foo:bla#>.
:Berlin owl:equivalentClass [ a owl:Restriction;
    owl:onProperty mon:name; owl:hasValue "Berlin"]. [Filename: RDF/has-literal-value.n3]
```

```
prefix : <foo:bla#>
select ?X
from <file:has-literal-value.n3>
from <file:mondial-europe.n3>
where {?X a :Berlin}
```

[Filename: RDF/has-literal-value.sparql]

- Often preferable: define an owl:DataRange (unary or enumeration), give it a url, and use some/allValuesFrom.

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DATATYPES

- it also accepts non-existing datatypes:

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix : <foo://bla#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
:john rdf:type :Person; :name "John";
    :age "35"^^xsd:integer, "35"^^xsd:bla.
```

[Filename: RDF/datatype-casting.n3]

- use jena -t for transform.

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DATATYPES: ... DECIMAL DOES NOT YET WORK

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
@prefix : <foo:bla#>.
:value a owl:FunctionalProperty; a owl:DatatypeProperty;
      rdfs:range xsd:decimal.
## OK: then it complains about more than one value:
#:foo :value "2"^^xsd:decimal; :value "1"^^xsd:decimal.
#next two cases: does not complain and returns three values:
:foo :value "2"^^xsd:decimal; :value "1.0"^^xsd:decimal.
:foo :value "2"^^xsd:decimal; :value "2.3"^^xsd:decimal.
## only when adding this it complains about more than one value:
#:foo :value "2.3E13"^^xsd:decimal.
```

```
prefix : <foo:bla#>
select ?X ?Y
from <file:decimal.n3>
where {?X :value ?Y}
[Filename: RDF/decimal.sparql]
```

```
[Filename: RDF/decimal.n3]
```

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INVERSEFUNCTIONALPROPERTY

- simple idea: if the inverse of a property is functional:
 xpy is inverse-functional, if for every y , there is at most one x such that xpy holds:
 - hasCarCode is functional: every country has one car code,
 - hasCarCode is also inverse functional: every car code uniquely identifies a country.
- would just be syntactical sugar (often even unintuitive),
- **can only be done if the inverse can be defined exists.**
- for DatatypeProperties, no inverse can be defined (it would have the datatype as domain)

```
@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;
      owl:inverseOf :isCarCodeOf.
:Germany :carCode "D".
```

```
[Filename: RDF/noinverse.n3]
```

- the specification is detected to be invalid.

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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.