INFO216:
Knowledge Graphs

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Session S05: RDF Schema (RDFS)

- Themes:
  - *why RDFS?*
  - *utility properties*
  - *classes and subclasses*
  - *properties and subproperties*
  - *entailments and axioms*
  - *overview*
  - *motivation for OWL*

Readings

- Allemang & Hendler (2011):
  Semantic Web for the Working Ontologist.
  - chapters 6 and 7
- Electronic materials in the wiki:
  - wiki.uib.no/info216

RDF Schema (RDFS)

From RDF to RDFS

- RDF is a good start
  - excellent normal form for facts about individuals
  - less suitable for complex concept systems
    - e.g., vocabularies, ontologies
- RDF Schema (RDFS):
  - small RDF vocabulary for more expressive graphs
    - in particular for defining other vocabularies
  - many vocabularies defined in plain RDFS
    - also the foundation for SKOS, OWL and OWL2
  - conventional prefix:
    - rdfs: http://www.w3.org/2000/01/rdf-schema#

Why RDF Schema (RDFS)

- *More expressive RDF graphs*, for example:
  - more specific types of resources
  - more specific types of predicates
  - which types of resources are the subjects and objects of which properties?
  - predefined *axioms*
  - data sets can *entail* additional triples (*inference*)
- *RDFS is expressed in RDF*
  - a small extension of the basic RDF vocabulary
  - RDF tools can be used on RDFS
    - ...but the semantics may get lost if inference is not supported

Schema-like stuff in RDF

- Some schema-like stuff in plain RDF too:
  - instances: rdf:type, rdf:Property
  - collections: rdf:List rdf:first rdf:rest rdf:nil
  - reified triples: rdf:subject, …, rdf:Statement
  - rdf:value
  - containers:
    - rdf:Alt rdf:Bag rdf:Seq
      - subclasses of rdfs:Container
    - rdf:_1 rdf:_2 ...
      - subclasses of rdfs:member
      - instances of rdfs:ContainerMembershipProperty

Utility properties in RDFS

- *Straightforward and much used:*
  - rdfs:label:
    - a human-readable label
  - rdfs:comment:
    - a human-readable comment
  - rdfs:seeAlso:
    - reference to further information
  - rdfs:isDefinedBy:
    - a human-readable definition
    - is a rdfs:subPropertyOf rdfs:seeAlso

...often take "language-tagged"@en strings as objects

Resource classes (categories, types...)

- Classes are resources that represent a type of similar resources, which are the individuals in the class
  - e.g., dbpedia:Person, schema:Person, foaf:Person
  - belonging to a class is expressed by rdf:type:
    <RDF individual> rdf:type <RDFS class> .
    <RDF individual> a <RDFS class> .
  - an individual can belong to several classes (usually!)
  - an RDFS class is defined as a resource that is the object of an rdf:type predicate *(→ entailment)*
  - every RDFS class has rdf:type rdfs:Class
- *By convention, classes are named with an upper-case initial letter, properties with lower-case initial letters...*

Resource classes (categories, types...)

- Why resource classes?
  - the type (class) of a resource is an important part of its semantics
  - we can describe the class further
    - as natural-language text
    - formally using RDFS and OWL DL
  - knowing the type (class) of a resource often means we can infer additional information about it (entailment)
  - classes are important for defining and using other RDFS concepts

Not (quite) like object-oriented programming

- *Typical* OOP:
  - classes are templates for instantiating objects
  - objects with fixed class
  - adding a property restricts a class
  - property encapsulation
  - property overriding
  - local value ranges:
    "Tigers only have parents that are Tigers and Humans only have parents that are Humans"
- RDFS *is different*:
  - the properties of a resource determines its class
  - resources change class
  - adding a property enriches a resource
  - global visibility
  - no property overriding
  - no local value ranges
    (but you can use subproperties or use RDFS along with a rule language)

Subclasses (rdfs:subClassOf)

- Whenever an individual resource belongs to some class, it necessarily belongs to another class too, e.g.,
  - dbpedia:Physician rdfs:subClassOf dbpedia:Person .
- Why subclasses?
  - arranging classes in subclass hierarchies makes their semantics more precise!
  - subclasses facilitate more complete query answering
  - knowing the type of a resource often means we can infer additional information about it (entailment)
  - subclasses are important because different vocabularies may define overlapping, but not identical, classes
    - introduce a new class in the merged data set
    - make the old classes subclasses of the new class

RDFS entailment

- The meaning of rdfs:subClassOf and the other RDFS concepts is defined by *entailment rules...*
- Example: classical *syllogism:*
  - *"All men are mortal."* *(Major Premise)*
  - *"Socrates is a man."* *(Minor Premise)*
  - *"Socrates is a mortal."* *(Valid conclusion)*

RDFS entailment

- The meaning of rdfs:subClassOf and the other RDFS concepts is defined by *entailment rules...*
- Example: classical *syllogism* in RDFS:
  - *ex:Man rdfs:SubclassOf ex:Mortal .* *(Major Premise)*
  - *ex:Socrates rdf:type ex:Man .* *(Minor Premise)*
  - *ex:Socrates rdf:type ex:Mortal .* *(Valid conclusion)*

Entailment means that *some triples are there in our RDFS models even when we have not asserted them*

RDFS entailment

- The meaning of rdfs:subClassOf and the other RDFS concepts is defined by *entailment rules...*
- Example: *pattern* for classical syllogism in RDFS:
  - *?c1 rdfs:SubclassOf ?c2 .* *(Major Premise)*
  - *?s rdf:type ?c1 .* *(Minor Premise)*
  - *?s rdf:type ?c2 .* *(Valid conclusion)*

Entailment means that *some triples are there in our RDFS models even when we have not asserted them*

This rule is built into all RDFS models!

RDFS entailment [rdfs9]

- The meaning of rdfs:subClassOf and the other RDFS concepts is defined by *entailment rules* [rdfs9]:
- "The triples ?s rdf:type ?c1 .
  ?c1 rdfs:subClassOf ?c2 .
  entail that ?s rdf:type ?c2 ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?s rdf:type ?c2 .
} WHERE {
        ?s rdf:type ?c1 .
        ?c1 rdfs:subClassOf ?c2 .
}
```

Here, we express the rule using SPARQL.

Writing rules like this in RDF and TURTLE is called SPIN (SPARQL Inferencing Notation).

(Internally, RDFS does not *really* use SPARQL/SPIN).

What does entailment mean?

- Entailment means that *some triples are there in our RDFS models even when we have not asserted them*
  - full list at http://www.w3.org/TR/rdf-mt/
  - around 30 entailment rules in RDFS
- *Different RDFS tools may support entailment rules in different ways*, e.g.:
  - strategy 1: always add entailed triples when possible
  - strategy 2: only extract entailed triples when needed
  - with RDFLib you can use *RDFSClosure* in the *OWL-RL* package for this:
    - https://github.com/RDFLib/OWL-RL
    - https://owl-rl.readthedocs.io/en/latest/owlrl.html

Transitive properties

- rdfs:subClassOf is *transitive*:
  - ex:Dolphins rdfs:subClassOf ex:Whales .
  - ex:Whales rdfs:subClassOf ex:Mammals .
  - ex:Dolphins rdfs:subClassOf ex:Mammals .
- Entails new rdf:type triples about which classes an individual belongs to

Transitive properties

- rdfs:subClassOf is *transitive*:
  - ?c1 rdfs:subClassOf ?c2 .
  - ?c2 rdfs:subClassOf ?c3 .
  - ---
  - ?c1 rdfs:subClassOf ?c3 .
- Entails new rdf:type triples about which classes an individual belongs to

RDFS entailment [rdfs11]

- rdfs:subClassOf is *transitive*:
- "The triples ?c1 rdfs:subClassOf ?c2 .
  ?c2 rdfs:subClassOf ?c3 .
  entail that ?c1 rdfs:subClassOf ?c3 ."

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

INSERT {
        ?c1 rdfs:subClassOf ?c3 .
} WHERE {
        ?c1 rdfs:subClassOf ?c2 .
        ?c2 rdfs:subClassOf ?c3 .
}
```

RDFS entailment [rdfs10]

- rdfs:subClassOf is also *reflexive*:
- "The triple ?c rdf:type rdfs:Class .
  entails that ?c rdfs:subClassOf ?c ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?c rdfs:subClassOf ?c .
} WHERE {
        ?c rdf:type rdfs:Class .
}
```

Properties

- All predicates have *rdf:type rdf:Property*
  - this is expressed by an *entailment (next slide!)*
  - properties have *domains* and *ranges*, i.e., their subjects and objects belong to particular classes
  - properties can be *transitive*
- Why properties?
  - needed in RDF (along with rdf:type) to express that only certain resources act as predicates in triples
  - as for classes/subclasses:
    - clearer semantics, entailment, complete answers to queries and defining other concepts*, e.g.,*
    - *most classes are defined by their properties...*

RDF entailment [rdf1]

- "The triple ?s ?p ?o .
  entails that ?p rdf:type rdf:Property ."

```
PREFIX rdf: <...>

INSERT {
        ?p rdf:type rdf:Property .
} WHERE {
        ?s ?p ?o .
}
```

- Resources *become properties* by being used as predicates in triples!

Domain and range of properties

- The subjects and objects that occur in triples along with some property belong to certain classes
- Example:
  - *<subject>* ex:hasPassportNumber *<object>* .
  - when we see this triple, we know that:
    - the *<subject>* has rdf:type ex:Person
    - the *<object>* has rdf:type ex:PassportNumber
  - this is part of the semantics of ex:hasPassportNumber
  - ...can be expressed as follows:
    - ex:hasPassportNumber rdfs:domain ex:Person .
    - ex:hasPassportNumber rdfs:range ex:PassportNumber .

RDFS entailment [rdfs2]

- “The triples ?s ?p ?o .
  ?p rdfs:domain ?t .
  entail that ?s rdf:type ?t .”

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?s rdf:type ?t .
} WHERE {
        ?s ?p ?o .
        ?p rdfs:domain ?t .
}
```

RDFS entailment [rdfs3]

- “The triples ?s ?p ?o .
  ?p rdfs:range ?t .
  entail that ?o rdf:type ?t .”

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?o rdf:type ?t .
} WHERE {
        ?s ?p ?o .
        ?p rdfs:range ?t .
}
```

RDFS axioms

- RDFS axioms:
  - triples that are “built into” RDFS
  - predefined in any RDFS graph
  - essential part of the semantics of RDFS
  - full list at http://www.w3.org/TR/rdf-mt/
  - 40 axioms and 3 axiom schemas
- Example axioms for *rdf:type*:
  - rdf:type rdfs:range rdfs:Class .
  - rdf:type rdfs:domain rdfs:Resource .

RDFS entailment [rdfs3]

- "The triples ?s ?p ?o .
  ?p rdfs:range ?t .
  entail that ?o rdf:type ?t ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?o rdf:type ?t .
} WHERE {
        ?s ?p ?o .
        ?p rdfs:range ?t .
}
```

Remember:
rdf:type rdfs:range rdfs:Class .
is an axiom in RDFS. This axiom fits straight into the rule:

?p = rdf:type
?t = rdfs:Class

RDFS entailment [rdfs3 + axiom]

- "The triples ?s rdf:type ?o .
  rdf:type rdfs:range rdfs:Class .
  entail that ?o rdf:type rdfs:Class ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?o rdf:type rdfs:Class .
} WHERE {
        ?s rdf:type ?o .
        rdf:type rdfs:range rdfs:Class .
}
```

Remember:
rdf:type rdfs:range rdfs:Class .
is an axiom in RDFS. This axiom fits straight into the rule!

This is an axiom in RDFS!

RDFS entailment

- "The triples ?s rdf:type ?o .
  ~~rdf:type rdfs:range rdfs:Class .~~
  entail that ?o rdf:type rdfs:Class ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?o rdf:type rdfs:Class .
} WHERE {
        ?s rdf:type ?o .
        rdf:type rdfs:range rdfs:Class .
}
```

Because
rdf:type rdfs:range rdfs:Class .
is an axiom in RDFS, this rule entails that every object in an rdf:type-triple is an RDFS class.

RDFS entailment

- "The triples ?s rdf:type ?o .
  entail that ?o rdf:type rdfs:Class ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?o rdf:type rdfs:Class .
} WHERE {
        ?s rdf:type ?o .
}
```

This rule entails that every object in an rdf:type-triple is an RDFS class.

It is not expressed explicitly in RDFS, but is always there in practice, because it is implied by the rule and the axiom we have just shown.

Subordinate properties (rdfs:subPropertyOf)

- Expresses that: whenever a subject resource and an object resource are related by a particular property, they are necessarily also related by another property, e.g.,
  - whenever this is a fact:
    dbpedia:Håkon_Opdahl ex:goalkeeperFor dbpedia:SK_Brann .
  - then this is necessarily also a fact:
    dbpedia:Håkon_Opdahl ex:playsFor dbpedia:SK_Brann .
  - *because* we have defined a *subproperty relationship*:
    ex:goalkeeperFor rdfs:subPropertyOf ex:playsFor .
- Is useful for connecting overlapping properties from distinct data sets, e.g.:
  - movie:actor_name, movie:film_name dc:name, rdfs:label
  - ...just like rdfs:subClassOf

RDFS entailment [rdfs7]

- "The triples ?s ?p1 ?o .
  ?p1 rdfs:subPropertyOf ?p2 .
  entail that ?s ?p2 ?o ."

```
PREFIX rdfs: <...>

INSERT {
        ?s ?p2 ?o .
} WHERE {
        ?s ?p1 ?o .
        ?p1 rdfs:subPropertyOf ?p2 .
}
```

RDFS entailment [rdfs5]

- rdfs:subPropertyOf is *transitive*:
- "The triples ?p1 rdfs:subPropertyOf ?p2 .
  ?p2 rdfs:subPropertyOf ?p3 .
  entail that ?p1 rdfs:subPropertyOf ?p3 ."

```
PREFIX rdfs: <...>

INSERT {
        ?p1 rdfs:subPropertyOf ?p3 .
} WHERE {
        ?p1 rdfs:subPropertyOf ?p2 .
        ?p2 rdfs:subPropertyOf ?p3 .
}
```

RDFS entailment [rdfs6]

- rdfs:subPropertyOf is *reflexive*:
- "The triple ?p rdf:type rdf:Property .
  entails that ?p rdfs:subPropertyOf ?p ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?p rdfs:subPropertyOf ?p .
} WHERE {
        ?p rdf:type rdf:Property .
}
```

Additional classes

- RDFS also defines rdfs;Class-es for:
  - resources: rdfs:Resource
    - the class of all resources
  - literals: rdfs:Literal
    - the class of all literals
    - rdfs:Literal rdfs:subClassOf rdfs:Resource .
  - datatypes: rdfs:Datatype
    - the class of all datatypes
    - rdfs:Datatype rdfs:subClassOf rdfs:Class .
  - all of them have rdf:type rdfs:Class
  - all of them have entailment rules and axioms

RDFS entailment [rdfs4a]

- *Every subject in a triple is a resource...*
- "The triple ?s ?p ?o .
  entails that ?s rdf:type rdfs:Resource ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?s rdf:type rdfs:Resource .
} WHERE {
        ?s ?p ?o .
}
```

RDFS entailment [rdfs4b]

- *...and every object too*
- "The triple ?s ?p ?o .
  entails that ?o rdf:type rdfs:Resource ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?o rdf:type rdfs:Resource .
} WHERE {
        ?s ?p ?o .
}
```

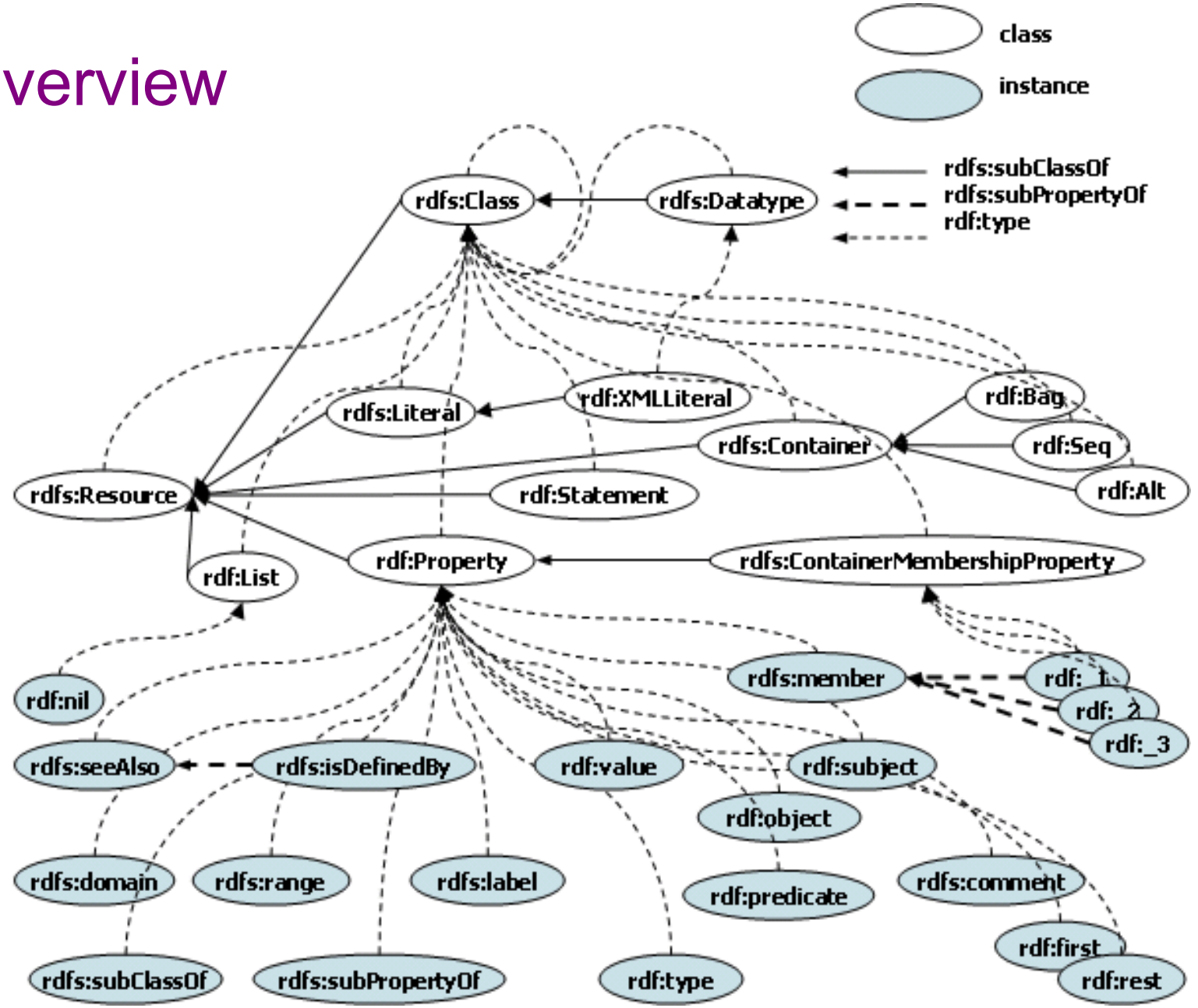
RDFS entailment [rdfs8]

- Every class corresponds to a set of resources.
  - ...or to a subset of the set of all resources.
- "The triple ?c rdf:type rdfs:Class .
  entails that ?c rdfs:subClassOf rdfs:Resource ."

```
PREFIX rdf: <...>
PREFIX rdfs: <...>

INSERT {
        ?c rdfs:subClassOf rdfs:Resource .
} WHERE {
        ?c rdf:type rdfs:Class .
}
```

Overview


class
instance
rdfs:subClassOf
rdfs:subPropertyOf
rdf:type
rdfs:Class
rdfs:Datatype
rdfs:Literal
rdf:XMLLiteral
rdf:Bag
rdfs:Container
rdf:Seq
rdf:Alt
rdfs:Resource
rdf:Statement
rdf:List
rdf:Property
rdfs:ContainerMembershipProperty
rdf:nil
rdfs:member
rdf:_1
rdf:_2
rdf:_3
rdfs:seeAlso
rdfs:isDefinedBy
rdf:value
rdf:subject
rdf:object
rdfs:domain
rdfs:range
rdfs:label
rdf:predicate
rdfs:comment
rdf:first
rdf:rest
rdfs:subClassOf
rdfs:subPropertyOf
rdf:type

Summary of resources and properties

- Resources:
  - rdfs:Class rdfs:Resource rdfs:Datatype rdfs:Literal
  - rdf:Property, rdf:XMLLiteral, rdf:HTML
  - rdfs:Container rdfs:ContainerMembershipProperty
  - rdf:Alt rdf:Bag rdf:Seq rdf:List rdf:Statement
- Properties:
  - rdfs:subClassOf rdfs:subPropertyOf
  - rdfs:domain rdfs:range
  - rdfs:comment rdfs:seeAlso rdfs:isDefinedBy rdfs:label
  - rdfs:member rdf:_1 rdf:_2 ...
  - rdf:first rdf:rest rdf:nil
  - rdf:subject rdf:predicate rdf:object
  - rdf:value

What we cannot express...

- RDFS has many limitations, e.g., it cannot say:
  - *"my ancestors' ancestors are also my ancestors"*
  - *"a Person has a unique birth number"*
  - *"a Person has exactly one father"*
  - *"a SoccerTeam has 11 players, but a BasketballTeam has 5"*
  - *"classes with different IRIs actually represent the same class"*
  - *"resources with different IRIs represent the same resource"*
  - *"properties with different IRIs are actually the same"*
  - *"two individuals with different IRIs are actually different"*
  - *"two classes cannot share individuals (they are disjoint)"*
  - *"a class is a combination (union or intersection) of other classes"*
  - *"a class is a negation of another class"*
- *Web Ontology Language (OWL) does all this and more!*