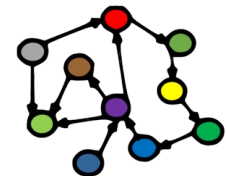


**Welcome to INF0216:
Knowledge Graphs
Spring 2022**

**Andreas L Opdahl
<Andreas.Opdahl@uib.no>**

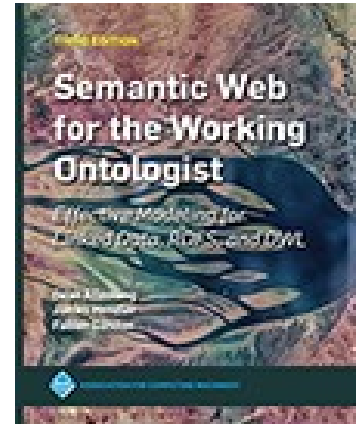
Session 7: Rules (RDFS)

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



Readings

- Sources:
 - **Allemang, Hendler & Gandler (2020):**
Semantic Web for the Working Ontologist, 3rd edition
(chapters 6-7)
 - **Blumauer & Nagy (2020):**
The Knowledge Graph Cookbook – Recipes that Work.
 - e.g., pages 101-106, 136-139
- Electronic materials in the wiki:
 - <http://wiki.uib.no/info216>
 - W3C's RDF Schema 1.1 (sections 1-3 and 6)

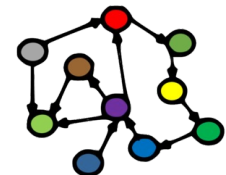


THE KNOWLEDGE GRAPH
COOKBOOK
RECIPES THAT WORK

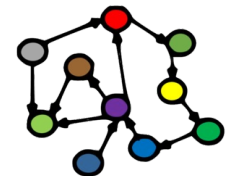


ANDREAS BLUMAUER
AND HELMUT NAGY

1st Edition, 2020

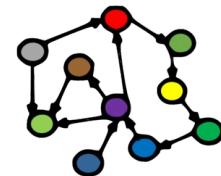


RDF Schema (RDFS)



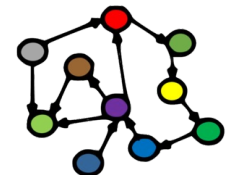
From RDF to RDFS

- 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#>



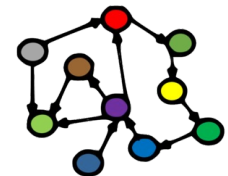
Why RDF Schema (RDFS)

- *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

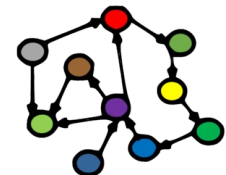
- Plain RDF contains some schema-like stuff too:
 - instances: `rdf:type`, `rdf:Property`
 - collections: `rdf:List` `rdf:first` `rdf:rest` `rdf:nil`
 - reified triples: `rdf:subject`, ..., `rdf:Statement`
 - `rdf:value`
 - containers:
 - `rdf:Alt` `rdf:Bag` `rdf:Seq`
 - subclasses of `rdfs:Container`
 - `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

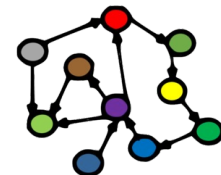


Resource classes (categories, types...)

- 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 (\rightarrow *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

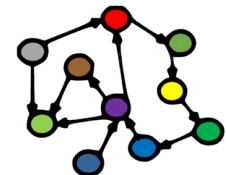


Not (quite) like object-oriented programming

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

Subclasses (rdfs:subClassOf)

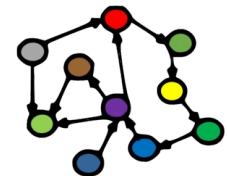
- Whenever an individual resource belongs to some class, it necessarily belongs to another class too, e.g.,
 - `dbpedia:Physician rdfs:subClassOf dbpedia:Person .`
- Why subclasses?
 - subclass hierarchies make the classes' semantics more precise!
 - subclasses facilitate more complete query answering
 - 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)

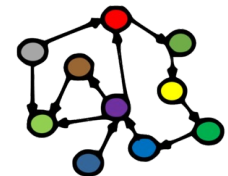


RDFS entailment

- 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*



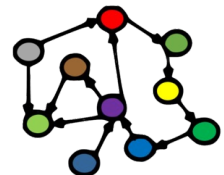
RDFS entailment

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

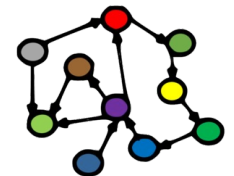
Here, we express the rule using SPARQL.

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?

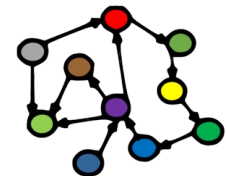
- Entailment means that *some triples are there in our RDFS graphs even when we have not asserted them*
 - full list at <http://www.w3.org/TR/rdf-mt/>
 - 14 entailment rules in RDFS (2 in RDF)
- *Different RDFS tools may support entailment rules in different ways*, e.g.:
 - strategy 1: always add entailed 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 .`

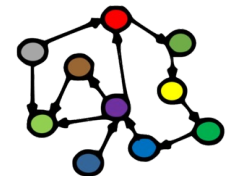
 - `ex:Dolphins rdfs:subClassOf ex:Mammals .`
- Entails new `rdf:type` triples about which classes an individual belongs to



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

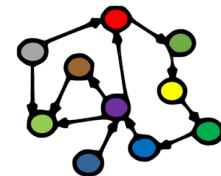


RDFS entailment [rdfs11]

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

PREFIX ...

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



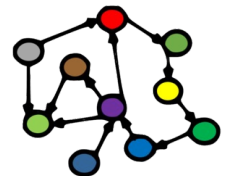
RDFS entailment [rdfs10]

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

PREFIX ...

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

- “Every class is its own subclass...”



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...*



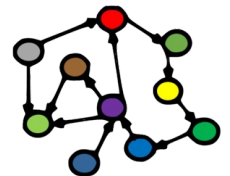
RDF entailment [rdf1]

- “The triple `?s ?p ?o .`
entails that `?p rdf:type rdf:Property .`”

PREFIX `rdf: <...>`

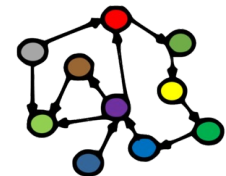
```
INSERT {  
    ?p rdf:type rdf:Property .  
} WHERE {  
    ?s ?p ?o .  
}
```

- 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 xsd:int
 - this is part of the semantics of ex:hasPassportNumber
 - ...can be expressed as follows:
 - ex:hasPassportNumber rdfs:domain ex:Person .
 - ex:hasPassportNumber rdfs:range xsd:int .



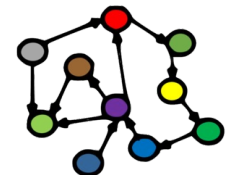
RDFS entailment [rdfs2]

- “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 .  
}
```



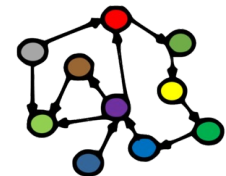
RDFS entailment [rdfs3]

- “The triples $?s ?p ?o .$
 $?p \text{ rdfs:range } ?t .$
entail that $?o \text{ rdf:type } ?t .$ ”

PREFIX rdf: <...>

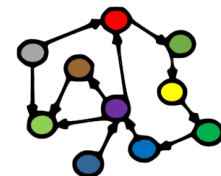
PREFIX rdfs: <...>

```
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: <...>
```

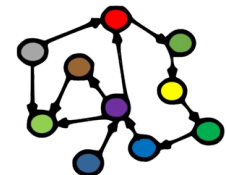
```
INSERT {  
    ?o rdf:type rdfs:Class .  
} WHERE {  
    ?s rdf:type ?o .  
}
```

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_Opdal ex:goalkeeperFor dbpedia:SK_Brann .
 - then this is necessarily also a fact:
dbpedia:Håkon_Opdal 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

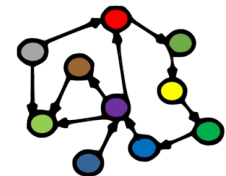


RDFS entailment [rdfs7]

- “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 .  
}
```

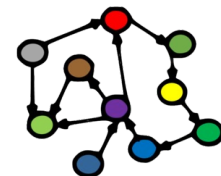


RDFS entailment [rdfs5]

- `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 .  
}
```



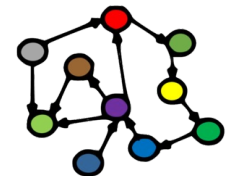
RDFS entailment [rdfs6]

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

PREFIX rdf: <...>

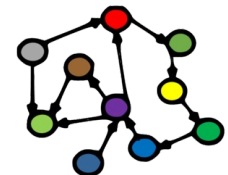
PREFIX rdfs: <...>

```
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



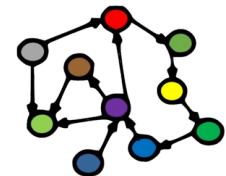
RDFS entailment [rdfs4a]

- *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 .  
}
```



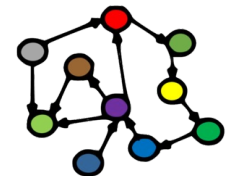
RDFS entailment [rdfs4b]

- *...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 .  
}
```



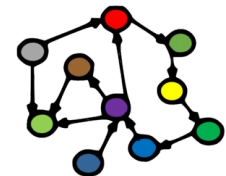
RDFS entailment [rdfs8]

- 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 .`”

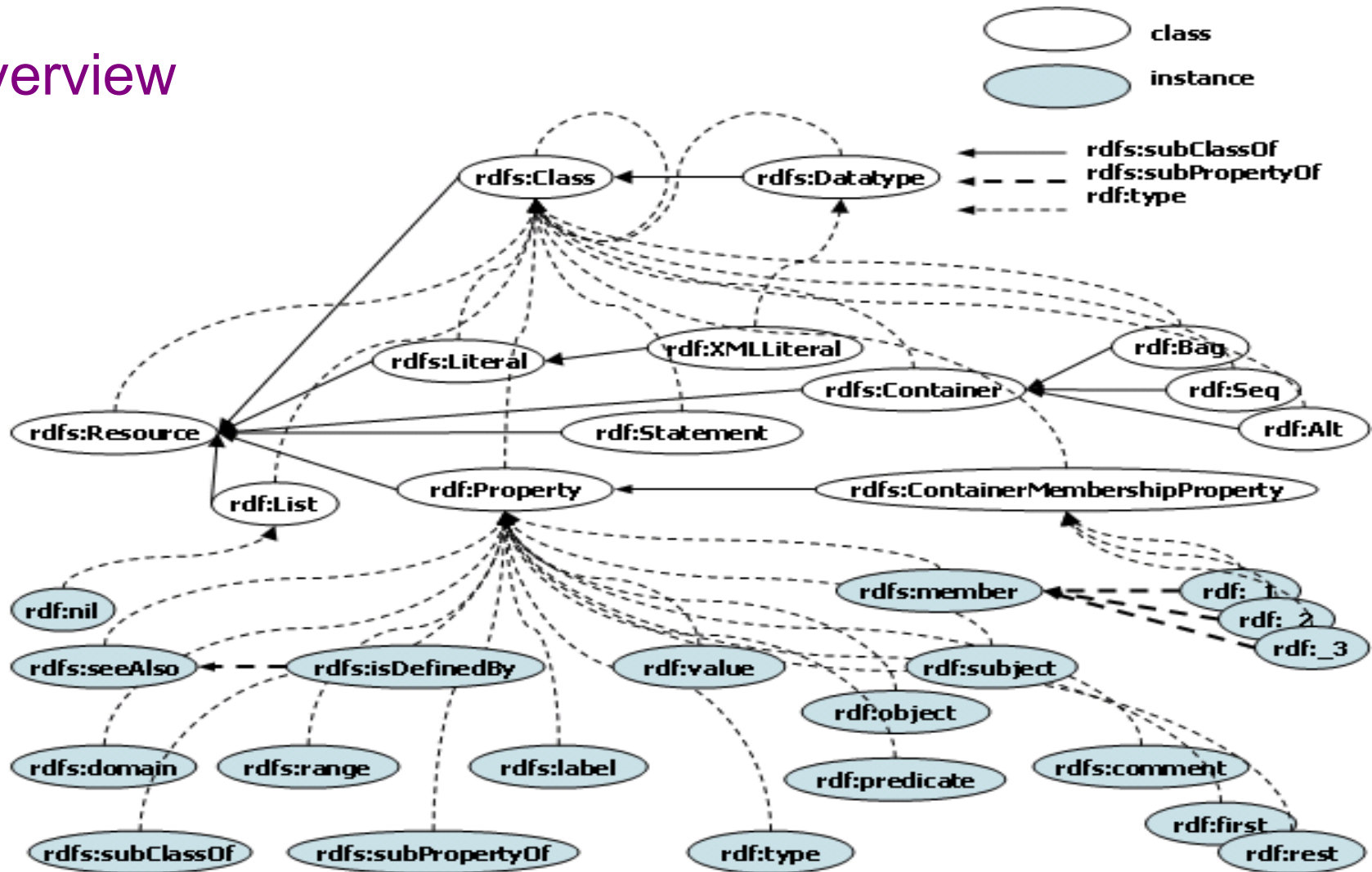
PREFIX rdf: <...>

PREFIX rdfs: <...>

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

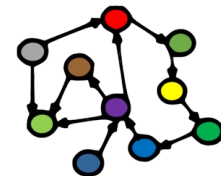


Overview



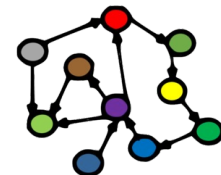
Summary of resources and properties

- 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 URIs actually represent the same class”*
 - *“resources with different URIs represent the same resource”*
 - *“properties with different URIs are actually the same”*
 - *“two individuals with different URIs 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!***



Next week:
Ontologies (OWL)