# Chapter 3

## RDF and RDFS Semantics

## Introduction

- RDF has a very simple data model
- But it is quite liberal in what you can say
- Semantics can be given using axiomatically
  - relating it to another representation, e.g., first order logic, for which a semantic model exists
  - May result in an executable semantics
- Semantics can be given by RDF Model Theory (MT)

## RDF/RDFS "Liberality"

- No distinction between classes and instances (individuals)

```
<Species, type, Class>
<Lion, type, Species>
<Leo, type, Lion>
```

- Properties can themselves have properties

```
<hasDaughter, subPropertyOf, hasChild>
<hasDaughter, type, familyProperty>
```

- No distinction between language constructors and ontology vocabulary, so constructors can be applied to themselves/each other

```
<type, range, Class>
<Property, type, Class>
<type, subPropertyOf, subClassOf>
```

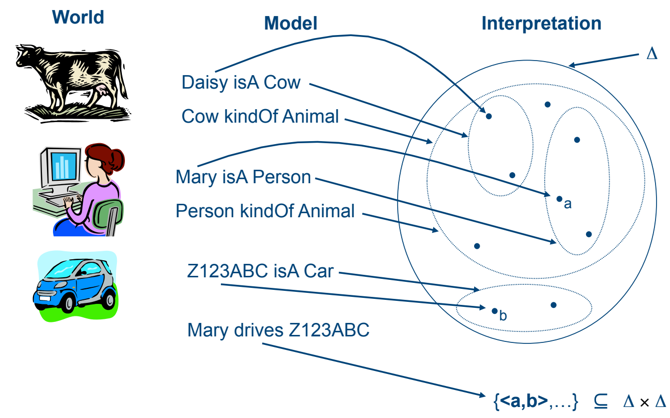
## Semantics and model theories

- Ontology/KR languages aim to model (part of) world
- Terms in language correspond to entities in world
- MT defines relationship between syntax and *interpretations*
  - Can be many interpretations (models) of one piece of syntax
  - Models supposed to be analogue of (part of) world
    - e.g., elements of model correspond to objects in world
  - Formal relationship between syntax and models
    - structure of models reflect relationships specified in syntax
  - Inference (e.g., subsumption) defined in terms of MT
    - e.g., T ² A v B iff in every model of T, ext(A) µ ext(B)

## Set Based Model Theory

- Many logics (including standard FOL) use a model theory based on Zermelo-Frankel set theory
- The domain of discourse (i.e., the part of the world being modelled) is represented as a set (often referred as $\Delta$)
- Objects in the world are interpreted as elements of $\Delta$
  - Classes/concepts (unary predicates) are subsets of $\Delta$
  - Properties/roles (binary predicates) are subsets of $\Delta$ $\Delta$ (i.e., $\Delta^2$)
  - Ternary predicates are subsets of $\Delta^3$ , etc.
- The sub-class relationship between classes can be interpreted as set inclusion
- Doesn't work for RDF, because in RDF a class (set) can be a member (element) of another class (set)
  - In Z-F set theory, elements of classes are atomic (no structure)

## Set Based Model Theory Example




## Set Based Model Theory Example

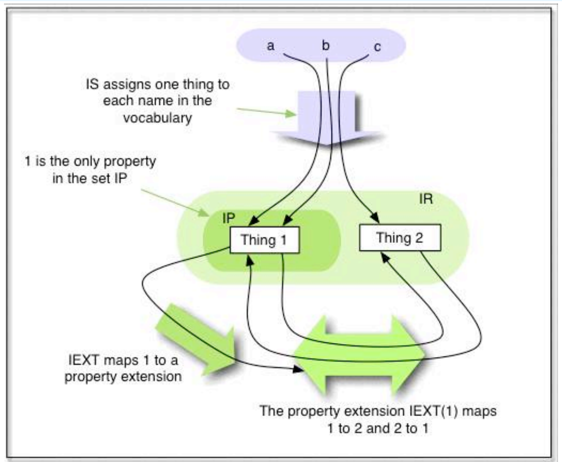
- Formally, the vocabulary is the set of names we use in our model of (part of) the world

  {Daisy, Cow, Animal, Mary, Person, Z123ABC, Car, drives, …}
- An interpretation **I** is a tuple h $\Delta$, ¢$^{I}$ i
  - $\Delta$ is the domain (a set)
  - ¢$^{I}$ is a mapping that maps
    - Names of objects to elements of $\Delta$
    - Names of unary predicates (classes/concepts) to subsets of $\Delta$
    - Names of binary predicates (properties/roles) to subsets of $\Delta \times \Delta$
    - And so on for higher arity predicates (if any)

## RDF Semantics

- RDF has "non-standard" semantics to deal with this
- Semantics given by RDF Model Theory (MT)
- In RDF MT, an interpretation **I** of a vocabulary V is:
  - IR, a non-empty set of resources (corresponds to $\Delta$)
  - IS, a mapping from V into IR (corresponds to ¢$^{I}$ )
  - IP, a distinguished subset of IR (the properties)
    - A vocabulary element v $\in$ V is a property iff IS(v) $\in$ IP
  - IEXT, a mapping from IP into the powerset of IR $\times$ IR
    - I.e., property elements mapped to subsets of IR $\times$ IR
  - IL, a mapping from typed literals into IR

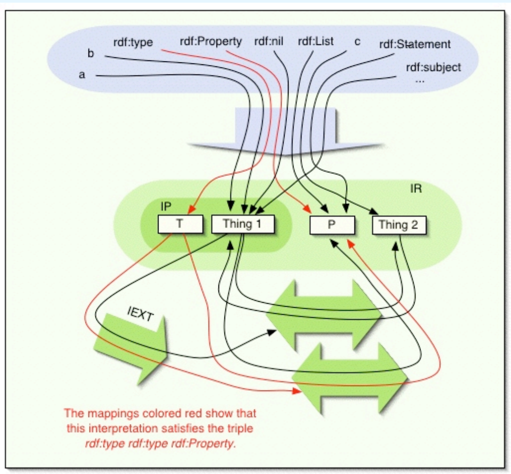
## Example RDF Simple Interpretation




## RDF Semantic Conditions

- RDF Imposes semantic conditions on interpretations, e.g.:
  - x is in IP iff <x, IS(rdf:Property)> is in IEXT(I(rdf:type))
- All RDF interpretations must satisfy certain axiomatic triples, e.g.:
  - rdf:type rdf:type rdf:Property
  - rdf:subject rdf:type rdf:Property
  - rdf:predicate rdf:type rdf:Property
  - rdf:object rdf:type rdf:Property
  - rdf:first rdf:type rdf:Property
  - rdf:rest rdf:type rdf:Property
  - rdf:value rdf:type rdf:Property
  - …

## Example RDF Interpretation




## RDFS Semantics

- RDFS simply adds semantic conditions and axiomatic triples that give meaning to schema vocabulary
- Class interpretation ICEXT simply induced by rdf:type, i.e.:
  - x is in ICEXT(y) if and only if <x,y> is in IEXT(IS(rdf:type))
- Other semantic conditions include:
  - If <x,y> is in IEXT(IS(rdfs:domain)) and <u,v> is in IEXT(x) then u is in ICEXT(y)
  - If <x,y> is in IEXT(IS(rdfs:subClassOf)) then x and y are in IC and ICEXT(x) is a subset of ICEXT(y)
  - IEXT(IS(rdfs:subClassOf)) is transitive and reflexive on IC
- Axiomatic triples include:
  - rdf:type rdfs:domain rdfs:Resource
  - rdfs:domain rdfs:domain rdf:Property

## RDFS Interpretation Example

- If RDFS graph includes triples

```
<Species, type, Class>
<Lion, type, Species>
<Leo, type, Lion>
<Lion, subClassOf, Mammal >
<Mammal, subClassOf, Animal>
```

- Interpretation conditions imply existence of triples

```
<Lion, subClassOf, Animal>
<Leo, type, Mammal>
<Leo, type, Animal>
…
```

## RDFS Axioms

- Another way to define the semantics of RDF and RDFS is to give axioms that relate it to well understood representation, such as FOL, that has a formal semantics.
- A benefit of this approach is that the axioms may provide the basis of an "executable semantics"
- For a list of FOL axioms (in N3) defining RDFS vocabulary, see

  http://www.csee.umbc.edu/691s/n3/rdfs-rules.n3

## RDFS Inference Rules

```
{?S ?P ?O} => {?P a rdf:Property}.
{?P rdfs:domain ?C. ?S ?P ?O} => {?S a ?C}.
{?P rdfs:range ?C. ?S ?P ?O} => {?O a ?C}.
{?S ?P ?O} => {?S a rdfs:Resource. ?O a rdfs:Resource}.
{?Q rdfs:subPropertyOf ?R. ?P rdfs:subPropertyOf ?Q}
    => {?P rdfs:subPropertyOf ?R}.
{?P @has rdfs:subPropertyOf ?R. ?S ?P ?O} => {?S ?R ?O}.
{?C a rdfs:Class} => {?C rdfs:subClassOf rdfs:Resource}.
{?A rdfs:subClassOf ?B. ?S a ?A} => {?S a ?B}.
{?B rdfs:subClassOf ?C. ?A rdfs:subClassOf ?B}
    => {?A rdfs:subClassOf ?C}.
{?X a rdfs:ContainerMembershipProperty}
    => {?X rdfs:subPropertyOf rdfs:member}.
{?X a rdfs:Datatype} => {?X rdfs:subClassOf rdfs:Literal}.
```

## RDFS Classes

rdf:Alt rdfs:subClassOf rdfs:Container.

rdf:Bag rdfs:subClassOf rdfs:Container.

rdfs:ContainerMembershipProperty rdfs:subClassOf rdf:Property.

rdfs:Datatype rdfs:subClassOf rdfs:Class.

rdf:Seq rdfs:subClassOf rdfs:Container.

rdf:XMLLiteral rdfs:subClassOf rdfs:Literal; a rdfs:Datatype.

## RDFS Properties

rdfs:label rdfs:domain rdfs:Resource; rdfs:range rdfs:Literal.
rdfs:comment rdfs:domain rdfs:Resource; rdfs:range rdfs:Literal.
rdfs:seeAlso rdfs:domain rdfs:Resource; rdfs:range rdfs:Resource.
rdfs:isDefinedBy rdfs:domain rdfs:Resource; rdfs:range rdfs:Resource;
rdfs:subPropertyOf rdfs:seeAlso.
rdfs:domain rdfs:domain rdf:Property; rdfs:range rdfs:Class.
rdfs:range rdfs:domain rdf:Property; rdfs:range rdfs:Class.
rdf:first rdfs:domain rdf:List; rdfs:range rdfs:Resource.
rdf:rest rdfs:domain rdf:List; rdfs:range rdf:List.
rdfs:member rdfs:domain rdfs:Container; rdfs:range rdfs:Resource.
rdfs:subClassOf rdfs:domain rdfs:Class; rdfs:range rdfs:Class.
rdfs:subPropertyOf rdfs:domain rdf:Property; rdfs:range rdf:Property.
rdf:subject rdfs:domain rdf:Statement; rdfs:range rdfs:Resource.
rdf:object rdfs:domain rdf:Statement; rdfs:range rdfs:Resource.
rdf:predicate rdfs:domain rdf:Statement; rdfs:range rdf:Property.
rdf:type rdfs:domain rdfs:Resource; rdfs:range rdfs:Class.
rdf:value rdfs:domain rdfs:Resource; rdfs:range rdfs:Resource.

## RDFS individuals

rdfs:first a owl:FunctionalProperty.

rdfs:rest a owl:FunctionalProperty

rdf:nil a rdf:List.

## Problems with RDFS

- RDFS too weak to describe resources in sufficient detail
  - No localised range and domain constraints
    - Can't say that the range of hasChild is person when applied to persons and elephant when applied to elephants
  - No existence/cardinality constraints
    - Can't say that all *instances* of person have a mother that is also a person, or that persons have exactly 2 parents
  - No transitive, inverse or symmetrical properties
    - Can't say that isPartOf is a transitive property, that hasPart is the inverse of isPartOf or that touches is symmetrical
  - …
- Difficult to provide reasoning support
  - No "native" reasoners for non-standard semantics
  - Possible to reason via FO axiomatisation

## Conclusions

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- But it is quite liberal in what you can say
- Semantics can be given using axiomatically
  - relating it to another representation, e.g., first order logic, for which a semantic model exists
  - May result in an executable semantics
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