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

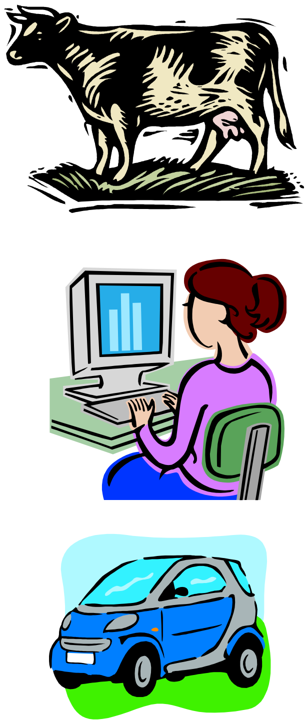
- Ontology/KR languages aim to model (part of) world
- Terms in language correspond to entities in world
- MT defines relationship between syntax and *interpretations*
  - Can be many interpretations (models) of one piece of syntax
  - Models supposed to be analogue of (part of) world
    - e.g., elements 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 Δ)
- Objects in the world are interpreted as elements of Δ
  - Classes/concepts (unary predicates) are subsets of Δ
  - Properties/roles (binary predicates) are subsets of $\Delta \times \Delta$ (i.e., Δ^2)
  - Ternary predicates are subsets of Δ^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)

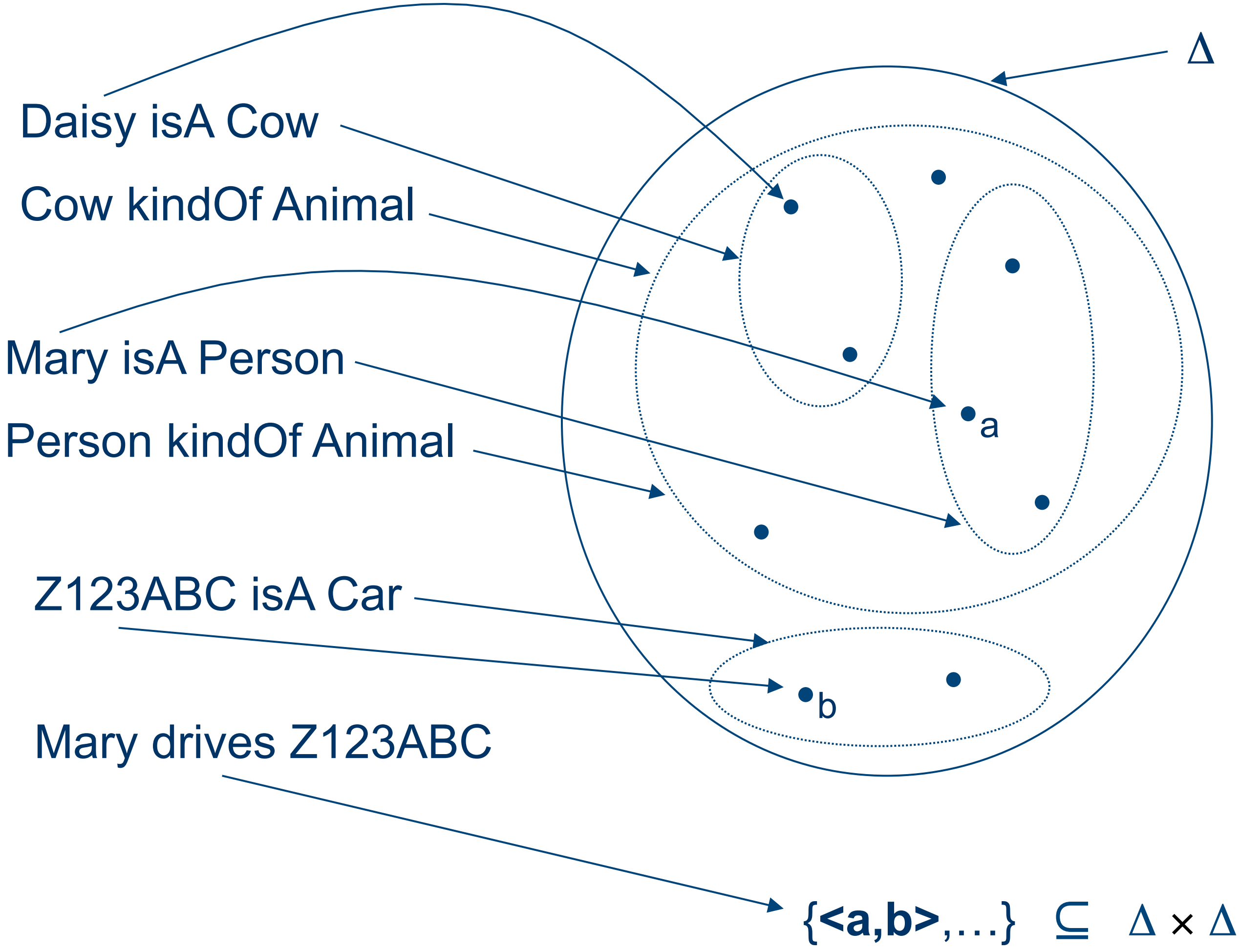
Set Based Model Theory Example

World



Model

Interpretation



Daisy isA Cow

Cow kindOf Animal

Mary isA Person

Person kindOf Animal

Z123ABC isA Car

Mary drives Z123ABC

$\{\langle \mathbf{a},\mathbf{b} \rangle, \ldots\} \subseteq \Delta \times \Delta$

Set Based Model Theory Example

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

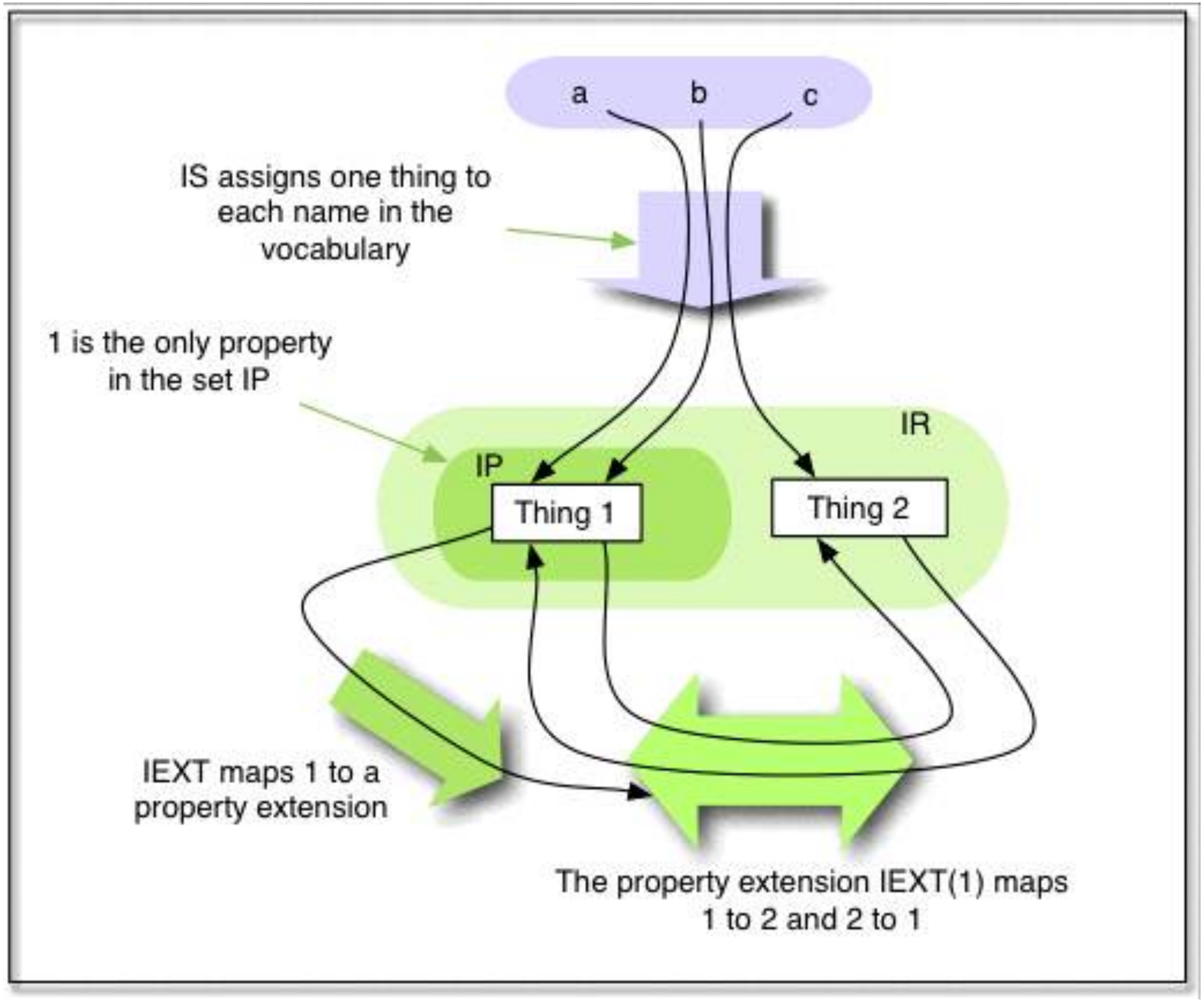
  {Daisy, Cow, Animal, Mary, Person, Z123ABC, Car, drives, …}

- An interpretation **I** is a tuple < Δ, ¢$^{\mathbf{I}}$ >
  - $\boldsymbol{\Delta}$ is the domain (a set)
  - ¢$^{\mathbf{I}}$ is a mapping that maps
    - Names of objects to elements of Δ
    - Names of unary predicates (classes/concepts) to subsets of Δ
    - 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 Δ)
  - IS, a mapping from V into IR (corresponds to ¢$^{\mathbf{I}}$)
  - 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

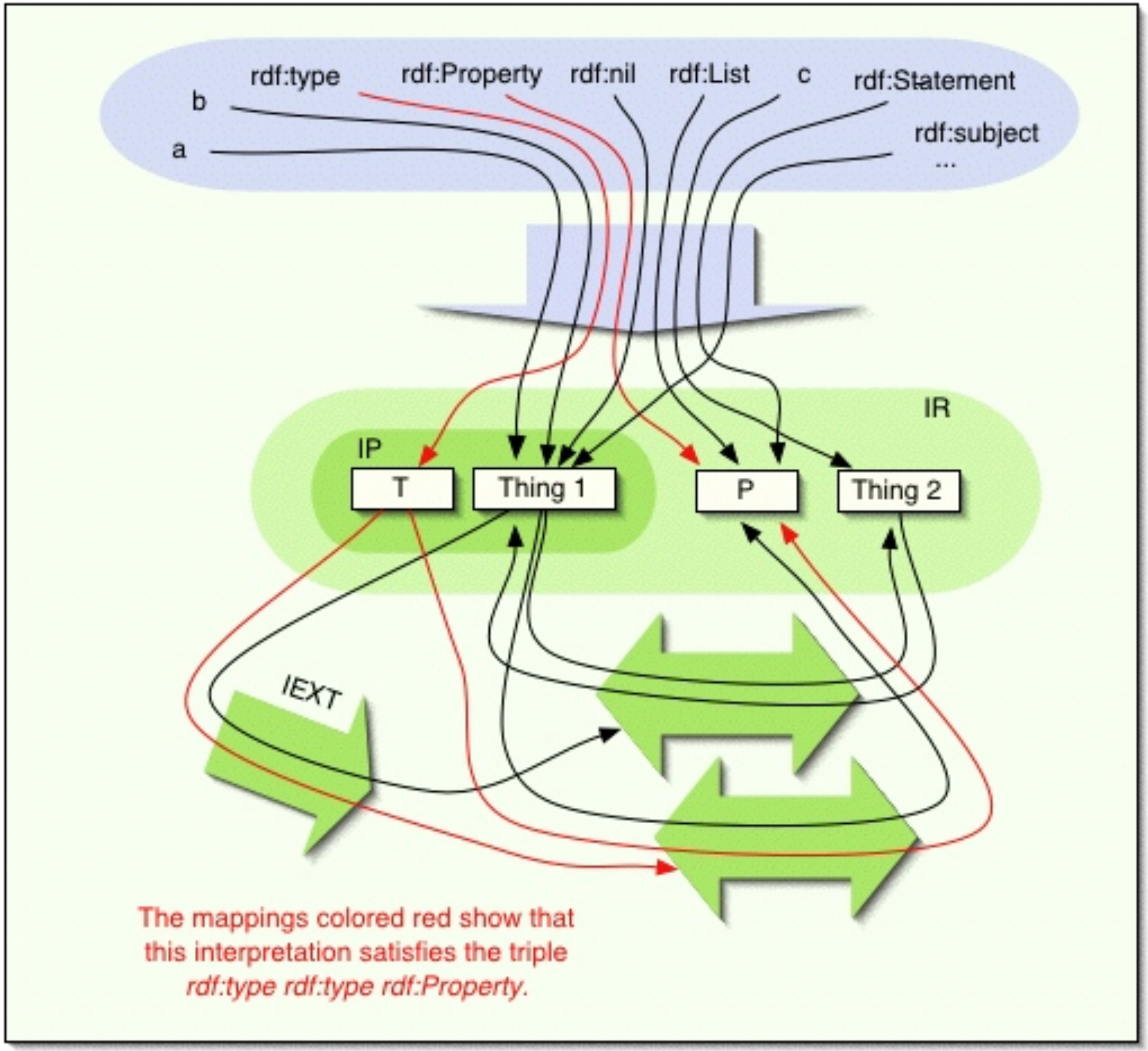
Example RDF Simple Interpretation



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



The mappings colored red show that this interpretation satisfies the triple *rdf:type rdf:type rdf:Property*.

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://691.finin.org/ex/n3rdfs-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

- 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
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