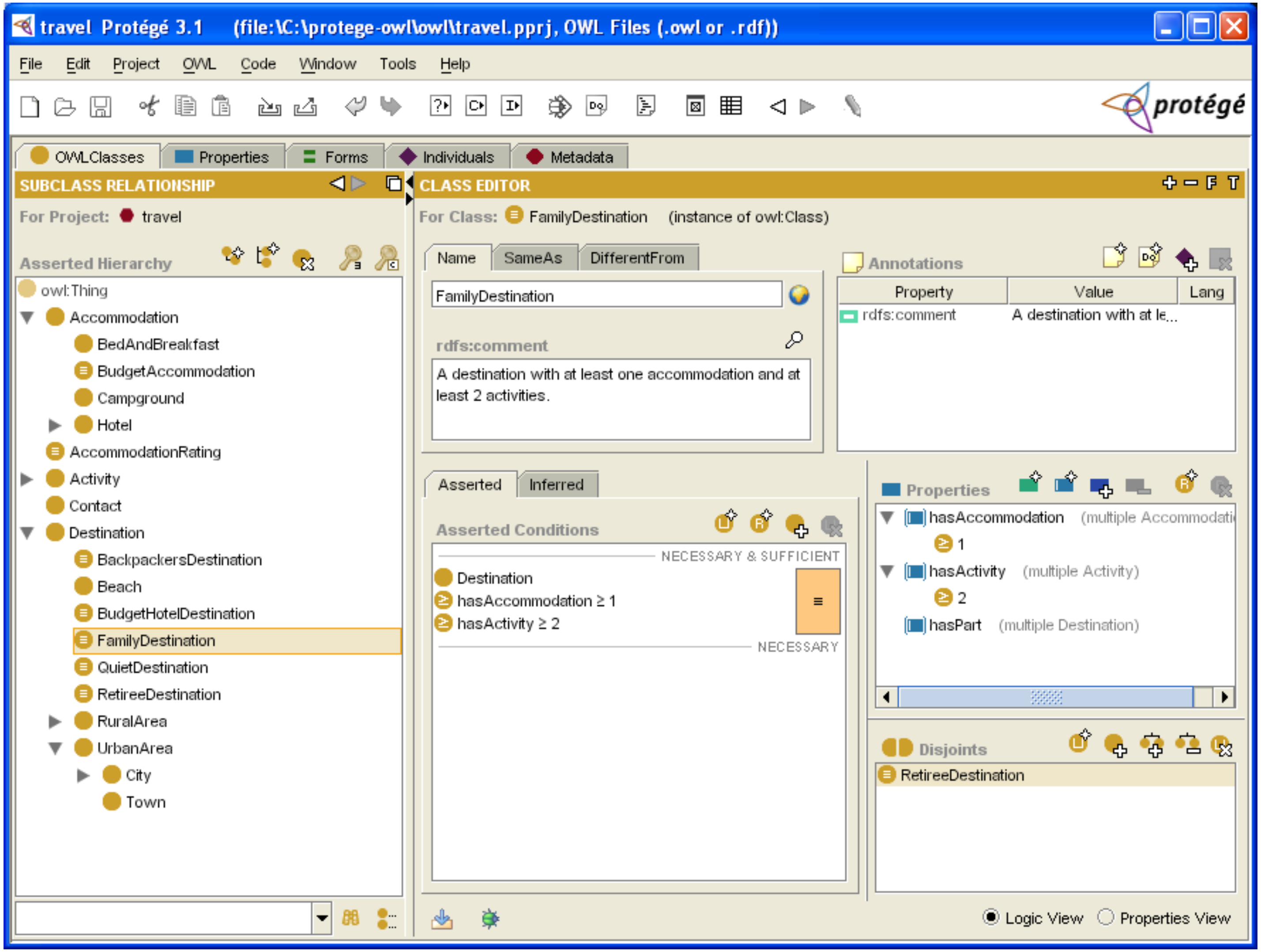
Chapter 3

RDF Schema

Introduction

- RDF has a very simple data model
- RDF Schema (RDFS) enriches the data model, adding vocabulary & associated semantics for
  - Classes and subclasses
  - Properties and sub-properties
  - Typing of properties
- Support for describing simple ontologies
- Adds an object-oriented flavor
- But with a logic-oriented approach and using "open world" semantics

RDFS is a simple KB Language



Several widely used Knowledge-Base tools can import and export in RDFS, including Stanford’s Protégé KB editor

RDFS Vocabulary

RDFS introduces the following terms, giving each a meaning w.r.t. the rdf data model

- Terms for classes
  - rdfs:Class
  - rdfs:subClassOf
- Terms for properties
  - rdfs:domain
  - rdfs:range
  - rdfs:subPropertyOf
- Special classes
  - rdfs:Resource
  - rdfs:Literal
  - rdfs:Datatype
- Terms for collections
  - rdfs:member
  - rdfs:Container
  - rdfs:ContainerMembershipProperty
- Special properties
  - rdfs:comment
  - rdfs:seeAlso
  - rdfs:isDefinedBy
  - rdfs:label

Modeling the semantics in logic

- We could represent any RDF triple with a binary predicate in logic, e.g.
  - **type(john, human)**
  - age(john, 32)
  - subclass(human, animal)
- But traditionally we model a class as a unary predicate
  - **human(john)**
  - age(john, 32)
  - subclass(human, animal)

Classes and Instances

- We distinguish between
  - Concrete “things” (individual objects) in the domain: *Discrete Math, Richard Chang,* etc.
  - Sets of individuals sharing properties called **classes**: lecturers, students, courses etc.
- Individual objects belonging to a class are referred to as **instances** of that class
- Relationship between instances and classes in RDF is through **rdf:type**
- Note similarity to *classes* and *objects* in an OO prog. language (but RDF classes stand for **sets**)

Classes are Useful

Classes let us impose restrictions on what can be stated in an RDF document using the schema

- As in programming languages

  E.g., A+1, where A is an array

- Disallow nonsense from being stated by detecting contradictions
- Allow us to infer a type of an object from how it is used -- like type inference in a programming language

Preventing nonsensical Statements

- *Discrete Math* is taught by *Calculus*
  - We want courses to be taught by lecturers only
  - Restriction on values of the property *"is taught by"* (**range restriction**)
- *Room ITE228* is taught by *Richard Chang*
  - Only *courses* can be taught
  - This imposes a restriction on the objects to which the property can be applied (**domain restriction**)

Class Hierarchies

- Classes can be organized in hierarchies
  - A is a **subclass** of B if and only if every instance of A is also an instance of B
  - We also say that B is a **superclass** of A
- Subclass graph needn't be a tree
  - A class may have multiple superclasses
- In logic:
  - $subclass(p, q) \Leftrightarrow p(x) \Rightarrow q(x)$
  - $subclass(p, q) \wedge p(x) \Rightarrow q(x)$

Domain and Range

- The domain & range properties let us associate classes with a property's subject and object
- Only a course can be taught
  - domain(isTaughtBy, course)
- Only an academic staff member can teach
  - range(isTaughtBy, academicStaffMember)
- Semantics in logic:
  - domain(pred, aclass) $\wedge$ pred(subj, obj) => aclass(subj)
  - range(pred, aclass) $\wedge$ pred(subj, obj) => aclass(obj)

Property Hierarchies

- Hierarchical relationships for properties
  - E.g., “is taught by” is a subproperty of “involves”
  - If a course C is taught by an academic staff member A, then C also involves A
- The converse is not necessarily true
  - E.g., A may be the teacher of the course C, or a TA who grades student homework but doesn’t teach
- Semantics in logic
  - subproperty(p, q) $\wedge$ p(subj, obj) => q(sub,obj)
  - e.g, subproperty(mother,parent), mother(p1, p2) => parent(p1, p2)

RDF Layer vs. RDF Schema Layer

- Discrete Math is taught by Richard Chang
- The schema is itself written in a formal language, RDF Schema, that can express its ingredients:
  - subClassOf, Class, Property, subPropertyOf, Resource, etc.

RDF Schema in RDF

- RDFS’s modelling primitives are defined using resources and properties (RDF itself is used!)
- To declare that *“lecturer”* is a subclass of *“academic staff member”*
  - Define resources **lecturer**, **academicStaffMember**, and **subClassOf**
  - define property **subClassOf**
  - Write triple (**subClassOf, lecturer, academicStaffMember**)

Core Classes

- **rdfs:Resource**: class of all resources
- **rdfs:Class**: class of all classes
- **rdfs:Literal**: class of all literals (strings)
- **rdf:Property**: class of all properties
- **rdf:Statement**: class of all reified statements

Core Properties

- **rdf:type**: relates a resource to its class

  The resource is declared to be an instance of that class

- **rdfs:subClassOf**: relates a class to one of its superclasses

  All instances of a class are instances of its superclass

- **rdfs:subPropertyOf**: relates a property to one of its superproperties

Core Properties

- **rdfs:domain**: specifies domain of property P
  - The class of those resources that may appear as subjects in a triple with predicate P
  - If domain not specified, any resource can be subject
- **rdfs:range**: specifies range of a property P
  - The class of those resources that may appear as object in a triple with predicate P
  - If range not specified, any resource can be object

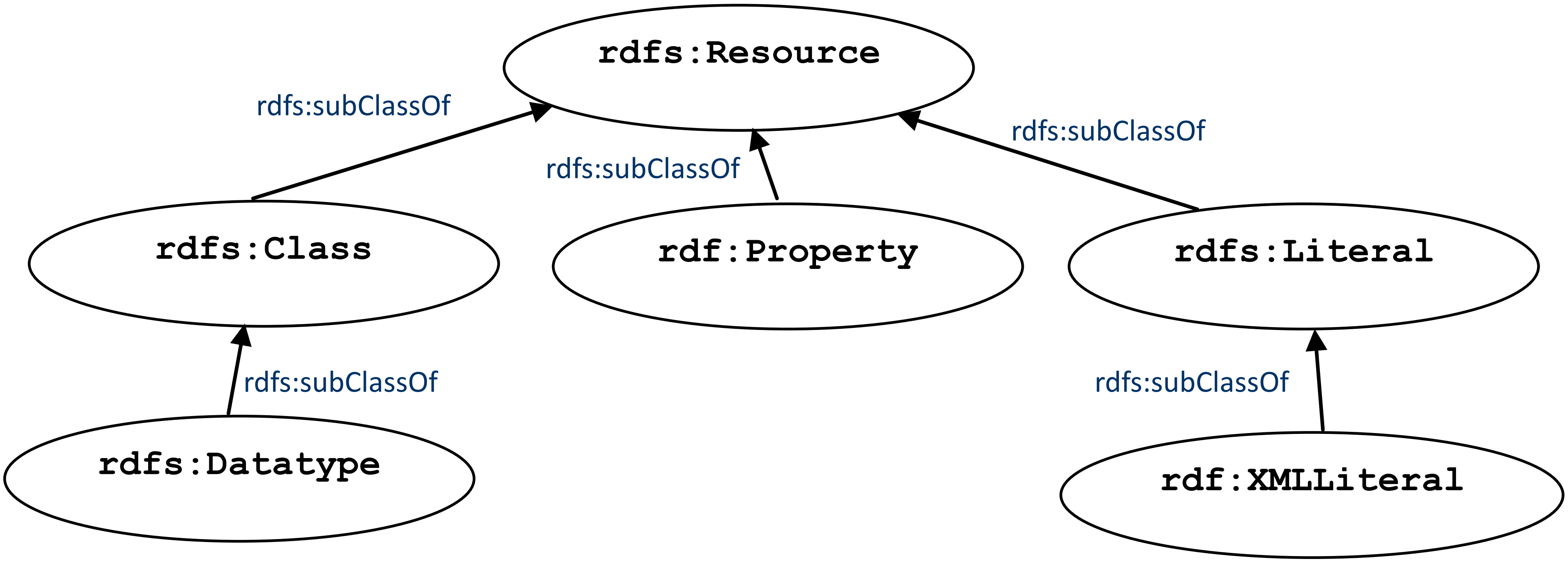
Examples (in Turtle)

```
:lecturer a rdfs:Class;
        rdfs:subCLassOf :staffMember .

:phone a rdfs:Class;
      rdfs:domain :staffMember;
      rdfs:range rdfs:Literal .
```

Relationships: Core Classes & Properties

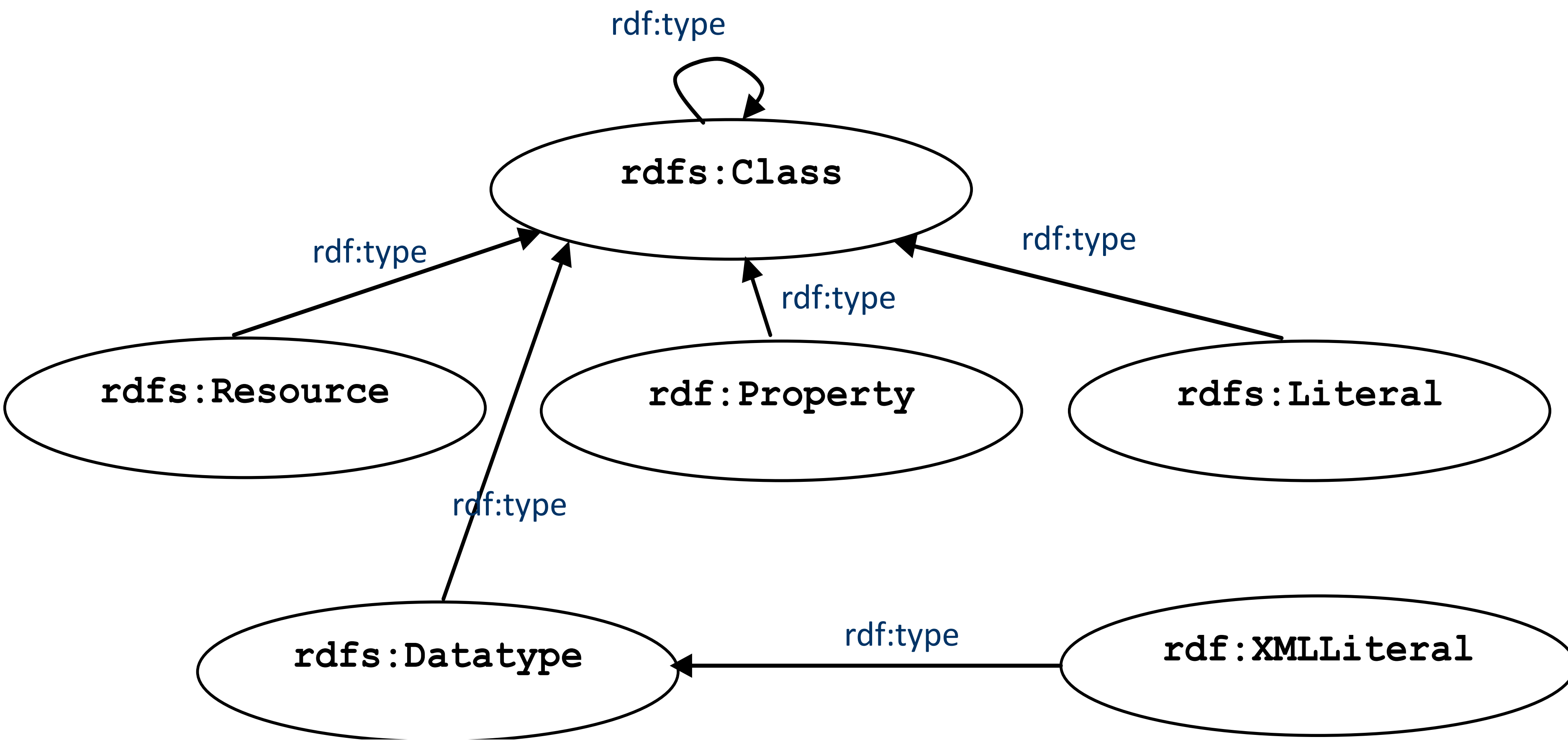
- **rdfs:subClassOf** and **rdfs:subPropertyOf** are transitive, by definition
- **rdfs:Class** is a subclass of **rdfs:Resource**
  - Because every class is a resource
- **rdfs:Resource** is an instance of **rdfs:Class**
  - **rdfs:Resource** is class of all resources, so it is a class
- Every class is an instance of **rdfs:Class**
  - For the same reason

Subclass Hierarchy of RDFS Primitives



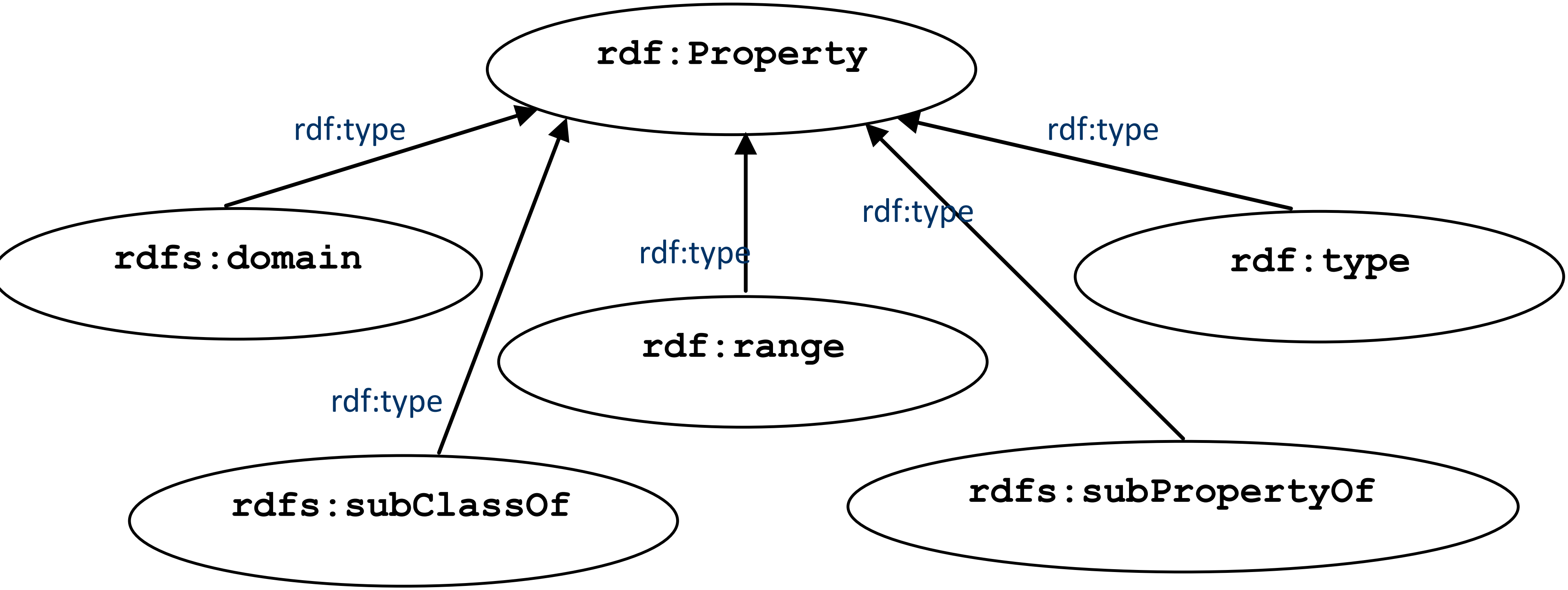
arrows represent the rdfs:subClassOf relation

Instance Relationships of RDFS Primitives



arrows represent the rdf:type relation

RDF and RDFS Property Instances



arrows represent the rdf:type relation

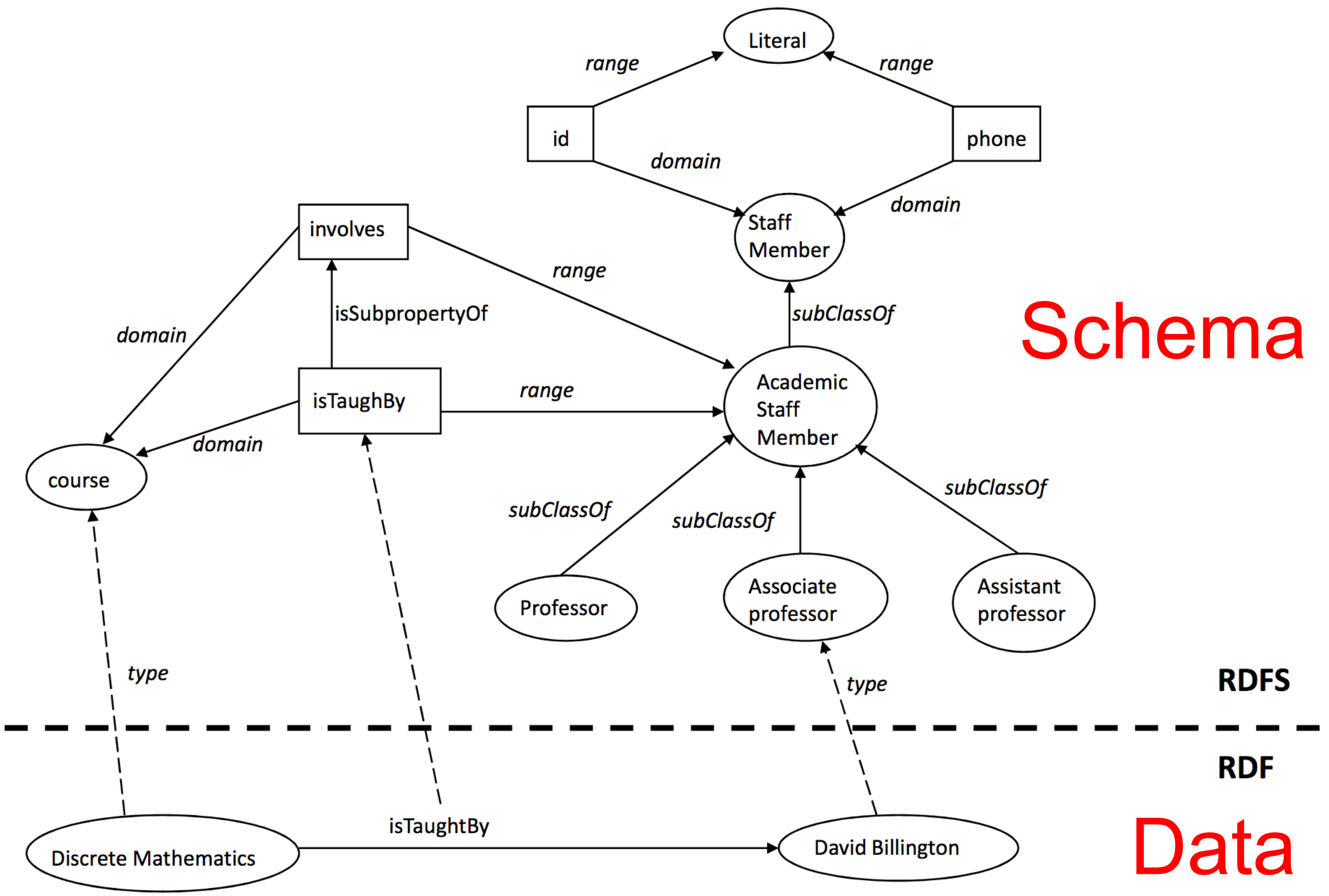
Reification and Containers

- **rdf:subject**: relates a reified statement to its subject
- **rdf:predicate**: relates a reified statement to its predicate
- **rdf:object**: relates a reified statement to its object
- **rdf:Bag**: the class of bags
- **rdf:Seq**: the class of sequences
- **rdf:Alt**: the class of alternatives
- **rdfs:Container**: a superclass of all container classes, including the three above

Utility Properties

- **rdfs:seeAlso** relates a resource to another resource that explains it
- **rdfs:isDefinedBy:** a subproperty of **rdfs:seeAlso** that relates a resource to the place where its definition, typically an RDF schema, is found
- **rfds:comment**. Comments, typically longer text, can be associated with a resource
- **rdfs:label**. A human-friendly label (name) is associated with a resource

Data and schema



Syntactically it's all just RDF. The data part only uses RDF vocabulary and the schema part uses RDFS vocabulary

Ex: University Lecturers – Prefix

```
<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"


>
```

Ex: University Lecturers -- Classes

```
<rdfs:Class rdf:ID="staffMember">
    <rdfs:comment>The class of staff members </rdfs:comment>
</rdfs:Class>

<rdfs:Class rdf:ID="academicStaffMember">
    <rdfs:comment>The class of academic staff members </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#staffMember"/>
</rdfs:Class>

<rdfs:Class rdf:ID="lecturer">
    <rdfs:comment> The class of lecturers. All lecturers are academic staff
    members.
    </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#academicStaffMember"/>
</rdfs:Class>

<rdfs:Class rdf:ID="course">
    <rdfs:comment>The class of courses</rdfs:comment>
</rdfs:Class>
```

Ex: University Lecturers -- Properties

```
<rdf:Property rdf:ID="isTaughtBy">
  <rdfs:comment>Assigns lecturers to courses. </rdfs:comment>
  <rdfs:domain rdf:resource="#course"/>
  <rdfs:range rdf:resource="#lecturer"/>
</rdf:Property>

<rdf:Property rdf:ID="teaches">
  <rdfs:comment>Assigns courses to lecturers. </rdfs:comment>
  <rdfs:domain rdf:resource="#lecturer"/>
  <rdfs:range rdf:resource="#course"/>
</rdf:Property>
```

Ex: University Lecturers -- Instances

```
<uni:lecturer rdf:ID="949318"
    uni:name="Richard Chang"
    uni:title="Associate Professor">
    <uni:teaches rdf:resource="#CIT1111"/>
    <uni:teaches rdf:resource="#CIT3112"/>
</uni:lecturer>
<uni:lecturer rdf:ID="949352"
    uni:name="Grigoris Antoniou"
    uni:title="Professor">
    <uni:teaches rdf:resource="#CIT1112"/>
    <uni:teaches rdf:resource="#CIT1113"/>
</uni:lecturer>
<uni:course rdf:ID="CIT1111"
    uni:courseName="Discrete Mathematics">
    <uni:isTaughtBy rdf:resource="#949318"/>
</uni:course>
<uni:course rdf:ID="CIT1112"
    uni:courseName="Concrete Mathematics">
    <uni:isTaughtBy rdf:resource="#949352"/>
</uni:course>
```

Example: A University

```
<rdfs:Class rdf:ID="lecturer">
    <rdfs:comment>
        The class of lecturers. All lecturers are
        academic staff members.
    </rdfs:comment>
    <rdfs:subClassOf
    rdf:resource="#academicStaffMember"/>
</rdfs:Class>
```

Example: A University

```
<rdfs:Class rdf:ID="course">
  <rdfs:comment>The class of courses</rdfs:comment>
</rdfs:Class>

<rdf:Property rdf:ID="isTaughtBy">
  <rdfs:comment>
     Inherits its domain ("course") and range ("lecturer")
     from its superproperty "involves”
  </rdfs:comment>
  <rdfs:subPropertyOf rdf:resource="#involves"/>
</rdf:Property>
```

Example: A University

```
<rdf:Property rdf:ID="phone">
  <rdfs:comment>
    It is a property of staff members
    and takes literals as values.
  </rdfs:comment>

  <rdfs:domain rdf:resource="#staffMember"/>
  <rdfs:range
    rdf:resource="http://www.w3.org/2000/01/rdf-
    schema#Literal"/>
</rdf:Property>
```

RDF and RDFS Namespaces

- The RDF, RDFS and OWL namespaces specify some constraints on the ‘languages’
  - http://www.w3.org/1999/02/22-rdf-syntax-ns#
  - http://www.w3.org/2000/01/rdf-schema#
  - http://www.w3.org/2002/07/owl#
- Strangely, each uses terms from all three to define its own terms
- Don’t be confused: the real semantics of the terms isn’t specified in the namespace files

RDF Namespace

```xml
<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:owl="http://www.w3.org/2002/07/owl#"
  xmlns:dc="http://purl.org/dc/elements/1.1/">

 <owl:Ontology
    rdf:about="http://www.w3.org/2000/01/rdf-schema#"
    dc:title="The RDF Schema vocabulary (RDFS)"/>

<rdfs:Class rdf:about="http://www.w3.org/2000/01/rdf-schema#Resource">
  <rdfs:isDefinedBy rdf:resource="http://www.w3.org/2000/01/rdf-schema#"/>
  <rdfs:label>Resource</rdfs:label>
  <rdfs:comment>The class resource, everything.</rdfs:comment>
</rdfs:Class>

…
```

RDF Namespace in turtle

```
@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 dc: <http://purl.org/dc/elements/1.1/> .

<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
  a owl:Ontology ;
  dc:title "The RDF Vocabulary (RDF)" ;
  dc:description "This is the RDF Schema for the RDF vocabulary defined in the RDF
     namespace." .

rdf:type a rdf:Property ;
  rdfs:isDefinedBy <http://www.w3.org/1999/02/22-rdf-syntax-ns#> ;
  rdfs:label "type" ;
  rdfs:comment "The subject is an instance of a class." ;
  rdfs:range rdfs:Class ;
  rdfs:domain rdfs:Resource .
```

RDF Namespace example

```
rdf:Statement a rdfs:Class ;
  rdfs:subClassOf rdfs:Resource ;
  rdfs:comment "The class of RDF statements." .

rdf:subject a rdf:Property ;
  rdfs:domain rdf:Statement ;
  rdfs:range rdfs:Resource .

rdf:predicate a rdf:Property ;
  rdfs:domain rdf:Statement ;
  rdfs:range rdfs:Resource .
```

RDF Namespace example

This example shows how RDFS terms are used to say something important about the RDF *predicate* property

```
<rdf:Property rdf:ID="predicate"
      rdfs:comment="Identifies the property of a
                   statement in reified form"/>
  <rdfs:domain rdf:resource="#Statement"/>
  <rdfs:range rdf:resource="#Property"/>
</rdf:Property>
```

predicate is a property from a Statement to a Property

RDF Namespace

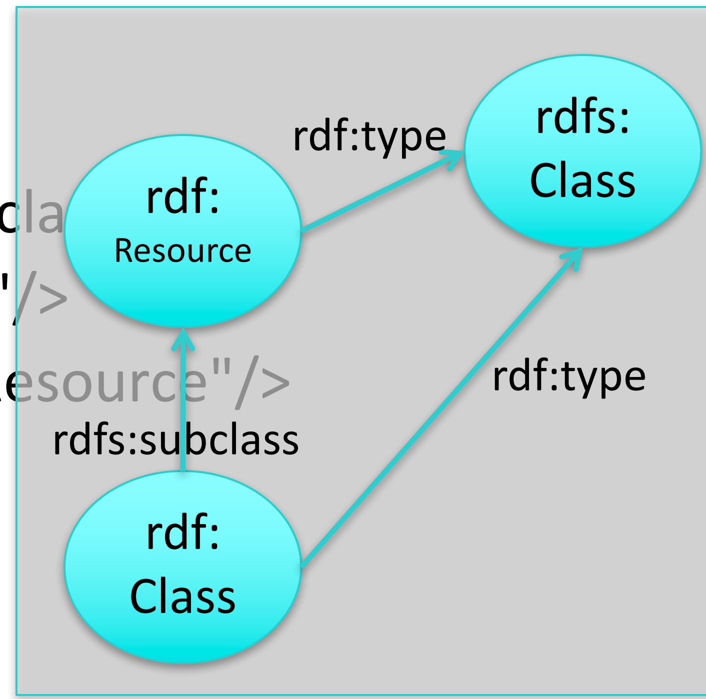
Define rdf:Resource and rdf:Class as instances of rdfs:Class & rdf:Class as a subclass of rdf:Resource

```
<rdfs:Class rdf:ID="Resource"
        rdfs:comment="The most general class"/>

<rdfs:Class rdf:ID="Class"
          rdfs:comment="The concept of classes.
                  All classes are resources"/>
        <rdfs:subClassOf rdf:resource="#Resource"/>
</rdfs:Class>
```

RDF Namespace

Define rdf:Resource and rdf:Class as instances of rdfs:Class & rdf:Class as a subclass of rdf:Resource

```
<rdfs:Class rdf:ID="Resource"
        rdfs:comment="The most general class"/>

<rdfs:Class rdf:ID="Class"
          rdfs:comment="The concept of cla
                    All classes are resources"/>
        <rdfs:subClassOf rdf:resource="#Resource"/>
</rdfs:Class>
```



RDFS Namespace

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
…
<http://www.w3.org/2000/01/rdf-schema#> a owl:Ontology ;
    dc:title "The RDF Schema vocabulary (RDFS)" .

rdfs:Resource a rdfs:Class ;
    rdfs:comment "The class resource, everything." .

rdfs:Class a rdfs:Class ;
    rdfs:subClassOf rdfs:Resource .

rdfs:subClassOf a rdf:Property ;
    rdfs:isDefinedBy <http://www.w3.org/2000/01/rdf-schema#> ;
    rdfs:label "subClassOf" ;
    rdfs:comment "The subject is a subclass of a class." ;
    rdfs:range rdfs:Class ;
    rdfs:domain rdfs:Class .
…
```

Namespaces vs. Semantics

- Consider **rdfs:subClassOf**
  - The namespace specifies only that it applies to classes and has a class as a value
  - The meaning of being a subclass not specified
- The meaning cannot be expressed in RDF
  - If it could RDF Schema would be unnecessary
- External definition of semantics required
  - Respected by RDF/RDFS processing software

RDFS vs. OO Models

- In OO models, an object class defines the properties that apply to it
  - Adding a new property means modifying the class
- In RDF, properties defined globally and not encapsulated as attributes in class definitions
  - We can define new properties w/o changing class
  - Properties can have properties

    :mother rdfs:subPropertyOf :parent; rdf:type :FamilyRelation.
  - But: can't narrow domain & range of properties in a subclass

Example

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix bio: <http://example.com/biology#> .
bio:Animal a rdfs:Class.
bio:offspring a rdfs:Property;
    rdfs:domain bio:Animal;
    rdfs:range bio:Animal.
bio:Human rdfs:subClassOf bio:Animal.
bio:Dog rdfs:subClassOf bio:Animal.
:fido a bio:Dog.
:john a bio:Human;
    bio:offspring :fido.
```

There is no way to say that the offspring of humans are humans and the offspring of dogs are dogs.

Example

Bio:child rdfs:subPropertyOf bio:offspring;

rdfs:domain bio:Human;

rdfs:range bio:Human.

Bio:puppy rdfs:subPropertyOf bio:offspring;

rdfs:domain bio:Dog;

rdfs:range bio:Dog.

:john bio:child :mary.

:fido bio:puppy :rover.

What do we know after each of the last two triples are asserted?

Suppose we also assert:

- :john bio:puppy :rover
- :john bio:child :fido

Not like types in OO systems

- Classes differ from types in OO systems in how they are used
  - They are not *constraints* on well-formedness
- Lack of *negation* and *open world assumption* in RDF+RDFS makes detecting contradictions **impossible!**
  - Can’t say that Dog and Human are disjoint classes
  - Not knowing any individuals who are both doesn’t mean it’s not possible

No disjunctions or union types

What does this mean?

```
bio:Human rdfs:subClassOf bio:Animal.
bio:Cat rdfs:subClassOf bio:Animal.
bio:Dog rdfs:subClassOf bio:Animal.
bio:hasPet a rdfs:Property;
  rdfs:domain bio:Human;
  rdfs:range bio:Dog;
  rdfs:range bio:Cat.
```

No disjunctions or union types

What does this mean?

Bio:Human rdfs:subClassOf bio:Animal.

bio:Cat rdfs:subClassOf bio:Animal.

Bio:Dog rdfs:subClassOf bio:Animal.

bio:hasPet a rdfs:Property;

  rdfs:domain bio:Human;

  rdfs:range bio:Dog;

  rdfs:range bio:Cat.

Consider adding:

:john bio:hasPet :spot

No disjunctions or union types

What does this mean?

bio:Human rdfs:subClassOf bio:Animal.

bio:Cat rdfs:subClassOf bio:Animal.

bio:Dog rdfs:subClassOf bio:Animal.

bio:hasPet a rdfs:Property;

rdfs:domain bio:Human;

rdfs:range bio:Dog;

rdfs:range bio:Cat.

:john bio:hasPet :spot

=>

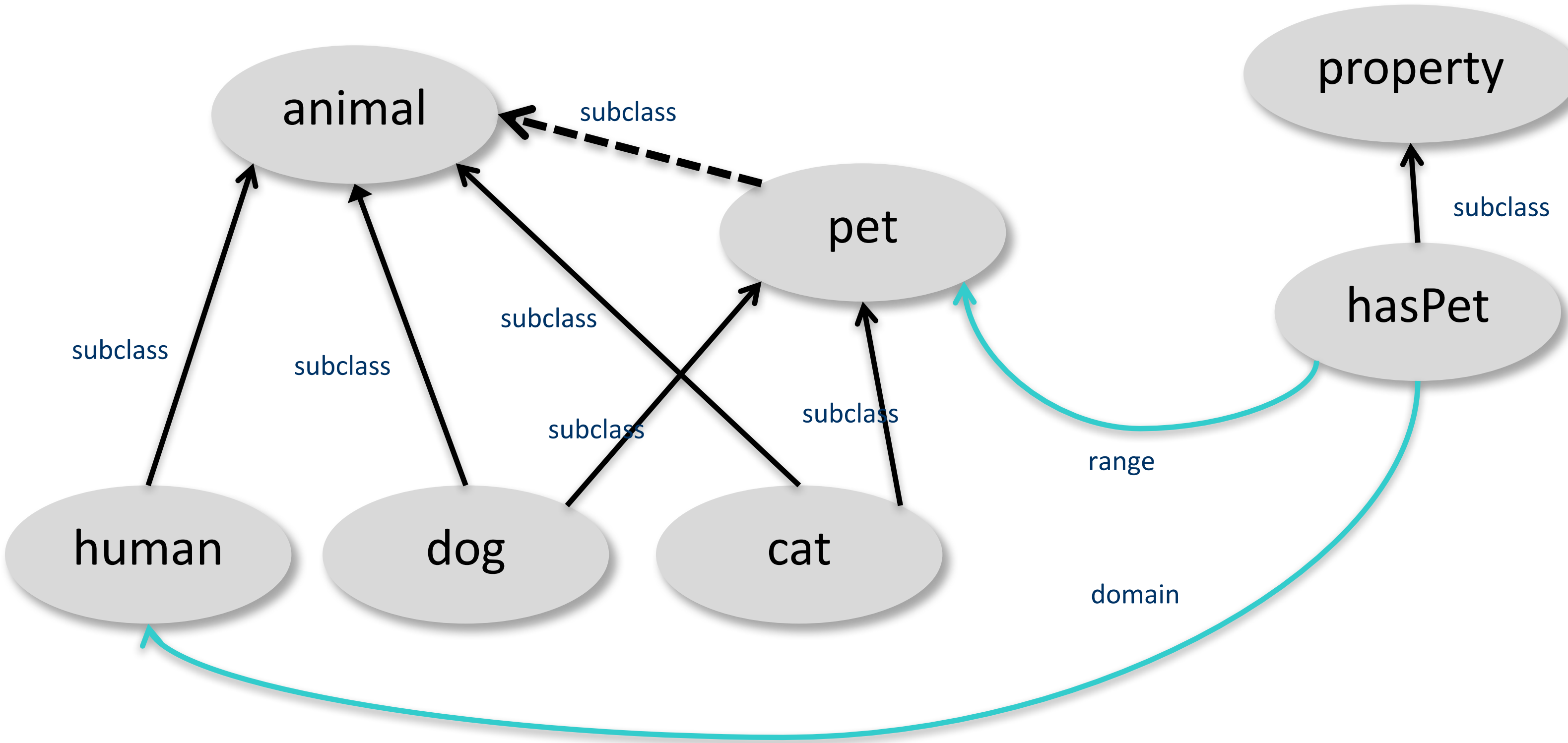
:john a bio:Human,
bio:Animal.

:spot a bio:Dog, bio:Cat,
bio:Animal.

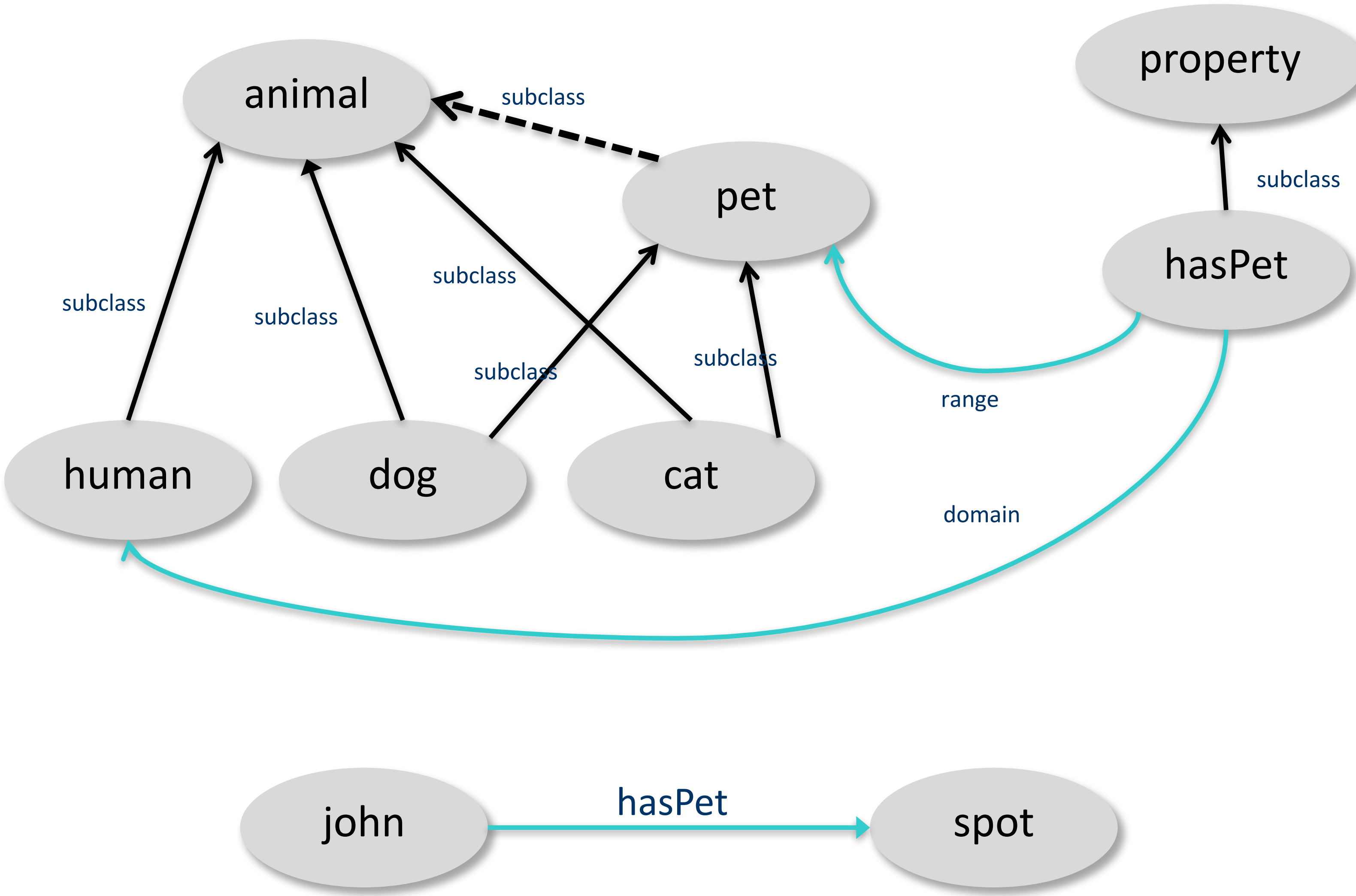
What do we want to say?

- Many different possibilities
  - Only a dog or cat can be an object of hasPet property
  - Dogs and cats and maybe other animals are possible as pets
  - Dogs and cats and maybe other things, not necessarily animals, are possible as pets
  - All dogs and all cats are pets
  - It's possible for some dogs and some cats to be pets
- Not all of these can be said in RDF+RDFS
- We can express all of these in OWL *(I think)*

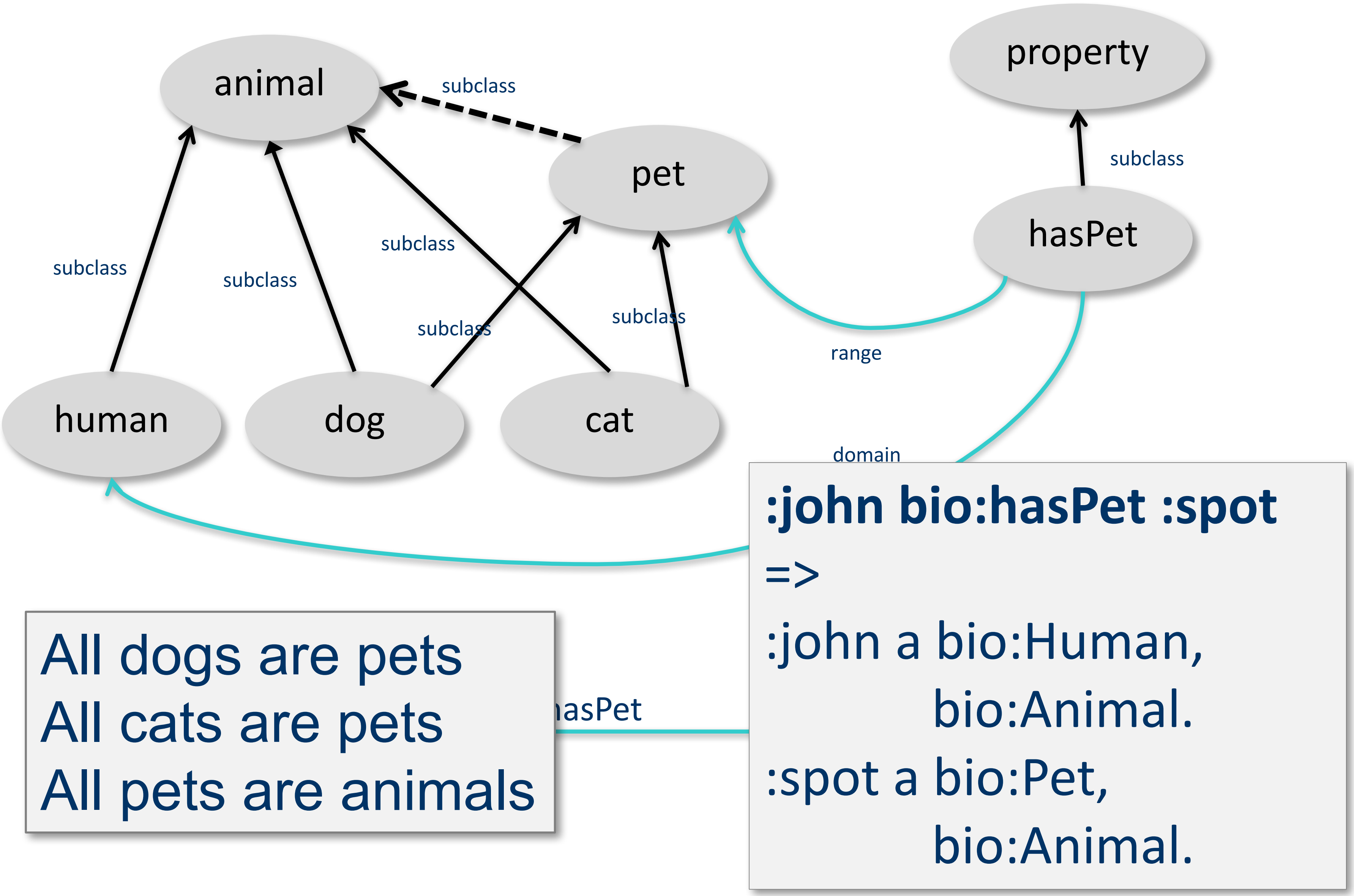
What do we want to say?



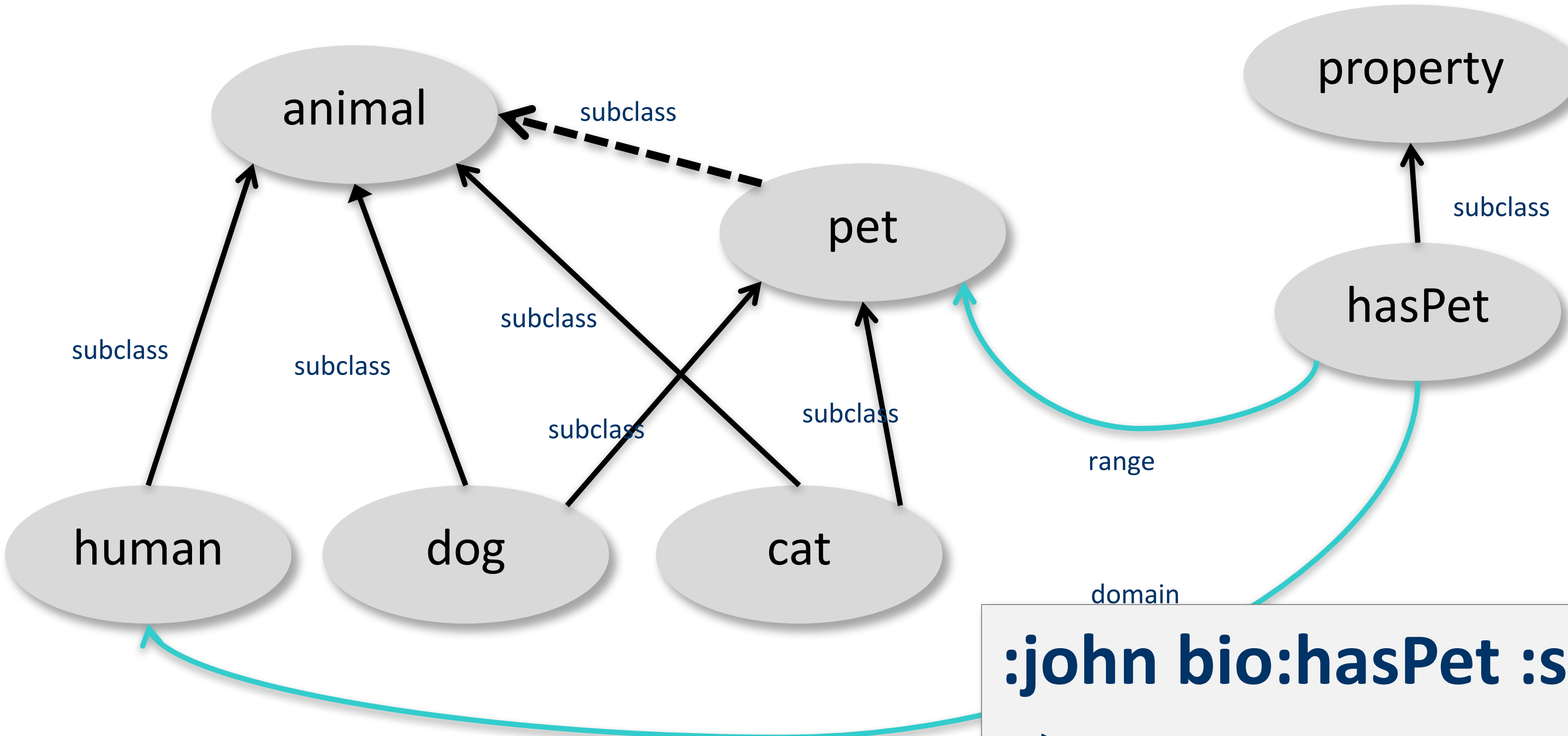
What do we want to say?



What do we want to say?



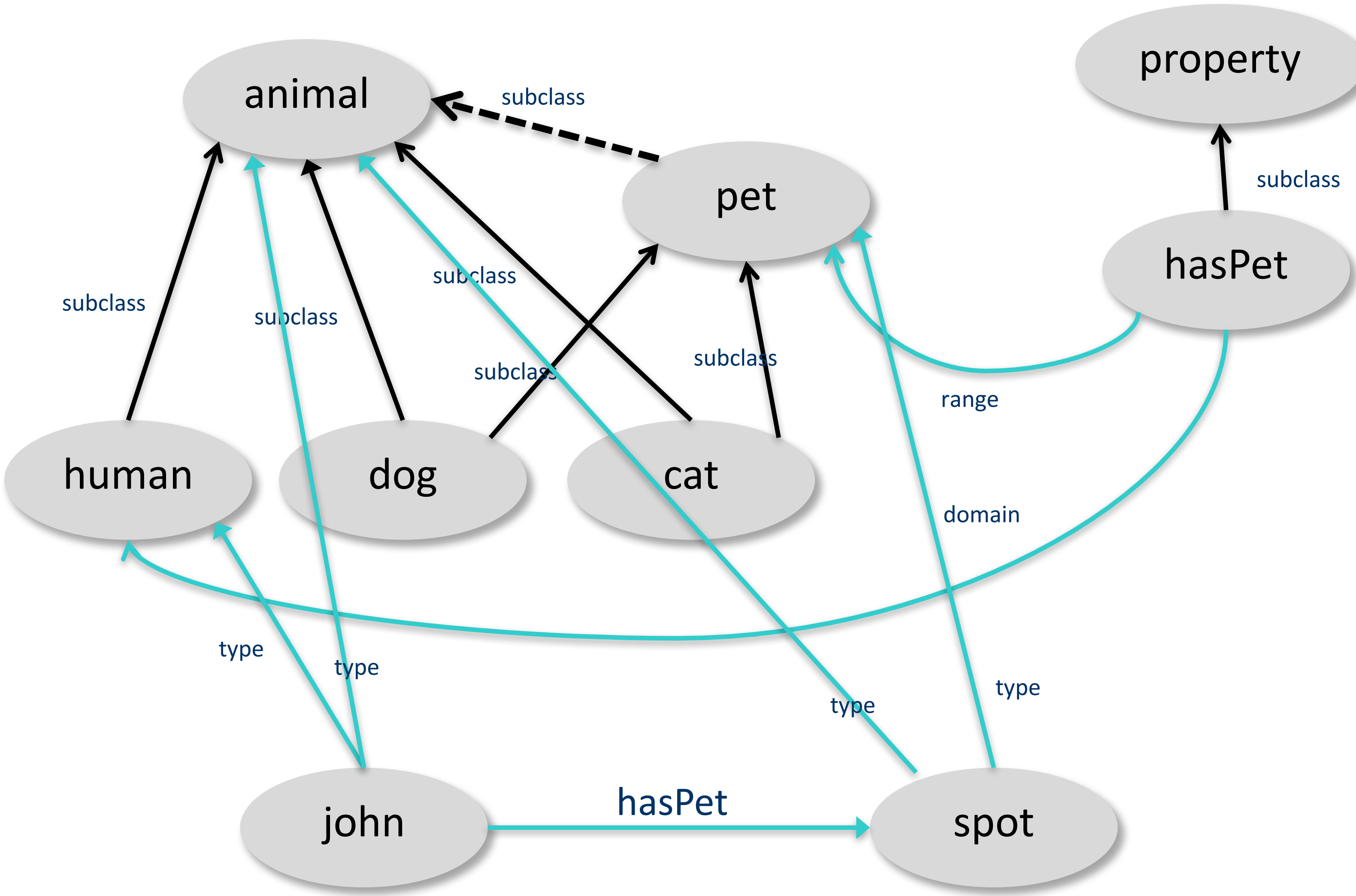
What do we want to say?



All dogs are pets
All cats are pets
All pets are animals

:john bio:hasPet :spot
=>
:john a bio:Human,
bio:Animal.
:spot a bio:Pet,
bio:Animal.

What do we want to say?



Classes and individuals are not disjoint

- In OO systems a thing is either a class or object
  - Many KR systems are like this also
- Not so in RDFS

```
bio:Species rdf:type rdfs:Class.
bio:Dog rdf:type rdfs:Species;
    rdfs:subClassOf bio:Animal.
:fido rdf:type bio:Dog.
```

- rdf:type links an individual to a class it belongs to
- rdfs:subClass links a class to a super-class it is part of

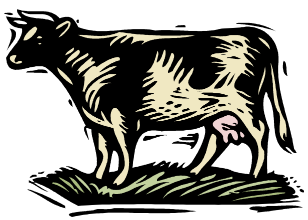
- Adds richness to language but causes problems
  - In OWL DL you can't do this
  - OWL has it's own notion of a Class, owl:Class

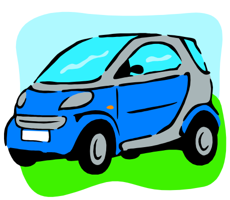
Inheritance is simple

- No defaults, overriding, shadowing
- What you say about a class is necessarily true of all sub-classes
- A class’s properties are not inherited by its members
  - Can’t say “Dog’s are normally friendly” or even “All dogs are friendly”
  - Meaning of the Dog class is a **set of individuals**
  - Sets cannot be friendly

Set Based Model Theory Example

World





Model

Daisy isA Cow

Cow kindOf Animal

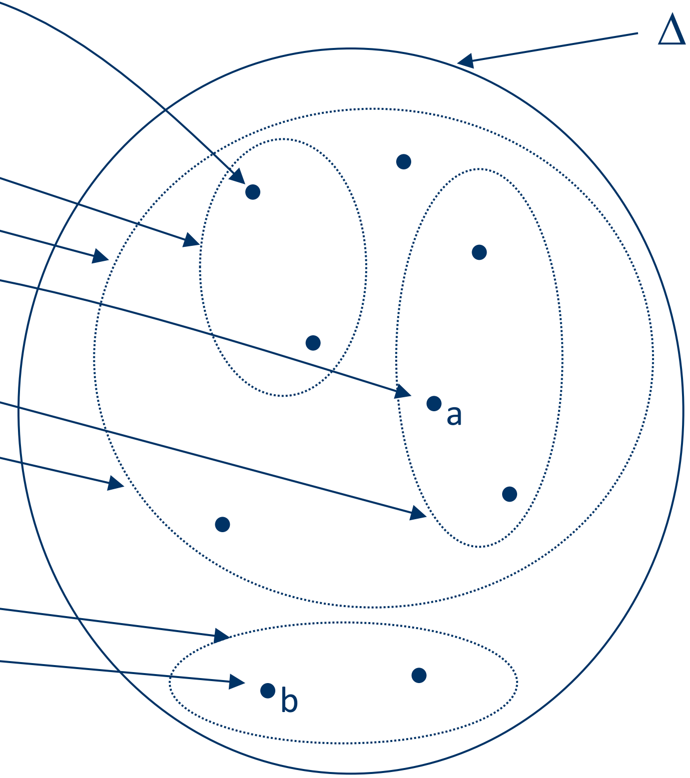
Mary isA Person

Person kindOf Animal

Z123ABC isA Car

Mary drives Z123ABC

Interpretation



{... list of facts about individuals ...}

Is RDF(S) better than XML?

Q: For a specific application, should I use XML or RDF?

A: It depends…

- XML's model is
  - a tree, i.e., a strong hierarchy
  - applications may rely on hierarchy position
  - relatively simple syntax and structure
  - not easy to *combine* trees
- RDF's model is
  - a *loose* collections of relations
  - applications may do "database"-like search
  - not easy to recover hierarchy
  - easy to combine relations in one big collection
  - great for the integration of heterogeneous information

RDFS too weak to describe resources in detail

- No *localised range and domain* constraints

  Can’t say range of hasChild is person when applied to persons and elephant when applied to elephants

- No *existence/cardinality* constraints

  Can’t say all *instances* of person have a mother that is a person, or that persons have exactly two parents

- No *transitive, inverse or symmetrical* properties

  Can’t say isPartOf is a transitive property, hasPart is the inverse of isPartOf or that touches is symmetrical

We need RDF terms providing these and other features: this is where OWL comes in

RDF Conclusions

- Simple **data model** based on a **graph,** independent of serializations (e.g., XML or N3)
- Has a **formal semantics** providing a dependable basis for reasoning about the meaning of RDF expressions
- Has an XML serialization, can use XML schema datatypes
- **Open world assumption:** anyone can make statements about any resource
- RDFS adds vocabulary with well defined semantics (e.g., Class, subClassOf, etc.)
- OWL addresses some of RDFS's limitations adding richness (and complexity)