RDF Meta Model and Schema

CS 431 – March 31, 2008

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Looking behind the curtain: RDF Meta-model

RDF Meta-Model provides base level for **inferences**

- Given a set of facts…
- Derive additional facts

- Some facts
  - Sam has a Prius
  - A Prius is a car
  - A Car is a type of vehicle
  - Sam has a bicycle
  - A bicycle is a type of vehicle

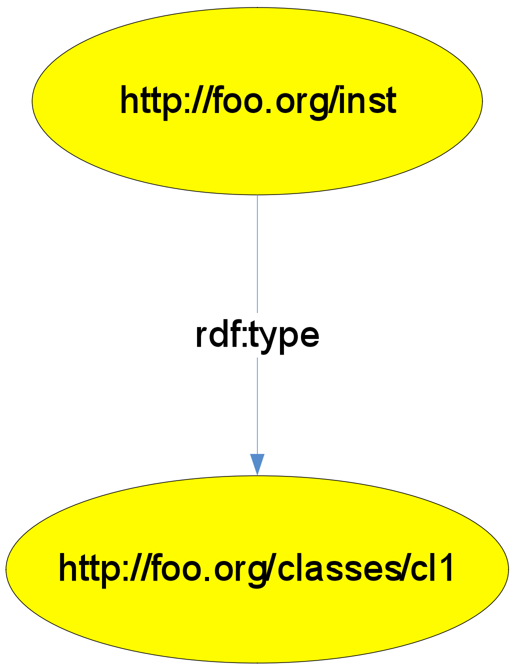
- Inference by subsumption: Sam has two vehicles
- Inference by human judgment: Sam is an environmentalist.

RDF meta-model basic elements

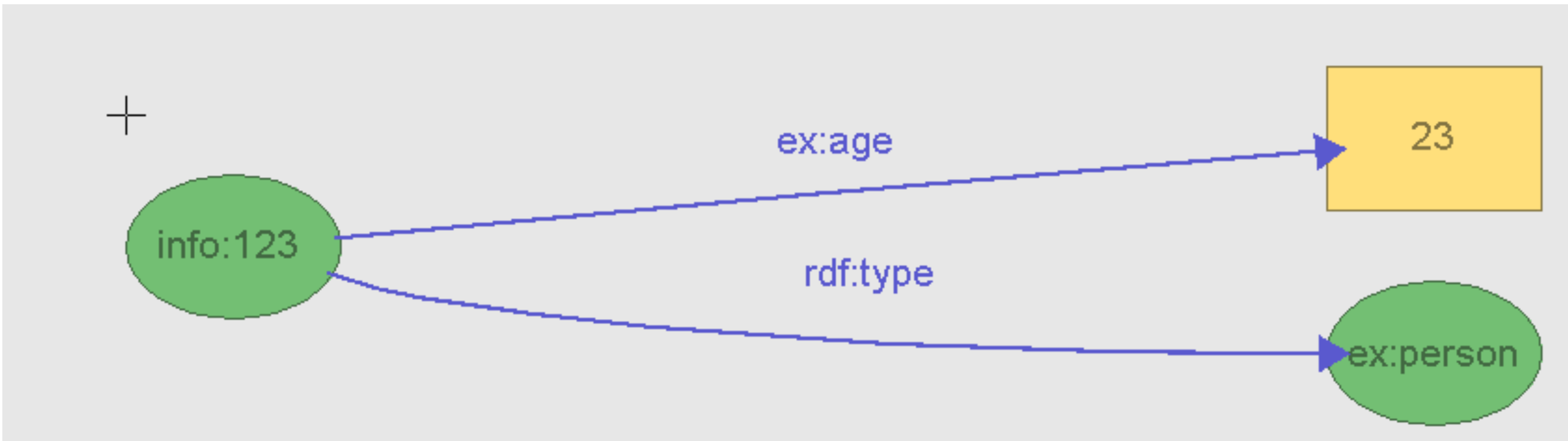
- All defined in rdf namespace
  - http://www.w3.org/1999/02/22-rdf-syntax-ns#
- Types (or classes)
  - rdf:Resource – everything that can be identified (with a URI)
  - rdf:Property – specialization of a resource expressing a binary relation between two resources
  - rdf:statement – a triple with properties rdf:subject, rdf:predicate, rdf:object
- Properties
  - rdf:type - subject is an **instance** of that category or class defined by the value
  - rdf:subject, rdf:predicate, rdf:object – relate elements of statement tuple to a resource of type statement.

Use of rdf:type

- "Resource named http://foo.org/inst is member of class http://foo.org/classes/cl1"
- <http://foo.org/inst> <rdf:type> <http://foo.org/classes/cl1>



Typing the Resources in Statements

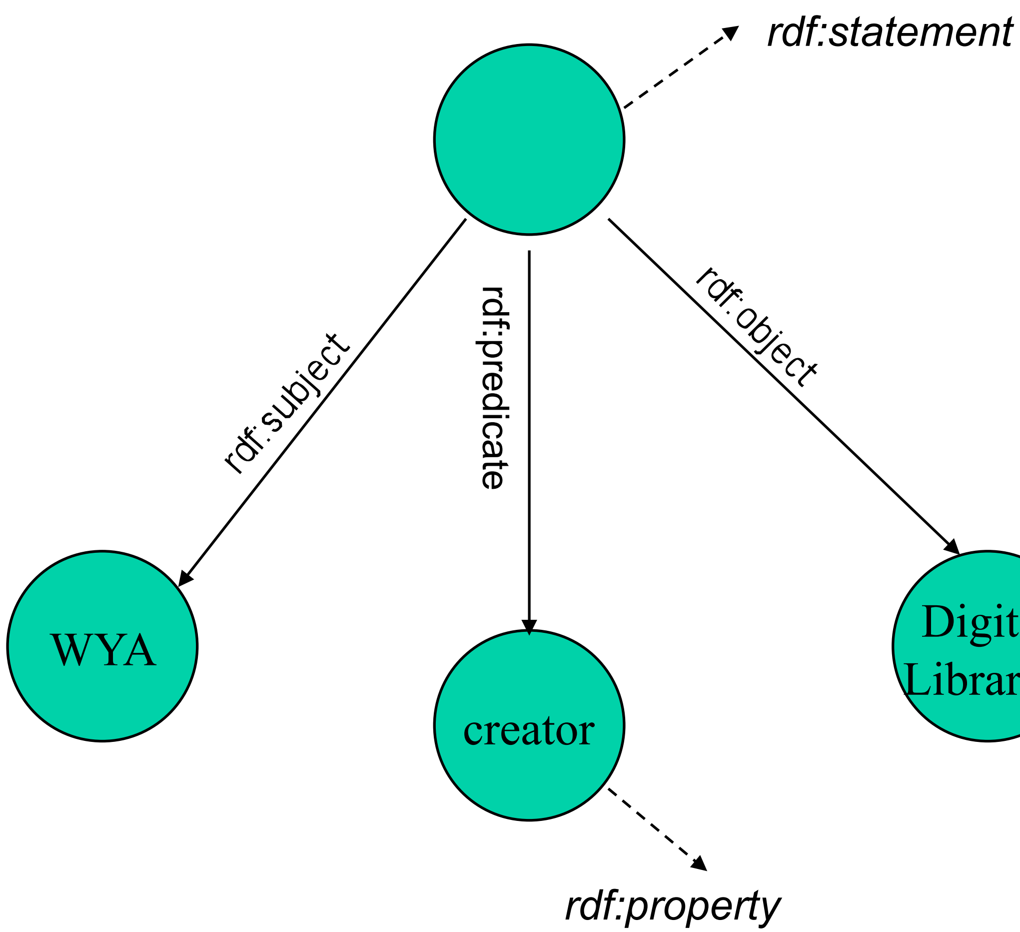



```
<?xml version="1.0" ?>
- <rdf:RDF xmlns:gss="http://www.w3.org/2001/11/IsaViz/graphstylesheets#"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:ex="http://example.org/terms#">
  - <ex:person rdf:about="info:123">
      <ex:age
        rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">23</ex:age>
    </ex:person>
  </rdf:RDF>
```

Formalizing a statement

- An RDF statement is a triple consisting of:
  - subject → rdf:type resource
  - property → rdf:type property
  - object → rdf:type resource | literal
  - Examples
    - <http://www.cs.cornell.edu/lagoze> <http://purl.org/dc/elements/creator>
      "Carl Lagoze"
    - <http://www.cs.cornell.edu/lagoze> <http://purl.org/dc/elements/creator>
      <mailto:lagoze@cs.cornell>
- Expressible as:
  - triple (ns1:s ns2:p ns3:o)

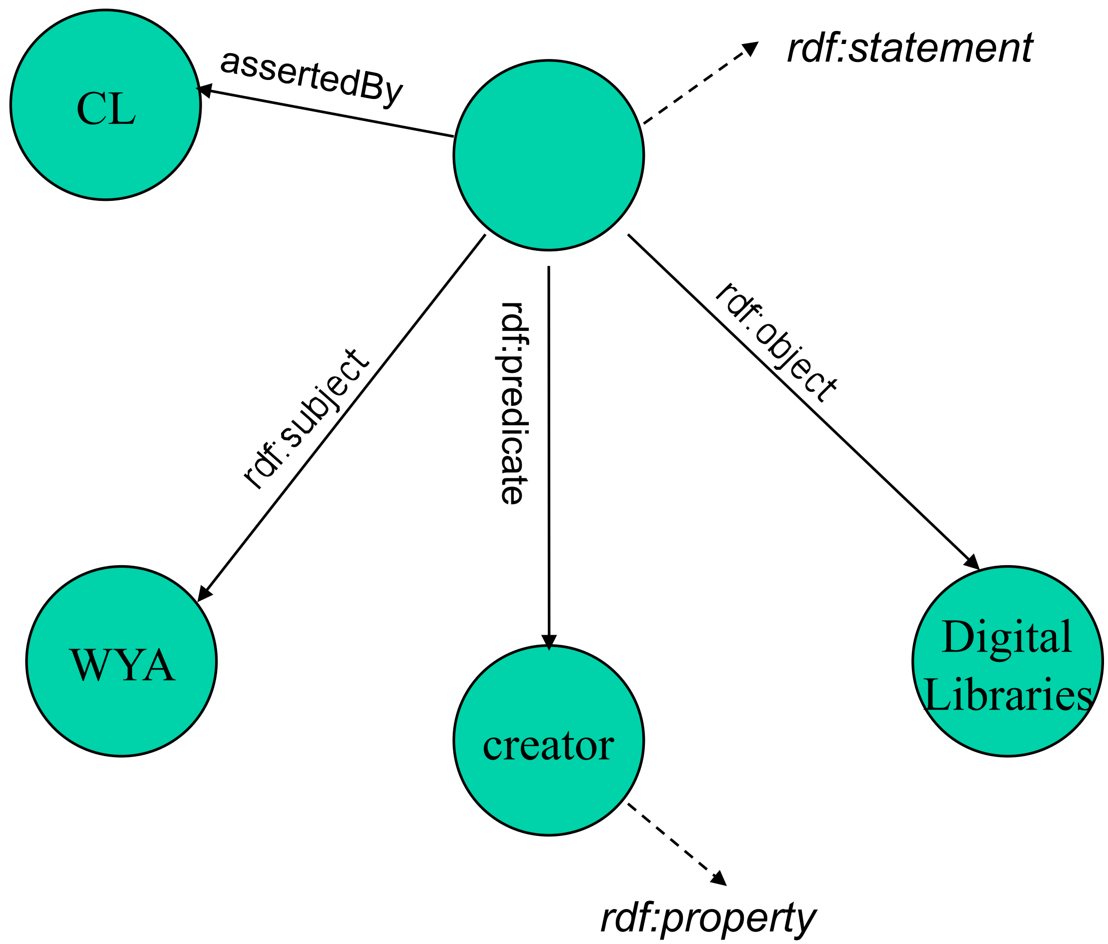
RDF statements and basic types



Simple type inferencing

explicit triple	Allows inference
(:s :p :o)	(:s rdf:type rdf:Resource) (:p rdf:type rdf:Property) (:o rdf:type rdf:Resource)

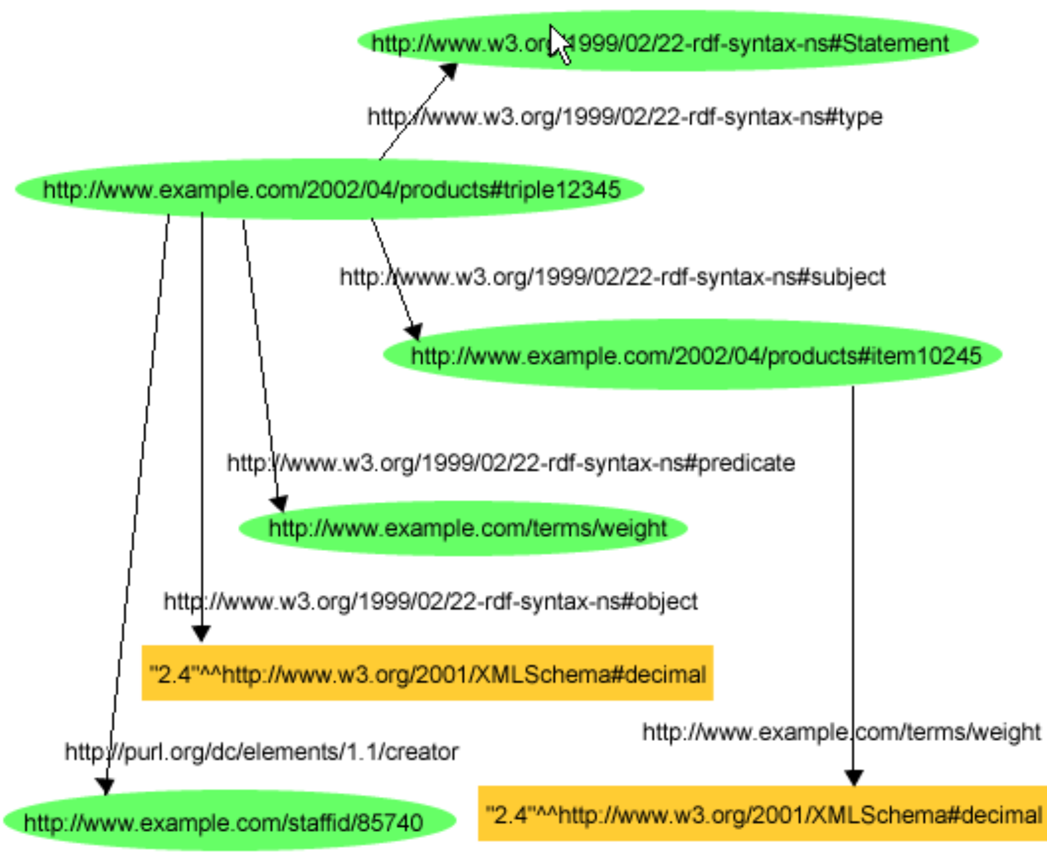
Reification – Statements about statements



"CL says 'WYA wrote Digital Libraries'"

Reification Structure

Staff member 85740 said the weight of item 10245 is 2.4 units

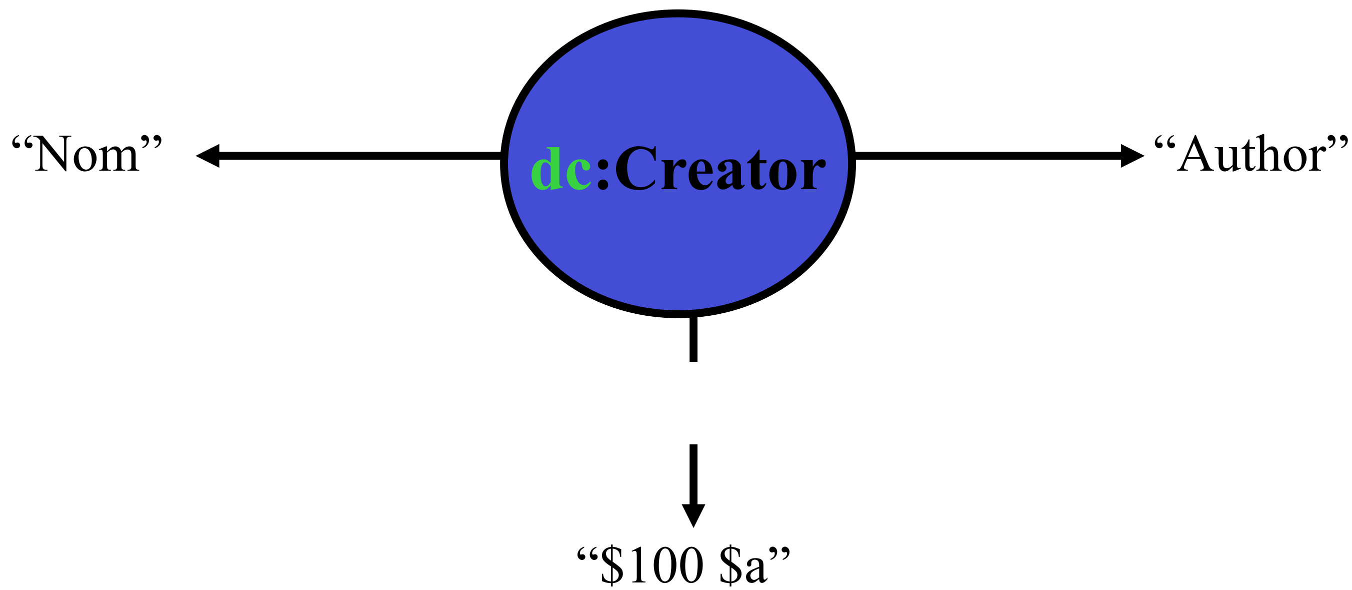


Reification XML

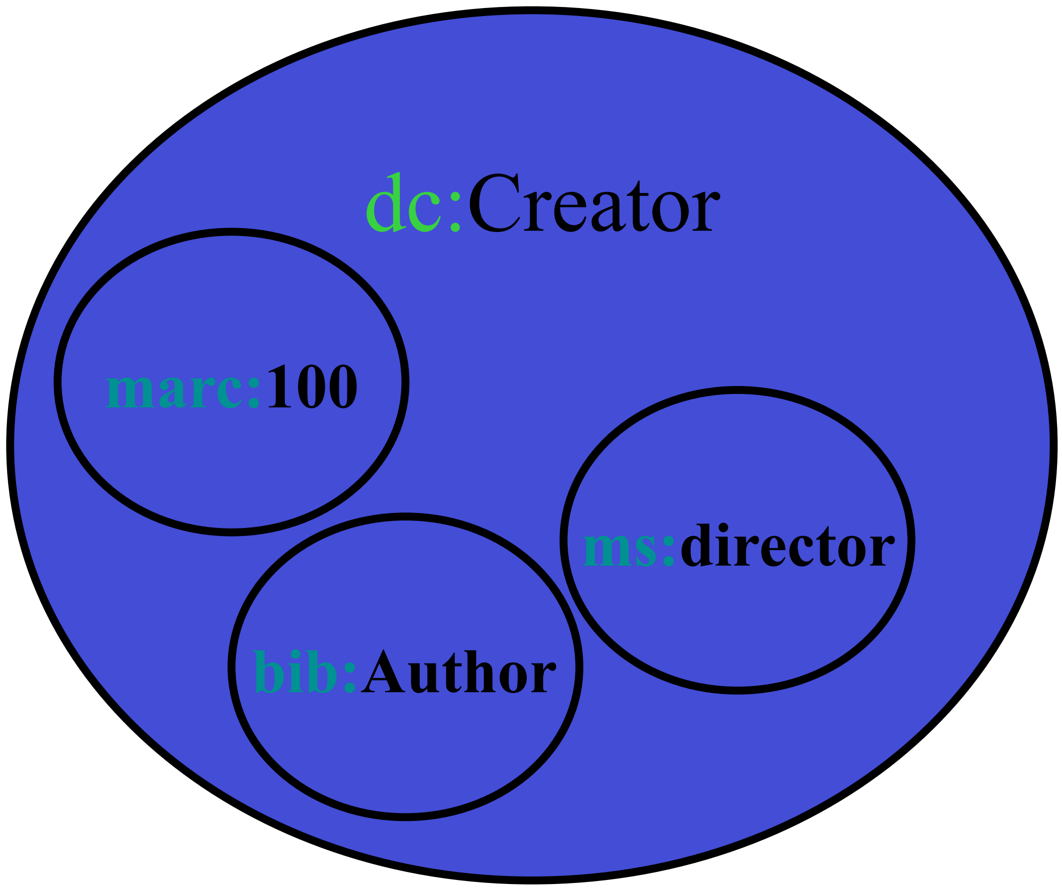
```
<?xml version="1.0"?>
<!DOCTYPE rdf:RDF [<!ENTITY xsd "http://www.w3.org/2001/XMLSchema#">]>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
            xmlns:dc="http://purl.org/dc/elements/1.1/"
            xmlns:exterms="http://www.example.com/terms/"
            xml:base="http://www.example.com/2002/04/products">

  <rdf:Description rdf:ID="item10245">
     <exterms:weight rdf:datatype="&xsd;decimal">2.4</exterms:weight>
  </rdf:Description>

  <rdf:Statement rdf:about="#triple12345">
     <rdf:subject rdf:resource="http://www.example.com/2002/04/products#item10245"/>
     <rdf:predicate rdf:resource="http://www.example.com/terms/weight"/>
     <rdf:object rdf:datatype="&xsd;decimal">2.4</rdf:object>

     <dc:creator rdf:resource="http://www.example.com/staffid/85740"/>
  </rdf:Statement>

</rdf:RDF>
```

Why Schema (1)?

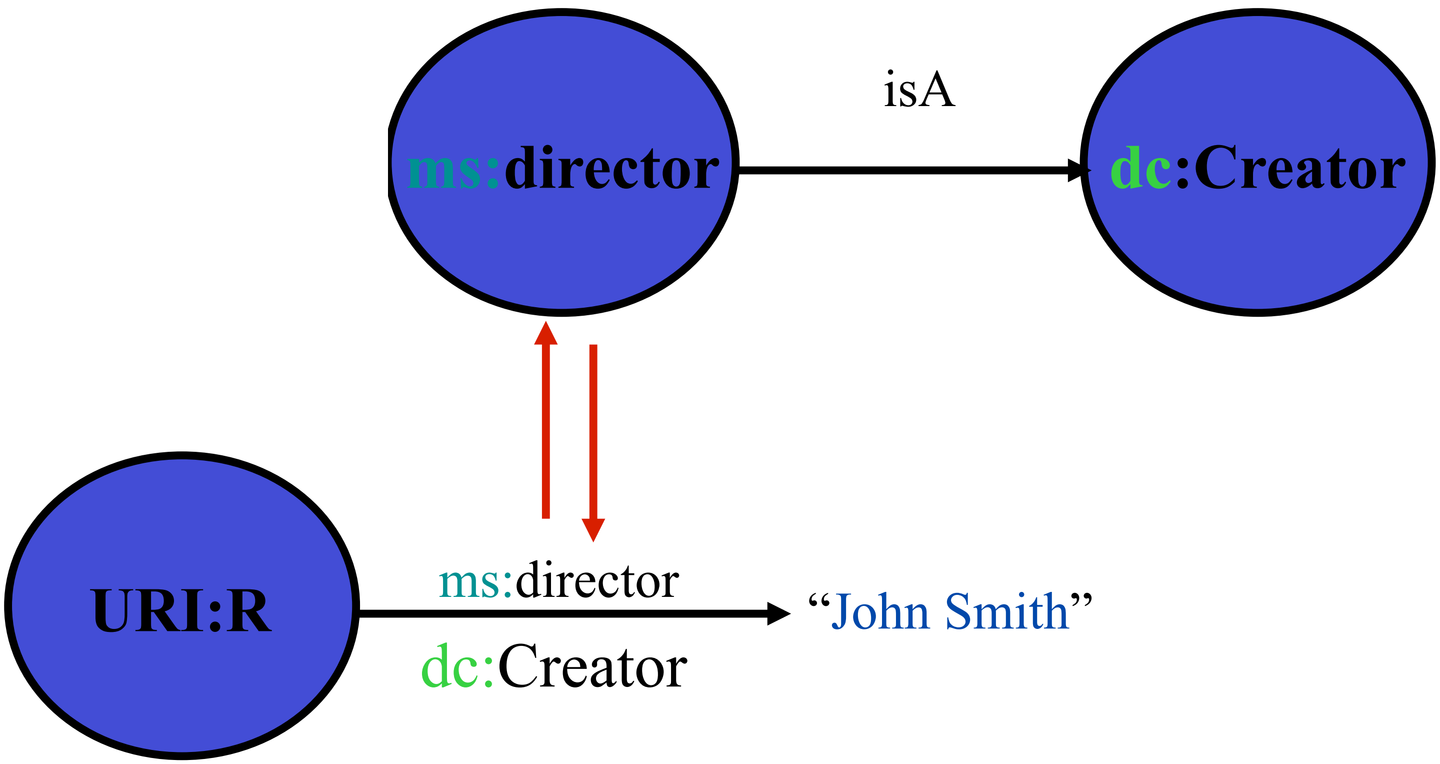
- Enables communities to share machine readable tokens and locally define human readable labels.



Why Schema (2)?
Relationships among vocabularies



Why Schema(3)?
Relationships among vocabulary elements



RDF Schemas

- Declaration of vocabularies
  - classes, properties, and relationships defined by a particular community
  - relationship of properties to classes
- Provides substructure for inferences based on existing triples
- NOT prescriptive, but descriptive
  - NOTE: This is different from XML Schema
- Schema language is an expression of basic RDF model
  - uses meta-model constructs: resources, statements, properties
  - schema are "legal" rdf graphs and can be expressed in RDF/XML syntax

RDFs Namespace

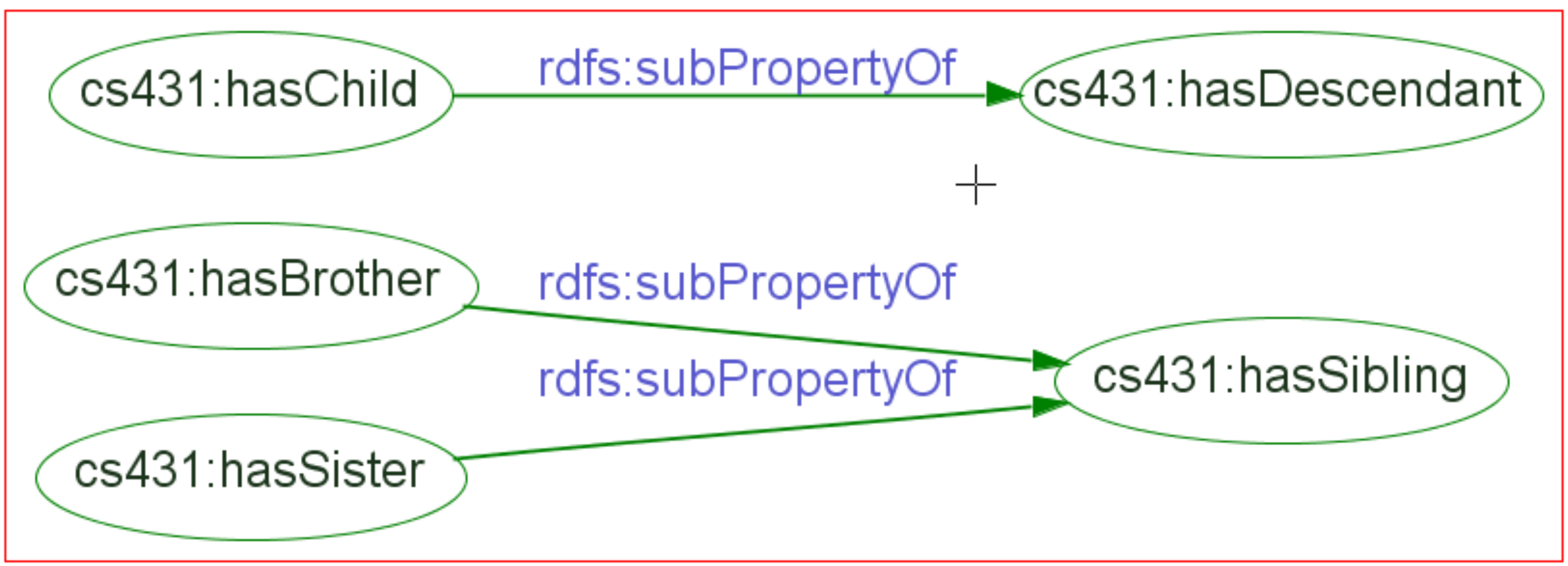
- Class-related
  - rdfs:Class, rdfs:subClassOf
- Property-related
  - rdfs:subPropertyOf, rdfs:domain, rdfs:range

RDF Schema: Specializing Properties

- rdfs:subPropertyOf – allows specialization of relations
  - E.g., the property "father" is a subPropertyOf the property parent
- subPropertyOf semantics

Explicit Model	Inferences
(:s rdfs:subPropertyOf :o)	(:s rdf:type rdf:Property) (:o rdf:type rdf:Property)
(:s :p :o) (:p rdfs:subPropertyOf :q)	(:s :q :o)
(:p rdfs:subPropertyOf :q) (:q rdfs:subPropertyOf :r)	(:p rdfs:subPropertyOf :r)

Inferences from Property Relationships



Sub-Property Semantics

- Note the inferences we can not make at this time:
  - E.g., transitivity, reflexity
- But, just wait (OWL)

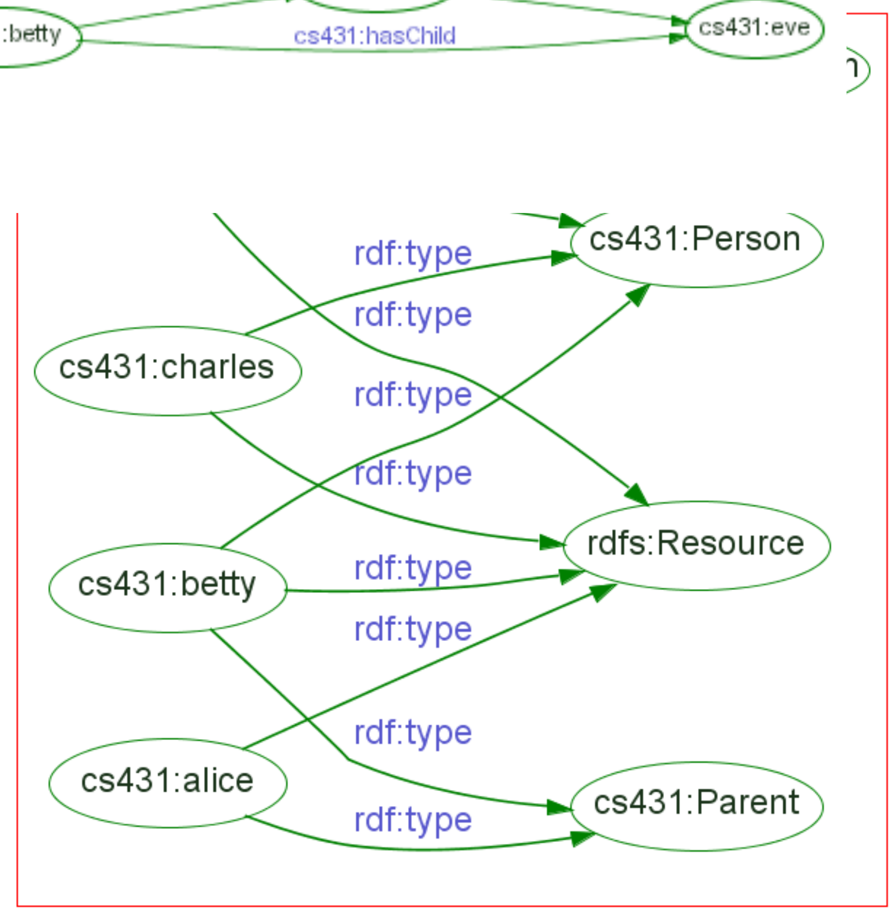
Property-based semantics

- Provide basis for type inference from properties
- NOT restrictive like xml schema constraints
- rdfs:domain
  - classes of resources that have a specific property
- rdfs:range
  - classes of resources that may be the value of a specific property

Explicit Model	Inferences
(:s :p :o) (:p rdfs:domain :t)	(:s rdf:type :t)
(:s :p :o) (:p rdfs:range :t)	(:o rdf:type :t)

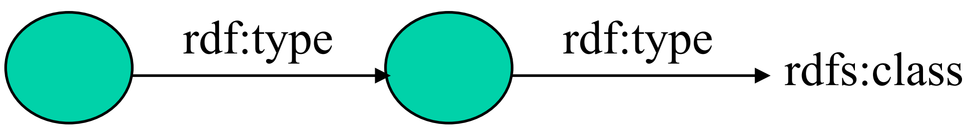
Inferences from Constraints


```
(:has-child rdfs:domain parent)
(:has-child rdfs:range person)

(:has-sibling rdfs:domain person)

(:has-brother rdfs:range :male-person)
(:has-sister rdfs:range :female-person)
```



Class Declaration

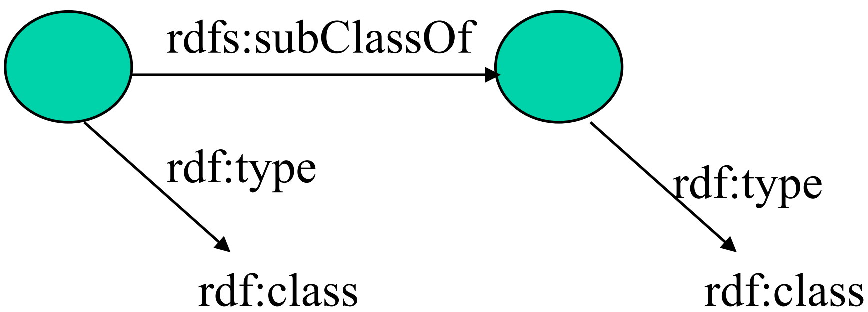
- rdfs:Class
  - A resources denoting a set of resources;
  - Range of rdf:type



ex:MotorVehicle rdf:type rdfs:Class
exthings:companyCar rdf:type ex:MotorVehicle

Class Hierarchy

- rdfs:subClassOf
  - Create class hierarchy

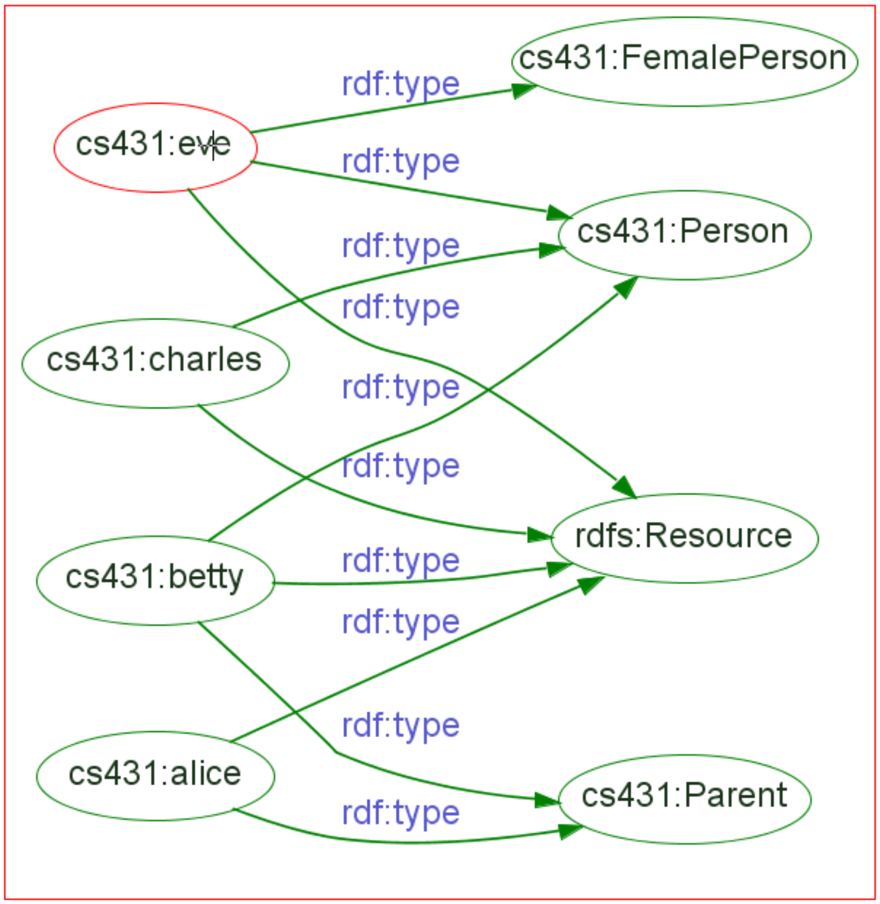


ex:MotorVehicle rdf:type rdfs:Class
ex:SUV rdf:type rdfs:Class
ex:SUV rdf:subClassOf ex:MotorVehicle
exthings:companyCar rdf:type ex:SUV

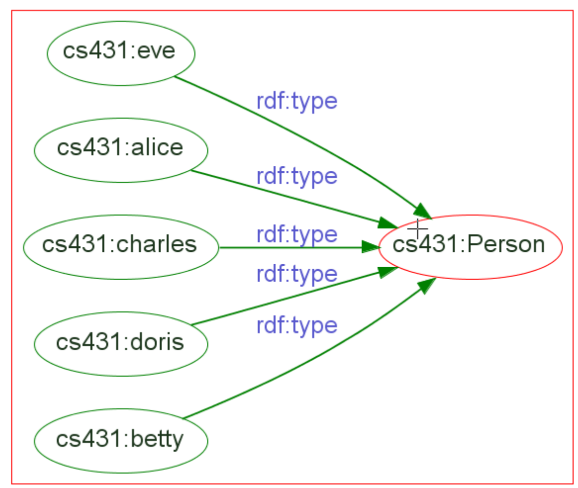
Sub-Class Inferencing

Explicit Model	Inferences
(:s rdf:type :o)	(:o rdf:type rdfs:Class)
(:s rdf:type :o) (:o rdfs:subClassOf :c)	(:s rdf:type :c)
(:s rdfs:subClassOf :o) (:o rdfs:subClassOf :c)	(:s rdfs:subClassOf :c)
(:s rdfs:subClassOf :o)	(:s rdf:type rdfs:Class) (:o rdf:type rdfs:Class)
(:s rdf:type rdfs:Class)	(:s rdfs:subClassOf rdf:Resource)

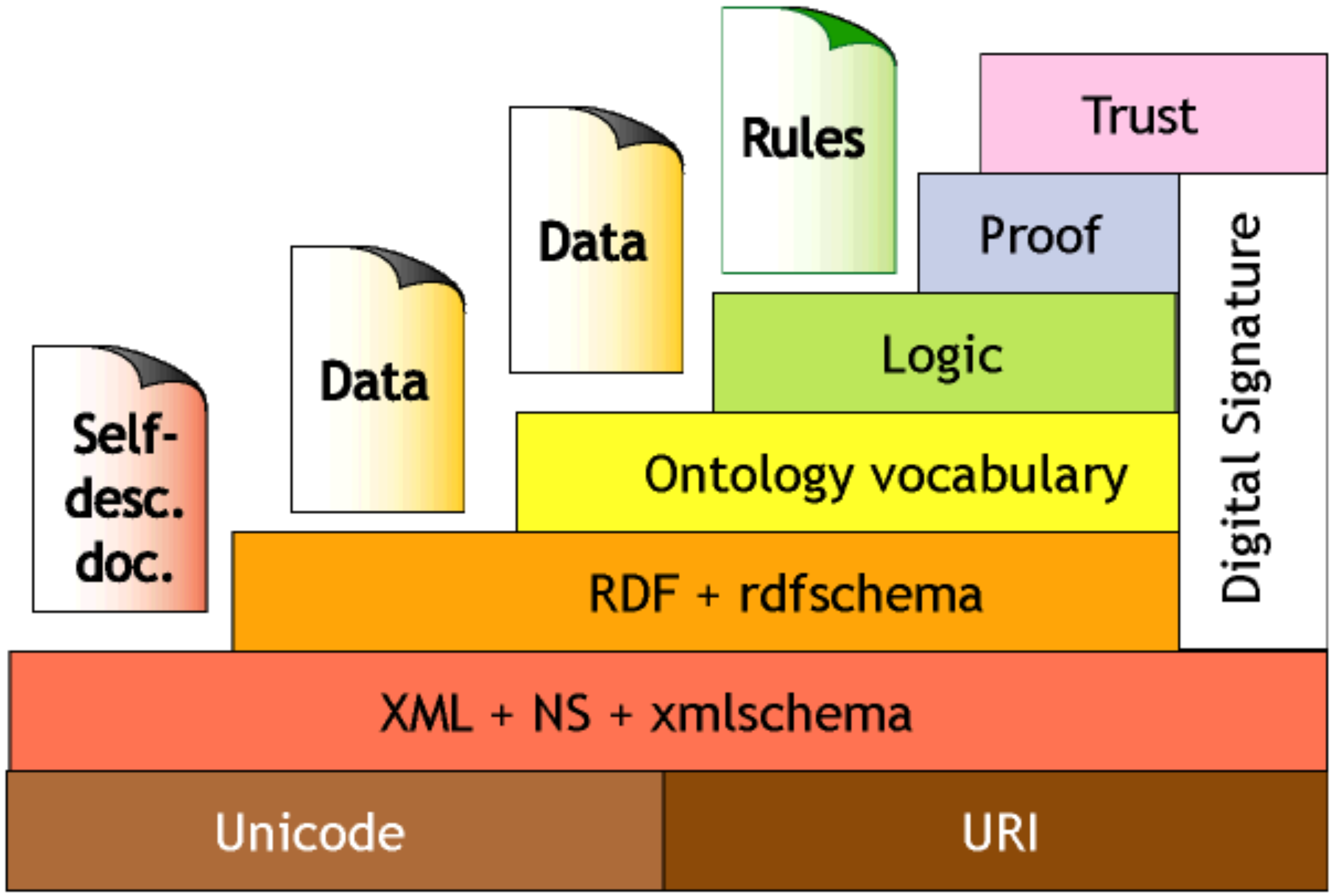
Sub-class Inferencing Example




```
(:parent rdfs:subClassOf :person)

(:male-person rdfs:subClassOf :person)
(:female-person rdfs:subClassOf :person)

(:mother rdfs:subClassOf :parent)
(:mother rdfs:subClassOf :female-person)
```



Components of the Semantic Web



Problems with RDF/RDFs Non-standard, overly "liberal" semantics

- No distinction between class and instances
  - <Species, type, Class>
  - <Lion, type, Species>
  - <Leo, type, Lion>
- Properties themselves can have properties
  - <hasDaughter, subPropertyOf, hasChild>
  - <hasDaugnter, type, Property>
- 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>
- No known reasoners for these non-standard semantics

Problems with RDF/RDFs Weaknesses in expressivity

- No localized domain and range constraints
  - Can't say the range of hasChild is person in context of persons and elephants in context of elephants
- No existence/cardinality constraints
  - Can't say that all instances of persons have a mother that is also a person
  - Can't say that persons have exactly two biological parents
- No transitive, inverse or symmetric properties
  - Can't say isPartOf is a transitive property
  - Can't say isPartOf is inverse of hasPart
  - Can't say touches is symmetric

So, we need a more expressive and well-grounded ontology language....

What is an **Ontology**?

- A formal specification of conceptualization shared in a community
- Vocabulary for defining a set of things that exist in a world view
- Formalization allows communication across application systems and extension
- Parallel concepts in other areas:
  - **Domains:** database theory
  - **Types**: AI
  - **Classes**: OO systems
  - **Types/Sorts**: Logic
- Global vs. Domain-specific

XML and RDF are **ontologically neutral**

- No standard vocabulary just primitives
  - Resource, Class, Property, Statement, etc.
- Compare to classic first order logic
  - Conjunction, disjunction, implication, existential, universal quantifier

Components of an Ontology

- Vocabulary (concepts)
- Structure (attributes of concepts and hierarchy)
- Relationships between concepts
- Logical characteristics of relationships
  - Domain and range restrictions
  - Properties of relations (symmetry, transitivity)
  - Cardinality of relations
  - etc.

Wordnet

- On-line lexical reference system, domain-independent
- >100,000 word meanings organized in a taxonomy with semantic relationships
  - Synonymy, meronymy, hyponymy, hypernymy
- Useful for text retrieval, etc.
- http://www.cogsci.princeton.edu/~wn/online/

CYC

- Effort in AI community to accommodate all of human knowledge!!!
- Formalizes concepts with logical axioms specifying constraints on objects and classes
- Associated reasoning tools
- Contents are proprietary but there is OpenCyc
  - http://www.opencyc.org/

So why re-invent ontologies for the Web

- Not re-invention
  - Same underlying formalisms (frames, slots, description logic)
- But new factors
  - Massive scale
    - Tractability
    - Knowledge expressiveness must be limited or reasoning must be incomplete
  - Lack of central control
    - Need for federation
    - Inconsistency, lies, re-interpretations, duplications
    - New facts appear and modify constantly
  - Open world vs. Close world assumptions
    - Contrast to most reasoning systems that assume anything absent from knowledge base is not true
    - Need to maintain monotonicity with tolerance for contradictions
  - Need to build on existing standards
    - URI, XML, RDF

Web Ontology Language (OWL)

- W3C Web Ontology Working Group (WebOnt)
- Follow on to DAML, OIL efforts
- W3C Recommendation
- Vocabulary extension of RDF

Species of OWL

- **OWL Lite**
  - Good for classification hierarchies with simple constraints (e.g., thesauri)
  - Reasoning is computational simple and efficient
- **OWL DL**
  - Computationally complete and decidable (computation in finite time)
  - Correspondence to **description logics** (decidable fragment of first-order logic)
- **OWL Full**
  - Maximum expressiveness
  - No computational guarantees (probably never will be)

- Each language is extension of simpler predecessor

Description Logics

- Fragment of first-order logic designed for logical representation of object-oriented formalisms
  - frames/classes/concepts
    - sets of objects
  - roles/properties
    - binary relations on objects
  - individuals
- Representation as a collection of statements, with unary and binary predicates that stand for concepts and roles, from which deductions can be made
- High expressivity with decidability and completeness
  - Decidable fragment of FOL

Description Logics Primitives

- Atomic Concept
  - Human
- Atomic Role
  - likes
- Conjunction
  - human **intersection** male
- Disjunction
  - nice **union** rich
- Negation
  - **not** rich
- Existential Restriction
  - **exists** has-child.Human
- Value Restriction
  - **for-all** has-child.Blond
- Number Restriction
  - ≥ 2 has-wheels
- Inverse Role
  - has-child, has-parent
- Transitive role
  - has-child

Description Logic - Tboxes

- Terminological knowledge
- Concept Definitions
  - Father is conjunction of Man and has-child.Human
- Axioms
  - motorcycle **subset-of** vehicle
  - has-favorite.Brewery **subrelation-of** drinks.Beer

Description Logics: Aboxes

- Assertional knowledge
- Concept assertions
  - John is-a Man
- Role assertions
  - has-child(John, Bill)

Description Logics: Basic Inferencing

- Subsumption
  - Is C1 subclass-of C2
  - Compute taxonomy
- Consistency
  - Can C have any individuals

Namespaces and OWL

```
<rdf:RDF
    xmlns     ="http://www.w3.org/TR/2004/REC-owl-guide-20040210/wine#"
    xmlns:vin ="http://www.w3.org/TR/2004/REC-owl-guide-20040210/wine#"
    xml:base  ="http://www.w3.org/TR/2004/REC-owl-guide-20040210/wine#"
    xmlns:food="http://www.w3.org/TR/2004/REC-owl-guide-20040210/food#"
    xmlns:owl ="http://www.w3.org/2002/07/owl#"
    xmlns:rdf ="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:xsd ="http://www.w3.org/2001/XMLSchema#">
```

OWL Class Definition

```
<owl:Class rdf:ID="Winery"/>
<owl:Class rdf:ID="Region"/>
<owl:Class rdf:ID="ConsumableThing"/>
```

```
<owl:Class rdf:ID="Wine">
  <rdfs:subClassOf rdf:resource="&food;PotableLiquid"/>
  <rdfs:label xml:lang="en">wine</rdfs:label>
  <rdfs:label xml:lang="fr">vin</rdfs:label>
  ...
</owl:Class>
```

Why owl:class vs. rdfs:class

- Rdfs:class is "class of all classes"
- In DL class can not be treated as individuals (undecidable)
- Thus owl:class, which is expressed as rdfs:subclass of rdfs:class
  - No problem for standard rdf processors since an owl:class "is a" rdfs:class
- Note: there are other times you want to treat class of individuals
  - Class drinkable liquids has instances wine, beer, ….
  - Class wine has instances merlot, chardonnay, zinfandel, …

OWL class building operations

- disjointWith
  - No vegetarians are carnivores
- sameClassAs (equivalence)
- Enumerations (on instances)
  - The Ivy League is Cornell, Harvard, Yale, ….
- Boolean set semantics (on classes)
  - Union (logical disjunction)
    - Class **parent** is union of **mother, father**
  - Intersection (logical conjunction of class with properties)
    - Class **WhiteWine** is conjunction of things of class **wine** and have property **white**
  - complimentOf (logical negation)
    - Class **vegetarian** is disjunct of class **carnivore**

OWL Properties

- Two types
  - ObjectProperty - relations between instances of classes
  - DatatypeProperty - relates an instance to an rdfs:Literal or XML Schema datatype

  (Both rdfs:subClassOf rdf:Property)

```
<owl:DatatypeProperty rdf:ID="name">
   <rdfs:domain rdf:resource="Person" />
   <rdfs:range rdf:resource=
        "http://www.w3.org/2001/XMLSchema/string" />
</owl:DatatypeProperty>
<owl:ObjectProperty rdf:ID="activity">
   <rdfs:domain rdf:resource="Person" />
   <rdfs:range rdf:resource="ActivityArea" />
</owl: ObjectProperty>
```

OWL property building operations & restrictions

- Transitive Property
  - P(x,y) and P(y,z) -> P(x,z)
- SymmetricProperty
  - P(x,y) iff P(y,x)
- Functional Property
  - P(x,y) and P(x,z) -> y=z
- inverseOf
  - P1(x,y) iff P2(y,x)
- InverseFunctional Property
  - P(y,x) and P(z,x) -> y=z
- Cardinality
  - Only 0 or 1 in lite and full

OWL DataTypes

- Full use of XML schema data type definitions
- Examples
  - Define a type age that must be a non-negative integer
  - Define a type clothing size that is an enumeration “small” “medium” “large”

OWL Instance Creation

- Create individual objects filling in slot/attribute/ property definitions

```
<Person ref:ID=“William Arms”>
    <rdfs:label>Bill</rdfs:label>
    <age><xsd:integer rdf:value=“57”/></age>
    <shoesize><xsd:decimal rdf:value=“10.5”/></shoesize>
</Person>
```

OWL Lite Summary

Schema constructs
- Class (i.e. owl:Class)
- rdf:Property
- rdfs:subClassOf
- rdfs:subPropertyOf
- rdfs:domain
- rdfs:range
- Individual

Property characteristics
- inverseOf
- TransitiveProperty
- FunctionalProperty
- InverseFunctionalProperty
- SymmetricProperty

Equality constructs
- equivalentClass
- equivalentProperty
- sameIndividualAs
- differentFrom
- allDifferent

Cardinality
- minCardinality (0 or 1)
- maxCardinality (0 or 1)
- Cardinality (0 or 1)

Class intersection
- intersectionOf

Headers
- imports
- priorVersion
- backwardCompatibleWith
- incompatibleWith

Property type restrictions
- allValuesFrom
- someValuesFrom

RDF datatyping

OWL DL and Full Summary

Class axioms	Class expressions
oneOf	equivalentClass
disjointWith	rdfs:subClassOf
	unionOf
	intersectionOf
	complementOf
Property fillers	**Arbirtary cardinality**
hasValue	minCardinality
	maxCardinality
	Cardinality

OWL DL vs. OWL-Full

- Same vocabulary
- OWL DL restrictions
  - Type separation
    - Class can not also be an individual or property
    - Property can not also be an individual or class
  - Separation of ObjectProperties and DatatypeProperties

Language Comparison

	DTD	XSD	RDF(S)	OWL
Bounded lists (“X is known to have exactly 5 children”)				X
Cardinality constraints (Kleene operators)	X	X		X
Class expressions (unionOf, complementOf)				X
Data types		X		X
Enumerations	X	X		X
Equivalence (properties, classes, instances)				X
Formal semantics (model-theoretic & axiomatic)				X
Inheritance			X	X
Inference (transitivity, inverse)				X
Qualified contraints (“all children are of type person”				X
Reification			X	X

Protégé and RACER – tools for building, manipulating and reasoning over ontologies

- Protégé - http://protege.stanford.edu/
  - Use the 3.x version
  - Multiple plug-ins are available
- Protégé OWL plug-in
  - http://protege.stanford.edu/plugins/owl/
- Other semantic web related plug-ins
  - http://protege.cim3.net/cgi-bin/wiki.pl?ProtegePluginsLibraryByTopic#nid349
- Racer
  - Description Logic based reasoning engine
  - Server-based
  - Integrates with Protégé-OWL