Semantic Web - OWL

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Carl Lagoze – Cornell University

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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.

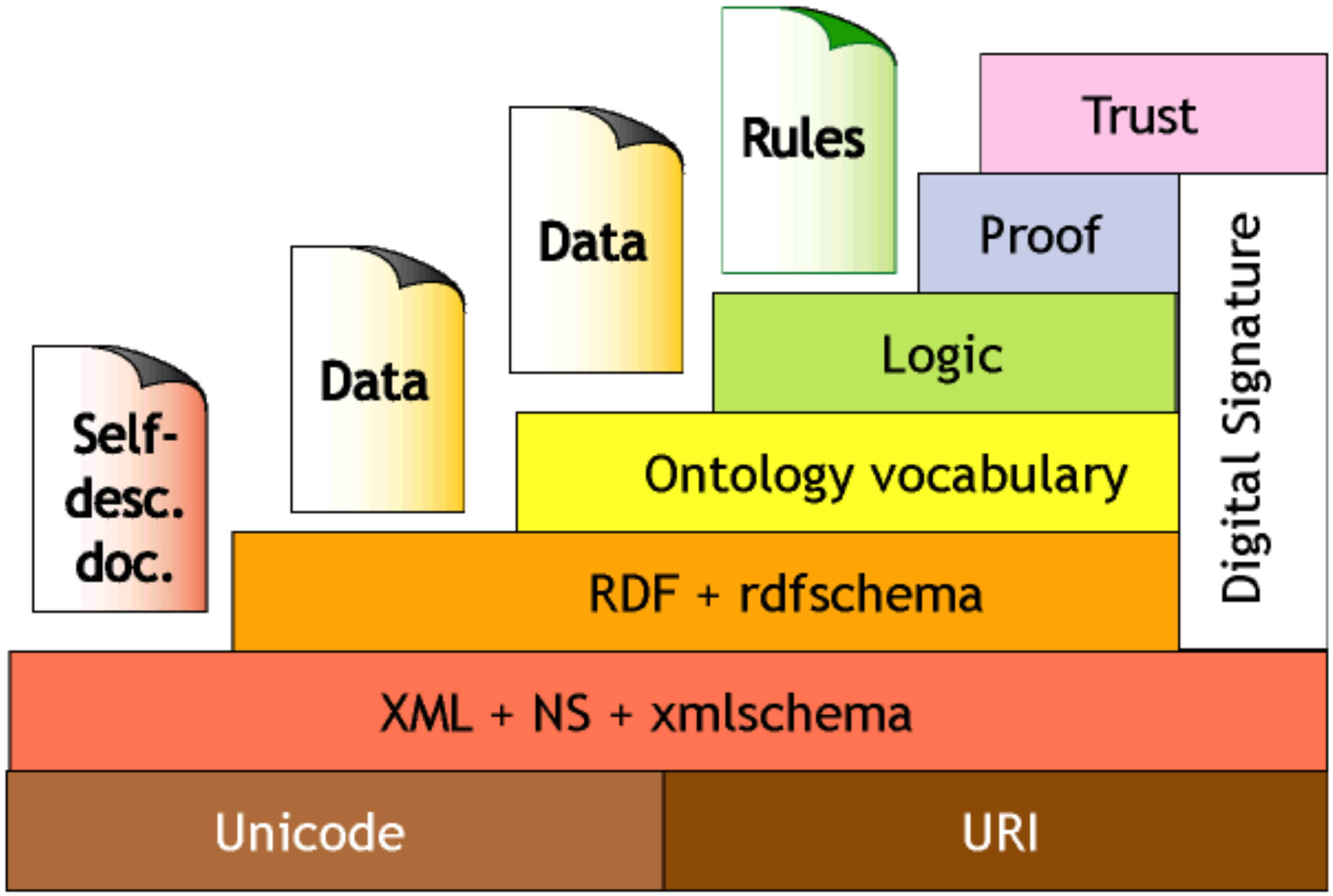
RDFs Namespace

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

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)

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….

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

Relationship between OWL and RDF(s)

- OWL Full is extension of RDF
- OWL Lite and DL are extensions of a restricted view of RDF
- Every OWL document is an RDF document
- Every RDF document is an OWL Full document
- Only some RDF documents are OWL Lite or OWL DC
- Constraining an RDF document to be OWL Lite or DL
  - Every individual must have class membership (at least owl:thing)
  - URIs for classes, properties, and individuals must be mutually disjoint.

The “DL” in Owl DL

- Description Logics
- Goal: want to be able to reason (infer information) about a knowledge base
- Remember: a knowledge base consists of both meta (schema) information and instance (individual) information
- Remember: we want to do this based on an open world assumption
- OWL (Lite/DL) is then an RDF expression of DL

Closed World

John has a sister Betty

Betty has a sister Mary

Does John have a brother?

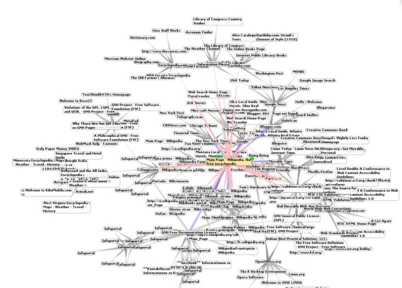
No!

Open World

John has a sister Betty

Betty has a sister Mary

Does John have a brother?



??

Description Logics

- Highly expressable fragment of FOL with:
  - Decidability: guaranteed that computation can be done in finite amount of time
  - Completeness: every question within the logical system can be answered, or there are no paradoxes
- Designed for logical representation of object-oriented formalisms
  - frames/classes/concepts
    - sets of objects
  - roles/properties
    - binary relations on objects
  - individuals
- Represented as a collection of statements, with unary and binary predicates that stand for concepts and roles, from which deductions can be made

Description Logics Primitives

- Atomic Concept
  - Human
- Atomic Role
  - likes
- Conjunction
  - human *intersection* male
- Disjunction
  - nice *union* rich
- Negation
  - *not* rich
- Existential Class Restriction
  - *exists* enrolledIn.CSclass
- Universal Class Restriction
  - *all.enrolledIn*.CSclass
- Cardinality Restriction
  - ≥ 2 has-wheels
- Inverse Roles
  - has-child, has-parent
- Transitive roles
  - 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

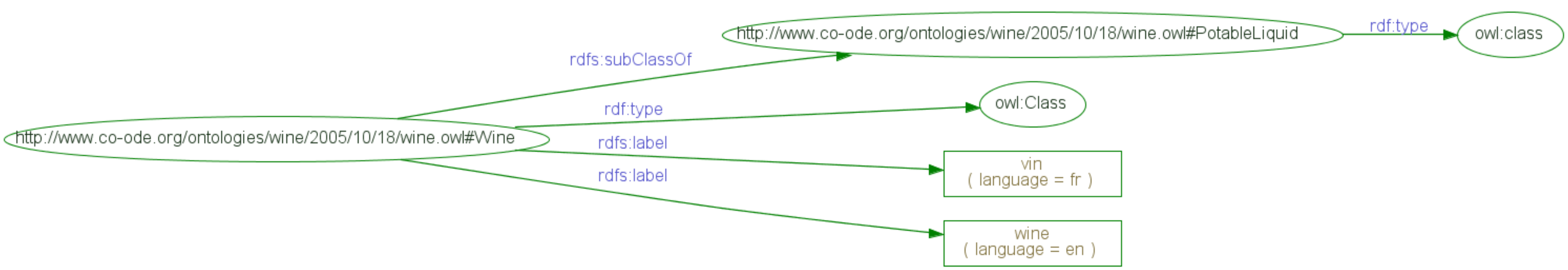
- Note what is NOT included
  - Does assertional knowledge follow constraints of terminological knowledge
  - Ontologies will provide an inference mechanisms, not a constraint mechanism (remember the open world)

Namespaces and OWL

```
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.co-ode.org/ontologies/wine/2005/10/18/wine.owl#"
  xml:base="http://www.co-ode.org/ontologies/wine/2005/10/18/wine.owl"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
  xmlns:dc="http://purl.org/dc/elements/1.1/"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:owl="http://www.w3.org/2002/07/owl#">
```

OWL Class Definition

```
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.co-ode.org/ontologies/wine/2005/10/18/wine.owl#"
  xml:base="http://www.co-ode.org/ontologies/wine/2005/10/18/wine.owl"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#" xmlns:dc="http://purl.org/dc/elements/1.1/"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:owl="http://www.w3.org/2002/07/owl#">
  <owl:class rdf:ID="PotableLiquid"/>
  <owl:Class rdf:ID="Wine">
    <rdfs:subClassOf rdf:resource="#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, but you give up decidability
  - Class drinkable liquids has instances wine, beer, ….
  - Class wine has instances merlot, chardonnay, zinfandel, …

OWL class building operations

- disjointWith
  - No individuals who are vegetarians are carnivores
- sameClassAs (equivalence)
  - All individuals that are in class human are in class homo sapien
  - Relationship is reflexive, unlike subClass
- Enumerations (on instances)
  - The Ivy League only has individuals 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 *bad wine* is compliment of class *French wine*

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>
```

All properties must be one or the other.

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

All this allows a whole bunch of new inferences

- Candy bar time….
- RDQLPlus - http://rdqlplus.sourceforge.net/doc/ridiql.html

Class/Property Example

```xml
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.co-ode.org/ontologies/wine/2005/10/18/wine.owl#"
  xml:base="http://www.co-ode.org/ontologies/wine/2005/10/18/wine.owl"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#" xmlns:dc="http://purl.org/dc/elements/1.1/"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:owl="http://www.w3.org/2002/07/owl#">
  <owl:class rdf:ID="PotableLiquid"/>
  <owl:Class rdf:ID="Wine">
    <rdfs:subClassOf rdf:resource="#PotableLiquid"/>
    <rdfs:label xml:lang="en">wine</rdfs:label>
    <rdfs:label xml:lang="fr">vin</rdfs:label>
  </owl:Class>
  <owl:DatatypeProperty rdf:ID="color">
    <rdfs:domain rdf:resource="#Wine"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema/string"/>
  </owl:DatatypeProperty>
  <owl:Class rdf:ID="Appellation"/>
  <owl:ObjectProperty rdf:ID="hasAppellation">
    <rdfs:domain rdf:resource="#Wine"/>
    <rdfs:range rdf:resource="#Appellation"/>
  </owl:ObjectProperty>
  <owl:ObjectProperty rdf:ID="producesWine">
    <rdfs:range rdf:resource="#Wine"/>
    <rdfs:domain rdf:resource="#Appellation"/>
    <owl:inverseOf rdf:resource="#hasAppellation"/>
  </owl:ObjectProperty>
</rdf:RDF>
```

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

RDF Schema Features:

- Class (Thing, Nothing)
- rdfs:subClassOf
- rdf:Property
- rdfs:subPropertyOf
- rdfs:domain
- rdfs:range
- Individual

(In)Equality:

- equivalentClass
- equivalentProperty
- sameAs
- differentFrom
- AllDifferent
- distinctMembers

Property Characteristics:

- ObjectProperty
- DatatypeProperty
- inverseOf
- TransitiveProperty
- SymmetricProperty
- FunctionalProperty
- InverseFunctionalProperty

Property Restrictions:

- Restriction
- onProperty
- allValuesFrom
- someValuesFrom

Restricted Cardinality:

- minCardinality (only 0 or 1)
- maxCardinality (only 0 or 1)
- cardinality (only 0 or 1)

Header Information:

- Ontology
- imports

Class Intersection:

- intersectionOf

Datatypes

- xsd datatypes

Versioning:

- versionInfo
- priorVersion
- backwardCompatibleWith
- incompatibleWith
- DeprecatedClass
- DeprecatedProperty

Annotation Properties:

- rdfs:label
- rdfs:comment
- rdfs:seeAlso
- rdfs:isDefinedBy
- AnnotationProperty
- OntologyProperty

OWL DL and Full Summary

Class Axioms:

- *oneOf, dataRange*
- *disjointWith*
- *equivalentClass* (applied to class expressions)
- *rdfs:subClassOf* (applied to class expressions)

Boolean Combinations of Class Expressions:

- *unionOf*
- *complementOf*
- *intersectionOf*

Arbitrary Cardinality:

- *minCardinality*
- *maxCardinality*
- *cardinality*

Filler Information:

- *hasValue*

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

Storing and querying RDF-based models

- Persistent storage implementations
  - Jena 2 - http://www.hpl.hp.com/semweb/jena2.htm
    - Relational databases (mysql , postgres, oracle)
  - Kowari – http://www.kowari.org
    - Mapped files
  - Sesame - http://www.openrdf.org/
    - Relational databases (mysql, postgres, oracle)
- Query languages
  - RDQL (Kowari, Jena)
  - SPARQL
    - W3C working draft
    - http://www.w3.org/TR/rdf-sparql-query/

RDQL-by-example

- RDF source
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-db-3.rdf
- Queries
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q1
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q2
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q3
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q4
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q5
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q6
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q7
  - http://www.cs.cornell.edu/courses/cs431/2006sp/examples/RDQL/vc-q8

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