Semantic Web Schema and Ontologies

CS 431 – April 3, 2006

Carl Lagoze – Cornell University

Acknowledgements for various slides and ideas

- Ian Horrocks (Manchester U.K.)
- Eric Miller (W3C)
- Dieter Fensel (Berlin)
- Volker Haarslev (Montreal)

Jena Toolkit

- Robust tools for building and manipulating RDF models
  - HP Labs Bristol
  - Capabilities
    - Model construction
    - XML and N3 parsing
    - Model persistence (DB foundation)
    - Model querying
    - Ontology building
    - Inferencing
- http://jena.sourceforge.net/index.html

RDQLPlus

- Simple RDF and OWL experimentation application
- http://rdqlplus.sourceforge.net/
- Chris Wilper - Cornell

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

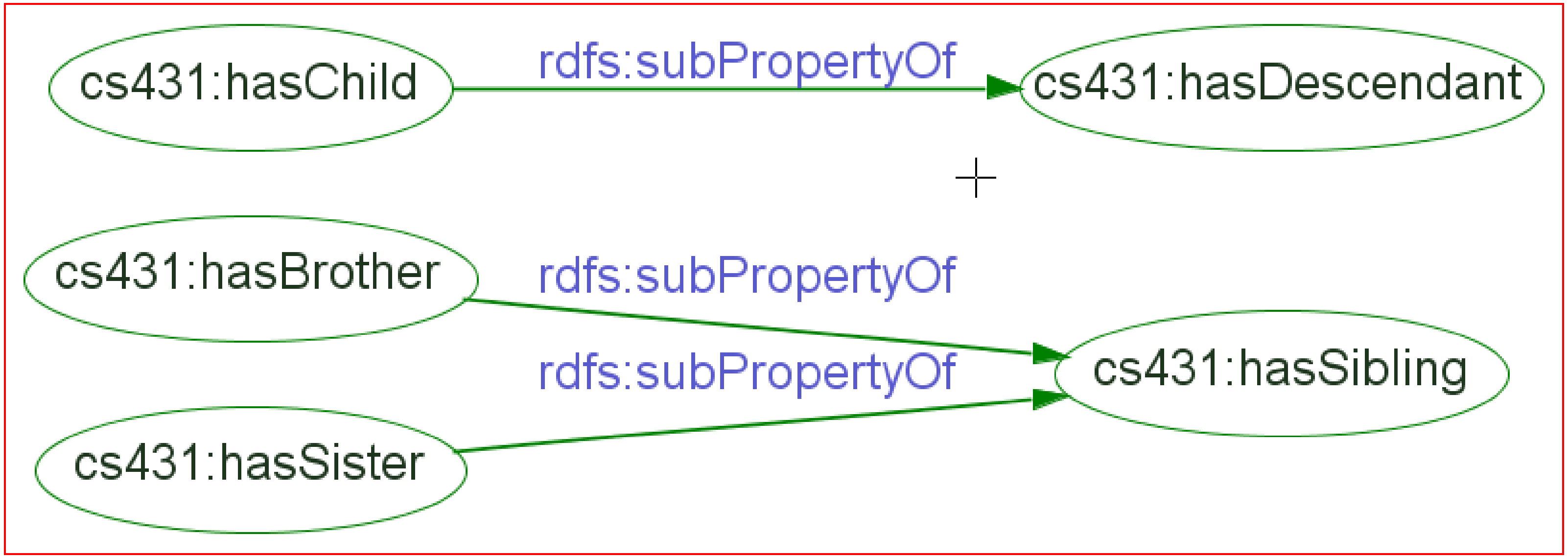
- Class-related
  - rdfs:Class, rdfs:subClassOf
- Property-related
  - rdfs:subPropertyOf, rdfs:domain, rdfs:range

RDF Schema: Specializing Properties

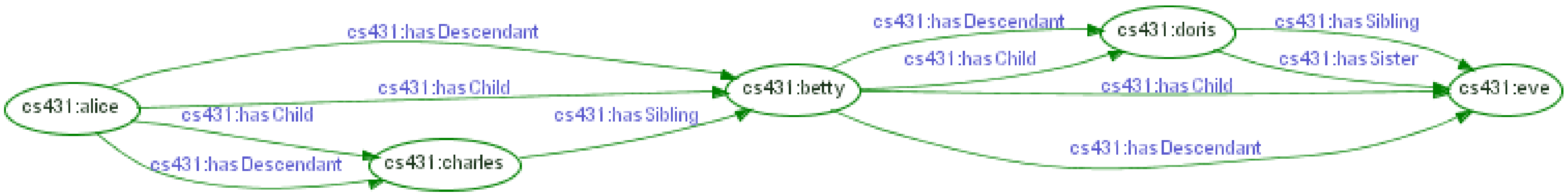
- rdfs:subPropertyOf – allows specialization of relations
  - E.g., the property “father” is a subPropertyOf the property parent
- subPropertyOf semantics

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

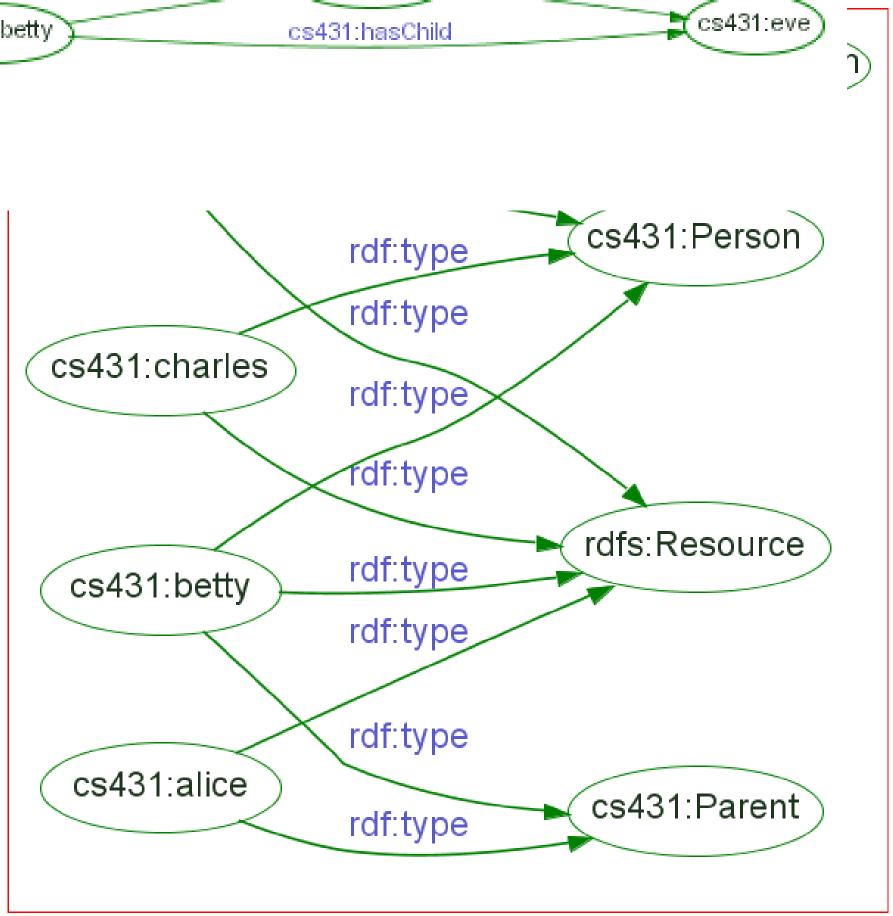
Explicit Model	Inferences
(:s :p :o) (:p rdfs:domain :t)	(:s rdf:type :t)
(:s :p :o) (:p rdfs:range :t)	(:o rdf:type :t)

Inferences from Constraints

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

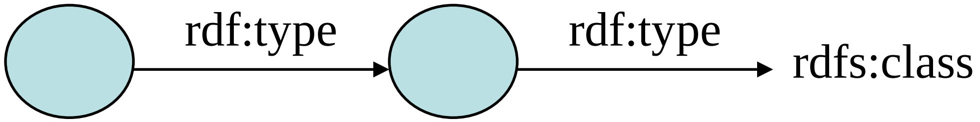
(:has-sibling rdfs:domain person)

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



Class Declaration

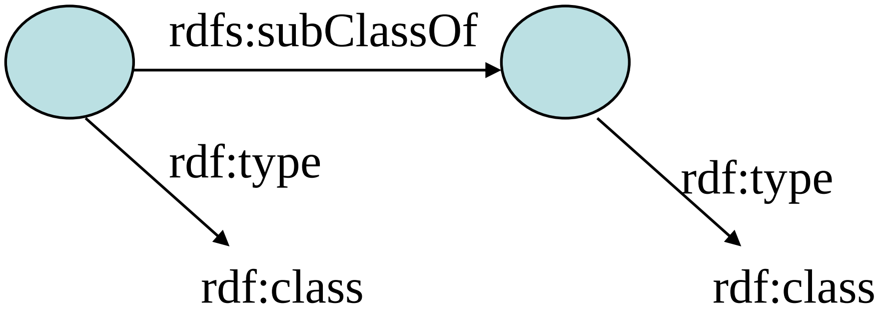
- rdfs:Class
  - A resources denoting a set of resources;
  - Range of rdf:type



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

Class Hierarchy

- rdfs:subClassOf
  - Create class hierarchy

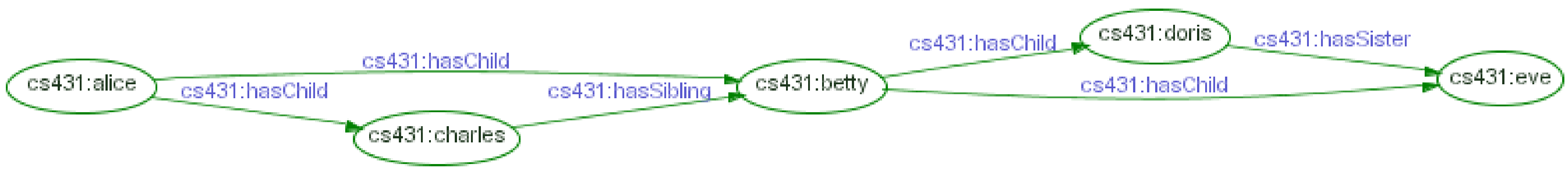


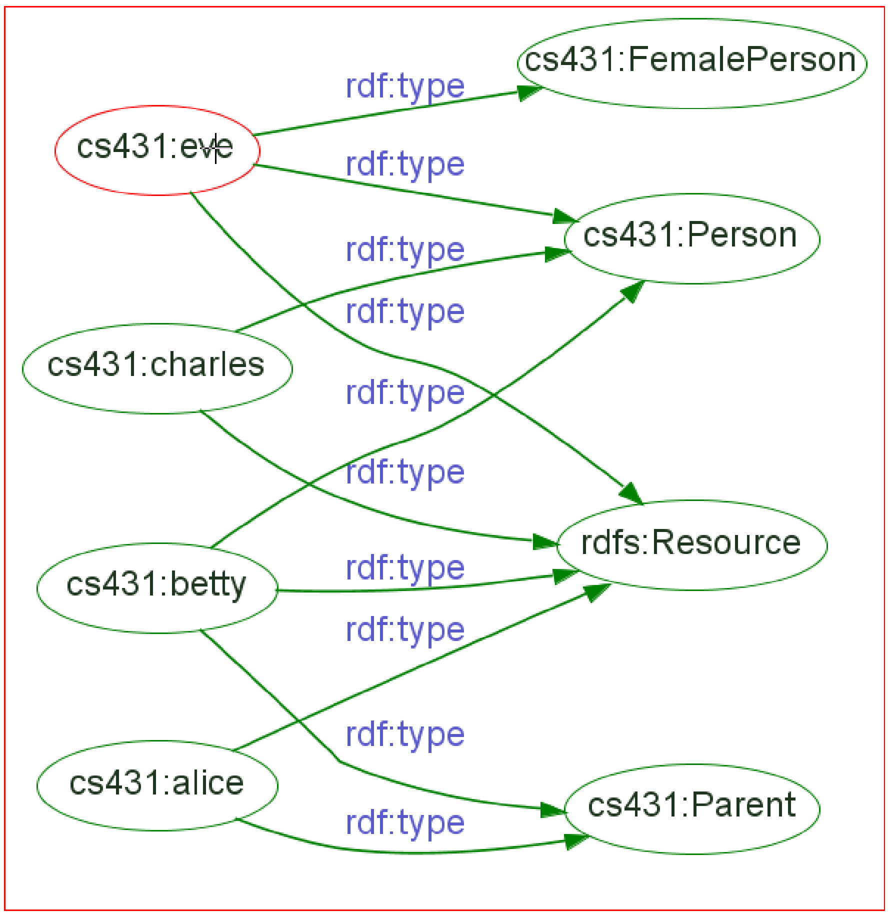
ex:MotorVehicle rdf:type rdfs:Class
ex:SUV rdf:type rdfs:Class
ex:SUV rdf:subClassOf ex:MotorVehicle
exthings:companyCar rdf:type ex:SUV

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

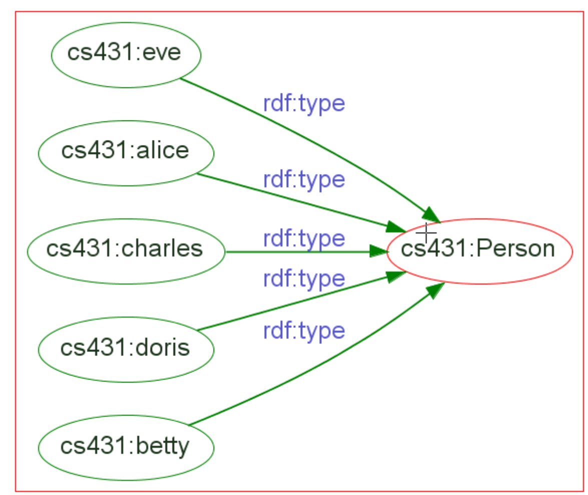




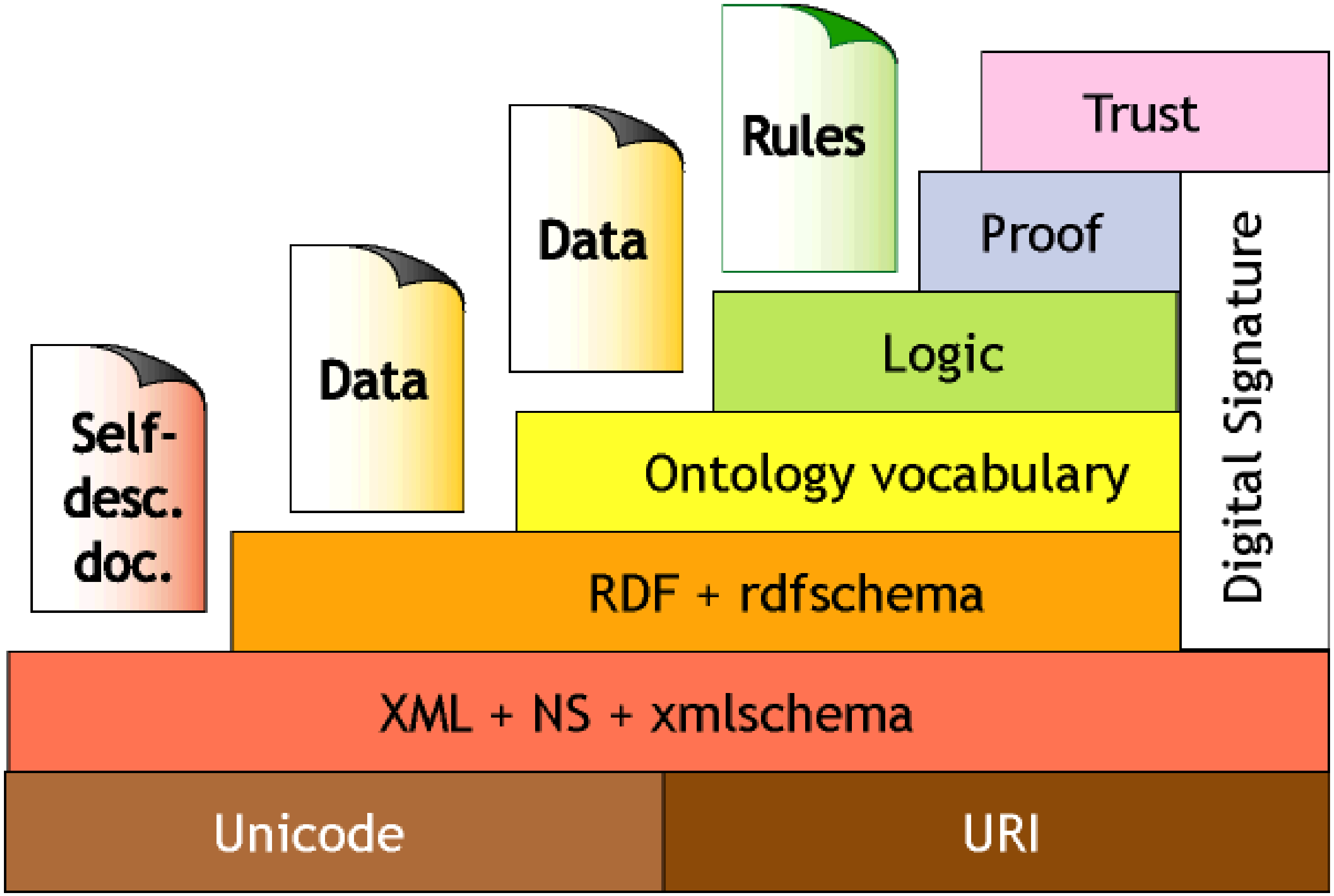
(:parent rdfs:subClassOf :person)

(: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
  - $\geq$ 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