Semantic Web Technologies
Lecture 1: Web Ontology Language OWL

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RDFS as an Ontology Language

- Classes
- Properties
- Class hierarchies
- Property hierarchies
- Domain and range restrictions

Outline

Limitations of RDFS

Web Ontology Language OWL
Design of OWL
OWL Layering
OWL and Description Logics
OWL Syntaxes

Layering OWL on top of RDF(S)

Slides based on Jos de Bruijn’s slides of SWT ’08/’09

Expressive limitations of RDF(S)

- Only binary relations
- Characteristics of Properties (e.g. inverse, transitive, symmetric)
- Local range restrictions (e.g. for Class Person, the property hasName has range xsd:string)
- Complex concept descriptions (e.g. Person is defined by Man and Woman)
- Cardinality restrictions (e.g. a Person may have at most 1 name)
- Disjointness axioms (e.g. nobody can be both a Man and a Woman)
Layering issues

- Syntax
  - Only binary relations in RDF
  - Verbose Syntax
  - No limitations on graph in RDF
    - Every graph is valid

- Semantics
  - Malformed graphs
  - Use of vocabulary in language
    - e.g. (rdfs:Class,rdfs:subClassOf,ex:a)
  - Meta-classes
    - e.g. (ex:a,rdf:type,ex:a)

Stack of Languages

- XML
  - Surface syntax, no semantics
- XML Schema
  - Describes structure of XML documents
- RDF
  - Datamodel for “relations” between “things”
- RDF Schema
  - RDF Vocabulary Definition Language
- OWL
  - A more expressive Vocabulary Definition Language

Design Goals for OWL

- Shareable
- Changing over time
- Interoperability
- Inconsistency detection
- Balancing expressivity and complexity
- Ease of use
- Compatible with existing standards
- Internationalization
**Requirements for OWL**

- Ontologies are **object on the Web**
- with their own meta-data, versioning, etc...
- Ontologies are **extendable**
- They contain **classes, properties, data-types**, range/domain, **individuals**
- **Equality** (for classes, for individuals)
- **Classes as instances**
- **Cardinality** constraints
- XML syntax

**Objectives for OWL**

**Objectives:**
- layered language
- complex datatypes
- digital signatures
- decidability (in part)
- local unique names (in part)

**Disregarded:**
- default values
- closed world option
- property chaining
- arithmetic
- string operations
- partial imports
- view definitions
- procedural attachments

**Extending RDF Schema**

- Leveraging experiences with OWL's predecessors SHOE, OIL, DAML-ONT, and DAML+OIL (frames, OO, DL)
- OWL extends RDF Schema to a full-fledged knowledge representation language for the Web
  - Logical expressions (and, or, not)
  - (in)equality
  - local properties
  - required/optional properties
  - required values
  - enumerated classes
  - symmetry, inverse

**Species of OWL**

- OWL Lite
  - Classification hierarchy
  - Simple constraints
- OWL DL
  - Maximal expressiveness
  - While maintaining tractability
  - Standard formalization in a DL
- OWL Full
  - Very high expressiveness
  - Losing tractability
  - All syntactic freedom of RDF (self-modifying)
Features of OWL languages

- **OWL Lite**
  - (sub)classes, individuals
  - (sub)properties, domain, range
  - conjunction
  - (in)equality
  - (unqualified) cardinality
  - 0/1
  - datatypes
  - inverse, transitive, symmetric properties
  - someValuesFrom
  - allValuesFrom

- **OWL DL**
  - Negation
  - Disjunction
  - (unqualified) Full cardinality
  - Enumerated classes
  - hasValue

- **OWL Full**
  - Meta-classes
  - Modify language

- **No restriction on use of vocabulary** (as long as legal RDF)
  - Classes as instances (and much more)

- **RDF style model theory**
  - Reasoning using FOL engine
  - Semantics should correspond to OWL DL for restricted KBs

- **Use of vocabulary restricted**
  - Cannot be used to do “nasty things” (e.g., modify OWL)
  - No classes as instances (this will be discussed in a later lecture)
  - Defined by abstract syntax

- **Standard DL-based model theory**
  - Direct correspondence with a DL
  - Automated reasoning with DL reasoners (e.g., Racer, Pellet, FaCT++)

- **No explicit negation or union**
- **Restricted cardinality (0/1)**
- **No nominals (oneOf)**
- **DL-based semantics**
  - Automated reasoning with DL reasoners (e.g., Racer, Pellet, FaCT++)
More on OWL species

- **OWL Full** is not a Description Logic
- **OWL Lite** has strong syntactic restrictions, but only limited semantics restrictions cf. **OWL DL**
  - Negation can be encoded using disjointness
  - With negation an conjunction, you can encode disjunction
- For instance:

  ```
  Class(C complete unionOf(B C))
  ```

  is equivalent to:

  ```
  DisjointClasses(notB B)
  DisjointClasses(notC C)
  Class(notBandnotC complete notB notC)
  DisjointClasses(notBandnotC BorC)
  Class(C complete notBandnotC)
  ```

**OWL and Description Logics**

- **OWL Lite** corresponds to the **DL** $SHIF(D)$
  - Named classes ($A$)
  - Named properties ($P$)
  - Individuals ($C(o)$)
  - Property values ($P(o, a)$)
  - Intersection ($C \cap D$)
  - Union ($C \cup D$)
  - Negation ($\neg C$)
  - Existential value restrictions ($\exists P.C$)
  - Universal value restrictions ($\forall P.C$)
  - Unqualified (0/1) number restrictions ($\geq nP, \leq nP, = nP$), $0 \leq n \leq 1$
- **OWL DL** corresponds to the **DL** $SHOIN(D)$
  - Arbitrary number restrictions ($\geq nP, \leq nP, = nP$), $0 \leq n$
  - Property value ($\exists P.C$)
  - Enumeration ($\{o_1, \ldots, o_n\}$)

**OWL constructs**

<table>
<thead>
<tr>
<th>OWL Construct</th>
<th>DL</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>intersectionOf</td>
<td>$C_1 \cap \ldots \cap C_n$</td>
<td>$\text{Human} \cap \text{Male}$</td>
</tr>
<tr>
<td>unionOf</td>
<td>$C_1 \cup \ldots \cup C_n$</td>
<td>$\text{Doctor} \cup \text{Lawyer}$</td>
</tr>
<tr>
<td>complementOf</td>
<td>$\neg C$</td>
<td>$\neg \text{Male}$</td>
</tr>
<tr>
<td>oneOf</td>
<td>${o_1, \ldots, o_n}$</td>
<td>${\text{john}, \text{mary}}$</td>
</tr>
<tr>
<td>allValuesFrom</td>
<td>$\forall P.C$</td>
<td>$\forall \text{hasChild}.\text{Doctor}$</td>
</tr>
<tr>
<td>someValuesFrom</td>
<td>$\exists P.C$</td>
<td>$\exists \text{hasChild}.\text{Lawyer}$</td>
</tr>
<tr>
<td>value</td>
<td>$\exists P.{o}$</td>
<td>$\exists \text{citizenOf}.\text{USA}$</td>
</tr>
<tr>
<td>minCardinality</td>
<td>$\geq nP.C$</td>
<td>$\geq 2\text{hasChild}.\text{Lawyer}$</td>
</tr>
<tr>
<td>maxCardinality</td>
<td>$\leq nP.C$</td>
<td>$\leq 1\text{hasChild}.\text{Male}$</td>
</tr>
<tr>
<td>cardinality</td>
<td>$= nP.C$</td>
<td>$= 1\text{hasParent}.\text{Female}$</td>
</tr>
</tbody>
</table>

+ XML Schema datatypes: int, string, real, etc...
OWL axioms

<table>
<thead>
<tr>
<th>OWL Axiom</th>
<th>DL</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>SubClassOf</td>
<td>$C_1 \sqsubseteq C_2$</td>
<td>$\text{Human} \sqsubseteq \text{Animal} \sqinter \text{Biped}$</td>
</tr>
<tr>
<td>EquivalentClasses</td>
<td>$C_1 \equiv \ldots \equiv C_n$</td>
<td>$\text{Man} \equiv \text{Human} \sqinter \text{Male}$</td>
</tr>
<tr>
<td>SubPropertyOf</td>
<td>$P_1 \sqsubseteq P_2$</td>
<td>$\text{hasDaughter} \sqsubseteq \text{hasChild}$</td>
</tr>
<tr>
<td>EquivalentProperties</td>
<td>$P_1 \equiv \ldots \equiv P_n$</td>
<td>$\text{cost} \equiv \text{price}$</td>
</tr>
<tr>
<td>SameIndividual</td>
<td>$o_1 = \ldots = o_n$</td>
<td>$\text{President_Bush} = \text{G_W_Bush}$</td>
</tr>
<tr>
<td>DisjointClasses</td>
<td>$C_i \sqsubseteq \neg C_j$</td>
<td>$\text{Male} \sqsubseteq \neg \text{Female}$</td>
</tr>
<tr>
<td>DifferentIndividuals</td>
<td>$o_i \neq o_j$</td>
<td>$\text{john} \neq \text{peter}$</td>
</tr>
<tr>
<td>inverseOf</td>
<td>$P_1 \equiv P_2^\neg$</td>
<td>$\text{hasChild} \equiv \neg \text{hasParent}$</td>
</tr>
<tr>
<td>Transitive</td>
<td>$P^+ \sqsubseteq \neg P^\neg$</td>
<td>$\text{ancestor}^+ \sqsubseteq \neg \text{ancestor}$</td>
</tr>
<tr>
<td>Symmetric</td>
<td>$P \equiv P^\neg$</td>
<td>$\text{connectedTo} \equiv \neg \text{connectedTo}$</td>
</tr>
</tbody>
</table>

DL-based OWL species as Semantic Web languages vs DLs

- OWL uses URI references as names (like used in RDF, e.g., http://www.w3.org/2002/07/owl#Thing)
- OWL gathers information into ontologies stored as documents written in RDF/XML, things like owl:imports
- RDF data types and XML schema data types for the ranges of data properties (attributes) (DataPropertyRange)
- OWL-DL and OWL-Lite with a frame-like abstract syntax, whereas RDF/XML is the official exchange syntax for OWL
- Annotations
- Note: DLs will receive full attention in the “Knowledge Representation and Ontologies” course in the next semester

Syntaxes of OWL

- RDF
  - Official exchange syntax
  - Hard for humans
  - RDF parsers are hard to write!
- XML
  - Not the RDF syntax
  - Still hard for humans, but more XML than RDF tools available
- Abstract syntax
  - Not defined for OWL Full
  - To some, considered human readable
- User-usable ones
  - e.g., Manchester syntax, informal and limited matching with UML

Example from [OwlGuide]:

```xml
<!ENTITY vin "http://www.w3.org/TR/2004/REC-owl-guide-20040210/wine#" >
<!ENTITY food "http://www.w3.org/TR/2004/REC-owl-guide-20040210/food#" > ...
   xmlns:food="http://www.w3.org/TR/2004/REC-owl-guide-20040210/food#" > ...

<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>

<owl:Class rdf:ID="Pasta" > <rdfs:subClassOf
   rdf:resource="#EdibleThing"/>
   ...
</owl:Class>
</rdf:RDF>
```
Limitations of RDFS

Web Ontology Language OWL
Layering OWL on top of RDF(S)
Summary

OWL Abstract syntax

Class( professor partial ) Class( associateProfessor partial academicStaffMember )
DisjointClasses( associateProfessor assistantProfessor )
DisjointClasses( professor associateProfessor )
Class( faculty complete academicStaffMember )

27/44

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OWL Abstract syntax

In DL syntax:
associateProfessor ∩ academicStaffMember
associateProfessor ∩ ¬ assistantProfessor
professor ∩ ¬ associateProfessor
faculty ≡ academicStaffMember

28/44

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Summary

More examples

DatatypeProperty( age range(xsd:nonNegativeInteger) )
ObjectProperty( lecturesIn )
ObjectProperty( isTaughtBy domain(course) range(academicStaffMember) )
SubPropertyOf( isTaughtBy involves )
ObjectProperty( teaches inverseOf( isTaughtBy ) domain(academicStaffMember) range(course) )
EquivalentProperties( lecturesIn teaches )
ObjectProperty( hasSameGradeAs Transitive Symmetric domain(student) range( student ) )

29/44

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More examples

In DL syntax:
⊤ ⊑ ∀ age . xsd:nonNegativeInteger
⊤ ⊑ ∀ isTaughtBy ¬ . course
⊤ ⊑ ∀ isTaughtBy . academicStaffMember
isTaughtBy ⊑ involves teaches ≡ isTaughtBy ¬
⊤ ⊑ ∀ teaches ¬ . academicStaffMember
teaches ≡ isTaughtBy ¬
⊤ ⊑ ∀ teaches . course lecturesIn ≡ teaches
hasSameGradeAs ⊑ hasSameGradeAs
hasSameGradeAs ≡ hasSameGradeAs ¬
⊤ ⊑ ∀ hasSameGradeAs ¬ . student
teaches ≡ isTaughtBy ¬

30/44
More examples

Individual (949318 type(lecturer))

Individual (949352 type(academicStaffMember), value(age "39" &xsd:integer))

ObjectProperty(isTaughtBy Functional)

Individual (CIT1111 type(course), value(isTaughtBy 949352)

DifferentIndividuals (949318 949352) DifferentIndividuals (949352 949111 949318)

In DL syntax:

firstYearCourse ⊑∀isTaughtBy Professor

mathCourse ⊑∃isTaughtBy {949352}

academicStaffMember ⊑∃teaches undergraduateCourse

course ⊑≥1isTaughtBy
department ⊑≥10hasMember ⊓≤30hasMember
More examples

Class(course partial complementOf(staffMember))

Class(peopleAtUni complete unionOf(staffMember student))

Class(facultyInCS complete intersectionOf(faculty restriction (belongsTo hasValue (CSDepartment))))

Class(adminStaff complete intersectionOf(staffMember complementOf(unionOf(faculty techSupportStaff)))))

Layering on top of RDF(S)

- RDF(S) bottom layer in Semantic Web stack
- Higher languages layer on top of RDFS

Syntactic Layering

- Every valid RDF statement is a valid statement in a higher language
- This includes triples containing keywords of these languages(!)

Semantic Layering

For RDFS graph $G$ and higher-level language $L$:
If $G \models_{RDFS} G'$ then $G \models_{L} G'$, and ideally
if $G \models_{L} G'$ then $G \models_{RDFS} G'$

Syntactically layering OWL on RDF(S)

OWL Lite, OWL DL

- OWL Lite, OWL DL subsets of RDF
- Allowed triples defined through mapping from abstract syntax
- Partial layering:
  - every OWL Lite/DL ontology is an RDF graph
  - some RDF graphs are OWL Lite/DL ontologies

OWL Full

- OWL Full encompasses RDF
- Complete layering:
  - every OWL Full is an RDF graph
  - all RDF graphs are OWL Full ontologies
Semantically layering OWL on RDF(S)

OWL Lite, OWL DL

- OWL Lite/DL semantics not related to RDFS semantics
- Redefine semantics of RDFS keywords, e.g., rdfs:subClassOf
- Work ongoing to describe correspondence between subset of RDFS and OWL Lite/DL

OWL Full

- OWL Full semantics is extension of RDFS semantics
- OWL Full is undecidable
- OWL Full semantics hard to understand

OWL Lite/DL vs. RDF

- Not every RDF graph is OWL Lite/DL ontology
- Example:
  
  A rdf:type A

- How to check whether an RDF graph G is OWL DL?
  1. Construct an OWL ontology O in Abstract Syntax
  2. Translate to RDF graph G'
  3. If G = G', then G is OWL DL
     * Otherwise, go to step (1)

Summary

- RDF Graph defined through translation from Abstract Syntax
- Example:
  
  Class(Human partial Animal
  restriction(hasLegs cardinality(2))
  restriction(hasName allValuesFrom(xsd:string)))

Human rdf:type owl:Class
Human rdfs:subClassOf Animal
Human rdfs:subClassOf :X1
:X1 rdf:type owl:Restriction
:X1 owl:onProperty hasLegs
:X1 owl:cardinality "2" xsd:nonNegativeInteger
Human rdfs:subClassOf :X2
:X2 rdf:type owl:Restriction
:X2 owl:onProperty hasName
:X2 owl:allValuesFrom xsd:string
The future of OWL... is now

- Section 8 of Horrocks et. al.'s paper outlines possible “Future extensions”
- OWL 2 has become a W3C recommendation on 27 Oct 2009
- We look at the new recommendation in the following lectures