Semantic Web Technologies

Web Ontology Language OWL

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Outline

RDFS as an Ontology Language

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

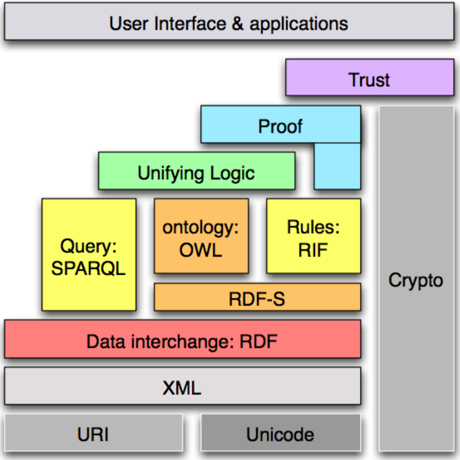
Expressive limitations of RDF(S)

- 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⟩

Where were we?



[following slides in part due to Frank van Harmelen
http://www.cs.vu.nl/~frankh/spool/SemWebSlides/OWL.ppt]

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

RDF Schema recap

- RDFS provides
  - Classes
  - Class hierarchies
  - Properties
  - Property hierarchies
  - Domain and range restrictions
- RDFS does not provide
  - Property characteristics (inverse, transitive, ...)
  - Local range restrictions
  - Complex concept definitions
  - Cardinality restrictions
  - Disjointness axioms

Extending RDF Schema

- 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

Design Goals for OWL

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

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

Language layers of OWL

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

Features of OWL language layers

- OWL Lite
  - (sub)classes, individuals
  - (sub)properties, domain, range
  - conjunction
  - (in)equality
  - cardinality 0/1
  - datatypes
  - inverse, transitive, symmetric properties
  - someValuesFrom
  - allValuesFrom
- OWL DL
  - Negation
  - Disjunction
  - Full cardinality
  - Enumerated types
  - hasValue
- OWL Full
  - Meta-classes
  - Modify language

OWL Full

- **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

OWL DL

- Use of vocabulary restricted
  - Can't be used to do "nasty things" (e.g. modify OWL)
  - No classes as instances
  - Defined by abstract syntax
- Standard DL-based model theory
  - Direct correspondence with a DL
  - Reasoning via DL engines

OWL Lite

- No explicit negation or union
- Restricted cardinality (0/1)
- No nominals (oneOf)
- DL-based semantics
  - Reasoning via DL engines (+datatypes)
- Semantically, only small restriction on OWL DL
  - No nominals
  - No arbitrary cardinality

OWL and Description Logics

- OWL Lite corresponds to the DL $\mathcal{SHIF}(\mathbf{D})$
  - Named classes (A)
  - Named properties (P)
  - Individuals ($C(o)$)
  - Property values ($P(o, a)$)
  - Intersection ($C \sqcap D$)
  - Union(!) ($C \sqcup D$)
  - 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 $\mathcal{SHOIN}(\mathbf{D})$
  - Arbitrary number restrictions ($\geq nP$, $\leq nP$, $= nP$), $0 \leq n$
  - Property value ($\exists P.\{o\}$)
  - Enumeration ($\{o_1, ..., o_n\}$)

OWL constructs

OWL Construct	DL	Example
intersectionOf	$C_1 \sqcap ... \sqcap C_n$	$Human \sqcap Male$
unionOf	$C_1 \sqcup ... \sqcup C_n$	$Doctor \sqcup Lawyer$
complementOf	$\neg C$	$\neg Male$
oneOf	$\{o_1, ..., o_n\}$	$\{john, mary\}$
allValuesFrom	$\forall P.C$	$\forall hasChild.Doctor$
someValuesFrom	$\exists P.C$	$\exists hasChild.Lawyer$
value	$\exists P.\{o\}$	$\exists citizenOf.USA$
minCardinality	$\geq nP.C$	$\geq 2hasChild.Lawyer$
maxCardinality	$\leq nP.C$	$\leq 1hasChild.Male$
cardinality	$= nP.C$	$= 1hasParent.Female$

$+$ XML Schema datatypes: int, string, real, etc...

OWL axioms

OWL Axiom	DL	Example
SubClassOf	$C_1 \sqsubseteq C_2$	$Human \sqsubseteq Animal \sqcap Biped$
EquivalentClasses	$C_1 \equiv \ldots \equiv C_n$	$Man \equiv Human \sqcap Male$
SubPropertyOf	$P_1 \sqsubseteq P_2$	$hasDaughter \sqsubseteq hasChild$
EquivalentProperties	$P_1 \equiv \ldots \equiv P_n$	$cost \equiv price$
SameIndividual	$o_1 = \ldots = o_n$	$President\_Bush = G\_W\_Bush$
DisjointClasses	$C_i \sqsubseteq \neg C_j$	$Male \sqsubseteq \neg Female$
DifferentIndividuals	$o_i \neq o_j$	$john \neq peter$
inverseOf	$P_1 \equiv P_2^-$	$hasChild \equiv hasParent^-$
Transitive	$P^+ \sqsubseteq P$	$ancestor^+ \sqsubseteq ancestor$
Symmetric	$P \equiv P^-$	$connectedTo \equiv connectedTo^-$

More on OWL species

- OWL Full is **not** a Description Logic
- OWL Lite has strong syntactic restrictions, but only limites semantics restrictions, compared with OWL DL
  - Negation can be encoded using disjointness
  - With negation an conjunction, you can encode disjunction

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)

More on layering

- For an OWL DL-restricted KB, OWL Full semantics is **not** equivalent to OWL DL semantics

John friend Susan .

OWL Full entails:

John rdf:type owl:Thing . Susan rdf:type owl:Thing . friend rdf:type owl:ObjectProperty .

John rdf:type _:x . _:x owl:onProperty friend . _:x owl:minCardinality "1"^^xsd:nonNegativeInteger .

Syntaxes of OWL

- RDF
  - Official exchange syntax
  - Hard for humans
  - RDF parsers are hard to write!
- UML
  - Large user base
- XML
  - Not the RDF syntax
  - Better for humans
  - More XML than RDF tools available
- Abstract syntax
  - Not defined for OWL Full
  - Human readable

OWL in RDF/XML

Example from [OwlGuide]:

```
<!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#" > ...
<rdf:RDF
xmlns:vin="http://www.w3.org/TR/2004/REC−owl−guide−20040210/wine#"
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>
```

OWL Abstract syntax

Class(professor partial) Class(associateProfessor partial academicStaffMember)

DisjointClasses (associateProfessor assistantProfessor)
DisjointClasses (professor associateProfessor)

Class(faculty complete academicStaffMember)

OWL Abstract syntax

In DL syntax:

$$
\begin{aligned}
&\text{associateProfessor} \sqsubseteq \text{academicStaffMember}\\
&\text{associateProfessor} \sqsubseteq \neg\ \text{assistantProfessor}\\
&\text{professor} \sqsubseteq \neg\ \text{associateProfessor}\\
&\text{faculty} \equiv \text{academicStaffMember}
\end{aligned}
$$

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))
```

More examples

In DL syntax:

$\top \sqsubseteq \forall age.xsd : nonNegativeInteger$
$\top \sqsubseteq \forall isTaughtBy^{-}.course$
$\top \sqsubseteq \forall isTaughtBy.academicStaffMember$
$isTaughtBy \sqsubseteq involves$
$teaches \equiv isTaughtBy^{-}$
$\top \sqsubseteq \forall teaches^{-}.academicStaffMember$
$\top \sqsubseteq \forall teaches.course$
$lecturesIn \equiv teaches$
$hasSameGradeAs^{+} \sqsubseteq hasSameGradeAs$
$hasSameGradeAs \equiv hasSameGradeAs^{-}$
$\top \sqsubseteq \forall hasSameGradeAs^{-}.student$
$\top \sqsubseteq \forall hasSameGradeAs.student$

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) value(isTaughtBy 949318))

DifferentIndividuals (949318 949352) DifferentIndividuals (949352 949111 949318)

More examples

In DL syntax:

$949318 : lecturer$
$949352 : academicStaffMember$
$\langle 949352, "39"\char`^\char`^\&xsd; integer \rangle : age$
$\top \sqsubseteq \leq 1 isTaughtBy$
$CIT1111 : course$
$\langle CIT1111, 949352 \rangle : isTaughtBy$
$\langle CIT1111, 949318 \rangle : isTaughtBy$
$949318 \neq 949352$
$949352 \neq 949111$
$949111 \neq 949318$
$949352 \neq 949318$

More examples

Class(firstYearCourse partial restriction (isTaughtBy allValuesFrom (Professor)))

Class(mathCourse partial restriction (isTaughtBy hasValue (949352)))

Class(academicStaffMember partial restriction (teaches someValuesFrom (undergraduateCourse)))

Class(course partial restriction (isTaughtBy minCardinality (1)))

Class(department partial restriction (hasMember minCardinality(10)) restriction (hasMember maxCardinality(30)))

More examples

In DL syntax:

$$firstYearCourse \sqsubseteq \forall isTaughtBy.Professor$$
$$mathCourse \sqsubseteq \exists isTaughtBy.\{949352\}$$
$$academicStaffMember \sqsubseteq \exists teaches.undergraduateCourse$$
$$course \sqsubseteq \geq 1 isTaughtBy$$
$$department \sqsubseteq \geq 10 hasMember \sqcap \leq 30 hasMember$$

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))))

More examples

In DL syntax:

$$course \sqsubseteq \neg staffMember$$
$$peopleAtUni \equiv staffMember \sqcup student$$
$$facultyInCS \equiv faculty \sqcap \exists belongsTo.\{CSDepartment\}$$
$$adminStaff \equiv staffMember \sqcap \neg(faculty \sqcup techSupportStaff)$$

Summary

Required reading

- OWL Guide: http://www.w3.org/TR/owl-guide/
- Ian Horrocks, Peter F. Patel-Schneider, and Frank van Harmelen. From SHIQ and RDF to OWL: The making of a web ontology language. **Journal of Web Semantics**, 1(1):7, 2003.

Further reading

- Semantic Web Primer, Chapter 4
- I. Horrocks and P. F. Patel-Schneider. Reducing OWL entailment to description logic satisfiability. In **Proc. of the ISWC2003**.
- Jos de Bruijn: **Using Ontologies. Enabling Knowledge Sharing and Reuse on the Semantic Web.** DERI Technical Report DERI-2003-10-29, 2003. http://www.deri.org/publications/techpapers/documents/DERI-TR-2003-10-29.pdf
- OWL Reference: http://www.w3.org/TR/owl-ref/