OWL
Sights and Insights

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Ontology Languages

- Formal languages to describe ontologies
- Include reasoning rules

Examples

- CycL
- KIF (Knowledge Interchange Format)
- FLogic (frame based)
- RDF (Resource Description Framework) and RDFS (RDF Schema)
- OIL (Ontology Inference Layer)
- OWL (Web Ontology Language)

Using RDFS, you can..

- Declare classes like `Country`, `Person`, `Student` and `Indian`
- State that `Student` is a subclass of `Person`
- State that India and China are instances of class `Country`
- Declare `nationality` as a property relating classes `Person` and `Country`
- State that `age` is a property with `Person` as its domain and integer as its range
- State that Ram is an instance of class `Indian`, and that his `age` has value 48

Using OWL, you can..

- State that `Country` and `Person` are disjoint classes
- State that India and China are distinct individuals
- Declare `hasCitizen` as the Inverse property of `nationality`
- State that the class `Stateless` is defined precisely as those members of class `Person` that have no values for property `nationality`

Using OWL, you can..

- State that class `MultipleNationals` is defined precisely as those members of class `Person` that have at least 2 values for property `nationality`
- State that class `Indian` is defined precisely as those members of class `Person` that have India as the value of `nationality`

OWL-Ingredients

- Description Logic
- Frames
- RDF/XML
- RDFS
- OIL+DAML

DL Influence

- Formalization of semantics
- Automated reasoning to check knowledge base consistency and entailment
- OWL design based on SH family of DL
  - SHIF
  - SHIQ
  - SHOQ(D)

Frames influence

- Frames group together info about each class, easier reading and understanding
- Class frame=DL axiom
- Property frame=set of axioms asserting domain, range, transitivity etc
- OWL abstract syntax heavily influenced by frames

RDF influence

- Goal: Max upward compatibility with RDF
- Effort to make OWL semantics consistent with RDF semantics
  - Problems

DAML+OIL

- DAML – Darpa Agent Markup Language (US)
- OIL (Europe)
  - First to use DL to describe ontologies
  - Fully compatible with RDF syntactically, but not semantically
- DAML+OIL
  - Uses RDF and RDFS vocabulary to a greater extent
  - No standard theory of inference

OWL species

- OWL DL
  - Decidable inference, uses DL
  - Well formed RDF graphs a necessity
- OWL Lite
  - More tractable inference
  - Syntactic subset of OWL DL
- OWL Full
  - Syntactic and semantic extension of RDF & RDFS
  - Reasoning undecidable
  - Arbitrary RDF graphs

OWL-DL

- Vocabulary partitioning
- Explicit typing
- Property separation
- No transitive cardinality restrictions
- Uses SHOIN(D)
- Non deterministic exponential time reasoning

OWL Lite

- No unions and complements
- No individuals in class axioms
- Cardinalities only 0-1
- SHIF(D)
- Deterministic exponential time reasoning
- FaCT and RACER reasoners

OWL Full

- Goes well outside DL framework
- Eg: You can even impose cardinality restriction on `rdfs:subClassOf`

OWL to DL mapping

Abstract Syntax	DL Syntax	Semantics
Descriptions (C)		
A (URI reference)	A	$A^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$
`owl:Thing`	$\top$	$\texttt{owl:Thing}^{\mathcal{I}} = \Delta^{\mathcal{I}}$
`owl:Nothing`	$\bot$	$\texttt{owl:Nothing}^{\mathcal{I}} = \{\}$
`intersectionOf(`C_1 C_2 `...)`	$C_1 \sqcap C_2$	$(C_1 \sqcap D_1)^{\mathcal{I}} = C_1^{\mathcal{I}} \cap D_2^{\mathcal{I}}$
`unionOf(`C_1 C_2 `...)`	$C_1 \sqcup C_2$	$(C_1 \sqcup C_2)^{\mathcal{I}} = C_1^{\mathcal{I}} \cup C_2^{\mathcal{I}}$
`complementOf(`C`)`	$\neg C$	$(\neg C)^{\mathcal{I}} = \Delta^{\mathcal{I}} \setminus C^{\mathcal{I}}$
`oneOf(`o_1 `...)`	$\{o_1, \ldots\}$	$\{o_1, \ldots\}^{\mathcal{I}} = \{o_1^{\mathcal{I}}, \ldots\}$
`restriction(`R `someValuesFrom(`C`))`	$\exists R.C$	$(\exists R.C)^{\mathcal{I}} = \{x \mid \exists y.\langle x,y\rangle \in R^{\mathcal{I}} \text{ and } y \in C^{\mathcal{I}}\}$
`restriction(`R `allValuesFrom(`C`))`	$\forall R.C$	$(\forall R.C)^{\mathcal{I}} = \{x \mid \forall y.\langle x,y\rangle \in R^{\mathcal{I}} \rightarrow y \in C^{\mathcal{I}}\}$
`restriction(`R `hasValue(`o`))`	$R : o$	$(\forall R.o)^{\mathcal{I}} = \{x \mid \langle x, o^{\mathcal{I}}\rangle \in R^{\mathcal{I}}\}$
`restriction(`R `minCardinality(`n`))`	$\geqslant n\, R$	$(\geqslant n\, R)^{\mathcal{I}} = \{x \mid \sharp(\{y.\langle x,y\rangle \in R^{\mathcal{I}}\}) \geqslant n\}$
`restriction(`R `minCardinality(`n`))`	$\leqslant n\, R$	$(\geqslant n\, R)^{\mathcal{I}} = \{x \mid \sharp(\{y.\langle x,y\rangle \in R^{\mathcal{I}}\}) \leqslant n\}$
`restriction(`U `someValuesFrom(`D`))`	$\exists U.D$	$(\exists U.D)^{\mathcal{I}} = \{x \mid \exists y.\langle x,y\rangle \in U^{\mathcal{I}} \text{ and } y \in D^{\mathbf{D}}\}$
`restriction(`U `allValuesFrom(`D`))`	$\forall U.D$	$(\forall U.D)^{\mathcal{I}} = \{x \mid \forall y.\langle x,y\rangle \in U^{\mathcal{I}} \rightarrow y \in D^{\mathbf{D}}\}$
`restriction(`U `hasValue(`v`))`	$U : v$	$(U : v)^{\mathcal{I}} = \{x \mid \langle x, v^{\mathcal{I}}\rangle \in U^{\mathcal{I}}\}$
`restriction(`U `minCardinality(`n`))`	$\geqslant n\, U$	$(\geqslant n\, U)^{\mathcal{I}} = \{x \mid \sharp(\{y.\langle x,y\rangle \in U^{\mathcal{I}}\}) \geqslant n\}$
`restriction(`U `maxCardinality(`n`))`	$\leqslant n\, U$	$(\leqslant n\, U)^{\mathcal{I}} = \{x \mid \sharp(\{y.\langle x,y\rangle \in U^{\mathcal{I}}\}) \leqslant n\}$
Data Ranges (D)		
D (URI reference)	D	$D^{\mathbf{D}} \subseteq \Delta_{\mathbf{D}}^{\mathcal{I}}$
`oneOf(`v_1 `...)`	$\{v_1, \ldots\}$	$\{v_1, \ldots\}^{\mathcal{I}} = \{v_1^{\mathcal{I}}, \ldots\}$
Object Properties (R)		
R (URI reference)	R	$R^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$
	R^{-}	$(R^{-})^{\mathcal{I}} = (R^{\mathcal{I}})^{-}$
Datatype Properties (U)		
U (URI reference)	U	$U^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta_{\mathbf{D}}^{\mathcal{I}}$
Individuals (o)		
o (URI reference)	o	$o^{\mathcal{I}} \in \Delta^{\mathcal{I}}$
Data Values (v)		
v (RDF literal)	v	$v^{\mathcal{I}} = v^{\mathbf{D}}$

Fig. 1. OWL DL descriptions, data ranges, properties, individuals and data values.

OWL to DL mapping

Abstract Syntax	DL Syntax	Semantics
Class(A partial C_1 ...C_n)	$A \sqsubseteq C_1 \sqcap \ldots \sqcap C_n$	$A^\mathcal{I} \subseteq C_1^\mathcal{I} \cap \ldots \cap C_n^\mathcal{I}$
Class(A complete C_1 ...C_n)	$A = C_1 \sqcap \ldots \sqcap C_n$	$A^\mathcal{I} = C_1^\mathcal{I} \cap \ldots \cap C_n^\mathcal{I}$
EnumeratedClass(A o_1 ...o_n)	$A = \{o_1, \ldots, o_n\}$	$A^\mathcal{I} = \{o_1^\mathcal{I}, \ldots, o_n^\mathcal{I}\}$
SubClassOf(C_1 C_2)	$C_1 \sqsubseteq C_2$	$C_1^\mathcal{I} \subseteq C_2^\mathcal{I}$
EquivalentClasses(C_1 ...C_n)	$C_1 = \ldots = C_n$	$C_1^\mathcal{I} = \ldots = C_n^\mathcal{I}$
DisjointClasses(C_1 ...C_n)	$C_i \sqcap C_j = \bot, i \neq j$	$C_i^\mathcal{I} \cap C_j^\mathcal{I} \{\}, i \neq j$
Datatype(D)		$D^\mathcal{I} \subseteq \Delta_\mathbf{D}^\mathcal{I}$
DatatypeProperty(U super(U_1)...super(U_n))	$U \sqsubseteq U_i$	$U^\mathcal{I} \subseteq U_i^\mathcal{I}$
domain(C_1) ...domain(C_m)	$\geqslant 1\, U \sqsubseteq C_i$	$U^\mathcal{I} \subseteq C_i^\mathcal{I} \times \Delta_\mathbf{D}^\mathcal{I}$
range(D_1) ...range(D_l)	$\top \sqsubseteq \forall U.D_i$	$U^\mathcal{I} \subseteq \Delta^\mathcal{I} \times D_i^\mathcal{I}$
[Functional])	$\top \sqsubseteq \leqslant 1\, U$	$U^\mathcal{I}$ is functional
SubPropertyOf(U_1 U_2)	$U_1 \sqsubseteq U_2$	$U_1^\mathcal{I} \subseteq U_2^\mathcal{I}$
EquivalentProperties(U_1 ...U_n)	$U_1 = \ldots = U_n$	$U_1^\mathcal{I} = \ldots = U_n^\mathcal{I}$
ObjectProperty(R super(R_1)...super(R_n)	$R \sqsubseteq R_i$	$R^\mathcal{I} \subseteq R_i^\mathcal{I}$
domain(C_1) ...domain(C_m)	$\geqslant 1\, R \sqsubseteq C_i$	$R^\mathcal{I} \subseteq C_i^\mathcal{I} \times \Delta^\mathcal{I}$
range(C_1) ...range(C_l)	$\top \sqsubseteq \forall R.C_i$	$R^\mathcal{I} \subseteq \Delta^\mathcal{I} \times C_i^\mathcal{I}$
[inverseOf(R_0]	$R = (^- R_0)$	$R^\mathcal{I} = (R_0^\mathcal{I})^-$
[Symmetric]	$R = (^- R)$	$R^\mathcal{I} = (R^\mathcal{I})^-$
[Functional]	$\top \sqsubseteq \leqslant 1\, R$	$R^\mathcal{I}$ is functional
[InverseFunctional]	$\top \sqsubseteq \leqslant 1\, R^-$	$(R^\mathcal{I})^-$ is functional
[Transitive])	$Tr(R)$	$R^\mathcal{I} = (R^\mathcal{I})^+$
SubPropertyOf(R_1 R_2)	$R_1 \sqsubseteq R_2$	$R_1^\mathcal{I} \subseteq R_2^\mathcal{I}$
EquivalentProperties(R_1 ...R_n)	$R_1 = \ldots = R_n$	$R_1^\mathcal{I} = \ldots = R_n^\mathcal{I}$
AnnotationProperty(S)		
Individual(o type(C_1) ...type(C_n)	$o \in C_i$	$o^\mathcal{I} \in C_i^\mathcal{I}$
value(R_1 o_1)...value(R_n o_n)	$\langle o, o_i \rangle \in R_i$	$\langle o^\mathcal{I}, o_i^\mathcal{I} \rangle \in R_i^\mathcal{I}$
value(U_1 v_1)...value(U_n v_n))	$\langle o, v_i \rangle \in U_i$	$\langle o^\mathcal{I}, v_i^\mathcal{I} \rangle \in U_i^\mathcal{I}$
SameIndividual(o_1 ...o_n)	$o_1 = \ldots = o_n$	$o_i^\mathcal{I} = o_j^\mathcal{I}$
DifferentIndividuals(o_1 ...o_n)	$o_i \neq o_j, i \neq j$	$o_i^\mathcal{I} \neq o_j^\mathcal{I}, i \neq j$

Fig. 2. OWL DL axioms and facts.

OWL Syntax – class elements

```
<owl:Class rdf:ID="associateProfessor">
   <rdfs:subClassOf rdf:resource="#academicStaffMember"/>
</owl:Class>

<owl:Class rdf:about="associateProfessor">
   <owl:disjointWith rdf:resource="#professor"/>
   <owl:disjointWith rdf:resource="#assistantProfessor"/>
</owl:Class>

<owl:Class rdf:ID="faculty">
   <owl:equivalentClass rdf:resource="#academicStaffMember"/>
</owl:Class>
```

Properties

```
<owl:DatatypeProperty rdf:ID="age">
   <rdfs:range rdf:resource="
http://www.w3.org/2001/XLMSchema#nonNegativeInteger"/>
</owl:DatatypeProperty>


<owl:ObjectProperty rdf:ID="isTaughtBy">
   <owl:domain rdf:resource="#course"/>
   <owl:range rdf:resource="#academicStaffMember"/>
   <rdfs:subPropertyOf rdf:resource="#involves"/>
</owl:ObjectProperty>
```

Property restrictions

```
<owl:Class rdf:about="#firstYearCourse">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#isTaughtBy"/>
            <owl:allValuesFrom rdf:resource="#Professor"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>

<owl:Class rdf:about="#course">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#isTaughtBy"/>
            <owl:minCardinality
rdf:datatype="&xsd;nonNegativeInteger">
                1
            </owl:minCardinality>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

Boolean Combinations

```
<owl:Class rdf:ID="peopleAtUni">
   <owl:unionOf rdf:parseType="Collection">
      <owl:Class rdf:about="#staffMember"/>
      <owl:Class rdf:about="#student"/>
   </owl:unionOf>
</owl:Class>



<owl:Class rdf:ID="nonAcademicStaff">
   <owl:intersectionOf rdf:parseType="Collection">
      <owl:Class rdf:about="#staffMember"/>
      <owl:complementOf>
         <owl:unionOf rdf:parseType="Collection">
            <owl:Class rdf:about="#faculty"/>
            <owl:Class rdf:about="#techSupportStaff"/>
         </owl:unionOf>
      </owl:complementOf>
   </owl:intersectionOf>
</owl:Class>
```

Enumerations

```
<owl:oneOf rdf:parseType="Collection">
   <owl:Thing rdf:about="#Monday"/>
   <owl:Thing rdf:about="#Tuesday"/>
   <owl:Thing rdf:about="#Wednesday"/>
   <owl:Thing rdf:about="#Thursday"/>
   <owl:Thing rdf:about="#Friday"/>
   <owl:Thing rdf:about="#Saturday"/>
   <owl:Thing rdf:about="#Sunday"/>
</owl:oneOf>
```

Instances

```
<academicStaffMember rdf:ID="949352">
   <uni:age rdf:datatype="&xsd;integer">39</uni:age>
</academicStaffMember>

<course rdf:about="CIT1111">
   <isTaughtBy rdf:resource="949318">
   <isTaughtBy rdf:resource="949352">
</course>
```

References

- I. Horrocks, P. P. Schneider, and F. van Harmelen, "*From SHIQ and RDF to OWL: The making of a web ontology language*", Journal of Web Semantics, vol. 1, no. 1, pp. 7-26, 2003.
- *“Web Ontology Language: OWL”,* Grigoris Antoniou, Department of Computer Science, University of Crete and Frank van Harmelen, Department of AI, Vrije Universiteit Amsterdam