

Semantic Web Technologies

Relations between Semantic Web Languages

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Outline

RDF and OWL

- Layering OWL on top of RDF

- Ontology Modeling in RDFS vs. OWL DL

RDF and F-Logic

- Encoding RDF in F-Logic

- Ontology Modeling in RDFS vs. F-Logic

OWL DL and F-Logic Programming

RDF Recap

- ▶ RDF
 - ▶ Graph-based data model
 - ▶ RDF statements are triples (subject, predicate, object)
 - ▶ URIs as identifiers for resources and properties
 - ▶ Literals as concrete data values
 - ▶ RDF/XML as “default” syntax
 - ▶ RDF vocabulary: `rdf:type`, `rdf:Property`, ...

RDF Recap

- ▶ RDFS (RDF Vocabulary Description)
 - ▶ Vocabulary for describing RDF classes and properties
 - ▶ `rdfs:Class`, `rdfs:Resource`, `rdfs:domain`, `rdfs:range`, ...
 - ▶ Simple ontology language
 - ▶ Allows additional entailments:
 - ▶ $(?x \text{ rdfs:type } ?y), (?y \text{ rdfs:subClassOf } ?z) \Rightarrow (?x \text{ rdfs:type } ?z)$
 - ▶ $(?x \text{ rdfs:subClassOf } ?y), (?y \text{ rdfs:subClassOf } ?z) \Rightarrow (?x \text{ rdfs:subClassOf } ?z)$
 - ▶ $(?x ?p ?y), (?p \text{ rdfs:subPropertyOf } ?q) \Rightarrow (?x ?q ?y)$
 - ▶ $(?p \text{ rdfs:domain } ?x), (?y ?p ?z) \Rightarrow (?y \text{ rdfs:type } ?x)$
 - ▶ $(?p \text{ rdfs:range } ?x), (?y ?p ?z) \Rightarrow (?z \text{ rdfs:type } ?x)$

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 $G \models_{RDFS} G'$

Web Ontology Language OWL

- ▶ OWL Lite
 - ▶ Layered on subset of RDFS
 - ▶ Symmetric, transitive, inverse properties
 - ▶ Complete class definitions
 - ▶ Limited types of restrictions
 - ▶ Based on Description Logic *SHIN*(**D**)
- ▶ OWL DL
 - ▶ Full-fledged Description Logic *SHOIN*(**D**)
 - ▶ Negation
 - ▶ Disjunction
 - ▶ Full cardinality
- ▶ OWL Full
 - ▶ Extension of RDFS, OWL DL
 - ▶ Meta-modeling
 - ▶ Statements about language primitives
 - ▶ Every RDF graph is valid OWL Full

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 (**why?**)
- ▶ OWL Full semantics hard to understand

OWL Lite/DL vs. RDF

- ▶ 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

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)

Modeling style

- ▶ Modeling Triples
 - ▶ Statements of the form $\langle A, B, C \rangle$
 - ▶ Special vocabulary for ontology modeling
 - ▶ $\langle A, \text{rdf:type}, C \rangle$ (class membership)
 - ▶ $\langle A, \text{rdfs:subClassOf}, C \rangle$ (class hierarchy)
 - ▶ $\langle A, \text{rdfs:subPropertyOf}, C \rangle$ (property hierarchy)
 - ▶ $\langle A, \text{rdfs:domain}, C \rangle$ (domain restrictions)
 - ▶ $\langle A, \text{rdfs:range}, C \rangle$ (range restrictions)
 - ▶ No restrictions on use of vocabulary
 - ▶ Language constructs in the language
- ▶ Modeling DL
 - ▶ Class axioms: $C \sqsubseteq D$
 - ▶ Property axioms: $P \sqsubseteq Q$
 - ▶ Local property restrictions: $C \sqsubseteq \forall R.D$
 - ▶ Separation of vocabulary
 - ▶ class, property, individual identifiers disjoint
 - ▶ No use of language constructs in language

Expressiveness

- ▶ OWL DL allows
 - ▶ Arbitrary class axioms
 - ▶ Local property restrictions
 - ▶ Cardinality restrictions
 - ▶ (in)equality statements
 - ▶ inverse, transitive, symmetric properties
 - ▶ disjunction
 - ▶ disjointness, negation
- ▶ RDFS allows
 - ▶ Using classes as instances
 - ▶ Modifying language
 - ▶ Using language constructs in language

Translating RDF to F-Logic

- ▶ Translate triples to attribute molecules
- ▶ $\langle A, B, C \rangle \mapsto A [B \rightarrow C]$
- ▶ Axiomatize RDF semantics
 - ▶ Add facts for axiomatic triples
 - ▶ Add rules for entailment rules
- ▶ Treat bNodes as skolem constants
 - ▶ “rigid” bNodes
 - ▶ anonymous resources

bNodes as Anonymous Resources

- ▶ Unnumbered anonymous resource: `_#`
 - ▶ Globally unique constant identifier
 - ▶ Every occurrence is **fresh** identifier
- ▶ Numbered anonymous resource: `_#1`, `_#2`, ...
 - ▶ Resource has **scope**: formula
 - ▶ Within scope, different occurrences denote the same resource
- ▶ Anonymous resources are **not** existential variables
- ▶ Thus, semantics of bNodes cannot be captured completely

Expressiveness

- ▶ F-Logic allows
 - ▶ Arbitrary rules
 - ▶ Functional (single-valued) attributes
 - ▶ Local attributes, rather than global properties
- ▶ RDFS allows
 - ▶ Modifying language
 - ▶ Using language constructs in language
 - ▶ Global property restrictions, property hierarchy
 - ▶ Can be simulated using rules
 - ▶ bNodes as existentials
 - ▶ Form of non-ground entailment

Expressiveness of DL vs LP

- ▶ Description Logics allow
 - ▶ Existential quantification
 - ▶ Disjunction
 - ▶ Classical negation
 - ▶ Non-ground entailment
 - ▶ Equality
- ▶ Logic Programming allows
 - ▶ n -ary predicates
 - ▶ Chaining variables over predicates
 - ▶ Default negation (negation-as-failure)

Ontology Modeling in OWL DL vs F-Logic

- ▶ F-Logic allows quantification over class, attribute names, e.g. $\text{john}:X, \text{john}[X \rightarrow \text{mary}]$
- ▶ F-Logic allows modeling classes-as-instances: $\text{b747}:\text{airplane}, \text{x567}:\text{b747}$
- ▶ In F-Logic, attributes “belong” to a class: $\text{person}[\text{hasChild} \Rightarrow \text{person}]$ vs. $\text{person} \sqsubseteq \forall \text{hasChild}.\text{person}$
- ▶ Interpretation of classes, properties
 - ▶ In DLs, classes, attributes are interpreted **directly** as sets, binary relations, e.g. $\text{person}^{\mathcal{I}} \subseteq \Delta$
 - ▶ In F-Logic
 - ▶ Terms interpreted as elements of the domain, e.g. $\mathbf{I}_F(\text{person}) = a$
 - ▶ Elements of the domain are **associated with** sets, functions, relations, e.g. $\{k \mid k \in_U a\} \subseteq U$

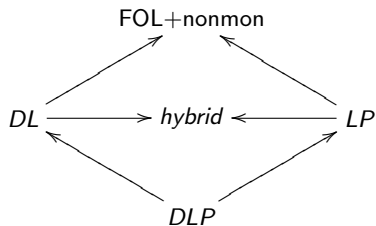
$A \sqsubseteq B$ vs. $A :: B$

- ▶ Compare subsumption in DLs with subclass statements in F-Logic
- ▶ Subsumption in Description Logics: $A \sqsubseteq B$
 - ▶ A, B may be arbitrary concept descriptions
 - ▶ For interpretation \mathcal{I} , $\mathcal{I} \models A \sqsubseteq B$ iff $A^{\mathcal{I}} \subseteq B^{\mathcal{I}}$
 - ▶ Interpretation of A, B directly as sets
 - ▶ $A \sqsubseteq B$ is entailed if $A^{\mathcal{I}} \subseteq B^{\mathcal{I}}$ for all models
- ▶ Subclass in F-Logic: $A :: B$
 - ▶ A, B are terms
 - ▶ For interpretation \mathbf{I} , $\mathbf{I} \models A :: B$ iff $\mathbf{I}_F(A) \preceq_U \mathbf{I}_F(B)$
 - ▶ $A :: B$ is entailed if $A :: B$ or $A :: \dots :: B$ explicitly asserted
 - ▶ Recall: **if** $a \in_U b$ **and** $b \preceq_U c$ **then** $a \in_U c$ (only one direction!)
 - ▶ Can be checked with ground entailment (Logic Programming)

Minimizing the cardinality of the domain

- ▶ Restricting size of the domain
- ▶ F-Logic requires objects for classes, attributes
- ▶ If domain is restricted, classes, attributes are “forced” to be interpreted the same
- ▶ Example: $\{\forall x(x = a); a : b\} \models a : c$
 - ▶ domain of every interpretation has cardinality one
 - ▶ thus, a, b, c always interpreted the same
- ▶ Description Logics: $\{\top \sqsubseteq \{a\}, a \in B\} \not\models a \in C$
 - ▶ domain of every interpretation has cardinality one
 - ▶ however, B, C may still be interpreted differently

Integration of DLs and rules



- ▶ Extension of DLP
 - ▶ Interoperation only for inexpressive ontologies
- ▶ Unified language
 - ▶ Undecidable; little research has been done
- ▶ Hybrid integration
 - ▶ Full DL and LP
 - ▶ Several existing approaches

DLs and F-Logic can interoperate in certain restricted cases

Summary

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Further reading

- ▶ Ian Horrocks, Peter F. Patel-Schneider: Three theses of representation in the semantic web. WWW 2003: 39–47.
- ▶ J. de Bruijn, A. Polleres, R. Lara, and D. Fensel. OWL DL vs. OWL Flight: Conceptual modeling and reasoning on the semantic web. In WWW2005, Chiba, Japan, 2005. ACM.
- ▶ J. de Bruijn and S. Heymans. Translating ontologies from predicate-based to frame-based languages. In RuleML-2006, Athens, Georgia, USA, November 10–11 2006. IEEE.