

## 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

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## 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, ...

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## 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:
    - ▶  $(?x \text{ rdf:type } ?y), (?y \text{ rdfs:subClassOf } ?z) \Rightarrow (?x \text{ rdf:type } ?z)$
    - ▶  $(?x \text{ rdfs:subClassOf } ?y), (?y \text{ rdfs:subClassOf } ?z) \Rightarrow (?x \text{ rdfs:subClassOf } ?z)$
    - ▶  $(?x ?p ?y), (?p \text{ rdfs:subPropertyOf } ?q) \Rightarrow (?x ?q ?y)$
    - ▶  $(?p \text{ rdfs:domain } ?x), (?y ?p ?z) \Rightarrow (?y \text{ rdf:type } ?x)$
    - ▶  $(?p \text{ rdfs:range } ?x), (?y ?p ?z) \Rightarrow (?z \text{ rdf:type } ?x)$

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## 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  $G \models_{RDFS} G'$

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## 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  $SHIN(\mathbf{D})$
- ▶ OWL DL
  - ▶ Full-fledged Description Logic  $SHOIN(\mathbf{D})$ 
    - ▶ Negation
    - ▶ Disjunction
    - ▶ Full cardinality
- ▶ OWL Full
  - ▶ Extension of RDFS, OWL DL
    - ▶ Meta-modeling
    - ▶ Statements about language primitives
  - ▶ Every RDF graph is valid OWL Full

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## 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

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## 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

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## 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
  
```

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## 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)

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## Modeling style

- ▶ Modeling Triples
  - ▶ Statements of the form (A,B,C)
  - ▶ Special vocabulary for ontology modeling
    - ▶ (A,rdf:type,C) (class membership)
    - ▶ (A,rdfs:subClassOf,C) (class hierarchy)
    - ▶ (A,rdfs:subPropertyOf,C) (property hierarchy)
    - ▶ (A,rdfs:domain,C) (domain restrictions)
    - ▶ (A,rdfs:range,C) (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

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## 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

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## 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

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## bNodes as Anonymous Resources

- ▶ Unnumbered anonymous resource:  $_{\#}$ 
  - ▶ Globally unique constant identifier
  - ▶ Every occurrence is **fresh** identifier
- ▶ Numbered anonymous resource:  $_{\#1}, _{\#2}, \dots$ 
  - ▶ 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

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## 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

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## 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)

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## 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.  $\text{person}^I \subseteq \Delta$
  - ▶ In F-Logic
    - ▶ Terms interpreted as elements of the domain, e.g.  $I_F(\text{person}) = a$
    - ▶ Elements of the domain are **associated with** sets, functions, relations, e.g.  $\{k \mid k \in U, a\} \subseteq U$

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## $A \sqsubseteq B$ 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  $A^I \subseteq B^I$
  - ▶ Interpretation of  $A, B$  directly as sets
  - ▶  $A \sqsubseteq B$  is entailed if  $A^I \subseteq B^I$  for all models
- ▶ Subclass in F-Logic:  $A : B$ 
  - ▶  $A, B$  are terms
  - ▶ For interpretation  $\mathcal{I}, \mathcal{I} \models A : B$  iff  $I_F(A) \preceq_U I_F(B)$
  - ▶  $A : B$  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)

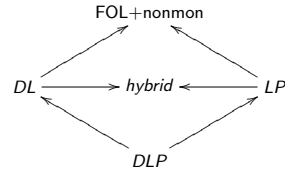
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## Minimizing the cardinality of the domain

- ▶ 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:  $\{T \sqsubseteq \{a\}, a \in B\} \not\models a \in C$ 
  - ▶ domain of every interpretation has cardinality one
  - ▶ however,  $B, C$  may still be interpreted differently

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## 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

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## Summary

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### OWL DL and F-Logic Programming

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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.

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