# COMP718: Ontologies and Knowledge Bases

## Lecture 3: The Web Ontology Language OWL

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# Outline

# Recap previous week

- First Order Predicate Logic, model theoretic-semantics
- Description Logics
- Tableau reasoning (exercises with the graph and with vegans and vegetarians)
  - Soundness (if $\Gamma \vdash \phi$ then $\Gamma \models \phi$) and completeness (if $\Gamma \models \phi$ then $\Gamma \vdash \phi$) [recollect "$\vdash$" derivable with a set of inference rules, and "$\models$" as implies, i.e., every truth assignment that satisfies $\Gamma$ also satisfies $\phi$]
  - If the algorithm is incomplete, then there exist entailments that cannot be computed (hence, missing some results)
  - If the algorithm is unsound then false conclusions can be derived from true premises, which his even more undesirable

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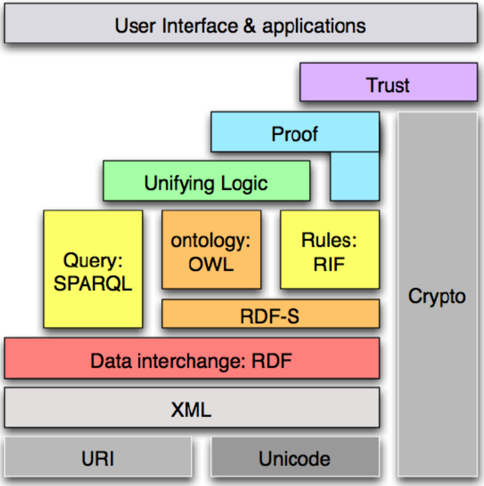
# Outline

# Toward one ontology language for the Web

- Plethora of ontology languages; e.g., KIF, KL-ONE, LOOM, F-logic, DAML, OIL, DAML+OIL, ....
- Lack of a lingua franca; hence, ontology interoperation problems even on the syntactic level
- Advances in expressive DL languages and, more importantly, in automated reasoners for expressive DL languages (mainly: FaCT++, then Racer)
- Limitations of RDF(S) as Semantic Web 'ontology language'

# Outline

# The layer cake



# 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

# Outline

# RDFS as an Ontology Language

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

# Expressive limitations of RDF(S)

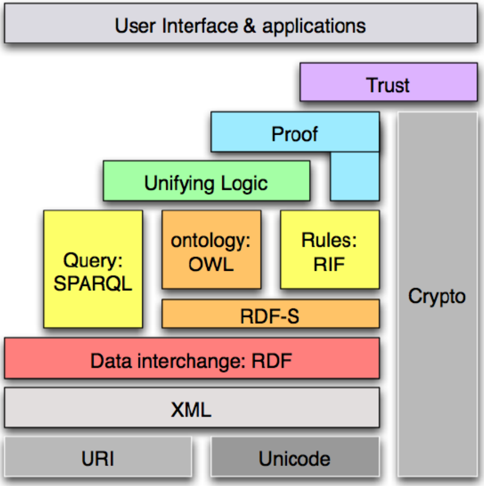
- Only binary relations
- Characteristics of Properties (e.g. inverse, transitive, symmetric)
- Local range restrictions (e.g. for Class Person, the property hasName has range xsd:string)
- Complex concept descriptions (e.g. Person is defined by Man and Woman)
- Cardinality restrictions (e.g. a Person 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⟩

# Outline

# The place of OWL in the layer cake



# Stack of Languages

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- RDF
  - Datamodel for “relations” between “things”
- RDF Schema
  - RDF Vocabulary Definition Language
- OWL
  - **A more expressive Vocabulary Definition Language**

# Outline

1. Introduction
   - W3C's layer cake
   - Limitations of RDFS
2. OWL
   - Design of OWL
   - OWL family of languages
   - OWL and Description Logics
   - OWL Syntaxes
   - Layering OWL on top of RDF(S)

# 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

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# 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

# Outline

# 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)

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# 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

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# 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
  - 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$^{++}$)

# OWL Lite

- 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)
```

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# OWL lite

OWL Lite corresponds to the DL $\mathcal{SHIF}(\mathbf{D})$. It has:

- 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

OWL DL corresponds to the DL $\mathcal{SHOIN}(\mathbf{D})$. In addition to all of OWL Lite, it has also:

- Arbitrary number restrictions ($\geq nP$, $\leq nP$, $= nP$), $0 \leq n$
- Property value ($\exists P.\{o\}$)
- Enumeration ($\{o_1, ..., o_n\}$)

# OWL constructs (summarised from the standard)

| 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 | $\{o_1, ..., o_n\}$ | $\{giselle, juan\}$ |
| allValuesFrom | $\forall P.C$ | $\forall hasChild.Doctor$ |
| someValuesFrom | $\exists P.C$ | $\exists hasChild.Lawyer$ |
| value | $\exists P.\{o\}$ | $\exists citizenOf.\{RSA\}$ |
| minCardinality | $\geq nP$ | $\geq 2 hasChild$ |
| maxCardinality | $\leq nP$ | $\leq 1 hasChild$ |
| cardinality | $= nP$ | $= 2 hasParent$ |

+ 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 | $C_1 \equiv ... \equiv C_n$ | $Man \equiv Human \sqcap Male$ |
| SubPropertyOf | $P_1 \sqsubseteq P_2$ | $hasDaughter \sqsubseteq hasChild$ |
| EquivalentProperties | $P_1 \equiv ... \equiv P_n$ | $cost \equiv price$ |
| SameIndividual | $o_1 = ... = o_n$ | $President\_Zuma = J\_Zuma$ |
| DisjointClasses | $C_i \sqsubseteq \neg C_j$ | $Male \sqsubseteq \neg Female$ |
| DifferentIndividuals | $o_i \neq o_j$ | $sally \neq shereen$ |
| inverseOf | $P_1 \equiv P_2^-$ | $hasChild \equiv hasParent^-$ |
| Transitive | $P^+ \sqsubseteq P$ | $ancestor^+ \sqsubseteq ancestor$ |
| Symmetric | $P \equiv P^-$ | $connectedTo \equiv connectedTo^-$ |

# Outline

# 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, pseudo-NL verbalizations (mainly in English only)

# 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)

*In DL syntax:*

$\text{associateProfessor} \sqsubseteq \text{academicStaffMember}$
$\text{associateProfessor} \sqsubseteq \neg\ \text{assistantProfessor}$
$\text{professor} \sqsubseteq \neg\ \text{associateProfessor}$

$\text{faculty} \equiv \text{academicStaffMember}$

# 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:

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

# 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))))

*In DL syntax:*

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

# Outline

# 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

- 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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| _: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)

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# 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