OWL 2
Web Ontology Language

Some material adapted from presentations by Ian Horrocks and by Feroz Farazi
Introduction

• **OWL 2** extends OWL 1.1 and is backward compatible with it
• The new features of OWL 2 based on real applications, use cases and user experience
• Adopted as a W3C recommendation in December 2012
• All new features were justified by use cases and examples
• Most OWL software supports OWL 2
Features and Rationale

• Syntactic sugar
• New constructs for properties
• Extended datatypes
• Punning
• Extended annotations
• Some innovations
• Minor features
Syntactic Sugar

• OWL 2 adds features that
  – Don’t change expressiveness, semantics, complexity
  – Makes some patterns easier to write
  – Allowing more efficient processing in reasoners

• New features include:
  – DisjointClasses
  – DisjointUnion
  – NegativeObjectPropertyAssertion
  – NegativeDataPropertyAssertion
Syntactic sugar: disJointClasses

• It’s common to want to assert that a set of classes are pairwise disjoint
  – No individual can be an instance of two of the classes in set
• Faculty, staff and students are all disjoint
  [a owl:allDisjointClasses;
   owlmembers (:faculty :staff :students)]
• In OWL 1.1 we’d have to make three assertions
  – :faculty owl:disjointWith :staff
  – :faculty owl:disjointWith :student
  – :staff owl:disjointWith :staff
• Which gets cumbersome for large sets
Syntactic sugar: disJointUnion

• Need for disjointUnion construct
  – A :CarDoor is exclusively either
    • a :FrontDoor, a :RearDoor or a :TrunkDoor
    • and not more than one of them

• In OWL 2
  :CarDoor a owl:disjointUnionOf (:FrontDoor :RearDoor :TrunkDoor).

• In OWL 1.1
  :CarDoor owl:unionOf (:FrontDoor :RearDoor :TrunkDoor).
  :FrontDoor owl:disjointWith :ReadDoor .
  :FrontDoor owl:disjointWith :TrunkDoor .
  :RearDoor owl:disjointWith :TrunkDoor .
Syntactic sugar: disJointUnion

• It’s common for a concept to have more than one decomposition into disjoint union sets
• E.g.: every person is either male or female (but not both), either a minor or adult (but not both) and either living or dead (but not both)

foaf:Person

   owl:disjointUnionOf (:Male :Female);
   owl:disjointUnionOf (:Minor :Adult);
   owl:disjointUnionOf (:Living :Dead);
Syntactic sugar: negative assertions

• Asserts that a property doesn’t hold between two instances or between an instance and a literal
  • NegativeObjectPropertyAssertion
    – Barack Obama was not born in Kenya
  • NegativeDataPropertyAssertion
    – Barack Obama is not 60 years old
• Encoded using a “reification style”
Syntactic sugar: negative assertions

@prefix dbr: <http://dbpedia.org/resource/> .
@prefix dbo: <http://dbpedia.org/ontology/> .

[a owl:NegativeObjectPropertyAssertion;
 owl:sourceIndividual dbr:Barack_Obama ;
 owl:assertionProperty dbo:bithPlace ;

[a owl:NegativeDataPropertyAssertion;
 owl:sourceIndividual dbo:Barack_Obama ;
 owl:assertionProperty dbo:age ;
 owl:targetIndividual "60" ] .
Syntactic sugar: negative assertions

• Note that the negative assertions are about two individuals
• Suppose we want to say that :john has no spouse?
• Or to define the concept of an unmarried person?
• Can we use a negative assertion to do it?
Syntactic sugar: negative assertions

• Suppose we want to say that :john has no spouse?

  [a owl:NegativeObjectPropertyAssertion;
   owl:sourceIndividual  :john ;
   owl:assertionProperty dbpo:spouse ;
   owl:targetIndividual  ?????????? ] .

• We can’t do this with a negative assertion 😞

• It requires a variable, e.g., there is no ?X such that (:john, dbpo:spouse, ?X) is true
Syntactic sugar: negative assertions

• The negative assertion feature is limited
• Can we define a concept :unmarriedPerson and assert that :john is an instance of this?
• We can do it this way in OWL:
  – An unmarried person is a kind of person
  – and a kind of thing with exactly 0 spouses
John is not married

:john a :unmarriedPerson .
:unmarriedPerson
  a Person;
  a [a owl:Restriction;
    onProperty dbpo:spouse;
    owl:cardinality “0”] .
New property Features

• Self restriction
• Qualified cardinality restriction
• Object properties
• Disjoint properties
• Property chain
• Keys
Self restriction

• Classes of objects that are related to themselves by a given property
  – E.g., the class of processes that regulate themselves
• It is also called *local reflexivity*
  – E.g., Auto-regulating processes regulate themselves
• Narcissists are things who love themselves

LEASE: Narcissist owl:equivalentClass

[a owl:Restriction;
 owl:onProperty :loves;
 owl:hasSelf "true"^^xsd:boolean] .
Qualified cardinality restrictions

• Qualifies the instances to be counted

• Six varieties: \{Data | Object\}\{Min | Exact | Max\} Type

• Examples
  – People with \textbf{exactly} 3 children who are girls
  – People with \textbf{at least} 3 names
  – Each individual has \textbf{at most} 1 SSN
  – E.g., pizzas with exactly four toppings all of which are cheeses
Qualified cardinality restrictions

• Done via new properties with domain owl:Restriction, namely \{\textit{min}|\textit{max}|\} \textit{QualifiedCardinality} and \textit{onClass}

• E.g.: people with exactly 3 children who are girls

  [a owl:restriction;
    owl:onProperty :hasChild;
    owl:onClass [owl:subClassOf :Female;
      owl:subClassOf :Minor].
  
  QualifiedCardinality “3”.

• Or: hasChild \textbf{exactly} 3 Female \textbf{and} Minor
Object properties

• ReflexiveObjectProperty
  – Globally reflexive
  – Everything is part of itself

• IrreflexiveObjectProperty
  – Nothing can be a proper part of itself

• AsymmetricObjectProperty
  – If x is proper part of y, then the opposite does not hold
Disjoint properties

• E.g., you can’t be both the parent of and child of the same person

• DisjointObjectProperties (for object properties)
  E.g., :hasParent owl:propertyDisjointWith :hasChild

• DisjointDataProperties (for data properties)
  E.g., :startTime owl:disjointWith :endTime

• AllDisjointProperties for pairwise disjointness
  [a owl:AlldisjointProperties ;
   owl:members (:hasSon :hasDaughter :hasParent) ] .
A Dissertation Committee

Here is a relevant real-world example.

A dissertation committee has a candidate who must be a student and five members all of whom must be faculty. One member must be the advisor, another can be a co-advisor and two must be readers. The readers can not serve as advisor or co-advisor.

How can we model it in OWL?
A dissertation committee has a candidate who must be a student and five members all of whom must be faculty. One member must be the advisor, another can be a co-advisor and two must be readers. The readers can not serve as advisor or co-advisor.

• Define a DissertationCommittee class

• Define properties it can have along with appropriate constraints
A Dissertation Committee

:DC a owl:class; [a owl:Restriction;
   owl:onProperty :co-advisor; owl:maxCardinality "1"] .

:candidate a owl:FunctionalProperty;
   rdfs:domain :DC; rdfs:range :Student.

:advisor a owl:FunctionalProperty;
   rdfs:domain :DC; rdfs:range :Faculty.

:co-advisor owl:ObjectProperty;
   rdfs:domain :DC; rdfs:range :Faculty, owl:propertyDisjointWith :advisor .

...
Property Chains

• A common pattern in a graph representation is a chain of properties, e.g. parent\textbullet parent

• Properties can be defined as a composition of other properties

• The brother of your parent is your uncle
  :uncle owl:propertyChainAxiom (:parent :brother).

• Your parent’s sister’s spouse is your uncle
Property chains: OWL vs. SPARQL

- SPARQL also supports property chains (aka paths) and adds expressivity with a regex-like grammar.
- Operators include ? (0 or 1), + (one or more), * (any number), ^ (inverse), # constraints, ...

<table>
<thead>
<tr>
<th>Syntax Form</th>
<th>Matches</th>
</tr>
</thead>
<tbody>
<tr>
<td>uri</td>
<td>A URI or a prefixed name. A path of length one.</td>
</tr>
<tr>
<td>^elt</td>
<td>Inverse path (object to subject).</td>
</tr>
<tr>
<td>(elt)</td>
<td>A group path elt, brackets control precedence.</td>
</tr>
<tr>
<td>elt1 / elt2</td>
<td>A sequence path of elt1, followed by elt2</td>
</tr>
<tr>
<td>elt1 ^ elt2</td>
<td>Shorthand for elt1 / ^elt2, that is elt1 followed by the inverse of elt2.</td>
</tr>
<tr>
<td>elt1 / elt2</td>
<td>A alternative path of elt1, or elt2 (all possibilities are tried).</td>
</tr>
<tr>
<td>elt*</td>
<td>A path of zero or more occurrences of elt.</td>
</tr>
<tr>
<td>elt+</td>
<td>A path of one or more occurrences of elt.</td>
</tr>
<tr>
<td>elt?</td>
<td>A path of zero or one elt.</td>
</tr>
<tr>
<td>elt{n,m}</td>
<td>A path between n and m occurrences of elt.</td>
</tr>
<tr>
<td>elt{n}</td>
<td>Exactly n occurrences of elt. A fixed length path.</td>
</tr>
<tr>
<td>elt{n,}</td>
<td>n or more occurrences of elt.</td>
</tr>
<tr>
<td>elt{0,n}</td>
<td>Between 0 and n occurrences of elt.</td>
</tr>
</tbody>
</table>
Property chains: OWL vs. SPARQL

• Common usecase: find all of an entities types
  SELECT DISTINCT ?class WHERE {
    dbr:Barack_Obama rdf:type/owl:subclassOf* ?class }

• Another: find all birth places using isPartOf
  SELECT DISTINCT ?place WHERE {
    dbr:Barack_Obama dbo:birthplace/dbo:isPartOf* ?place}

• Another: find all ancestors
  SELECT DISTINCT ?person WHERE {
    dbr:Barack_Obama ^dbo:child+ ?person}
Keys

• Individuals can be identified uniquely
• Identification can be done using
  – A data or object property (equivalent to inverse functional)
  – A set of properties
• Examples
  foaf:Person
    owl:hasKey (foaf:mbox),
    (:homePhone :foaf:name).
Extended datatypes

• Extra datatypes
  – Examples: owl:real, owl:rational, xsd:pattern

• Datatype restrictions
  – Range of datatypes
  – For example, a teenager has age between 13 and 18
Extended datatypes

• Data range combinations
  – Intersection of
    • DataIntersectionOf( \textit{xsd:nonNegativeInteger} \textit{xsd:nonPositiveInteger} )
  – Union of
    • DataUnionOf( \textit{xsd:string} \textit{xsd:integer} )
  – Complement of data range
    • DataComplementOf( \textit{xsd:positiveInteger} )
An Example: Teenager

:Teenager a
  [owl:Restriction ;
   owl:onProperty :hasAge ;
   owl:someValuesFrom _:y .]
_:y a rdfs:Datatype ;
   owl:onDatatype xsd:integer ;
   owl:withRestrictions ( _:z1 _:z2 ) .
_:z1 xsd:minInclusive   "13"^^xsd:integer .
_:z2 xsd:maxInclusive   "19"^^xsd:integer .
An Example: Teenager (2)

:Teenager a

[owl:Restriction ;
  owl:onProperty :hasAge ;
  owl:someValuesFrom
    [a rdfs:Datatype ;
      owl:onDatatype xsd:integer ;
      owl:withRestrictions
        ( [xsd:minInclusive "13"^^xsd:integer ]
Punning

• **OWL 1 DL** things can’t be both a class and instance
  – E.g., :SnowLeopard can’t be both a subclass of :Feline and an instance of :EndangeredSpecies

• **OWL 2 DL** offers better support for *meta-modeling* via *punning*
  – A URI denoting an owl thing can have two distinct views, e.g., as a **class** and as an **instance**
  – The one intended is determined by its **use**
  – A *pun* is often defined as a joke that exploits the fact that a word has two different senses or meanings
Punning Restrictions

• Some puns are not allowed 😞

• Classes and object properties also can have the same name
  — For example, :mother can be both a property and a class of people

• But classes and datatype properties can not have the same name

• Also datatype properties and object properties can not have the same name
Punning Example

@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.

foaf:Person a owl:Class.
:Woman a owl:Class.
:Parent a owl:Class.

:mother a owl:ObjectProperty;
  rdfs:domain foaf:Person;
  rdfs:range foaf:Person .

:mother a owl:Class;
  owl:intersectionOf (:Woman :Parent).

validate via http://owl.cs.manchester.ac.uk/validator/
Annotations

• In OWL annotations comprise information that carries no official meaning
• Some properties in OWL 1 are annotation properties, e.g., owl:comment, rdf:label and rdf:seeAlso
• OWL 1 allowed RDF reification as a way to say things about triples, again w/o official meaning

    [a rdf:Statement;
     rdf:subject :Barack_Obama;
     rdf:predicate dbpo:born_in;
     rdf:object :Kenya;
     :certainty “0.01” ].
Annotations

• OWL 2 has native support for annotations, including
  – Annotations on owl axioms (i.e., triples)
  – Annotations on entities (e.g., a Class)
  – Annotations on annotations
• The mechanism is again reification
Annotations

:Man rdfs:subClassOf :Person .
_:x rdf:type owl:Axiom ;
   owl:subject :Man ;
   owl:predicate rdfs:subClassOf ;
   owl:object :Person ;
   :probability "0.99"^^xsd:integer ;
   rdfs:label "Every man is a person." .
Inverse object properties

• Some object property can be the inverse of another property
• For example, partOf and hasPart
• ObjectInverseOf( :partOf ) expression represents the inverse property of :partOf
• Makes writing ontologies easier by avoiding the need to explicitly name an inverse
OWL Sub-languages

• OWL 1 had sub-languages: OWL FULL, OWL DL and OWL Lite
• OWL FULL is undecidable
• OWL DL is worst case highly intractable
• Even OWL Lite turned out to be not very tractable (EXPTIME-complete)
• OWL 2 introduced three sub-languages, called *profiles*, designed for different use cases
OWL 2 Profiles

OWL 2 defines three new tractable profiles:

- **EL**: polynomial time reasoning for schema and data
  - Useful for ontologies with large conceptual part
- **QL**: fast (logspace) query answering using RDBMs via SQL
  - Useful for large datasets already stored in RDBs
- **RL**: fast (polynomial) query answering using rule-extended DBs
  - Useful for large datasets stored as RDF triples
OWL Profiles

• Profiles considered
  – Useful computational properties, e.g., reasoning complexity
  – Implementation possibilities, e.g., using RDBs

• There are three profiles
  – OWL 2 EL
  – OWL 2 QL
  – OWL 2 RL
OWL 2 EL

• A (near maximal) fragment of OWL 2 such that
  – Satisfiability checking is in PTime (**PTime-Complete**)  
  – Data complexity of query answering is PTime-Complete

• Based on **EL** family of description logics
  – Existential (someValuesFrom) + conjunction

• Does not allow disjunction or *universal restrictions*
• *Saturation* is an efficient reasoning technique

• It can capture the expressive power used by many large-scale ontologies, e.g., **SNOMED CT**
Basic Saturation-based Technique

Normalise ontology axioms to standard form:
\[
A \subseteq B \quad A \cap B \subseteq C \quad A \subseteq \exists R. B \quad \exists R. B \subseteq C
\]

- Saturate using inference rules:
\[
\begin{align*}
A \subseteq B & \quad B \subseteq C & \quad A \subseteq C \\
A \subseteq B & \quad A \subseteq C & \quad B \cap C \subseteq D & \quad A \subseteq D
\end{align*}
\]
\[
A \subseteq \exists R. B \quad B \subseteq C \quad \exists R. C \subseteq D & \quad A \subseteq D
\]

- Extension to Horn fragment requires (many) more rules

Saturation is a general reasoning technique in which you first compute the deductive closure of a given set of rules and add the results to the KB. Then run your prover.
Saturation-based Technique

Performance with large bio-medical ontologies

<table>
<thead>
<tr>
<th>Concepts:</th>
<th>GO</th>
<th>NCI</th>
<th>Galen v.0</th>
<th>Galen v.7</th>
<th>SNOMED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FACT++</strong></td>
<td>15.24</td>
<td>6.05</td>
<td>465.35</td>
<td>—</td>
<td>650.37</td>
</tr>
<tr>
<td><strong>HERMIT</strong></td>
<td>199.52</td>
<td>169.47</td>
<td>45.72</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>PELLET</strong></td>
<td>72.02</td>
<td>26.47</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>CEL</strong></td>
<td>1.84</td>
<td>5.76</td>
<td>—</td>
<td>—</td>
<td>1185.70</td>
</tr>
<tr>
<td><strong>CB</strong></td>
<td>1.17</td>
<td>3.57</td>
<td>0.32</td>
<td>9.58</td>
<td>49.44</td>
</tr>
<tr>
<td><strong>Speed-Up:</strong></td>
<td>1.57X</td>
<td>1.61X</td>
<td>143X</td>
<td>∞</td>
<td>13.15X</td>
</tr>
</tbody>
</table>

Galen and Snomed are large ontologies of medical terms; both have OWL versions. NCI is a vocabulary of cancer-related terms. GO is the gene ontology.
OWL 2 QL

• The QL acronym reflects its relation to the standard relational **Query Language**

• It does not allow *existential* and *universal restrictions* to a class expression or a data range
  – enable a tight integration with RDBMSs
  – reasoners can be implemented on top of standard relational databases

• Can answer complex queries (in particular, unions of conjunctive queries) over the instance level (ABox) of a DL knowledge base
OWL 2 QL

We can exploit query rewriting based reasoning technique

– Computationally optimal
– Data storage and query evaluation can be delegated to standard RDBMS
– Can be extended to more expressive languages (beyond AC$^0$) by delegating query answering to a Datalog engine
What is **Datalog**?

- Truly declarative logic programming language that’s a subset of Prolog
  - Just rules and facts
  - No data structures, cut
  - Rule ordering unimportant
- Used as a query language for **deductive databases**
- Queries on finite sets sets guaranteed to terminate

parent(bill,mary).
pARENT(mary,john).

ancestor(X,Y) :- parent(X,Y).
ancestor(X,Y) :- parent(X,Z), ancestor(Z,Y).
Query Rewriting Technique (basics)

• Given ontology $O$ and query $Q$, use $O$ to rewrite $Q$ as $Q^0$ such that, for any set of ground facts $A$:

$$\text{ans}(Q, O, A) = \text{ans}(Q^0, ;, A)$$

• Resolution based query rewriting
  – **Clausify** ontology axioms
  – **Saturate** (clausified) ontology and query using resolution
  – **Prune** redundant query clauses
OWL 2 RL

• RL acronym reflects relation to *Rule Languages*

• OWL 2 RL designed to accommodate
  – OWL 2 applications that can trade the full expressivity of the language for efficiency
  – RDF(S) applications needing added expressivity from OWL 2

• Not allowed: existential quantification to a class, union and disjoint union to class expressions

• Restrictions allow OWL 2 RL to be implemented using rule-based technologies such as rule extended DBMSs, Jess, Prolog, etc.
Profiles

Profile selection depends on

– Expressiveness required by the application
– Priority given to reasoning on classes or data
– Size of the datasets
## Key OWL 2 Documents

<table>
<thead>
<tr>
<th>Part</th>
<th>Type</th>
<th>Document</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>For Users</td>
<td><strong>Document Overview.</strong> A quick overview of the OWL 2 specification that includes a description of its relationship to OWL 1. This is the starting point and primary reference point for OWL 2.</td>
</tr>
<tr>
<td>2</td>
<td>Core Specification</td>
<td><strong>Structural Specification and Functional-Style Syntax</strong> defines the constructs of OWL 2 ontologies in terms of both their structure and a functional-style syntax, and defines OWL 2 DL ontologies in terms of global restrictions on OWL 2 ontologies.</td>
</tr>
<tr>
<td>3</td>
<td>Core Specification</td>
<td><strong>Mapping to RDF Graphs</strong> defines a mapping of the OWL 2 constructs into RDF graphs, and thus defines the primary means of exchanging OWL 2 ontologies in the Semantic Web.</td>
</tr>
<tr>
<td>4</td>
<td>Core Specification</td>
<td><strong>Direct Semantics</strong> defines the meaning of OWL 2 ontologies in terms of a model-theoretic semantics.</td>
</tr>
<tr>
<td>5</td>
<td>Core Specification</td>
<td><strong>RDF-Based Semantics</strong> defines the meaning of OWL 2 ontologies via an extension of the RDF Semantics.</td>
</tr>
<tr>
<td>6</td>
<td>Core Specification</td>
<td><strong>Conformance</strong> provides requirements for OWL 2 tools and a set of test cases to help determine conformance.</td>
</tr>
<tr>
<td>7</td>
<td>Specification</td>
<td><strong>Profiles</strong> defines three sub-languages of OWL 2 that offer important advantages in particular applications scenarios.</td>
</tr>
<tr>
<td>8</td>
<td>For Users</td>
<td><strong>OWL 2 Primer</strong> provides an approachable introduction to OWL 2, including orientation for those coming from other disciplines.</td>
</tr>
<tr>
<td>9</td>
<td>For Users</td>
<td><strong>OWL 2 New Features and Rationale</strong> provides an overview of the main new features of OWL 2 and motivates their inclusion in the language.</td>
</tr>
<tr>
<td>10</td>
<td>For Users</td>
<td><strong>OWL 2 Quick Reference Guide</strong> provides a brief guide to the constructs of OWL 2, noting the changes from OWL 1.</td>
</tr>
<tr>
<td>11</td>
<td>Specification</td>
<td><strong>XML Serialization</strong> defines an XML syntax for exchanging OWL 2 ontologies, suitable for use with XML tools like schema-based editors and XQuery/XPath.</td>
</tr>
<tr>
<td>12</td>
<td>Specification</td>
<td><strong>Manchester Syntax</strong> (WG Note) defines an easy-to-read, but less formal, syntax for OWL 2 that is used in some OWL 2 user interface tools and is also used in the Primer.</td>
</tr>
<tr>
<td>13</td>
<td>Specification</td>
<td><strong>Data Range Extension: Linear Equations</strong> (WG Note) specifies an optional extension to OWL 2 which supports advanced constraints on the values of properties.</td>
</tr>
</tbody>
</table>

Conclusion

• Most of the new features of OWL 2 in comparing with the initial version of OWL have been discussed
• Rationale behind the inclusion of the new features have also been discussed
• Three profiles – EL, QL and RL – are provided that fit different use cases and implementation strategies