INFO216:

Knowledge Graphs

Andreas L. Opdahl
<Andreas.Opdahl@uib.no>

Session S12 OWL 2

- Themes:
  - restriction classes
  - anatomy of OWL
  - more examples of *Turtle* (+ *Manchester Syntax*)
  - builds on *S06: OWL1 (RDFS Plus)*
    - *what and why?*
    - *basic OWL constructs*
    - *complex classes*
- Themes for *S13: Rules and reasoning (OWL DL)*:
  - rules, description logic, decision problems
  - perhaps the OWL API and reasoners

Readings

- Forum links (cursory):
  - OWL 2 Overview: *http://www.w3.org/TR/owl-overview/*
  - OWL 2 Primer: *http://www.w3.org/TR/owl-primer/*
    - show: Turtle and Manchester syntax
    - hide: other syntaxes
- Support:
  - Allemang & Hendler (2011): Semantic Web for the Working Ontologist Chapter 11 (“Basic OWL”) and 12 (even more OWL!)

Web Ontology Language (OWL)

RDFS is a useful starting point... (S05-06)

- But there's lots of simple stuff it cannot express, e.g.:
  - “every ancestor of an ancestor is an ancestor too”
  - “the BirthNumber of a Person is unique”
  - “a Republic has exactly one President”
  - “a FootballTeam has 11 players, a VolleyballTeam only 6”
  - “a StringQuartet has two violins but only one viola and one cello”
  - “classes with different IRIs actually represent the same class”
  - “resources with different IRIs represent the same resource”
  - “properties with different IRIs are actually the same”
  - “two individuals are different”, “two classes are disjoint”
  - “a class is a union (or intersection) of other classes”
  - “a class is a negation of another class”
- *OWL expresses all this and more!*

What does OWL offer?

- Extensions of RDFS, e.g.:
  - more *specific types* of properties
  - *identical and different* classes, properties, individuals
  - *defining new classes*:
    - complex classes (union, intersection, complement)
    - property restrictions, enumeration of individuals
  - *defining new properties* based on existing ones
  - *mathematical formality* (for large parts of OWL)
    - certain OWL ontologies are also logical systems
      - *description logic (DL)*
      - *OWL DL* has good computational behaviours
    - *(appearance of)* more powerful *entailments*

The Core
OWL Concepts

Classes, properties, and individuals

- Web Ontology Language (OWL):
  - builds on RDF and RDFS (but not SKOS)
  - uses classes and properties from RDF and RDFS
  - adds precision and formality
- Basic OWL-concepts:
  - owl:Class rdfs:subClassOf rdfs:Class .
  - "owl:Property" rdfs:subClassOf rdf:Property .
  - "owl:Individual" rdfs:subClassOf rdfs:Resource .
    - good practice: keep these three *disjoint*, i.e., no resource has more than one of them as *rdf:type*
    - *in OWL DL, this is a requirement...*

Building blocks

- OWL 2 has three building blocks:
  - *entities:*
    - refer to real-world entities using IRIs
    - owl:NamedClass, owl:NamedIndividual
    - owl:ObjectProperty, owl:DatatypeProperty, owl:AnnotationProperty, owl:ObjectProperty
  - *axioms:*
    - basic statements the OWL ontology expresses
    - every triple in the RDF graph is an axiom
  - *expressions:*
    - combining simpler entities (classes, individuals, or properties) to define more complex ones
    - based on *constructors*

Building blocks

- OWL 2 has three building blocks:
  - *entities:*
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    - owl:NamedClass, owl:NamedIndividual
    - owl:ObjectProperty, owl:DatatypeProperty, owl:AnnotationProperty, owl:ObjectProperty
  - *axioms:* ← *can be true or false!*
    - basic statements the OWL ontology expresses
    - every triple in the RDF graph is an axiom
  - *expressions:*
    - combining simpler entities (classes, individuals, or properties) to define more complex ones
    - based on *constructors*

Things and named individuals

- owl:Thing:
  - is equivalent to *rdfs:Resource*
- owl:Nothing
  - is the empty set
  - no resource has it as its *rdf:type*
- owl:NamedIndividual
  - is an *owl:Thing* with an IRI
  - defined in OWL2 DL

Named and constructed classes

- owl:NamedClass (with an IRI):
  - semantics are given by:
    - IRI-s, labels and other annotations
    - domain, range, subClassOf and other relationships
- *Constructed* (or *complex*) owl:Class:
  - built from existing classes, properties, individuals
    - which can be named *or anonymous*
  - constructed classes are *anonymous upon declaration,*
    - but can be *named* later
  - *unions, intersections* and *negations* of existing classes
  - *restrictions* on existing properties
  - *enumeration* of existing individuals

Object and datatype properties

- RDF triples: object is either a resource or a literal
  - OWL has two corresponding types of predicates
- owl:ObjectProperty:
  - rdfs:range (“verdiområde”) is an OWL-class of individuals
  - corresponds to RDF triples with a *resource* object
- owl:DatatypeProperty:
  - rdfs:range is an RDFS-datatype
  - corresponds to RDF triples with a *literal* object
- rdfs:domain (“definisjonsmengden”) for OWL properties is always an OWL-class of individuals

Annotation and ontology properties

- Annotation properties are used to annotate
  - whole *ontologies* (e.g., version)
  - ontology *entities* (*classes, individuals, properties*)
  - ontology *axioms* (*triples*)
  - for example: *rdfs:comment...*
- Ontology properties are used to manage ontologies
  - for example: *owl:imports...*
- They have *RDFS-semantics*
  - but no specific *description logic* (DL) semantics
  - often not "counted" alongside object and datatype properties

Summary: basic OWL types

- owl:Thing, owl:Nothing, owl:NamedIndividual
- owl:NamedClass, owl:Class
- owl:ObjectProperty, owl:DatatypeProperty
- owl:AnnotationProperty, owl:OntologyProperty

Summary: more precise properties (S06)

- owl:inverseOf
- owl:SymmetricProperty, owl:AsymmetricProperty
- owl:ReflexiveProperty, owl:IrreflexiveProperty
- owl:TransitiveProperty
- owl:FunctionalProperty, owl:InverseFunctionalProperty
- owl:hasKey
- Also:
  - negated properties *(today!)*
  - chained properties, e.g.:

    fam:hasGrandparent
        owl:propertyChainAxiom (:hasParent :hasParent) .

Summary: sameness and difference (S06)

- Individuals:
  - pairwise: owl:sameAs, owl:differentFrom
  - groupwise difference: owl:AllDifferent
- Classes:
  - pairwise: owl:equivalentClass, owl:disjointWith
  - groupwise difference: owl:AllDisjointClasses
- Properties:
  - pairwise: equivalentProperty, propertyDisjointWith
  - groupwise difference: owl:AllDisjointProperties
- Membership in the groups:
  - owl:distinctMembers *(preferred)* or owl:members

Complex OWL classes

Enumeration classes

- An *enumeration class* is defined by exhaustively listing all its member individuals, e.g.:
  - [a owl:Class ;
    owl:oneOf (cal:Spring ... cal:Winter)] .
- An enumeration class is *closed*
  - there are no other member individuals
  - ensured by using *RDF Collections:*
    - rdf:List, rdf:first, rdf:rest, rdf:nil
- Does *not* imply that the individuals are distinct
  - this must be stated explicitly

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    - rdf:List, rdf:first, rdf:rest, rdf:nil
- Does *not* imply that the individuals are distinct
  - this must be stated explicitly

Other ways to write complex classes

- This is allowed:

  cal:Season
  owl:oneOf (cal:Spring ... cal:Winter) .

- But this is more explicit and common:

  cal:Season owl:equivalentClass [
  owl:oneOf (cal:Spring ... cal:Winter)] .

- or (a weaker claim):

  cal:Season rdfs:subClassOf [
  owl:oneOf (cal:Spring ... cal:Winter)] .

- Reason:
  - sometimes we just need *rdfs:subClassOf*
    - and it can be computationally more efficient
  - *owl:equivalentClass* entails two-way *rdfs:subClassOf*

Union classes

- A union class contains all the individuals in *either of* two or more other classes, e.g.,
  - fam:Parent
    a owl:Class;
    owl:unionOf (fam:Father fam:Mother) .
- Entailment rule:
  - if *C owl:equivalentClass owl:unionOf (C1... Cn)* then
    - C1 rdfs:subClassOf C . ... Cn rdfs:subClassOf C .
- why not say just, e.g.,:
  - fam:Father rdfs:subClassOf fam:Parent .
  - fam:Mother rdfs:subClassOf fam:Parent .

?

Intersection classes

- An intersection class contains all the individuals in *all of* two or more other classes, e.g.
  - uib:StudentAssistant
    a owl:Class;
    owl:intersectionOf (uib:Student uib:Teacher) .
- Entailment rule:
  - if *C owl:equivalentClass owl:intersectionOf (C1... Cn)* then
    - C rdfs:subClassOf C1 . ... C rdfs:subClassOf Cn .
- why not say, e.g.:
  - uib:StudentAssistant rdfs:subClassOf uib:Student .
  - uib:StudentAssistant rdfs:subClassOf uib:Teacher .

?

Complement classes

- A complement class contains all the individuals *that are not* in another class:
  - fam:Father owl:complementOf fam:Mother .

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  - *...but is this correct?!*

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    a owl:Class;
    owl:complementOf fam:Mother .

Complement classes

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  - fam:Father

```
owl:intersectionOf (
        fam:Parent
        owl:complementOf fam:Mother
) .
```

Complement classes

- A complement class contains all the individuals *that are not* in another class:
  - fam:Father

```
owl:intersectionOf (
        fam:Parent
        [   a owl:Class ;
            owl:complementOf fam:Mother
        ]
) .
```

Complement classes

- A complement class contains all the individuals *that are not* in another class:
  - fam:Father

```
        owl:intersectionOf (
                fam:Parent
                [  owl:complementOf fam:Mother  ]
        ) .
```

Closed World Assumption (CWA)

- Whenever something is not explicitly stated in the ontology, can we assume that the opposite is the case?
  - DBpedia only lists three James Dean movies – can we thus assume that he only played in three?
- Classical logic and many ICT languages assume so:
  - this is the *"Closed World Assumption" (CWA)*
- *In RDF and OWL, we do not assume that something is false just because it is not stated*
  - this is the *"Open World Assumption" (OWA)*

Negated properties (OWL 2)

- A negated property states that a triple with a particular subject, predicate and object would not correspond to a fact, e.g.,
  - []
    ```
    []      rdf:type owl:NegativePropertyAssertion ;
            owl:sourceIndividual      :Bill ;
            owl:assertionProperty     :hasWife ;
            owl:targetIndividual      :Mary .
    ```
  - means that it is not correct that "Bill has Mary as his wife"
  - an ontology with such a triple and its negation is inconsistent

Negated properties (OWL 2)

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  - [] rdf:type owl:NegativePropertyAssertion ;
    owl:sourceIndividual :Bill ;
    owl:assertionProperty :hasWife ;
    owl:targetIndividual :Mary .
  - [rdf:type owl:NegativePropertyAssertion ;
    owl:sourceIndividual :Bill ;
    owl:assertionProperty :hasWife ;
    owl:targetIndividual :Mary] .
- The structure is similar to *triple reification*

Summary: complex classes

- owl:oneOf
- owl:unionOf
- owl:intersectionOf
- owl:complementOf (and the *CWA*)
- owl:NegativePropertyAssertion, owl:sourceIndividual, owl:assertionProperty, owl:targetIndividual

OWL restriction classes

Property value restrictions

- Defining a class by a particular value on one of its properties, e.g.:
  - fam:Woman
    a owl:Restriction ;
    owl:onProperty fam:hasGender ;
    owl:hasValue fam:Female .

Property value restrictions

- Defining a class by a particular value on one of its properties, e.g.:
  - ~~fam:Woman~~
    ~~a owl:Restriction ;~~
    ~~owl:onProperty fam:hasGender ;~~
    ~~owl:hasValue fam:Female .~~
  - fam:Woman owl:intersectionOf (
    fam:Person
    [a owl:Restriction ;
    owl:onProperty fam:hasGender ;
    owl:hasValue fam:Female]
) .

Existential property restrictions

- Defining a class by the existence of a relation (object property) to an individual in (another or the same) class, e.g.:
  - fam:Brother owl:intersectionOf (
```
                fam:Male
                [    a owl:Restriction ;
                     owl:onProperty fam:hasSibling ;
                     owl:someValuesFrom owl:Thing      ]
  ) .
```
- *owl:someValuesFrom:* each individual in the defined class has *at least one* object property (given by owl:onProperty) to an individual in the other class (given by owl:someValuesFrom)

Existential property restrictions

- Defining a class by the existence of a relation (object property) to an individual in (another or the same) class, e.g.:
  - fam:Uncle owl:intersectionOf (

```
                fam:Male
                [     a owl:Restriction ;
                      owl:onProperty fam:hasSibling ;
                      owl:someValuesFrom fam:Parent     ]
    ) .
```

- *owl:someValuesFrom:* each individual in the defined class has *at least one* object property (given by owl:onProperty) to an individual in the other class (given by owl:someValuesFrom)

Universal property restrictions

- Defining a class by the necessity of a relation (object property) only to individuals in (another or the same) class, e.g.:
  - fam:HappyFather owl:intersectionOf (

```
fam:HappyFather owl:intersectionOf (
        fam:Male
        [   a owl:Restriction ;
            owl:onProperty fam:hasChild ;
            owl:allValuesFrom fam:HappyPerson   ]
) .
```

Universal property restrictions

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  - ```
    fam:HappyFather owl:intersectionOf (
                    fam:Male
                    [    a owl:Restriction ;
                         owl:onProperty fam:hasChild ;
                         owl:allValuesFrom fam:HappyPerson    ]
    ) .
    ```
  - *...but is this correct?!*
    ```

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```
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) .
```

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```
fam:HappyFather owl:intersectionOf (
        fam:Male
        [   a owl:Restriction ;
            owl:onProperty fam:hasChild ;
            owl:allValuesFrom fam:HappyPerson   ]
        [   a owl:Restriction ;
            owl:onProperty fam:hasChild ;
            owl:someValuesFrom fam:HappyPerson   ]
) .
```

Property value restriction

- Using an anonymous property, e.g.:
  - fam:Orphan owl:intersectionOf (

```
fam:Person
[ a owl:Restriction ;
  owl:onProperty [ owl:inverseOf  :hasChild ] ;
  owl:allValuesFrom  fam:Dead
]
[ a owl:Restriction ;
  owl:onProperty [ owl:inverseOf :hasChild ] ;
  owl:someValuesFrom  owl:Thing
]
) .
```

Property self-reflexion (OWL2)

- Defining a class by a *Self* value on one of its properties, e.g.:
  - fam:NarcissisticPerson

```
        a                   owl:Restriction ;
        owl:onProperty      fam:loves ;
        owl:hasSelf         "true"^^xsd:boolean .
```

Property value restriction

- Restrictions on data range, e.g.:
  - fam:personAge rdfs:range

```
[    a rdfs:Datatype;
     owl:onDatatype  xsd:integer;
     owl:withRestrictions (
          [ xsd:minInclusive  "0"^^xsd:integer ]
          [ xsd:maxInclusive  "150"^^xsd:integer ]  )
] .
```

  - :toddlerAge rdfs:range

```
[    a rdfs:Datatype;
     owl:oneOf ( "1"^^xsd:integer  "2"^^xsd:integer)
] .
```

Cardinality restriction

- Defining a class by the number of object values its individuals have for some property, e.g.:
  - music:Quartet owl:intersectionOf (
    music:Ensemble
    [a owl:Restriction ;
    owl:onProperty music:hasInstrument ;
    owl:cardinality 4]
) .
- owl:cardinality gives the *exact cardinality*
  owl:minCardinality gives the *least cardinality*
  owl:maxCardinality gives the *greatest cardinality*

Qualified cardinality restriction (OWL2)

- Defining a class by the number of object values its individuals have *of a given class* for some property, e.g.:
  - pol:Triumvirate owl:intersectionOf (

```
pol:Triumvirate owl:intersectionOf (
        pol:PoliticalLeadership
        [   a owl:Restriction ;
            owl:onProperty pol:hasMember ;
            owl:qualifiedCardinality 3 ;
            owl:onClass pol:PoliticalLeader   ]
    ) .
```

- owl:qualifiedCardinality gives the *exact cardinality*
  owl:minQualifiedCardinality gives the *least cardinality*
  owl:maxQualifiedCardinality gives the *greatest cardinality*
- *Perhaps the most important addition in OWL2!*

Qualified cardinality restriction (OWL2)

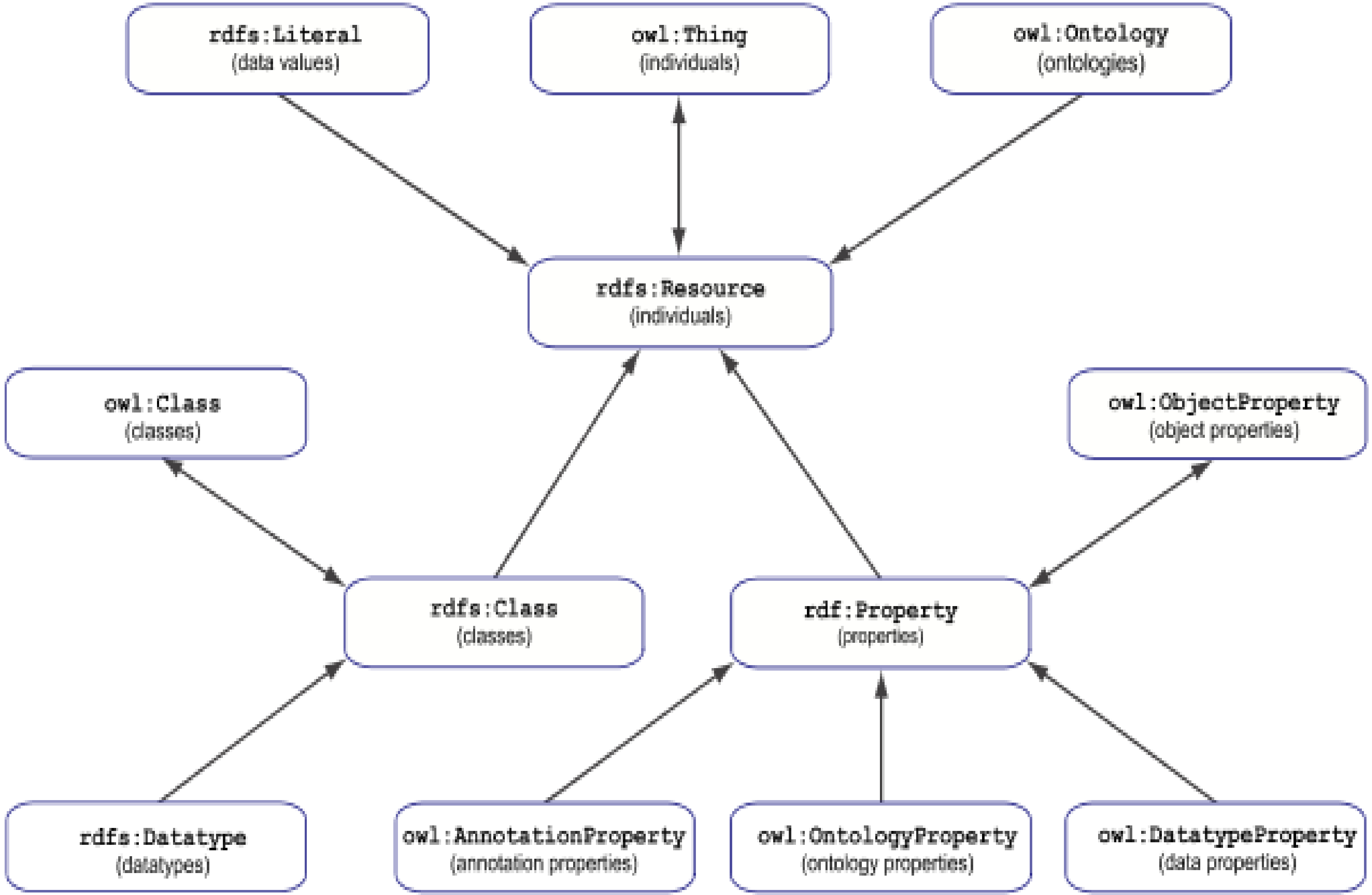
- music:StringQuartet owl:intersectionOf (

```
                music:MusicalQuartet
                [    a owl:Class ;
                     owl:onProperty music:hasInstrument ;
                     owl:qualifiedCardinality "2" ;
                     owl:onClass music:Violin    ]
                [    a owl:Class ;
                     owl:onProperty music:hasInstrument ;
                     owl:qualifiedCardinality "1" ;
                     owl:onClass music:Viola     ]
                [    a owl:Class ;
                     owl:onProperty music:hasInstrument ;
                     owl:qualifiedCardinality "1" ;
                     owl:onClass music:Cello     ]
        ) .
```

Summary: property restrictions

- owl:Restriction owl:onProperty
- owl:someValuesFrom, owl:allValuesFrom, owl:hasValue
- owl:cardinality, owl:minCardinality, owl:maxCardinality
- owl:onClass, owl:qualifiedCardinality, owl:minQualifiedCardinality, owl:maxQualifiedCardinality

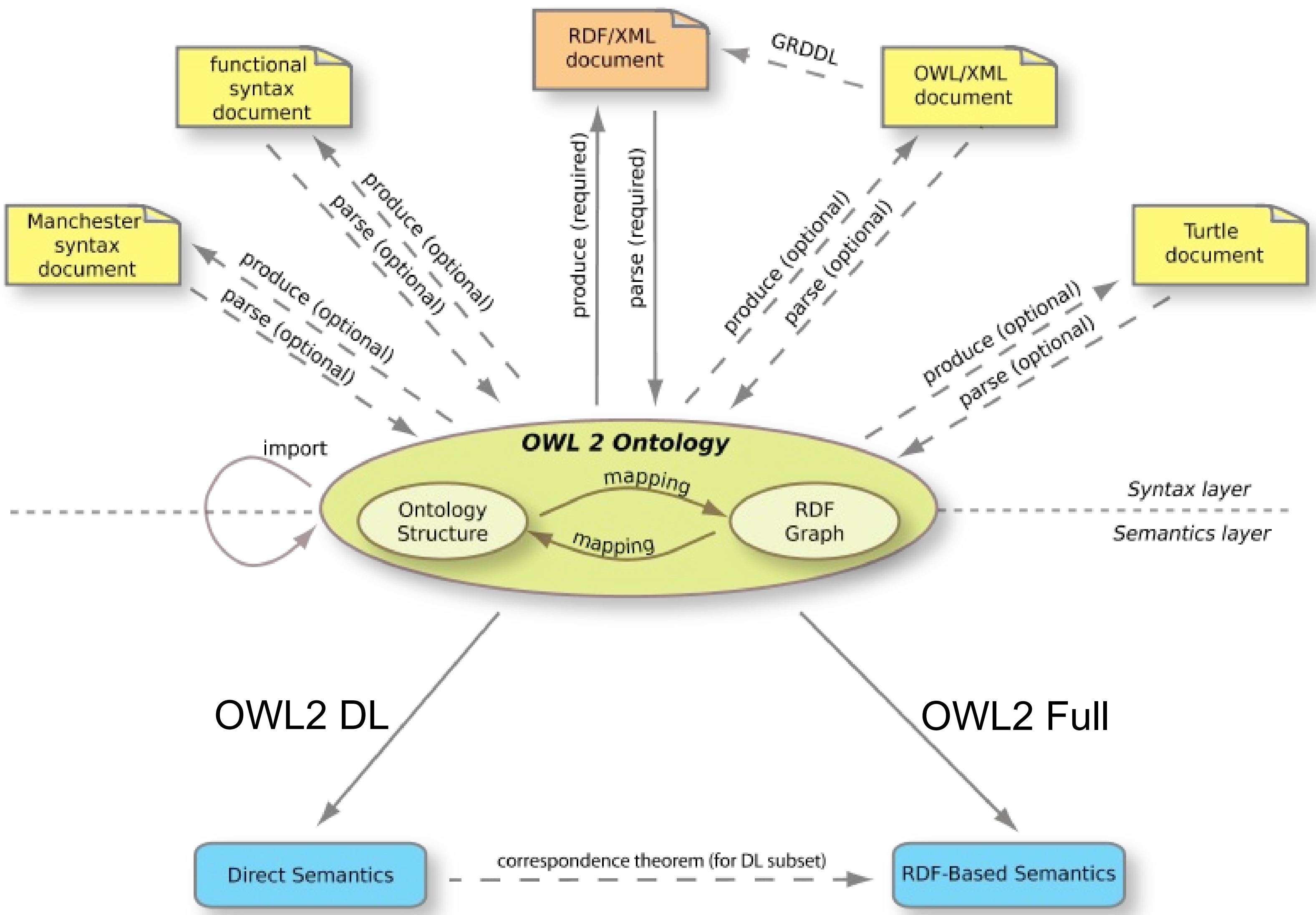
Anatomy of OWL



http://www.w3.org/TR/owl2-rdf-based-semantics/

OWL versions

- OWL “1” (2002):
  - OWL Full – anything goes
  - OWL DL – fragment of OWL Full,
    - formal semantics through *description logic*
  - OWL Lite – simple fragment of OWL DL, not much used
- OWL 2 (2008):
  - *backwards compatible* with OWL “1”!
  - OWL2 DL – fragment of OWL2 full, extension of OWL DL
  - *OWL2 DL* – has three further fragments:
    - OWL2 EL – quick reasoning, fragment of OWL2 DL
    - OWL2 RL – rule language, fragment of OWL2 DL
      - OWL LD – for Linked Data
    - OWL2 QL – query language, fragment of OWL2 DL



functional syntax document
RDF/XML document
GRDDL
OWL/XML document
Manchester syntax document
Turtle document
produce (optional)
parse (optional)
produce (optional)
parse (optional)
produce (required)
parse (required)
produce (optional)
parse (optional)
produce (optional)
parse (optional)
import
OWL 2 Ontology
Ontology Structure
mapping
mapping
RDF Graph
Syntax layer
Semantics layer
OWL2 DL
OWL2 Full
Direct Semantics
correspondence theorem (for DL subset)
RDF-Based Semantics

Summary of OWL terms

- owl:Ontology owl:Class owl:DatatypeProperty owl:ObjectProperty owl:NamedIndividual
- owl:Thing owl:Nothing owl:topObjectProperty owl:bottomObjectProperty owl:topDataProperty owl:bottomDataProperty
- owl:inverseOf owl:FunctionalProperty owl:InverseFunctionalProperty owl:TransitiveProperty owl:ReflexiveProperty owl:IrreflexiveProperty owl:SymmetricProperty owl:AsymmetricProperty owl:propertyChainAxiom
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- owl:complementOf owl:intersectionOf owl:unionOf owl:oneOf owl:datatypeComplementOf owl:onDatatype owl:withRestrictions
- owl:Restriction owl:onProperty owl:onProperties owl:allValuesFrom owl:someValuesFrom owl:onDataRange owl:hasValue owl:hasSelf owl:cardinality owl:qualifiedCardinality owl:minCardinality owl:maxCardinality owl:onClass owl:minQualifiedCardinality owl:maxQualifiedCardinality
- owl:hasKey
- owl:annotatedProperty owl:annotatedSource owl:annotatedTarget owl:Annotation owl:AnnotationProperty owl:Axiom owl:imports owl:versionInfo owl:versionIRI owl:priorVersion owl:backwardCompatibleWith owl:OntologyProperty owl:incompatibleWith owl:deprecated owl:DeprecatedClass owl:DeprecatedProperty
- deprecated: owl:DataRange