OWL
Web Ontology Language

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Most information based on [1]
Reading

http://www.w3.org/TR/owl2-primer/
In this lecture:

- Part 1: Introduction to OWL
- Part 2: OWL Basics
- Part 3: Class Expression Axioms
- Part 4: Property Axioms
- Part 5: Assertions
- Part 6: Class Expressions - Propositional Connectives and Enumeration
- Part 7: Class Expressions - Property Restrictions
- Part 8: Class Expressions - Cardinality Restrictions
What is OWL?

OWL stands for Web Ontology Language.


OWL is part of the "Semantic Web Vision" – The next generation of the Web (Web 3.0).

To describe the meaning/semantics of the Web data (RDF is written in terms of OWL)

OWL is called an ontology language. That is, what we specify in OWL is called an ontology (Ontology is about the exact description of things and their relationships.) For the web, ontology is about the exact description of web information and relationships between them.

OWL’s underpinning description logic is SHOIQ.
OWL versus RDFS and RDF

OWL and RDFS are much of the same thing, but OWL allow constrains and rules.

OWL can be seen as an extension of RDF/RDFS, OWL comes with a larger vocabulary and stronger syntax than RDF and RDFS.

OWL has three sublanguages (OWL full, OWL DL, OWL Lite).
Variations of OWL

**OWL Lite**
- A subset of OWL DL
- This part of OWL is easier for reasoning

**OWL DL**
- The part of OWL Full that is in the Description Logic framework.
- Known to have decidable reasoning.

**OWL Full**
- maximum expressiveness
- no computational guarantees (not undecidable reasoning)
OWL 2

• OWL 2, became a W3C recommendation in 27 October 2009.
• An ontology language for the semantic Web which is extended from OWL 1 and empowered by new features.
• OWL 2 DL underpinning description logic is SROIQ.
• OWL 2 is supported by several semantic reasoners such as RacerPro 2, Pellet, Hermit and FaCT++.
Versions of OWL 2

OWL 2 EL
- Allows for subclass axioms with intersection, existential quantification, top, bottom and closed classes with only one member.
- Disallow for negation, disjunction, arbitrary universal quantification, role inverses.

OWL 2 QL
- Allows for subproperties, domain, range and subclass statements.
- Disallow for closed classes.

OWL 2 RL
- Allows for all axiom types, cardinality restrictions (only \(\leq 1\) and \(\leq 0\) on right hand side) and closed classes with only one member.
- Disallow certain constructors (universal and negation on left hand side and extensional and union on right hand side of subclass statements).
In this lecture:

- Part 1: Introduction to OWL
- Part 2: OWL Basics (Classes, Individuals, Properties)
- Part 3: Class Expression Axioms
- Part 4: Property Axioms
- Part 5: Assertions
- Part 6: Class Expressions - Propositional Connectives and Enumeration
- Part 7: Class Expressions - Property Restrictions
- Part 8: Class Expressions - Cardinality Restrictions
Classes

Owl:Class

Unary predicates: Person(__), City(__).

User-defined classes which are subclasses of root class owl:Thing. A class may contain individuals, which are instances of the class, and other subclasses.

```xml
<?xml version="1.0"?>
<rdf:RDF
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:owl="http://www.w3.org/2002/07/owl#"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
  <owl:ontology rdf:about="http://www.example.com">
    <rdfs:comment> comments here</rdfs:comment>
  </owl:ontology>
  <owl:Class rdf:about="Person"/>
  <owl:Class rdf:about="City"/>
  <owl:Class rdf:about="Country"/>
</rdf:RDF>
```

⇒ Similar to Object-Type in ORM, Entity in EER, or Class in UML
Individuals

• **Constants**: Edward_Said, Palestine.
• An individual is a member/instance of a class

  <Man rdf:about="Edward_Said" />
  <Country rdf:about="Palestine" />
  <City rdf:about="Jerusalem" />

→ Notice that there is no way in ORM/UML/EER to add instance of concepts as part of the schema.
Properties (ObjectProperty)

owl:ObjectProperty
• A relation between instances of two classes.
• Binary predicates (hasAuthor(__, __)).

```xml
<owl:ObjectProperty rdf:about="hasAuthor">
    <rdfs:domain rdf:resource="# Book"/>
    <rdfs:range rdf:resource="#Person"/>
</owl:ObjectProperty>
```

→ Similar to a binary relation in ORM between two entity types.

But unlike ORM, property may not have domain and range, these are used for reasoning.
Properties (DatatypeProperty)

**owl:DataProperty**
- Relation between instances of classes and values.
- The range of a literal datatype (use XML Schema datatypes).
  ```xml
  <owl:DatatypeProperty rdf:about="hasTitle">
    <rdfs:domain rdf:resource="Book" />
    <rdfs:range rdf:resource="xsd:string"/>
  </owl:DatatypeProperty>

  <owl:DatatypeProperty rdf:about="hasPrice">
    <rdfs:domain rdf:resource="Book" />
    <rdfs:range rdf:resource="xsd:integer"/>
  </owl:DatatypeProperty>
  ```

→ Similar to a binary relation in ORM between an Entity and a Value.
Using Properties (Assertions)

Examples of using instances of properties

```xml
  <hasAuthor rdf:resource="http://en.wikipedia.org/wiki/Edward_Said"/>
  <hasTitle rdf:datatype="xsd:string">Orientalism</hasTitle>
  <hasPrice rdf:datatype="xsd:integer">51</hasPrice>
</rdf:Description>

<rdf:Description rdf:about="John">
  <hasWife rdf:resource="Mary"/>
</rdf:Description>
```
Special Classes and Properties

- **Top** class: $T$
  
  `owl:Thing`
  
  contains all individuals of the domain.

- **Bottom** class: $\bot$
  
  `owl:Nothing`
  
  contains no individuals (empty class).

- **Universal** property: $U$
  
  `owl:topObjectProperty`
  
  links every individual to every individual.
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Subclass Axioms

**rdfs:subClassOf**

Notice that `rdfs:subClassOf` is part of RDFS, not OWL. This to show that OWL extends RDF/RDFS.

\[
\text{SubClassOf( } a:Man \text{ a:Person }) \Rightarrow \text{ Each Man is a Person.}
\]

```xml
<owl:Class rdf:about="Man">
  <rdfs:subClassOf rdf:resource="Person"/>
</owl:Class>

<owl:Class rdf:about="Book">
  <rdfs:subClassOf rdf:resource="Publication" />
</owl:Class>
```

» Similar to the SubType relation ORM, UML and EER
Equivalent Classes

owl:equivalentClass

- States equivalence (i.e., class extension) of two named classes.

- Useful when integrating or mapping between two different ontologies.

  <owl:Class rdf:about="Palestine_President">
  <owl:equivalentClass rdf:resource="PrincipalResidentOfPlestine"/>
  </owl:Class>

- A class axiom may contain (multiple) owl:equivalentClass statements.
- The classes Being, Human and Person are semantically equivalent to each other.

  <owl:Class rdf:about="Being">
  <owl:equivalentClass rdf:resource="Human"/>
  <owl:equivalentClass rdf:resource="Person"/>
  </owl:Class>
Disjoint Classes

owl:AllDisjointClasses

• To state that these classes have no individuals in common.

• AllDisjointClasses (C1 ... Cn): all of the classes Ci, 1 ≤ i ≤ n, are pairwise disjoint; that is, no individual can be at the same time an instance of both Ci and Cj for i ≠ j.

```
<owl:AllDisjointClasses>
  <owl:members rdf:parseType="Collection">
    <owl:Class rdf:about="Woman"/>
    <owl:Class rdf:about="Man"/>
  </owl:members>
</owl:AllDisjointClasses>
```
Disjoint Union of Class Expressions

**owl:disjointUnionOf**

- **DisjointUnion** \((C \ C_1 \ldots \ C_n)\): a class \(C\) is a disjoint union of the classes \(C_i\), \(1 \leq i \leq n\), all of which are pairwise disjoint the extensions of all \(C_i\) exactly cover the extension of \(C\).

- **DisjointUnion** \((\text{Person Female Male})\) means each Person is either a Male or a Female, each Female is a Person, each Male is a Person, and nothing can be both a Female and a Male.

```xml
<owl:Class rdf:about="#Person">
  <owl:disjointUnionOf rdf:parseType="Collection">
    <rdf:Description rdf:about="#Female"/>
    <rdf:Description rdf:about="#Male"/>
  </owl:disjointUnionOf>
</owl:Class>
```
Example 1

- Here we illustrate a simple example represented in ORM and OWL 2.
- In the example, the illustrated OWL 2 constructs are Class, Subclass, Union of Classes and Disjoint Classes.

```xml
<owl:Class rdf:about="&Example1:Person"/>
<owl:Class rdf:about="&Example1:Female">
  <rdfs:subClassOf rdf:resource="&Example1:Person"/>
</owl:Class>
<owl:Class rdf:about="&Example1:Male">
  <rdfs:subClassOf rdf:resource="&Example1:Person"/>
</owl:Class>

<owl:Class rdf:about="&Example1:Person">
  <owl:equivalentClass>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="&Example1:Female"/>
        <rdf:Description rdf:about="&Example1:Male"/>
      </owl:unionOf>
    </owl:Class>
  </owl:equivalentClass>
</owl:Class>
<owl:equivalentClass>
</owl:Class>
<owl:Class>
</owl:Class>
<owl:AllDisjointClasses>
  <owl:members rdf:parseType="Collection">
    <owl:Class rdf:about="Female"/>
    <owl:Class rdf:about="Male"/>
  </owl:members>
</owl:AllDisjointClasses>
```
In this lecture:

- **Part 1**: Introduction to OWL
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- **Part 3**: Class Expression Axioms
- **Part 4**: Property Axioms (Subproperties, Equivalent, Disjoint, Inverse, Functional)
- **Part 5**: Assertions
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- **Part 8**: Class Expressions - Cardinality Restrictions
Object Subproperties

`rdfs:subPropertyOf`

Properties, like classes, can be arranged in a hierarchy.

SubPropertyOf (OP1 OP2): if an individual x is connected by OP1 to an individual y, then x is also connected by OP2 to y.

The `rdfs:subPropertyOf` means that anything with a Borrows property with value X also has a ChecksOut property with value X.

```xml
<owl:ObjectProperty rdf:about="Borrows">
    <rdfs:domain rdf:resource="Person"/>
    <rdfs:range rdf:resource="Book"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="ChecksOut">
    <rdfs:subPropertyOf rdf:resource="Borrows"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="hasWife">
    <rdfs:subPropertyOf rdf:resource="hasSpouse"/>
</owl:ObjectProperty>
```

→ Similar to the Subset constraint in ORM.
Equivalent Properties

owl:equivalentProperty

- EquivalentObjectProperties (OP₁ ... OPₙ): all of the object properties OPᵢ, 1 ≤ i ≤ n, are semantically equivalent to each other.

- EquivalentObjectProperties (a:hasBrother  a:hasMaleSibling)意味着having a brother is the same as having a male sibling.

```
<owl:ObjectProperty rdf:about="hasChild">  
  <owl:equivalentProperty rdf:resource="x:child"/>
</owl:ObjectProperty>

<owl:DatatypeProperty rdf:about="hasAge">  
  <owl:equivalentProperty rdf:resource="y:age"/>
</owl:DatatypeProperty>
```
Disjoint Properties

owl:propertyDisjointWith

• DisjointObjectProperties (OP₁ … OPₙ): all of the object properties OPᵢ, 1 ≤ i ≤ n, are pairwise disjoint; that is, no individual x can be connected to an individual y by both OPᵢ and OPⱼ for i ≠ j.

• DisjointObjectProperties( a:hasFather a:hasMother ) means that Fatherhood is disjoint with motherhood.

```xml
<rdf:Description rdf:about="hasFather">
   <owl:propertyDisjointWith rdf:resource="hasMother"/>
</rdf:Description>
```
Inverse Object Properties

**owl:inverseOf**

- If a property $P$ is tagged as the `owl:inverseOf` $Q$, then for all $x$ and $y$: $P(x,y)$ iff $Q(y,x)$.
- Note that the syntax for `owl:inverseOf` takes a property name as an argument. $A$ iff $B$ means $(A$ implies $B)$ and $(B$ implies $A)$.
- **InverseObjectProperties** $(OP_1 \ OP_2)$: the object property $OP_1$ is an inverse of the object property $OP_2$, that is if an individual $x$ is connected by $OP_1$ to an individual $y$, then $y$ is also connected by $OP_2$ to $x$, and vice versa.

```xml
<owl:ObjectProperty rdf:about="hasParent">
    <owl:inverseOf rdf:resource="hasChild"/>
</owl:ObjectProperty>
```

[Diagram: hasParent/hasChild]
**Property Domain**

**rdfs:domain**

- ObjectPropertyDomain (OP C): the domain of the object property OP is the class C, that is, if an individual x is connected by OP with some other individual, then x is an instance of C.

- ObjectPropertyDomain( a:hasDog a:Person ) means that only people can own dogs.

```
<owl:ObjectProperty rdf:about="hasDog">
  <rdfs:domain rdf:resource="Person"/>
  ...
</owl:ObjectProperty>
```

![Diagram showing the relationship between Person and hasDog property]
**Property Range**

**rdfs:range**

- **ObjectPropertyRange**(OP C): the range of the object property OP is the class C, that is, if some individual is connected by OP with an individual x, then x is an instance of C.
- **ObjectPropertyRange**( a:hasDog a:Dog ) means that the range of the a:hasDog property is the class a:Dog.

```xml
<owl:ObjectProperty rdf:about="#hasDog">
  ...
  <rdfs:range rdf:resource="#Dog"/>
</owl:ObjectProperty>
```

![Diagram](image.png)
**Functional Object Property**

**Owl:FunctionalProperty**

- **FunctionalObjectProperty** (OP): the object property OP is functional, that is, for each individual x, there can be at most one distinct individual y such that x is connected by OP to y.

- **FunctionalObjectProperty** (\textit{a:hasFather}) means that each individual can have at most one father.

\[
<\text{owl:FunctionalProperty} \text{ rdf:about="\#hasFather"/>}
\]

![Diagram](image.png)
**Inverse-Functional Object Property**

**Owl:InverseFunctionalProperty**

- InverseFunctionalObjectProperty (OPI): the object property OPI is inverse-functional, that is, for each individual x, there can be at most one individual y such that y is connected by OP with x.

- InverseFunctionalObjectProperty (a:fatherOf) means that each object can have at most one father.

<owl:InverseFunctionalProperty rdf:about="#FatherOf"/>

There is no inverse for Datatype properties
OWL2 Example2

• Here we illustrate a simple example represented in ORM and OWL 2.
• In the example, the illustrated OWL 2 constructs are Object Subproperties, Inverse Object Properties, Object Property Domain, Object Property Range and Functional Object Properties.

<owl:Class rdf:about="&OWL2Example2:Person"/>
<owl:Class rdf:about="&OWL2Example2:Vehicle"/>
<owl:Class rdf:about="&OWL2Example2:Gender"/>

<owl:ObjectProperty rdf:about="&OWL2Example2:Drives">
  <rdfs:domain rdf:resource="&OWL2Example2:Person"/>
  <rdfs:range rdf:resource="&OWL2Example2:Vehicle"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&DrivenBy">
  <owl:inverseOf rdf:resource="OWL2Example2:Drives"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&OWL2Example2:Owns">
  <rdfs:domain rdf:resource="&OWL2Example2:Person"/>
  <rdfs:range rdf:resource="&OWL2Example2:Vehicle"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&OWL2Example2:Owns">
  <rdfs:domain rdf:resource="&OWL2Example2:Person"/>
  <rdfs:range rdf:resource="&OWL2Example2:Vehicle"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&OWL2Example2:Owns">
  <rdfs:domain rdf:resource="&OWL2Example2:Person"/>
  <rdfs:range rdf:resource="&OWL2Example2:Vehicle"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&DrivenBy">
  <owl:inverseOf rdf:resource="OWL2Example2:Drives"/>
</owl:ObjectProperty>

<owl:FunctionalProperty rdf:about="&OWL2Example2:Has/"}
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- **Part 3:** Class Expression Axioms
- **Part 4:** Property Axioms
- **Part 5:** **Assertions** (Equality, Inequality)
- **Part 6:** Class Expressions - Propositional Connectives and Enumeration
- **Part 7:** Class Expressions - Property Restrictions
- **Part 8:** Class Expressions - Cardinality Restrictions
Individual Equality

owl:sameAs

- Identity between Individuals
- This mechanism is similar to that for classes, but declares two individuals to be identical.
- SameIndividual (a1 ... an): all of the individuals ai, 1 ≤ i ≤ n, are equal to each other (synonymes).

```
</rdf:Description>

<rdf:Description rdf:about="x:Edward_Said">
  <owl:sameAs rdf:resource="#E_Said"/>
</rdf:Description>
```
Individual Inequality

owl:differentFrom
• An owl:differentFrom statement indicates that two URI references refer to different individuals.

```xml
  <owl:differentFrom rdf:resource="http://www.youtube.com/watch?v=X3iA73JXIfo"/>
</rdf:Description>

<rdf:Description rdf:about="John">
  <owl:differentFrom rdf:resource="Bill"/>
</rdf:Description>
```
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**Intersection of Class Expressions**

**owl:intersectionOf**

Describes a class for which the class extension contains precisely those individuals that are members of the class extension of all class descriptions in the list.

```xml
<owl:Class rdf:about="Mother">
  <owl:equivalentClass>
    <owl:Class>
      <owl:intersectionOf rdf:parseType="Collection">
        <owl:Class rdf:about="Woman"/>
        <owl:Class rdf:about="Parent"/>
      </owl:intersectionOf>
    </owl:Class>
  </owl:equivalentClass>
</owl:Class>
```

![Proposed Notation Diagram]

A_Intersection

A_1 ⊓ A_2 ⊓ ... ⊓ A_n

Proposed Notation
Union of Class Expressions

owl:unionOf

The union of two classes contains every individual which is contained in at least one of these classes. Therefore we could characterize the class of all parents as the union of the classes Mother and Father:

```
<owl:Class rdf:about="Parent">
  <owl:equivalentClass>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="Mother"/>
        <owl:Class rdf:about="Father"/>
      </owl:unionOf>
    </owl:Class>
  </owl:equivalentClass>
</owl:Class>
```
Complement of Class Expressions

**owl:complementOf**

The complement of a class corresponds to logical negation: it consists of exactly those objects which are not members of the class itself. The following definition of childless persons uses the class complement and also demonstrates that class constructors can be nested:

```xml
<owl:Class rdf:about="ChildlessPerson">
  <owl:equivalentClass>
    <owl:Class>
      <owl:intersectionOf rdf:parseType="Collection">
        <owl:Class rdf:about="Person"/>
        <owl:Class>
          <owl:complementOf rdf:resource="Parent"/>
        </owl:Class>
      </owl:intersectionOf>
    </owl:Class>
  </owl:equivalentClass>
</owl:Class>
```

![Proposed Notation](image)
Enumeration of Individuals

**owl:one of**

- A way to describe a class is just to enumerate all its instances.
- These instances are the only members of PalestinianCities. Classes defined this way are sometimes referred to as closed classes or enumerated sets. We cannot have more, or less instances.

```
<owl:Class rdf:about="PalestinianCities">
  <owl:equivalentClass>
    <owl:Class>
      <owl:oneOf rdf:parseType="Collection">
        <rdf:Description rdf:about="Jerusalem"/>
        <rdf:Description rdf:about="Aka"/>
        <rdf:Description rdf:about="Ramallah"/>
        ...
      </owl:oneOf>
    </owl:Class>
  </owl:equivalentClass>
</owl:Class>
```
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Class Expressions - Property Restrictions

- Existential Quantification
- Universal Quantification
- Individual Value Restriction
- Self-Restriciton
owl:someValuesFrom

- Defines a class as the set of all individuals that are connected via a particular property to another individual which is an instance of a certain class.
- Each Account must have at least one Owner that is a Person.

```xml
<owl:Class rdf:about="Account">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#HasOwner" />
      <owl:someValuesFrom rdf:resource="#Person" />
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```
Object Property Restrictions- Universal Quantification

**owl:allValuesFrom**

- To describe a class of individuals for which all related individuals must be instances of a given class
- For every Account, if they have owners, all the owners must be Persons.

```xml
<owl:Class rdf:about="Account">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#HasOwner" />
      <owl:allValuesFrom rdf:resource="#Person" />
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```
Object Property Restrictions - Individual Value Restriction

**owl:hasValue**

ObjectHasValue( OP a ): consists of an object property OP and an individual a, and it contains all those individuals that are connected by OP to a. For example, we can create a class “BirzeitLovers” to include all those who love Birzeit.

```xml
<owl:Class rdf:about="BirzeitLovers">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#Loves"/>
      <owl:hasValue rdf:resource="#Birzeit"/>
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```

(Proposed Notation)
Object Property Restrictions - Self Restriction

owl:hasSelf

- ObjectHasSelf (OP): a class expression that contains all individuals that are connected to themselves via OPE
- ObjectHasSelf (a:loves) contains those individuals that love themselves.

```xml
<owl:Class rdf:about="SelfLover">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#loves"/>
      <owl:hasSelf rdf:datatype="&xsd:boolean">true</owl:hasSelf>
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```

(Proposed Notation)
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- Part 8: Class Expressions (Max, min, exact, Qualified Cardinality)
Class Expressions – Min Cardinality

**Owl:minCardinality**

- OWL allows us to place some restrictions on properties, such as `owl:minCardinality`.
- Each student must be EnrolledIn in 3 things, *at least*

```xml
<owl:Class rdf:about="Student">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:minCardinality rdf:datatype="&xsd;nonNegativeInteger"> 3
    </owl:minCardinality>
    <owl:onProperty rdf:resource="#EnrolledIn"/>
    <owl:Restriction>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```
Class Expressions - Max Cardinality

**Owl:maxCardinality**

- OWL allows us to place some restrictions on properties, such as `owl:maxCardinality`.
- Each student must be EnrolledIn in 6 things, at most

```xml
<owl:Class rdf:about="Student">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:maxCardinality rdf:datatype="&xsd;nonNegativeInteger"> 6
            </owl:maxCardinality>
            <owl:onProperty rdf:resource="EnrolledIn"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

\[ A \leq n \quad r_A \quad \text{Thing} \]
Class Expressions – Exact Cardinality

**Owl:Cardinality**

- OWL allows us to place some restrictions on properties, such as owl:Cardinality.
- Each student must be EnrolledIn in 5 things, **exactly**

```
<owl:Class rdf:about="Student">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:Cardinality rdf:datatype="&xsd;nonNegativeInteger"> 5
    </owl:Cardinality>
    <owl:onProperty rdf:resource="EnrolledIn"/>
  </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

\[A \overset{r_A}{=} n \text{Thing}\]
owl:qualifiedCardinality
- Same as owl:Cardinality, but we restrict the property with its range.
- Each student must be EnrolledIn in 5 courses, exactly

```xml
<owl:Class rdf:about="Student">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:qualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger"> 5
    </owl:qualifiedCardinality>
    <owl:onProperty rdf:resource="EnrolledIn"/>
    <owl:onClass rdf:resource="Course"/>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

Similarly, there is minQualifiedCardinality and maxQualifiedCardinality.
**XML Datatypes**

<table>
<thead>
<tr>
<th>xsd:string</th>
<th>xsd:int</th>
<th>xsd:gYearMonth</th>
</tr>
</thead>
<tbody>
<tr>
<td>xsd:normalizedString</td>
<td>xsd:short</td>
<td>xsd:gYear</td>
</tr>
<tr>
<td>xsd:boolean</td>
<td>xsd:byte</td>
<td>xsd:gMonthDay</td>
</tr>
<tr>
<td>xsd:decimal</td>
<td>xsd:unsignedLong</td>
<td>xsd:gMonth</td>
</tr>
<tr>
<td>xsd:float</td>
<td>xsd:unsignedInt</td>
<td>xsd:gDay</td>
</tr>
<tr>
<td>xsd:double</td>
<td>xsd:unsignedShort</td>
<td>xsd:anyURI</td>
</tr>
<tr>
<td>xsd:integer</td>
<td>xsd:unsignedByte</td>
<td>xsd:token</td>
</tr>
<tr>
<td>xsd:nonNegativeInteger</td>
<td>xsd:hexBinary</td>
<td>xsd:language</td>
</tr>
<tr>
<td>xsd:positiveInteger</td>
<td>xsd:base64Binary</td>
<td>xsd:NMToken</td>
</tr>
<tr>
<td>xsd:nonPositiveInteger</td>
<td>xsd:dateTime</td>
<td>xsd:Name</td>
</tr>
<tr>
<td>xsd:negativeInteger</td>
<td>xsd:time</td>
<td>xsd:NCName</td>
</tr>
<tr>
<td>xsd:long</td>
<td>xsd:date</td>
<td></td>
</tr>
</tbody>
</table>

The above datatypes, plus rdfs:Literal, form the built-in OWL datatypes.
References

[1] Mustafa Jarrar: Lecture Notes on RDF Data Model, Birzeit University, 2018


[4] Mustafa Jarrar: Lecture Notes on Data Web and Linked Data, Birzeit University, 2018


