Web Ontology Language: OWL
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Reference:
`A Semantic Web Primer', by Grigoris Antoniou and Frank van Harmelen, The MIT Press, 2004

Lecture Outline

1. Basic Ideas of OWL
2. The OWL Language
3. Examples
4. The OWL Namespace
5. Future Extensions

Requirements for Ontology Languages

- Ontology languages allow users to write explicit, formal conceptualizations of domain models
- The main requirements are:
  - a well-defined syntax
  - efficient reasoning support
  - a formal semantics
  - sufficient expressive power
  - convenience of expression

Tradeoff between Expressive Power and Efficient Reasoning Support

- The richer the language is, the more inefficient the reasoning support becomes
- Sometimes it crosses the border of *noncomputability*
- We need a compromise:
  - A language supported by reasonably efficient reasoners
  - A language that can express large classes of ontologies and knowledge.

Reasoning About Knowledge in Ontology Languages

- Class membership
  - If x is an instance of a class C, and C is a subclass of D, then we can infer that x is an instance of D
- Equivalence of classes
  - If class A is equivalent to class B, and class B is equivalent to class C, then A is equivalent to C, too

Reasoning About Knowledge in Ontology Languages (2)

- Consistency
  - X instance of classes A and B, but A and B are disjoint
  - This is an indication of an error in the ontology
- Classification
  - Certain property-value pairs are a sufficient condition for membership in a class A; if an individual x satisfies such conditions, we can conclude that x must be an instance of A

Uses for Reasoning

- Reasoning support is important for
  - checking the consistency of the ontology and the knowledge
  - checking for unintended relationships between classes
  - automatically classifying instances in classes
- Checks like the preceding ones are valuable for
  - designing large ontologies, where multiple authors are involved
  - integrating and sharing ontologies from various sources

Reasoning Support for OWL

- Semantics is a prerequisite for reasoning support
- Formal semantics and reasoning support are usually provided by
  - mapping an ontology language to a known logical formalism
  - using automated reasoners that already exist for those formalisms
- OWL is (partially) mapped on a description logic, and makes use of reasoners such as FaCT and RACER
- Description logics are a subset of predicate logic for which efficient reasoning support is possible

Limitations of the Expressive Power of RDF Schema

- RDF and RDFS allow the representation of some ontological knowledge.
- The main modeling primitives of RDF/RDFS concern the organization of vocabularies in typed hierarchies: subclass and subproperty relationships, domain and range restrictions, and instances of classes. However, a number of other features are missing.
- Local scope of properties
  - **rdfs:range** defines the range of a property (e.g. eats) for all classes
  - In RDF Schema we cannot declare range restrictions that apply to some classes only
  - E.g. we cannot say that cows eat only plants, while other animals may eat meat, too

Limitations of the Expressive Power of RDF Schema (2)

- Disjointness of classes
  - Sometimes we wish to say that classes are disjoint (e.g. **male** and **female**). But in RDF Schema we can only state subclass relationships, e.g., female is a subclass of person.
- Boolean combinations of classes
  - Sometimes we wish to build new classes by combining other classes using union, intersection, and complement
  - E.g. **person** is the disjoint union of the classes **male** and **female**
  - RDF Schema does not allow such definitions.

Limitations of the Expressive Power of RDF Schema (3)

- Cardinality restrictions
  - Sometimes we wish to place restrictions on how many distinct values a property may or must take.
  - E.g. a person has exactly two parents, a course is taught by at least one lecturer
- Special characteristics of properties
  - Transitive property (like “greater than”)
  - Unique property (like “is mother of”)
  - A property is the inverse of another property (like “eats” and “is eaten by”)

Combining OWL with RDF Schema

- Ideally, OWL would extend RDF Schema
  - Consistent with the layered architecture of the Semantic Web
- **But** simply extending RDF Schema would work against obtaining expressive power and efficient reasoning
- the richer the language is, the more inefficient the reasoning support becomes, often crossing the border of noncomputability.
- RDF Schema has some very powerful modeling primitives. Constructions such as rdfs:Class (the class of all classes) and rdf:Property (the class of all properties) are very expressive and would lead to uncontrollable computational properties if the logic were extended with such expressive primitives.
  - Combining RDF Schema with logic leads to uncontrollable computational properties

Three Species of OWL

- The full set of requirements for an ontology language that seem unobtainable: efficient reasoning support and convenience of expression for a language as powerful as a combination of RDF Schema with a full logic.
- Indeed, these requirements have prompted W3C'sWeb Ontology Working Group to define OWL as three different sublanguages, each geared toward fulfilling different aspects of this full set of requirements.
- W3C'sWeb Ontology Working Group defined OWL as three different sublanguages:
  - OWL Full
  - OWL DL
  - OWL Lite
- Each sublanguage geared toward fulfilling different aspects of requirements.

OWL Full

- It uses all the OWL languages primitives
- It allows the combination of these primitives in arbitrary ways with RDF and RDF Schema
- OWL Full is fully upward-compatible with RDF, both syntactically and semantically
- Any legal RDF document is also a legal OWL Full document, and any valid RDF/RDF Schema conclusion is also avalid OWL Full conclusion.
- OWL Full is so powerful that it is undecidable
  - No complete (or efficient) reasoning support

OWL DL

- OWL DL (Description Logic) is a sublanguage of OWL Full that restricts application of the constructors from OWL and RDF
  - Application of OWL's constructors' to each other is disallowed
  - Therefore it corresponds to a well studied description logic
- OWL DL permits efficient reasoning support
- **But** we lose full compatibility with RDF:
  - Not every RDF document is a legal OWL DL document.
  - Every legal OWL DL document is a legal RDF document.

OWL Lite

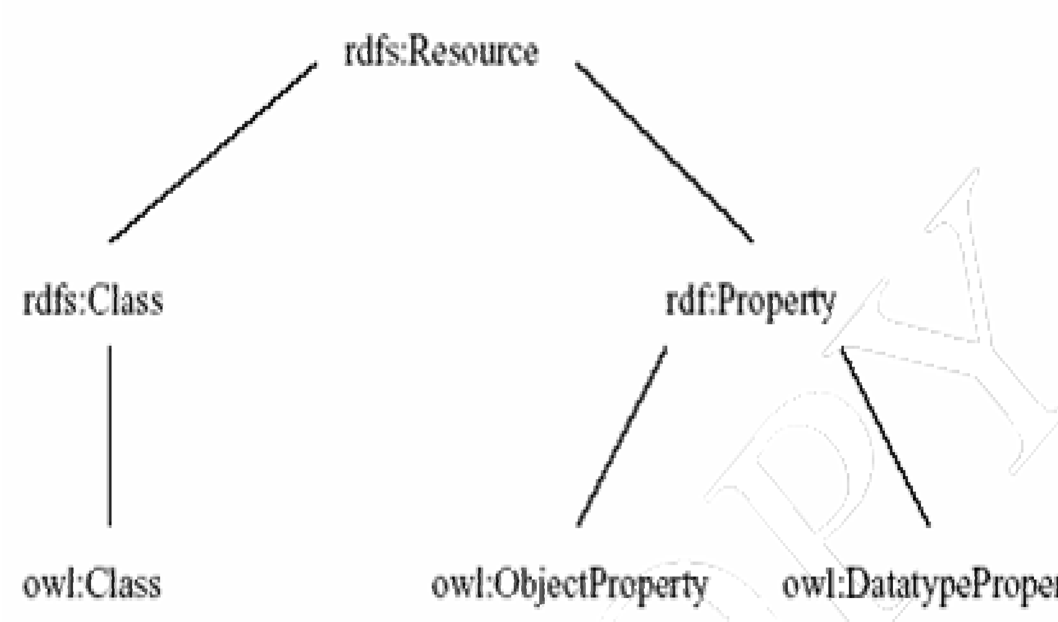
- An even further restriction limits OWL DL to a subset of the language constructors
  - E.g., OWL Lite excludes enumerated classes, disjointness statements, and arbitrary cardinality.
- The advantage of this is a language that is easier to
  - grasp, for users
  - implement, for tool builders
- The disadvantage is restricted expressivity

Upward Compatibility between OWL Species

- Every legal OWL Lite ontology is a legal OWL Dl ontology
- Every legal OWL DL ontology is a legal OWL Ful ontology
- Every valid OWL Lite conclusion is a valid OWL DL conclusion
- Every valid OWL DL conclusion is a valid OWL Full conclusion

OWL Compatibility with RDF Schema

- All varieties of OWL use RDF for their syntax
- Instances are declared as in RDF, using RDF descriptions and typing information
- OWL constructors are specialisations of their RDF counterparts



OWL Compatibility with RDF Schema (2)

- Semantic Web design aims at downward compatibility with corresponding reuse of software across the various layers
- The advantage of full downward compatibility for OWL is only achieved for OWL Full, at the cost of computational intractability

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OWL Syntactic Varieties

- OWL builds on RDF and uses RDF's XML-based syntax
- Other syntactic forms for OWL have also been defined:
  - An alternative, more readable XML-based syntax that does not follow the RDF conventions and is thus more easily read by human users.
  - An abstract syntax, that is much more compact and readable than the XML languages
  - A graphic syntax based on the conventions of UML

OWL XML/RDF Syntax: Header

- OWL documents are usually called OWL ontologies and are RDF documents. The root element of an OWL ontology is an rdf:RDF element, which also specifies a number of namespaces:

```
<rdf:RDF
   xmlns:owl ="http://www.w3.org/2002/07/owl#"
   xmlns:rdf ="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns:xsd ="http://www.w3.org/2001/XLMSchema#">
```

- An OWL ontology may start with a collection of assertions for housekeeping purposes using **owl:Ontology** element, which contains comments, version control, and inclusion of other ontologies. For example:

owl:Ontology

```
<owl:Ontology rdf:about="">
   <rdfs:comment>An example OWL ontology </rdfs:comment>
   <owl:priorVersion
    rdf:resource="http://www.mydomain.org/uni-ns-old"/>
   <owl:imports
    rdf:resource="http://www.mydomain.org/persons"/>
   <rdfs:label>University Ontology</rdfs:label>
</owl:Ontology>
```

owl:imports, which lists other ontologies whose content is assumed to be part of the current ontology. Note that while namespaces are used for disambiguation, imported ontologies provide definitions that can be used.

owl:imports is a transitive property, if ontology A imports ontology B, and ontology B imports ontology C, then ontology A also imports ontology C.

Classes

Classes are defined using **owl:Class**

- **owl:Class** is a subclass of **rdfs:Class**

```
<owl:Class rdf:ID="associateProfessor">
<rdfs:subClassOf rdf:resource="#academicStaffMember"/>
</owl:Class>
```

Disjointness is defined using **owl:disjointWith**

```
<owl:Class rdf:about="#associateProfessor">
  <owl:disjointWith rdf:resource="#professor"/>
  <owl:disjointWith    rdf:resource="#assistantProfessor"/>
</owl:Class>
```

Classes (2)

- **owl:equivalentClass** defines equivalence of classes

```
<owl:Class rdf:ID="faculty">
  <owl:equivalentClass rdf:resource=
  "#academicStaffMember"/>
</owl:Class>
```

- **owl:Thing** is the most general class, which contains everything
- **owl:Nothing** is the empty class

Properties

- **In OWL there are two kinds of properties**
  - **Object properties, which relate objects to other objects**
    - **E.g. is-TaughtBy, supervises**
  - **Data type properties, which relate objects to datatype values**
    - **E.g. phone, title, age, etc.**
- OWL does not have any predefined data types, nor does it provide special definition facilities. Instead, it allows one to use XML Schema data types, thus making use of the layered architecture of the Semantic Web

Datatype Properties

- OWL makes use of XML Schema data types, using the layered architecture of the SW

```
<owl:DatatypeProperty rdf:ID="age">
   <rdfs:range rdf:resource=
   "http://www.w3.org/2001/XLMSchema
   #nonNegativeInteger"/>
</owl:DatatypeProperty>
```

Object Properties

- User-defined data types will usually be collected in an XML schema and then used in an OWL ontology.
- Here is an example of an object property:

```
<owl:ObjectProperty rdf:ID="isTaughtBy">
   <owl:domain rdf:resource="#course"/>
   <owl:range rdf:resource=   "#academicStaffMember"/>
   <rdfs:subPropertyOf rdf:resource="#involves"/>
</owl:ObjectProperty>
```

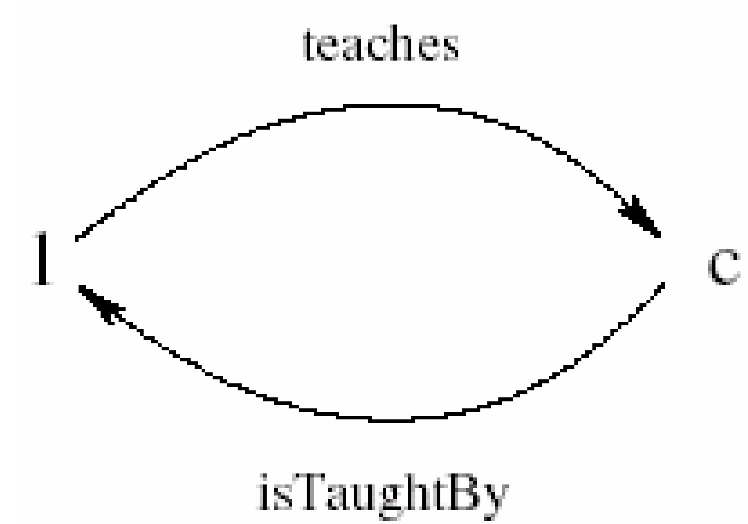
- More than one domain and range may be declared. In this case the intersection of the domains, respectively ranges, is taken.

Inverse Properties

```
<owl:ObjectProperty rdf:ID="teaches">
  <rdfs:range rdf:resource="#course"/>
  <rdfs:domain rdf:resource=
  "#academicStaffMember"/>
  <owl:inverseOf rdf:resource="#isTaughtBy"/>
</owl:ObjectProperty>
```

Inverse Properties

- The next figure shows the relationship between a property and its inverse.
- Actually domain and range can be inherited from the inverse property (interchange domain with range).



Equivalent Properties

- Equivalence of properties can be defined through the use of the element owl:equivalentProperty.

```
<owl:equivalentProperty
   <owl:ObjectProperty rdf:ID="lecturesIn">
   <owl:equivalentProperty   rdf:resource="#teaches"/>
</owl:ObjectProperty>
```

Property Restrictions

- With rdfs:subClassOf we can specify a class C to be subclass of another class C'; then every instance of C is also an instance of C'.
- Suppose we wish to declare, instead, that the class C satisfies certain conditions, that is, all instances of C satisfy the conditions. This is equivalent to saying that C is subclass of a class C', where C' collects all objects that satisfy the conditions. That is exactly how it is done in OWL.
- Note that, in general, C' can remain anonymous.

Property Restrictions (2)

- A (restriction) class is achieved through an **owl:Restriction** element
- This element contains an **owl:onProperty** element and one or more restriction declarations
- One type defines cardinality restrictions (at least one, at most 3,…)

Property Restrictions (3)

- The other type defines restrictions on the kinds of values the property may take
  - **owl:allValuesFrom** specifies universal quantification
  - **owl:hasValue** specifies a specific value
  - **owl:someValuesFrom** specifies existential quantification

owl:allValuesFrom

- **“First year courses to be taught by professors only”**

```
<owl:Class rdf:about="#firstYearCourse">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#isTaughtBy"/>
      <owl:allValuesFrom
  rdf:resource="#Professor"/>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

owl:hasValue

- **“Courses on mathematics are taught by David Billington”**

```
<owl:Class rdf:about="#mathCourse">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource=
        "#isTaughtBy"/>
            <owl:hasValue rdf:resource=
        "#949352"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

owl:someValuesFrom

- **“ To declare that all academic staff members must teach at least one undergraduate course”**

```
<owl:Class rdf:about="#academicStaffMember">
    <rdfs:subClassOf>
      <owl:Restriction>
    <owl:onProperty rdf:resource="#teaches"/>
    <owl:someValuesFrom rdf:resource=
    "#undergraduateCourse"/>
      </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

Cardinality Restrictions

- We can specify minimum and maximum number using **owl:minCardinality** and **owl:maxCardinality**
- It is possible to specify a precise number by using the same minimum and maximum number
- For convenience, OWL offers also **owl:cardinality**

Cardinality Restrictions (2)

```
<owl:Class rdf:about="#course">
  <rdfs:subClassOf>
  <owl:Restriction>
    <owl:onProperty rdf:resource="#isTaughtBy"/>
    <owl:minCardinality rdf:datatype=
  "&xsd;nonNegativeInteger">
    1
    </owl:minCardinality>
  </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

Special Properties

- **owl:TransitiveProperty (**transitive property)
  - E.g. “has better grade than”, “is ancestor of”
- **owl:SymmetricProperty** (symmetry)
  - E.g. “has same grade as”, “is sibling of”
- **owl:FunctionalProperty** defines a property that has at most one value for each object
  - E.g. “age”, “height”, “directSupervisor”
- **owl:InverseFunctionalProperty** defines a property for which two different objects cannot have the same value, e.g Voter Id is assigned to one person only.

Special Properties (2)

```
<owl:ObjectProperty rdf:ID="hasSameGradeAs">
    <rdf:type rdf:resource="&owl;TransitiveProperty"/>
    <rdf:type rdf:resource="&owl;SymmetricProperty"/>
        <rdfs:domain rdf:resource="#student"/>
        <rdfs:range rdf:resource="#student"/>
</owl:ObjectProperty>
```

Boolean Combinations

- We can combine classes using Boolean operations (union, intersection, complement)
- We can say that courses and staff members are disjoint classes

```
<owl:Class rdf:about="#course">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:complementOf rdf:resource=
            "#staffMember"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

- This can be expressed using owl:disjointWith

Boolean Combinations (2)

- It is possible for a staff member to be a student

```
<owl:Class rdf:ID="peopleAtUni">
    <owl:unionOf rdf:parseType="Collection">
    <owl:Class rdf:about="#staffMember"/>
    <owl:Class rdf:about="#student"/>
    </owl:unionOf>
</owl:Class>
```

- The new class is not a subclass of the union, but rather equal to the union
  - We have stated an equivalence of classes

Boolean Combinations (3)

```
<owl:Class rdf:ID="facultyInCS">
  <owl:intersectionOf rdf:parseType="Collection">
  <owl:Class rdf:about="#faculty"/>
  <owl:Restriction>
  <owl:onProperty rdf:resource="#belongsTo"/>
  <owl:hasValue rdf:resource= "#CSDepartment"/>
  </owl:Restriction>
  </owl:intersectionOf>
</owl:Class>
```

Nesting of Boolean Operators

- It defines admin staff to be those staff members that are neither faculty nor technical support staff

```
<owl:Class rdf:ID="adminStaff">
    <owl:intersectionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#staffMember"/>
        <owl:complementOf>
            <owl:unionOf rdf:parseType="Collection">
            <owl:Class rdf:about="#faculty"/>
            <owl:Class rdf:about="#techSupportStaff"/>
            </owl:unionOf>
        </owl:complementOf>
    </owl:intersectionOf>
```

Enumerations with owl:oneOf

```
<owl:oneOf rdf:parseType="Collection">
        <owl:Thing rdf:about="#Monday"/>
        <owl:Thing rdf:about="#Tuesday"/>
        <owl:Thing rdf:about="#Wednesday"/>
        <owl:Thing rdf:about="#Thursday"/>
        <owl:Thing rdf:about="#Friday"/>
        <owl:Thing rdf:about="#Saturday"/>
        <owl:Thing rdf:about="#Sunday"/>
</owl:oneOf>
```

Declaring Instances

- Instances of classes are declared as in RDF:

```
<rdf:Description rdf:ID="949352">
    <rdf:type rdf:resource=
        "#academicStaffMember"/>
</rdf:Description>
```

- Providing further information

```
<academicStaffMember rdf:ID="949352">
        <uni:age rdf:datatype="&xsd;integer">
        39<uni:age>
</academicStaffMember>
```

No Unique-Names Assumption

- Unlike typical DBMS, OWL does not adopt the unique-names assumption of database systems
  - If two instances have a different name or ID does not imply that they are different individuals
- Suppose we state that each course is taught by at most one staff member, and that a given course is taught by two staff members

```
<owl:ObjectProperty rdf:ID="isTaughtBy">
<rdf:type rdf:resource="&owl;FunctionalProperty" />
</owl:ObjectProperty>
```

- and we subsequently state that a given course is taught by two staff members

```
<course rdf:ID="CIT1111">
<isTaughtBy rdf:resource="#949318"/>
<isTaughtBy rdf:resource="#949352"/>
</course>
```

  - An OWL reasoner does not flag an error
  - Instead it infers that the two resources are equal

Distinct Objects

- To ensure that different individuals are indeed recognized as such, we must explicitly assert their inequality:

```
<lecturer rdf:about="949318">
    <owl:differentFrom rdf:resource="949352"/>
</lecturer>
```

Distinct Objects (2)

- OWL provides a shorthand notation to assert the pairwise inequality of all individuals in a given list

```
<owl:allDifferent>
    <owl:distinctMembers rdf:parseType="Collection">
        <lecturer rdf:about="949318"/>
        <lecturer rdf:about="949352"/>
        <lecturer rdf:about="949111"/>
    </owl:distinctMembers>
</owl:allDifferent>
```

- Note that owl:distinctMembers can only be used in combination with owl:allDifferent.

Data Types in OWL

- XML Schema provides a mechanism to construct user-defined data types
  - E.g., the data type of **adultAge** includes all integers greater than 18
- Such derived data types cannot be used in OWL
  - The OWL reference document lists all the XML Schema data types that can be used
  - These include the most frequently used types such as **string**, **integer**, **Boolean**, **time**, and **date**.

Versioning Information

- **owl:priorVersion** indicates earlier versions of the current ontology
  - No formal meaning, can be exploited for ontology management
- **owl:versionInfo** generally contains a string giving information about the current version, e.g. keywords

Versioning Information (2)

- **owl:backwardCompatibleWith** contains a reference to another ontology
  - All identifiers from the previous version have the same intended interpretations in the new version
  - Thus documents can be safely changed to commit to the new version
- **owl:incompatibleWith** indicates that the containing ontology is a later version of the referenced ontology but is not backward compatible with it

Combination of Features

- In different OWL languages there are different sets of restrictions regarding the application of features
- In **OWL Full**, all the language constructors may be used in any combination as long as the result is legal RDF

Restriction of Features in OWL DL

- Vocabulary partitioning
  - Any resource is allowed to be only a class, a data type, a data type property, an object property, an individual, a data value, or part of the built-in vocabulary, and not more than one of these
- Explicit typing
  - The partitioning of all resources must be stated explicitly (e.g. a class must be declared if used in conjunction with **rdfs:subClassOf**)

Restriction of Features in OWL DL (2)

- Property Separation
  - The set of object properties and data type properties are disjoint
  - Therefore the following can never be specified for data type properties:

    owl:inverseOf

    owl:FunctionalProperty

    owl:InverseFunctionalProperty

    owl:SymmetricProperty

Restriction of Features in OWL DL (3)

- No transitive cardinality restrictions
  - No cardinality restrictions may be placed on transitive properties
- Restricted anonymous classes: Anonymous classes are only allowed to occur as:
  - the domain and range of either **owl:equivalentClass** or **owl:disjointWith**
  - the range (but not the domain) of **rdfs:subClassOf**

Restriction of Features in OWL Lite

- Restrictions of OWL DL and more
- **owl:oneOf**, **owl:disjointWith**, **owl:unionOf**, **owl:complementOf** and **owl:hasValue** are not allowed
- Cardinality statements (minimal, maximal, and exact cardinality) can only be made on the values 0 or 1
- **owl:equivalentClass** statements can no longer be made between anonymous classes but only between class identifiers

Inheritance in Class Hierarchies

- Range restriction: **Courses must be taught by academic staff members only**
- Michael Maher is a professor
- He inherits the ability to teach from the class of academic staff members
- This is done in RDF Schema by fixing the semantics of "is a subclass of"
  - It is not up to an application (RDF processing software) to interpret "is a subclass of

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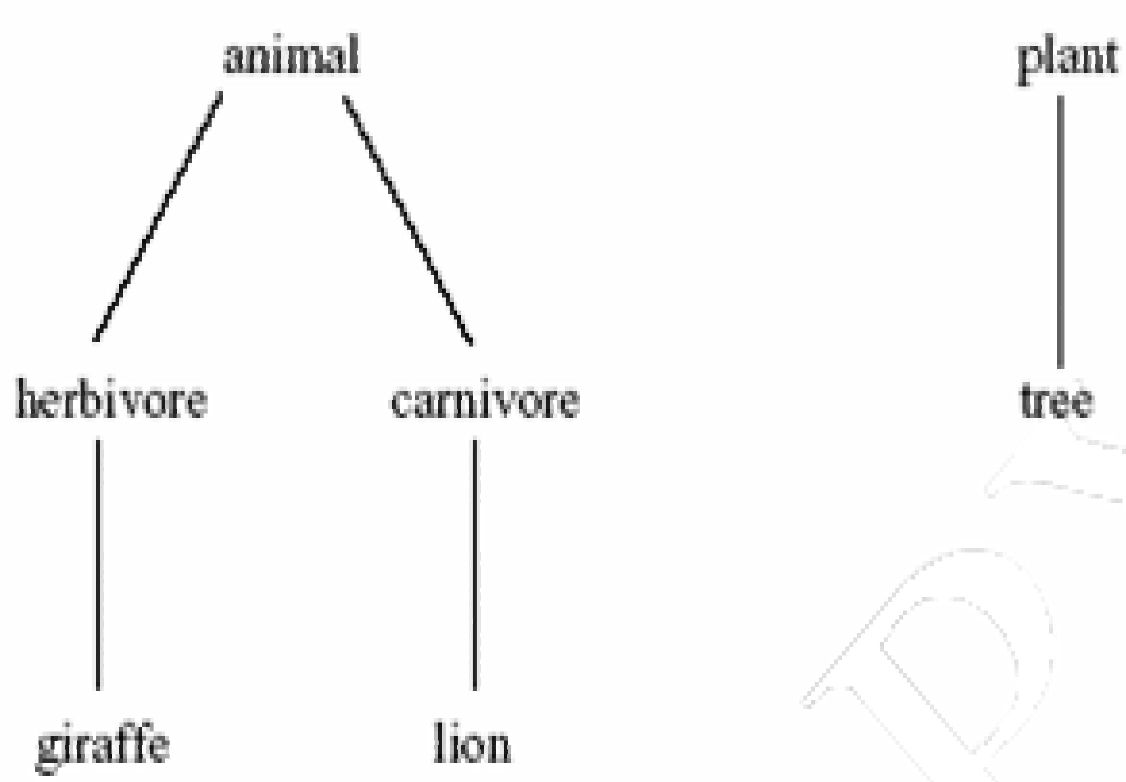
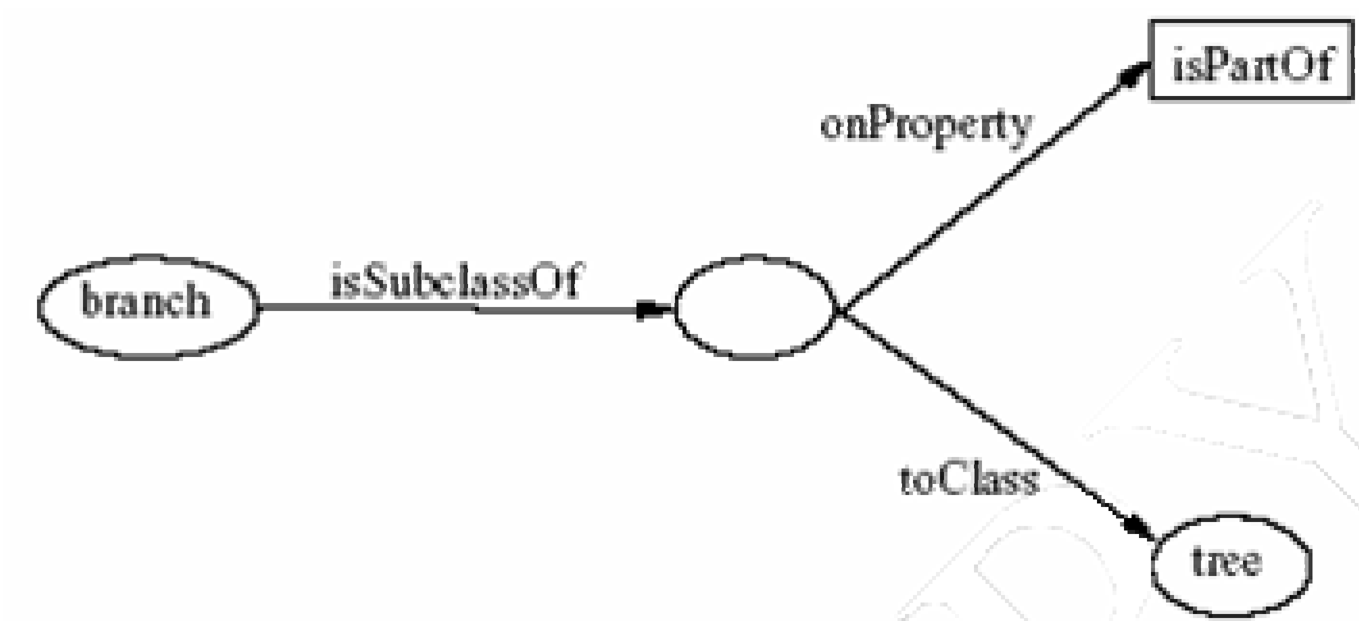
An African Wildlife Ontology – Class Hierarchy



An African Wildlife Ontology – Schematic Representation

Branches are parts of trees



An African Wildlife Ontology – Properties

```
<owl:TransitiveProperty rdf:ID="is-part-of"/>
<owl:ObjectProperty rdf:ID="eats">
    <rdfs:domain rdf:resource="#animal"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="eaten-by">
    <owl:inverseOf rdf:resource="#eats"/>
</owl:ObjectProperty>
```

An African Wildlife Ontology – Plants and Trees

```
<owl:Class rdf:ID="plant">
    <rdfs:comment>Plants are disjoint from animals.
    </rdfs:comment>
    <owl:disjointWith="#animal"/>
</owl:Class>
<owl:Class rdf:ID="tree">
    <rdfs:comment>Trees are a type of plant.
    </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#plant"/>
</owl:Class>
```

An African Wildlife Ontology – Branches

```
<owl:Class rdf:ID="branch">
    <rdfs:comment>Branches are parts of trees. </rdfs:comment>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#is-part-of"/>
            <owl:allValuesFrom rdf:resource="#tree"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

An African Wildlife Ontology – Leaves

```
<owl:Class rdf:ID="leaf">
    <rdfs:comment>Leaves are parts of branches.
    </rdfs:comment>
    <rdfs:subClassOf>
        <owl:Restriction>
                <owl:onProperty rdf:resource="#is-part-of"/>
                <owl:allValuesFrom rdf:resource="#branch"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

An African Wildlife Ontology – Carnivores

```
<owl:Class rdf:ID="carnivore">
    <rdfs:comment>Carnivores are exactly those animals
    that eat also animals.</rdfs:comment>
    <owl:intersectionOf rdf:parsetype="Collection">
    <owl:Class rdf:about="#animal"/>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#eats"/>
            <owl:someValuesFrom rdf:resource="#animal"/>
        </owl:Restriction>
```

An African Wildlife Ontology – Herbivores

```
<owl:Class rdf:ID="herbivore">
        <rdfs:comment>
                Herbivores are exactly those animals
                that eat only plants or parts of plants.
        </rdfs:comment>
        <rdfs:comment>
                Try it out! See book for code.
        <rdfs:comment>
</owl:Class>
```

An African Wildlife Ontology – Giraffes

```
<owl:Class rdf:ID="giraffe">
    <rdfs:comment>Giraffes are herbivores, and they
    eat only leaves.</rdfs:comment>
    <rdfs:subClassOf rdf:type="#herbivore"/>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#eats"/>
            <owl:allValuesFrom rdf:resource="#leaf"/>
        </owl:Restriction>
```

An African Wildlife Ontology – Lions

```
<owl:Class rdf:ID="lion">
    <rdfs:comment>Lions are animals that eat
    only herbivores.</rdfs:comment>
    <rdfs:subClassOf rdf:type="#carnivore"/>
    <rdfs:subClassOf>
        <owl:Restriction>
                <owl:onProperty rdf:resource="#eats"/>
                <owl:allValuesFrom rdf:resource="#herbivore"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

An African Wildlife Ontology – Tasty Plants

owl:Class rdf:ID="tasty-plant">

<rdfs:comment>Plants eaten both by herbivores and carnivores </rdfs:comment>

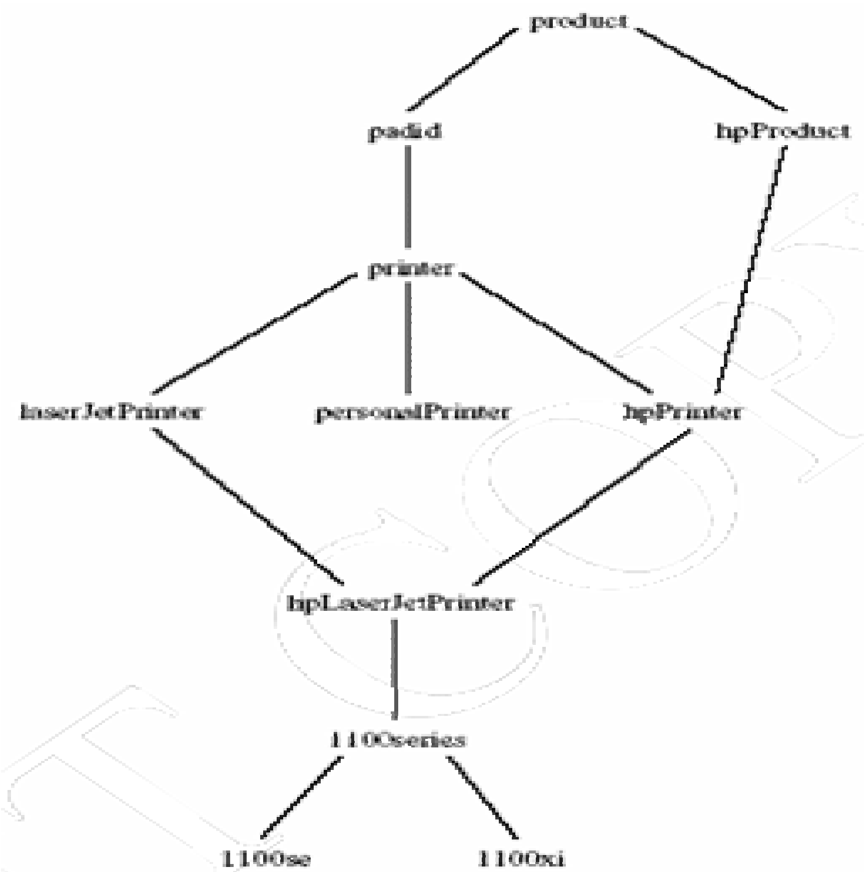
<rdfs:comment>

Try it out! See book for code.

<rdfs:comment>

</owl:Class>

A Printer Ontology – Class Hierarchy



A Printer Ontology – Products and Devices

```
<owl:Class rdf:ID="product">
    <rdfs:comment>Products form a class. </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="padid">
    <rdfs:comment>Printing and digital imaging devices
    form a subclass of products.</rdfs:comment>
    <rdfs:label>Device</rdfs:label>
    <rdfs:subClassOf rdf:resource="#product"/>
</owl:Class>
```

A Printer Ontology – HP Products

```
<owl:Class rdf:ID="hpProduct">
    <owl:intersectionOf>
        <owl:Class rdf:about="#product"/>
        <owl:Restriction>
          <owl:onProperty rdf:resource="#manufactured-by"/>
          <owl:hasValue>
                <xsd:string rdf:value="Hewlett Packard"/>
          </owl:hasValue>
        </owl:Restriction>
    </owl:intersectionOf>
</owl:Class>
```

A Printer Ontology – Printers and Personal Printers

```
<owl:Class rdf:ID="printer">
    <rdfs:comment>Printers are printing and digital imaging
    devices.</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#padid"/>
</owl:Class>
<owl:Class rdf:ID="personalPrinter">
    <rdfs:comment>Printers for personal use form
    a subclass of printers.</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#printer"/>
</owl:Class>
```

A Printer Ontology – HP LaserJet 1100se Printers

```
<owl:Class rdf:ID="1100se">
    <rdfs:comment>1100se printers belong to the 1100 series
        and cost $450.</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#1100series"/>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#price"/>
            <owl:hasValue><xsd:integer rdf:value="450"/>
            </owl:hasValue>
        </owl:Restriction>
    </rdfs:subClassOf>
```

A Printer Ontology – Properties

```
<owl:DatatypeProperty rdf:ID="manufactured-by">
    <rdfs:domain rdf:resource="#product"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</owl:DatatypeProperty>
<owl:DatatypeProperty rdf:ID="printingTechnology">
    <rdfs:domain rdf:resource="#printer"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</owl:DatatypeProperty>
```

Lecture Outline

1. Basic Ideas of OWL
2. The OWL Language
3. Examples
4. The OWL Namespace
5. Future Extensions

OWL in OWL

- We present a part of the definition of OWL in terms of itself
- The following captures some of OWL's meaning in OWL
  - It does **not** capture the entire semantics
  - A separate semantic specification is necessary
- The URI of the OWL definition is defined as the default namespace

Classes of Classes (Metaclasses)

- The class of all OWL classes is itself a subclass of the class of all RDF Schema classes:

```
<rdfs:Class rdf:ID="Class">
    <rdfs:label>Class</rdfs:label>
    <rdfs:subClassOf rdf:resource="&rdfs;Class"/>
</rdfs:Class>
```

Classes of Classes (Metaclasses) – Thing and Nothing

- **Thing** is most general object class in OWL
- **Nothing** is most specific class: the empty object class
- The following relationships hold:

$$Thing = Nothing \cup \overline{Nothing}$$

$$Nothing = \overline{Thing} = \overline{Nothing \cup \overline{Nothing}} = \overline{Nothing} \cap \overline{\overline{Nothing}} = \emptyset$$

Classes of Classes (Metaclasses) – Thing and Nothing (2)

```
<Class rdf:ID="Thing">
    <rdfs:label>Thing</rdfs:label>
    <unionOf rdf:parseType="Collection">
        <Class rdf:about="#Nothing"/>
        <Class>
            <complementOf rdf:resource="#Nothing"/>
        </Class>
    </unionOf>
</Class>
<Class rdf:ID="Nothing">
```

Class and Property Equivalences

```
<rdf:Property rdf:ID="EquivalentClass">
    <rdfs:label>EquivalentClass</rdfs:label>
    <rdfs:subPropertyOf rdf:resource="&rdfs;subClassOf"/>
    <rdfs:domain rdf:resource="#Class"/>
    <rdfs:range rdf:resource="#Class"/>
</rdf:Property>
<rdf:Property rdf:ID="EquivalentProperty">
    <rdfs:label>EquivalentProperty</rdfs:label>
    <rdfs:subPropertyOf
     rdf:resource="&rdfs;subPropertyOf"/>
</rdf:Property>
```

Class Disjointness

```
<rdf:Property rdf:ID="disjointWith">
        <rdfs:label>disjointWith</rdfs:label>
        <rdfs:domain rdf:resource="#Class"/>
        <rdfs:range rdf:resource="#Class"/>
</rdf:Property>
```

Equality and Inequality

- Equality and inequality can be stated between arbitrary things
  - In OWL Full this statement can also be applied to classes
- Properties **sameIndividualAs**, **sameAs** and **differentFrom**

Equality and Inequality (2)

```
<rdf:Property rdf:ID="sameIndividualAs">
        <rdfs:domain rdf:resource="#Thing"/>
        <rdfs:range rdf:resource="#Thing"/>
</rdf:Property>
<rdf:Property rdf:ID="sameAs">
     <EquivalentProperty rdf:resource=
        "#sameIndividualAs"/>
</rdf:Property>
```

Union and Intersection of Classes

- Build a class from a list, assumed to be a list of other class expressions

```
<rdf:Property rdf:ID="unionOf">
   <rdfs:domain rdf:resource="#Class"/>
   <rdfs:range rdf:resource="&rdf;List"/>
</rdf:Property>
```

Restriction Classes

- Restrictions in OWL define the class of those objects that satisfy some attached conditions

```
<rdfs:Class rdf:ID="Restriction">
   <rdfs:label>Restriction</rdfs:label>
   <rdfs:subClassOf rdf:resource="#Class"/>
</rdfs:Class>
```

Restriction Properties

- All the following properties (**onProperty**, **allValuesFrom**, **minCardinality**, etc.) are only allowed to occur within a restriction definition
  - Their domain is **owl:Restriction**, but they differ with respect to their range

Restriction Properties (2)

```
<rdf:Property rdf:ID="onProperty">
    <rdfs:label>onProperty</rdfs:label>
    <rdfs:domain rdf:resource="#Restriction"/>
    <rdfs:range rdf:resource="&rdf;Property"/>
</rdf:Property>
<rdf:Property rdf:ID="allValuesFrom">
    <rdfs:label>allValuesFrom</rdfs:label>
    <rdfs:domain rdf:resource="#Restriction"/>
    <rdfs:range rdf:resource="&rdfs;Class"/>
</rdf:Property>
```

Restriction Properties (3)

```
<rdf:Property rdf:ID="hasValue">
    <rdfs:label>hasValue</rdfs:label>
    <rdfs:domain rdf:resource="#Restriction"/>
</rdf:Property>
<rdf:Property rdf:ID="minCardinality">
    <rdfs:label>minCardinality</rdfs:label>
    <rdfs:domain rdf:resource="#Restriction"/>
    <rdfs:range rdf:resource=
    "&xsd;nonNegativeInteger"/>
</rdf:Property>
```

Properties

- **owl:ObjectProperty** and **owl:DatatypeProperty** are special cases of **rdf:Property**

```
<rdfs:Class rdf:ID="ObjectProperty">
   <rdfs:label>ObjectProperty</rdfs:label>
   <rdfs:subClassOf rdf:resource="&rdf;Property"/>
</rdfs:Class>
```

Properties (2)

- Symmetric, functional and inverse functional properties can only be applied to object properties

```
<rdfs:Class rdf:ID="TransitiveProperty">
   <rdfs:label>TransitiveProperty</rdfs:label>
   <rdfs:subClassOf rdf:resource=
   "#ObjectProperty"/>
</rdfs:Class>
```

Properties (3)

- **owl:inverseOf** relates two object properties:

```
<rdf:Property rdf:ID="inverseOf">
    <rdfs:label>inverseOf</rdfs:label>
    <rdfs:domain rdf:resource="#ObjectProperty"/>
    <rdfs:range rdf:resource="#ObjectProperty"/>
</rdf:Property>
```

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Future Extensions of OWL

- Modules and Imports
- Defaults
- Closed World Assumption
- Unique Names Assumption
- Procedural Attachments
- Rules for Property Chaining

Modules and Imports

- The importing facility of OWL is very trivial:
  - It only allows importing of an entire ontology, not parts of it
- Modules in programming languages based on **information hiding**: state functionality, hide implementation details
  - Open question how to define appropriate module mechanism for Web ontology languages

Defaults

- Many practical knowledge representation systems allow inherited values to be overridden by more specific classes in the hierarchy
  - treat inherited values as defaults
- No consensus has been reached on the right formalization for the nonmonotonic behaviour of default values

Closed World Assumption

- OWL currently adopts the open-world assumption:
  - A statement cannot be assumed true on the basis of a failure to prove it
  - On the huge and only partially knowable WWW, this is a correct assumption
- Closed-world assumption: a statement is true when its negation cannot be proved
  - tied to the notion of defaults, leads to nonmonotonic behaviour

Unique Names Assumption

- Typical database applications assume that individuals with different names are indeed different individuals
- OWL follows the usual logical paradigm where this is not the case
  - Plausible on the WWW
- One may want to indicate portions of the ontology for which the assumption does or does not hold

Procedural Attachments

- A common concept in knowledge representation is to define the meaning of a term by attaching a piece of code to be executed for computing the meaning of the term
  - Not through explicit definitions in the language
- Although widely used, this concept does not lend itself very well to integration in a system with a formal semantics, and it has not been included in OWL

Rules for Property Chaining

- OWL does not allow the composition of properties for reasons of decidability
- In many applications this is a useful operation
- One may want to define properties as general rules (Horn or otherwise) over other properties
- Integration of rule-based knowledge representation and DL-style knowledge representation is currently an active area of research

Summary

- OWL is the proposed standard for Web ontologies
- OWL builds upon RDF and RDF Schema:
  - (XML-based) RDF syntax is used
  - Instances are defined using RDF descriptions
  - Most RDFS modeling primitives are used

Summary (2)

- Formal semantics and reasoning support is provided through the mapping of OWL on logics
  - Predicate logic and description logics have been used for this purpose
- While OWL is sufficiently rich to be used in practice, extensions are in the making
  - They will provide further logical features, including rules