Chapter 4
OWL

Based on slides from Grigoris Antoniou and Frank van Harmelen

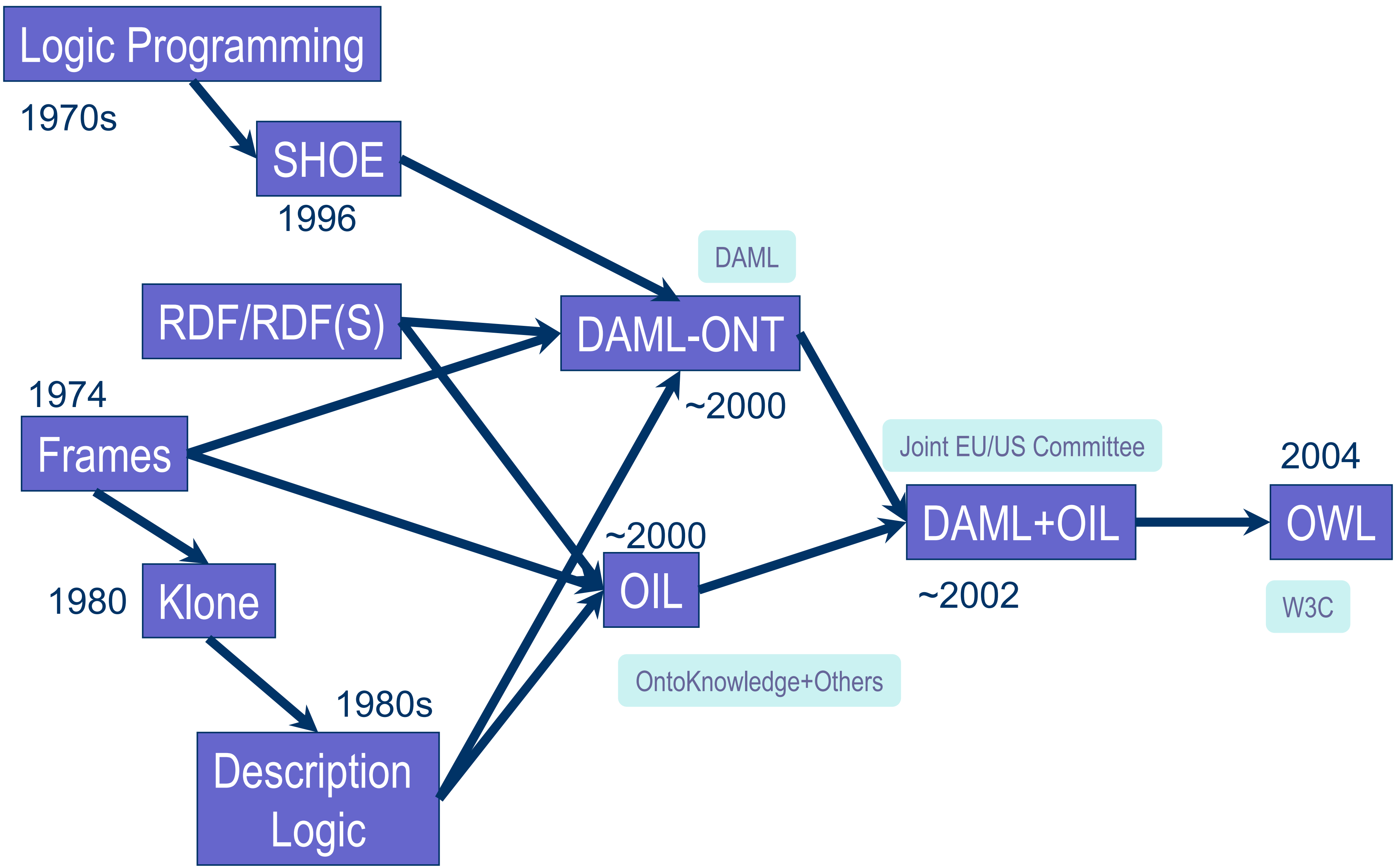
TL;DR: What is OWL

OWL defines new RDF predicates to RDF making it more expressive A knowledge representation language

Outline

1. **A bit of history**
2. Basic Ideas of OWL
3. The OWL Language
4. Examples
5. The OWL Namespace
6. OWL 2

The OWL Family Tree



A Brief History of OWL: SHOE

- Simple HTML Ontology Extensions
- Sean Luke, Lee Spector, and David Rager, 1996

  SHOE allows World-Wide Web authors to annotate their pages with ontology-based knowledge about page contents. We present examples showing how the use of SHOE can support a new generation of knowledge-based search and knowledge discovery tools that operate on the World-Wide Web.
- Add "semantic" tags defined in an ontology plus prolog-like rules to Web pages

A Brief History of OWL: SHOE

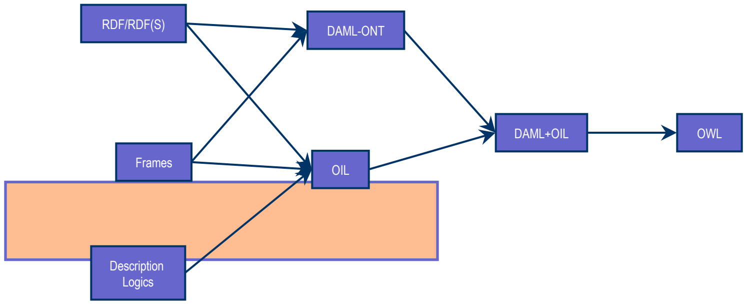
<META HTTP-EQUIV="Instance-Key" CONTENT="http://www.cs.umd.edu/~george"> <USE-ONTOLOGY "our-ontology" VERSION="1.0" PREFIX="our" URL="http://ont.org/our-ont.html">

…

<CATEGORY "our.Person">
<RELATION "our.firstName" TO="George">
<RELATION "our.lastName" TO="Cook">
<RELATION "our.marriedTo" TO="http://cs.umd.edu/~helena">
<RELATION "our.employee" FROM="http://cs.umd.edu">

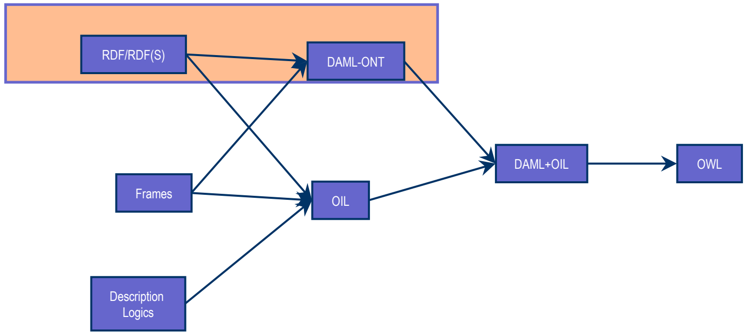
A Brief History of OWL: OIL

- Developed by group of (largely) European researchers (several from EU OntoKnowledge project)
- Based on frame-based KR languages
- Strong emphasis on formal rigour
- Semantics in terms of description dogics
- RDFS based syntax



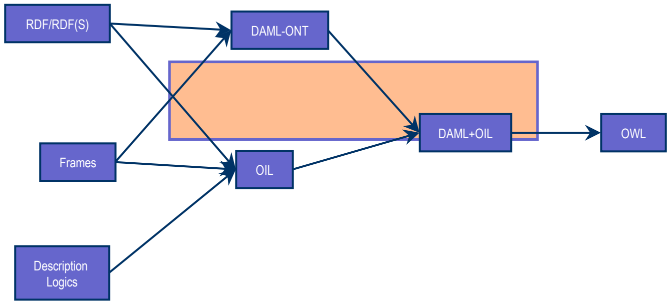
A Brief History of OWL: DAML-ONT

- DAML: Darpa Agent Markup Language
- Developed by DARPA DAML Program
  - Largely US based researchers
- Extended RDFS with constructors from OO and frame-based languages
- Rather weak semantic specification
  - Problems with machine interpretation
  - Problems with human interpretation



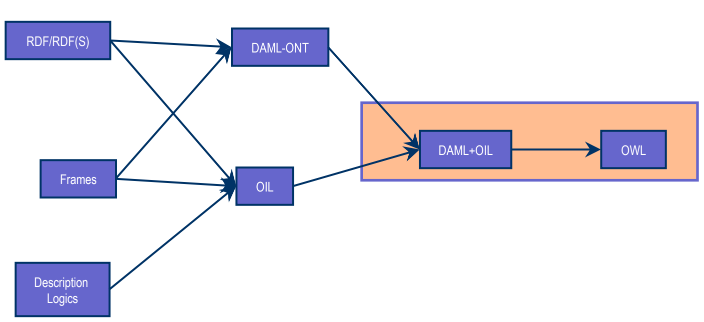
A Brief History of OWL: DAML+OIL

- Merging of DAML-ONT and OIL
- Basically a DL with an RDFS-based syntax
- Development carried out by “Joint EU/US Committee on Agent Markup Languages”
- Extends (“DL subset” of) RDF
- Submitted to W3C as basis for standardisation
  - Web-Ontology (**WebOnt**) Working Group formed



A Brief History of OWL: OWL

- W3C Recommendation (February 2004)
- Based on March 2001 DAML+OIL specification
- Well defined RDF/XML serializations
- Formal semantics
  - First order logic
  - Relationship with RDF
- Comprehensive test cases for tools/implementations
- Growing industrial take up



OWL 2

- An **extension of OWL**
  - Addressed deficiencies identified by users and developers (at **OWLED workshop**)
- Based on more expressive DL subset: **SROIQ**
- W3C **working group** chartered
  - http://www.w3.org/2007/OWL/wiki/OWL_Working_Group
  - Became W3C recommendation Oct. **2009**
- **Supported** by popular OWL tools
  - Protégé, TopBraid, FaCT++, Pellet, …

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2. **Basic Ideas of OWL**
3. The OWL Language
4. Examples
5. The OWL Namespace
6. OWL 2

Ontology and Data

- Philosophy: Ontologies are models of what exists in the world (kinds of things, relations, events, properties, etc.)
  - Information systems: a schema for info. or data
  - KR languages: model of classes & relations/properties & associated axioms, e.g., subPropertyOf is transitive
- Data is information about individual instances expressed with terms in the ontology
  - Some instances might be considered part of the ontology (e.g., God, George Washington, Baltimore)

Requirements for Ontology Languages

- **Ontology languages let users write explicit, formal conceptualizations of domain models**
- Requirements:
  - well-defined syntax
  - efficient reasoning support
  - formal semantics
  - sufficient expressive power
  - convenience of expression

Expressive Power vs. Efficient Reasoning

- Always a tradeoff between expressive power and efficient reasoning support
- The richer the language, the more inefficient the reasoning support becomes (in general)
- Reasoning can be undecidable or semi-decidable and even if decidable can be exponentially hard
- We need a compromise between:
  - Language supported by reasonably efficient reasoners
  - Language that can express large classes of ontologies and knowledge

Kinds of Reasoning about Knowledge

- **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

- **Consistency**
  - X instance of classes A and B, but A and B are disjoint
  - This is an indication of an error in the ontology or data

- **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**
  - Deriving new relations and properties
  - Automatically classifying instances in classes
  - Checking consistency of ontology and knowledge
  - checking for unintended relationships between classes
- **Checks like these 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 usually provided by
  - mapping an ontology language to known logical formalism
  - using automated reasoners that already exist for those formalisms
- OWL is (partially) mapped to a *description logic*

  DLs are a subset of logic for which efficient reasoning support is possible

RDFS's Expressive Power Limitations

- **Local scope of properties**
  - **rdfs:range** defines range of a property (e.g., eats) for **all** instances of a class
  - In RDF Schema we can't declare range restrictions that apply to only some
  - E.g., animals eat living_things but cows only eat plants
  - :eat rdfs:domain :animal; range :living_thing
    :eat rdfs:domain :cow; range :plant

RDFS's Expressive Power Limitations

- **Disjointness of classes**
  - Sometimes we wish to say that classes are disjoint (e.g. **male** and **female**)
- **Boolean combinations of classes**
  - Sometimes we want to define new classes by combining other classes using union, intersection, and complement
  - E.g., **person** equals disjoint union of **male** and **female** classes
  - E.g., weekdays equals set {:Monday, … :Sunday}

RDFS's Expressive Power Limitations

- **Cardinality restrictions**
  - 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 works against obtaining expressive power and efficient reasoning
  - Combining RDF Schema with logic leads to uncontrollable computational properties
- OWL uses RDF and most of RDFS

Three Species of OWL 1

- 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
- OWL Full is so powerful that it’s undecidable
  - No complete reasoning support

Soundness and completeness

- A sound reasoner only makes conclusions that logically follow from the input, i.e., all of its conclusions are correct
  - We typically require our reasoners to be sound
- A complete reasoner can make all conclusions that logically follow from the input
  - We cannot guarantee complete reasoners for full FOL and many subsets
  - So, we can’t do it for OWL Full

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
  - 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

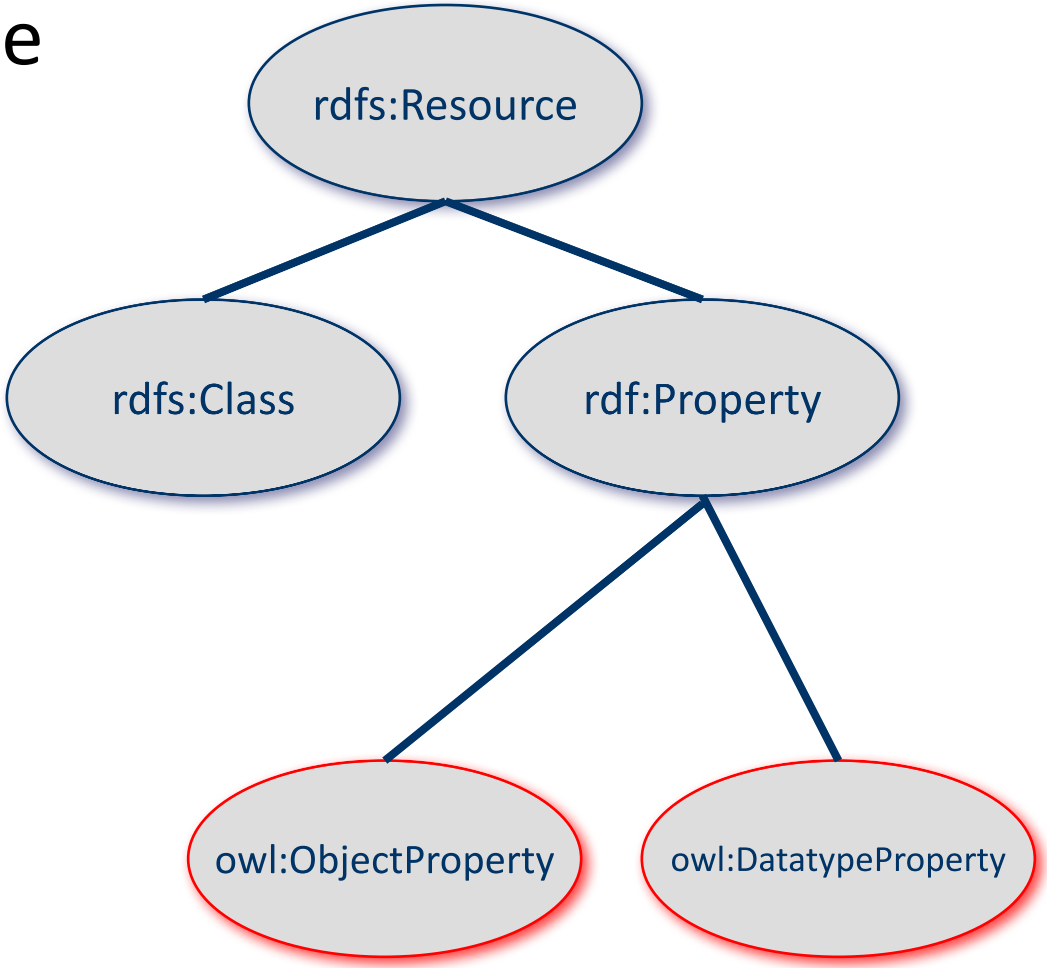
- An even further restriction limits OWL DL to a subset of the language constructors
  - E.g., OWL Lite excludes enumerated classes, disjointness statements, and arbitrary cardinality
- The advantage of this is a language that is easier to
  - grasp, for users
  - implement, for tool builders
- The disadvantage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

Upward Compatibility for OWL Species

- Every legal OWL Lite ontology is a legal OWL DL ontology
- Every legal OWL DL ontology is a legal OWL Full 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
- Typing information OWL constructors are specialisations of their RDF counterparts



OWL Compatibility with RDF Schema

- 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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6. Future Extensions

OWL Syntactic Varieties

- OWL builds on RDF and uses RDF's serializations
- Other syntactic forms for OWL have also been defined:
  - Alternative, more readable serializations

OWL XML/RDF Syntax: Header in Turtle

@prefix owl: <http://www.w3.org/2002/07/owl#> .

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .

@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .

@prefix xsd: <http://www.w3.org/2001/ XLMSchema#> .

- OWL documents are RDF documents
- and start with a typical declaration of namespaces
- The W3C recommendation for owl has the namespace http://www.w3.org/2002/07/owl#"

owl:Ontology

```
<> a owl:Ontology ;
  rdfs:comment "Example OWL ontology" ;
  owl:priorVersion <http://example.org/uni-ns-old> ;
  owl:imports <http://example.org/persons> ;
  rdfs:label "University Ontology" .
```

- **owl:imports,** a transitive property, indicates that the document commits to all of the terms as defined in its target
- **owl:priorVersion** points to an earlier version of this document

OWL Classes

```
:AssociateProfessor a owl:Class ;
    owl:disjointWith :Professor,
                     :AssistantProfessor .
```

- Classes are defined using **owl:Class**
  - **owl:Class** is a subclass of **rdfs:Class**
- Owl:Class is disjoint with datatypes (aka literals)
- Disjointness is defined using **owl:disjointWith**
  - Two disjoint classes are can share no instances

Another Example

:Man rdfs:subClassOf foaf:Person .

:Woman rdfs:subClassOf foaf:Person .

:Man owl:disjointWith :Woman .

Questions:

- Is :Man an rdfs:Class or a owl:Class?
- Why don't we need to assert that :Man is some kind of class?
- Do we need to assert the disjointness both ways?
- What happens of we assert :bob a :Man; a :Woman?

Separate Objects & Datatypes?

- **Philosophical reasons:**
  - Datatypes structured by built-in predicates
  - Inappropriate to form new datatypes using ontology language
- **Practical reasons:**
  - Note: Java does this, distinguishing classes from primitive datatypes
  - Ontology language remains simple and compact
  - Semantic integrity of ontology language not compromised
  - Implementability not compromised — can use hybrid reasoner
    - Only need sound and complete decision procedure for:

d^{I}_{1} Å … Å d^{I}_{n}, where d is a (possibly negated) datatype

OWL Classes

```
:Faculty a owl:Class;
    owl:equivalentClass :AcademicStaffMember .
```

- **owl:equivalentClass** asserts two classes are equivalent
  - Each must have the same members
- **owl:Thing** is the most general class, which contains everything
  - i.e., every owl class is rdfs:subClassOf owl:Thing
- **owl:Nothing** is the empty class
  - i.e., owl:NoThing is rdf:subClassOf every owl class

OWL Properties

- OWL has two kinds of properties
- **Object properties** relate objects to other objects
  - owl:ObjectProperty, e.g. is-TaughtBy, supervises
- **Data type properties** relate objects to datatype values
  - owl:DatatypeProperty, e.g. phone, title, age, …
- These were made separate to make it easier to create sound and complete reasoners

Datatype Properties

- OWL uses XML Schema data types, exploiting the layered architecture of the Semantic Web

```
:age a owl:DatatypeProperty;
   rdfs:domain foaf:Person;
   rdfs:range xsd:nonNegativeInteger .
```

OWL Object Properties

Typically user-defined data types

```
:isTaughtBy a owl:ObjectProperty;
    rdfs:domain :course;
    rdfs:range :AcademicStaffMember;
    rdfs:subPropertyOf :involves .
```

Inverse Properties

```
:teaches a owl:ObjectProperty;
    rdfs:range :course;
    rdfs:domain :AcademicStaffMember;
    owl:inverseOf :isTaughtBy .
```

Or just

```
:teaches owl:inverseOf :isTaughtBy .
```

A partial list of axioms:

```
owl:inverseOf rdfs:domain owl:ObjectProperty;
   rdfs:range owl:ObjectProperty;
   a owl:SymmetricProperty.
{?P  owl:inverseOf ?Q. ?S ?P ?O} => {?O ?Q ?S}.
{?P owl:inverseOf ?Q. ?P  rdfs:domain ?C} => {?Q rdfs:range ?C}.
{?A owl:inverseOf ?C. ?B owl:inverseOf ?C} => {?A rdfs:subPropertyOf ?B}.
```

Equivalent Properties

:lecturesIn owl:equivalentProperty :teaches .

- Two properties have the same property *extension*
- Axioms

  { ?A rdfs:subPropertyOf ?B.
     ?B rdfs:subPropertyOf ?A.}
     <=> {?A owl:equivalentProperty ?B.}.

Property Restrictions

- Declare that class C satisfies certain conditions
  - 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 (C' can remain anonymous)
- Example:
  - People whose sex is male and have at least one child whose sex is female and whose age is six
  - Things with exactly two arms and two legs

Property Restrictions

- **owl:Restriction** element describes such a class
- Element has an **owl:onProperty** element and one or more **restriction declarations**
- One type defines **cardinality restrictions**

  A Parent must have at least one child

```
:Parent rdfs:subClassOf
        [a owl:Restriction;
         owl:onProperty :hasChild;
         owl:minCardinalityQ "1"] .
```

Property Restrictions

- This statement **defines** Parent as any Person who has at least one child

```
:Parent owl:equivalentClass
  owl:intersectionOf (:Person ,
    [a owl:Restriction;
      owl:onProperty :hasChild;
      owl:minCardinalityQ "1”])
```

Property Restrictions

- Other restriction types 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

- Describe a class where all of the values of a property match some requirement
- E.g., Math courses taught by professors.

```
[a :mathCourse,
   [a owl:Restriction;
    owl:onProperty :isTaughtBy;
    owl:allValuesFrom :Professor] ].
```

Offspring of people are people

```
foaf:Person a owl:Class;
        rdfs:subClassOf
            [ a owl:Restriction;
              owl:allValuesFrom foaf:Person;
              owl:onProperty bio:offspring ] .
```

Offspring of people are people

```
foaf:Person a owl:Class;
        rdfs:subClassOf
            [ a owl:Restriction;
              owl:allValuesFrom foaf:Person;
              owl:onProperty bio:offspring ] .

:john a foaf:Person; bio:offspring :mary
```

What follows?

```
<foaf:Person> rdfs:subClassOf
   [owl:allValuesFrom <foaf:Person>;
    owl:onProperty <bio:offspring>] .
???
:bio:offspring rdfs:domain :animal;
               rdfs:range :animal.
???
:alice a foaf:Person;
       bio:offspring :bob.
???
:carol a foaf:Person.
:don bio:offspring :carol.
???
```

What follows?

```
<foaf:Person> rdfs:subClassOf
  [owl:allValuesFrom <foaf:Person>;
   owl:onProperty <bio:sprungFrom>] .

bio:sprungFrom rdfs:domain :animal;
               rdfs:range :animal;
               owl:inverse bio:offspring.

:carol a foaf:Person.
:don bio:offspring :carol.
???
```

owl:hasValue

- Describe a class with a particular value for a property
- E.g., Math courses taught by Professor Longhair

```
<!– Math courses taught by #949352 →
<owl:Class>
  <rdfs:subClassOf>rdf:resource="#mathCourse"/>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource= "#isTaughtBy"/>
      <owl:hasValue rdf:resource= "#949352"/>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

owl:hasValue

- Describe a class with a particular value for a property
- E.g., Math courses taught by Professor Longhair

```
# Math courses taught by :longhair
[ rdfs:subclassOf :mathCourse;
  [ a owl:restriction;
     owl:onProperty :isTaughtBy;
     owl:hasValue :longhair] .
```

Questions:

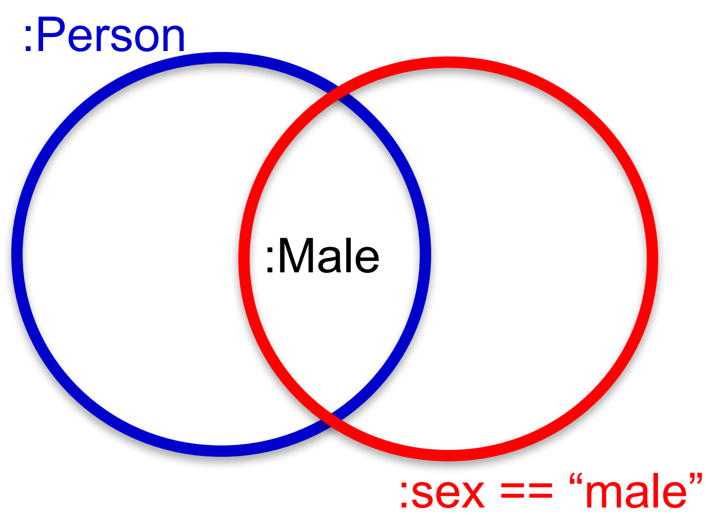
- Does this say all math courses are taught by :longhair?
- Does it say that there are some courses taught by :longhair?
- Can all classes, however defined, by paraphrased by a noun phrase in English?

A typical example

```
:Male owl:equivalentClass
   owl:intersectionOf
   (:Person,
     [a owl:Restriction;
       owl:onProperty :sex;
       owl:hasValue "male"] ).
```

A typical example

```
:Male owl:equivalentClass
  owl:intersectionOf
  (:Person,
    [a owl:Restriction;
      owl:onProperty :sex;
      owl:hasValue "male"] ).
```



Classes are sets in OWL

What follows?

:ed a :Male?

???

:frank a foaf:Person; :sex "male".

???

:gerry a foaf:Person; :sex "male"; :sex "female" .

owl:someValuesFrom

- Describe class requiring it to have *at least one value* for a property matching a description
- E.g., Academic staff members who teach **an** undergraduate course

```
[ a :academicStaffMember;
   a [owl:onProperty :teaches;
      owl:someValuesFrom :undergraduateCourse] ]
```

Cardinality Restrictions

- We can specify minimum and maximum number using **owl:minCardinality** & **owl:maxCardinality**
  - Courses with fewer than 10 students
  - Courses with between 10 and 100 students
  - Courses with more than 100 students
- Can specify a precise number by using the same minimum and maximum number
  - Courses with exactly seven students
- For convenience, OWL offers also **owl:cardinality**
  - E.g., exactly N

Cardinality Restrictions

E.g. courses taught be at least two people

```
[a owl:Restriction;
  owl:onProperty :isTaughtBy;
  owl:minCardinality
   “2”^^xsd;nonNegativeInteger] .
```

What does this say?

```
:Parent owl:equivalentClass
   [a owl:Restriction;
     owl:onProperty :hasChild;
     owl:minCardinality “1”^^xsd:integer] .
```

Questions:

- Must parents be humans?
- Must their children be humans?

Definition of a parent

The parent class is equivalent to the class of things that have at least one child

All(x): Parent(x) ⇔ Exisits(y) hasChild(x, y)

If hasChild is defined as having Person as it's domain, then Parents are also people.

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

Special Properties

```
hasSameGradeAs
  a owl:ObjectProperty, owl:SymmetricProperty;
  rdfs:domain student;
  rdfs:range student .
```

Boolean Combinations

- We can combine classes using Boolean operations (union, intersection, complement)
- Negation is introduced by the complementOf, *e.g., courses not taught be staffMembers*

```
[ a :course,
    owl:Restriction;
        owl:onProperty :teaches;
        owl:allValuesFrom [a owl:Class;
                                    owl:complementOf :staffMember]
 ] .
```

Boolean Combinations

- The new class is not a subclass of the union, but rather equal to the union
  - We have stated an equivalence of classes
- E.g., *university people is the union of staffMembers and Students*

```
:peopleAtUni
    owl:equivalentClass
        owl:unionOf (:staffMember :student) .
```

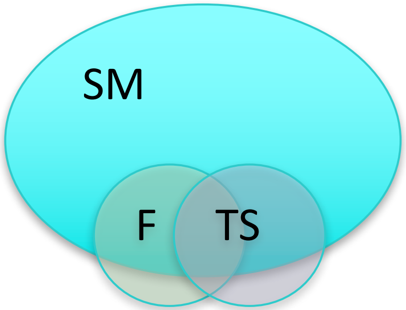
Boolean Combinations

E.g., CS faculty is the intersection of faculty and things that belongTo the CS Department.

```
:facultyInCS owl:equivalentClass
  owl:intersectionOf
    (:faculty
      [ a owl:Restriction;
        owl:onProperty :belongsTo;
        owl:hasValue :CSDepartment ]
    ) .
```

Nesting of Boolean Operators

E.g., administrative staff are staff members who are not faculty or technical staff members




```
:adminStaff owl:equivalentClass
  owl:intersectionOf
    (:staffMember
     [a owl:Class;
      owl:complementOf [a owl:Class;
                        owl:equivalentClass
                        owl:unionOf (:faculty :techSupportStaff)]])
```

Enumerations with owl:oneOf

- *E.g., a thing that is either Monday, Tuesday, …*

```
[a owl:Class;
 owl:oneOf (:Monday
           :Tuesday
           :Wednesday
           :Thursday
           :Friday
           :Saturday
           :Sunday) ]
```

Declaring Instances

Instances of OWL classes are declared as in RDF

```
:john
    a :academicStaffMember;
    uni:age 39^^xsd:integer .
```

No Unique-Names Assumption

- OWL does not adopt the unique-names assumption of database systems
  - That 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 #949318 and is taught by #949352
  - 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:

```
:john owl:differentFrom :mary .
```

Distinct Objects

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

```
[a owl:allDifferent;
   owl:distinctMembers (:alice :bob :carol :don) ].
```

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 can’t 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

- **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** says that the containing ontology is a later version of the referenced ontology but is not backward compatible with it

Combination of Features in OWL Profiles

- 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
- **OWL DL** removes or restricts some features to ensure that complete reasoning is *tractable* or to make reasoning implementations easier

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

- **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

- **No transitive cardinality restrictions**
  - No cardinality restrictions may be placed on transitive properties
  - e.g., people with more than 5 descendants
- **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**

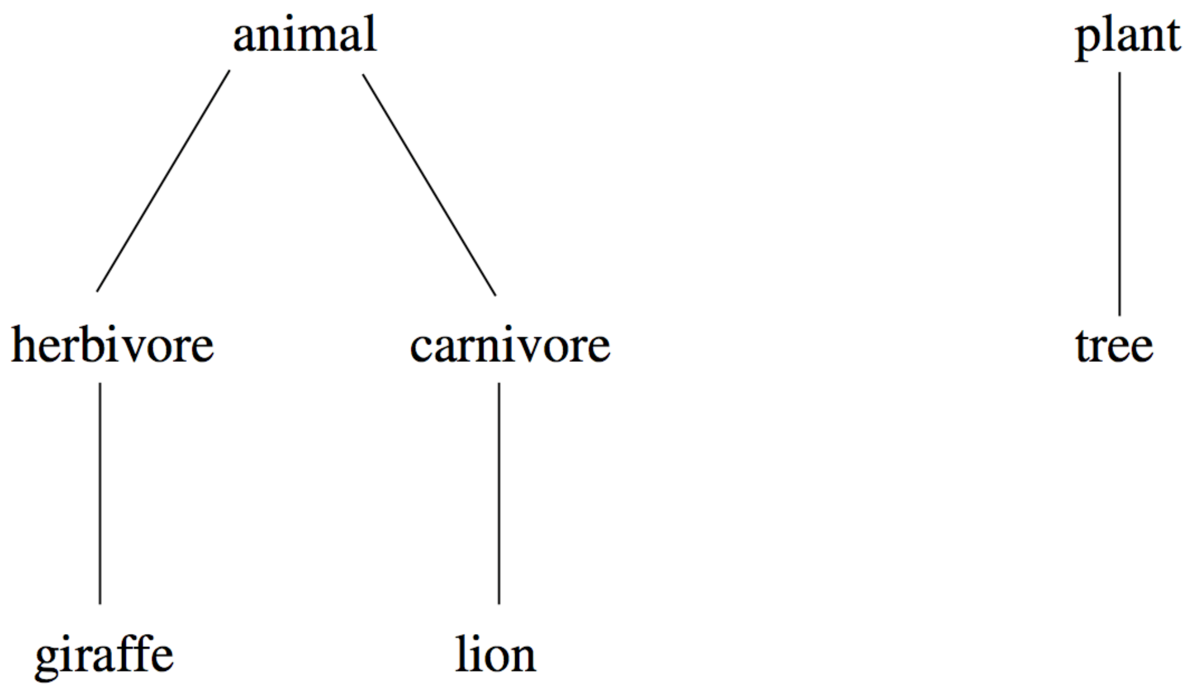
Restriction of Features in OWL Lite

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

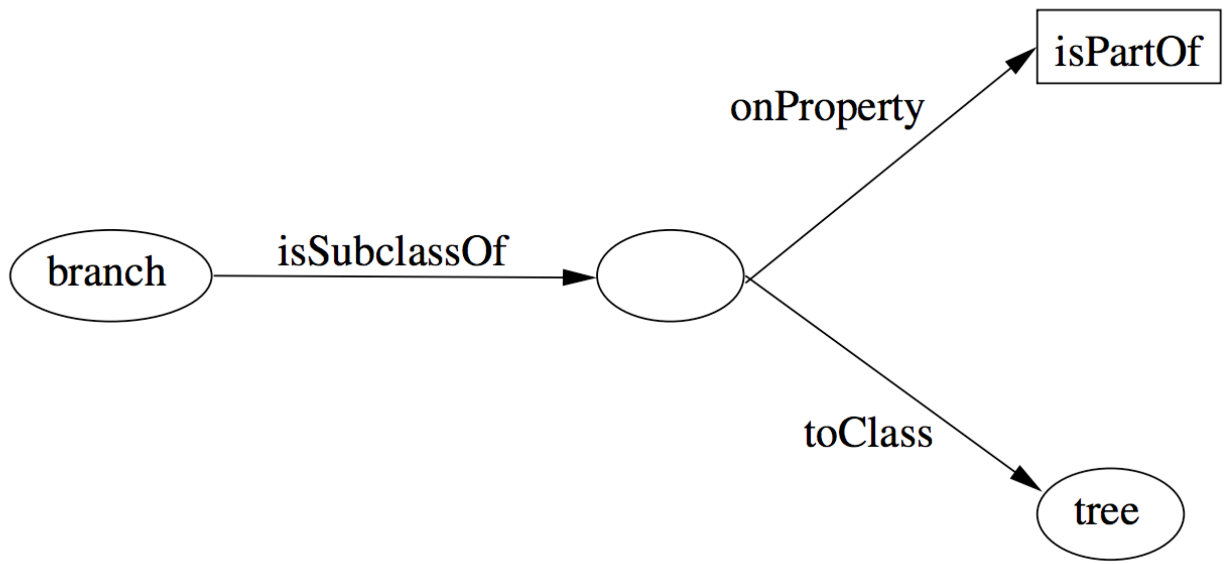
Outline

1. A bit of history
2. Basic Ideas of OWL
3. The OWL Language
4. **Examples**
5. The OWL Namespace
6. Future Extensions

African Wildlife Ontology: Classes



Branches are parts of trees



African Wildlife: 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>
```

African Wildlife: 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: 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>
```

African Wildlife: 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>
```

African Wildlife: 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>
  </owl:intersectionOf>
</owl:Class>
```

African Wildlife: Herbivores

How can we define Herbivores?

African Wildlife: Herbivores

Here is a start

```
:herbivore a owl:Class;
  rdfs:comment "Herbivores are exactly those
     animals that eat only plants or parts of plants” .
```

African Wildlife: Herbivores

```
:herbivore owl:equivalentClass
 [a owl:Class;
  owl:intersectionOf
   (:animal
    [a owl:Restriction
      owl:onProperty :eats;
      owl:allValuesFrom
        [a owl:Class;
         owl:equivalentClass
          owl:unionOf
           (:plant
            [a owl:Restriction;
             owl:onProperty :is_part_of;
             owl:allValuesFrom :plant])]]])]
```

African Wildlife: 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>
    </rdfs:subClassOf>
</owl:Class>
```

African Wildlife: 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>
```

African Wildlife: Tasty Plants

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

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

<rdfs:comment>

???????????????

<rdfs:comment>

</owl:Class>

```
<owl:Class rdf:ID="tasty-plant">
  <rdfs:subClassOf rdf:resource="#plant"/>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#eaten_by"/>
      <owl:someValuesFrom> <owl:Class rdf:about="#herbivore"/>
      </owl:someValuefrom>
     </owl:Restriction>
  </rdfs:subClassOf>
   <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#eaten_by"/>
      <owl:someValuesFrom> <owl:Class rdf:about="#carnivore"/>
        </owl:someValuefrom>
     </owl:Restriction>
   </rdfsSublassOf>
</owl:Class>
```

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1. A bit of history
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5. **The OWL Namespace**
6. OWL 2

Outline

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6. **OWL 2**

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 an area of research

OWL 2 adds

- Qualified cardinality
  - A hand has five digits, one of which is a thumb and four of which are fingers
- Stronger datatype/range support
- Additional property characteristics
  - E.g., reflexivity
- Role chains
  - E.g., hasParent.hasSibling.hasChild
- A better defined model for punning within DL
  - Allows a term to name both a concept and an individual
- More powerful annotations

Conclusions

- 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 modelling primitives are used
- 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