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Semantic Web in Depth: Web Ontology Language (OWL)

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Introducing OWL

- For many, RDF Schema is a sufficiently expressive ontology language
- However, there are use cases which require a more expressive formalism:
  - Instance classification
  - Consistency checking
  - Subsumption reasoning

OWL Feature Summary

- Necessary and sufficient conditions for class membership
- Property restrictions
  - Local range, cardinality, value constraints
- Equivalence and identity relations
- Property characteristics
  - Transitive, symmetric, functional
- Complex classes
  - Set operators, enumerated classes, disjoint classes

OWL Versions

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- Two versions of OWL:
  - OWL 1.0 (became Recommendation on 10 Feb 2004)
  - OWL 2 (became Recommendation on 29 Oct 2009)
- OWL 2 is more expressive than OWL 1.0, and takes advantage of developments in DL reasoning techniques in the intervening time
- We will initially concentrate on OWL 1.0

OWL 1.0 Species

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- Different subsets of OWL features give rise to the following sublanguages (colloquially known as **species**):
  - OWL Lite
  - OWL DL
  - OWL Full
- "There is a tradeoff between the expressiveness of a representation language and the difficulty of reasoning over the representations built using that language."

Brachman, R. J., and H. J. Levesque. (1984). The tractability of subsumption in frame-based description languages. In Proceedings of the 4th National Conference of the American Association for Artificial Intelligence (AAAI-84). Austin, TX, pp. 34-37.

OWL 1.0 Species

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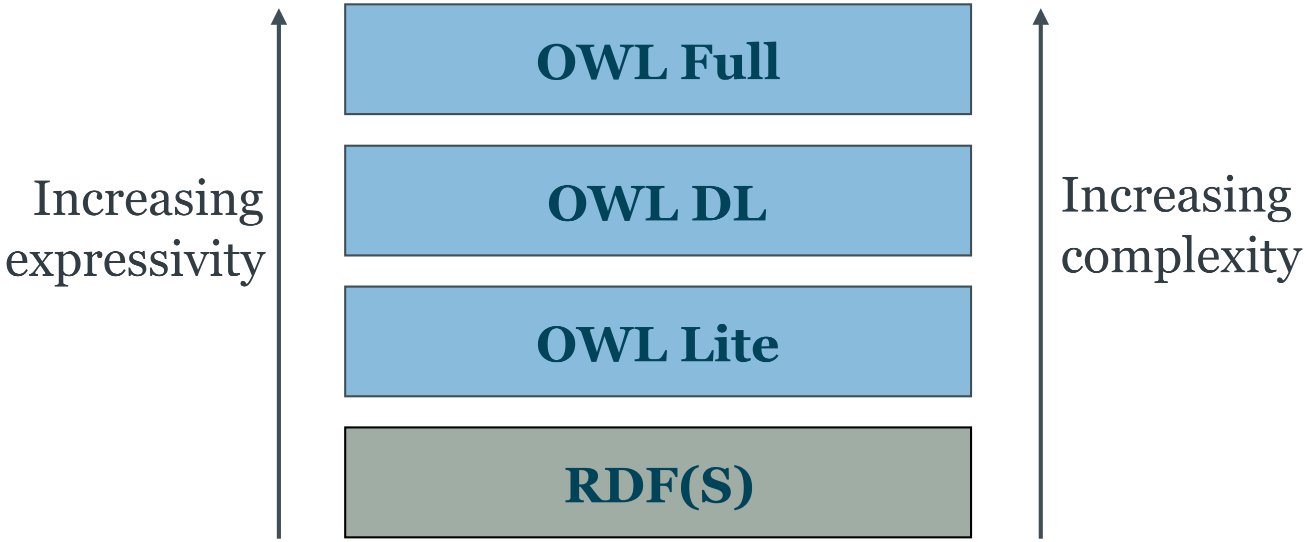

OWL Lite

- Description Logic-based
  - *SHIF*(D)
- Less complex reasoning at the expense of less expressive language
  - No enumerated classes, set operators, or disjoint classes
  - Restricted cardinality restrictions
    (values of 0 or 1 – required, permitted and excluded)
  - No value restrictions
  - equivalentClass/subClassOf cannot be applied to class expressions

OWL DL

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- Description Logic-based
  - *SHOIN*(D)
  - Complete and decidable
  - Higher worst-case complexity than OWL Lite
- Supports all OWL constructs, with some restrictions
  - Properties that take datatype values cannot be marked as inverse functional
  - Classes, properties, individuals and datatype values are disjoint

OWL Full

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- No restrictions on use of language constructs
  - All OWL DL and RDFS constructs
- Potentially undecidable

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OWL 1.0 Features and Syntax

Ontology header

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- Ontology header for metadata

```
<owl:Ontology rdf:about="“”>
  <owl:versionInfo>1.4</owl:versionInfo>
  <rdfs:comment>An example ontology</rdfs:comment>
  <owl:imports
    rdf:resource="http://www.example.org/base"/>
</owl:Ontology>
```

Versioning support

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- Version properties used in the ontology header
  - owl:versionInfo
    - Version number, etc
  - owl:priorVersion
    - Indicates that an ontology is a previous version of this
  - owl:backwardCompatibleWith
    - Indicates that the specified ontology is a previous version of this one, and that this is compatible with it
  - owl:incompatibleWith
    - Indicates that the specified ontology is a previous version of this one, but that this is incompatible with it

Versioning support

- Classes and properties may be marked as deprecated
  - owl:DeprecatedClass
  - owl:DeprecatedProperty

OWL class types

- owl:Class
  - Distinct from rdfs:Class – needed for OWL Lite/DL

- owl:Thing ($\top$)
  - The class that includes everything
- owl:Nothing ($\bot$)
  - The empty class

OWL property types

- owl:ObjectProperty
  - The class of resource-valued properties
- owl:DatatypeProperty
  - The class of literal-valued properties

- owl:AnnotationProperty
  - Used to type properties which annotate classes and properties (needed for OWL Lite/DL)

OWL versus RDF Schema

- Recall that the semantics of a description logic is specified by interpretation functions which map:
  - Instances to members of the domain of discourse
  - Classes to subsets of the domain of discourse
  - Properties to sets of pairs drawn from the domain of discourse
- Reflexive definitions of RDF Schema means that some resources are treated as both classes and instances, or instances and properties
- Ambiguous semantics for these resources
  - Can't tell from context whether they're instances or classes
  - Can't select the appropriate interpretation function
- The introduction of owl:Class, owl:ObjectProperty and owl:DatatypeProperty eliminates this ambiguity

OWL's Dirty Secret

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OWL Full

OWL DL

OWL Lite

RDF(S)

OWL's Dirty Secret Uncovered

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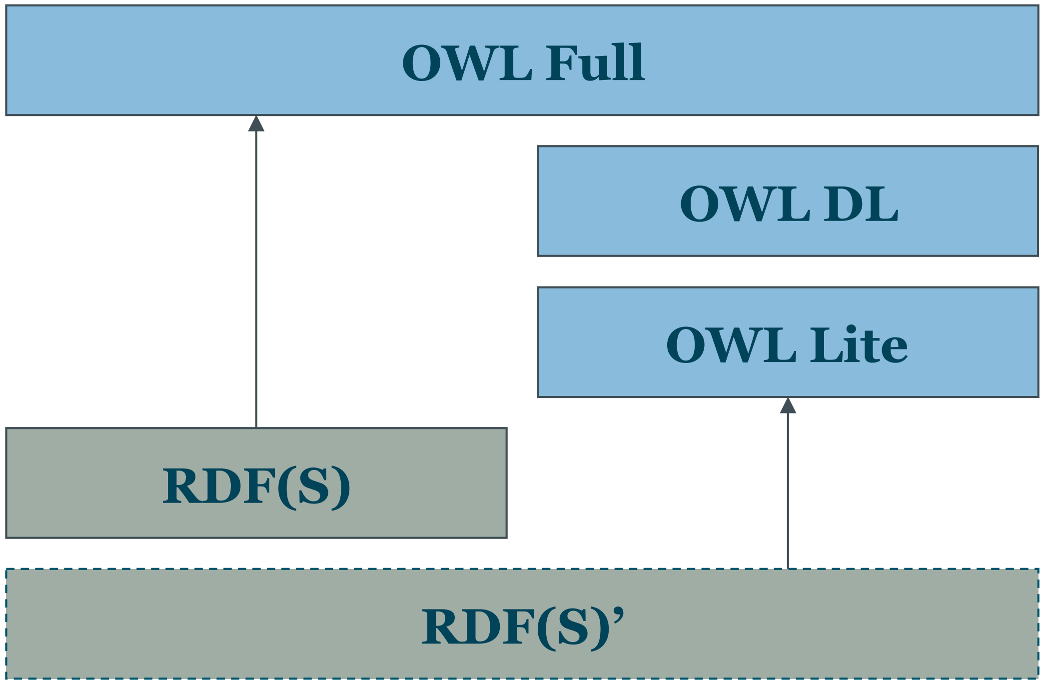

OWL restrictions

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- Class expression formed by constraints on properties
  - Local cardinality constraints
    $\leq n\ R$, $\geq n\ R$, $= n\ R$
  - Local range constraints
    $\exists R.C$, $\forall R.C$
  - Local value constraints
    $\exists R.\{x\}$
- Key concept in OWL

OWL restriction format

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```
<owl:Restriction>
  <owl:onProperty rdf:resource="property"/>
  constraint expression
</owl:Restriction>
```

Local cardinality constraints

- Defines a class based on the number of values taken by a property
- owl:minCardinality ($\geq$ n R)
  - "property R has at least n values"
- owl:maxCardinality ($\leq$ n R)
  - "property R has at most n values"
- owl:cardinality (= n R)
  - "property R has exactly n values"

- OWL Lite has restricted cardinalities

Local cardinality constraints

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- Single malt whiskies are whiskies which are distilled by one and only one thing

```
<owl:Class rdf:about="#SingleMaltWhisky">
  <owl:equivalentClass>
    <owl:Class>
      <owl:intersectionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#Whisky"/>
        <owl:Restriction>
          <owl:onProperty rdf:resource="#distilledBy"/>
          <owl:cardinality>1</owl:cardinality>
        </owl:Restriction>
      </owl:intersectionOf>
    <owl:Class>
  </owl:equivalentClass>
</owl:Class>
```

Local range constraints

- Defines a class based on the type of property values
- Distinct from global range constraint (rdfs:range) in RDF Schema
- owl:someValuesFrom ($\exists R.C$)
  - “there exists a value for property R of type C”
- owl:allValuesFrom ($\forall R.C$)
  - “property R has only values of type C”

- Can only be used with named classes or datatypes in OWL Lite

Local range constraints

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- Carnivores are things which eat some things which are animals (∃eats.Animal)

```
<owl:Class rdf:about="#Carnivore">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#eats"/>
      <owl:someValuesFrom rdf:resource="#Animal"/>
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```

Local range constraints

- Vegetarians are things which eat only things which are plants (∀eats.Plant)

```
<owl:Class rdf:about="#Vegetarian">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#eats"/>
      <owl:allValuesFrom rdf:resource="#Plant"/>
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```

Local value constraints

- Defines a class based on the existence of a particular property value
- owl:hasValue ($\exists R.\{x\}$)
    - "property R has a value which is X"

- Cannot be used in OWL Lite

Local value constraints

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- Green things are things which are coloured green
  ($\exists$ R. { Green })

```
<owl:Class rdf:about="#GreenThing">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#hasColour"/>
      <owl:hasValue rdf:resource="#Green"/>
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```

Set constructors

- owl:intersectionOf ($C \sqcap D$)
- owl:unionOf ($C \sqcup D$)
- owl:complementOf ($\neg C$)

- Restrictions on use with OWL Lite
  - owl:unionOf and owl:complementOf cannot be used
  - owl:intersectionOf can be used with named classes (not bNodes) and OWL restrictions only

Set constructors example

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```
<owl:Class rdf:about="GreenApple">
  <owl:equivalentClass>
    <owl:Class>
      <owl:intersectionOf rdf:parseType="Collection">
        <owl:Class rdf:about="Apple">
        <owl:Restriction>
          <owl:onProperty rdf:resource="hasColor"/>
          <owl:hasValue rdf:resource="Green"/>
        </owl:Restriction>
      </owl:intersectionOf>
    </owl:Class>
  </owl:equivalentClass>
</owl:Class>
```

Equivalence and identity relations

- Useful for ontology mapping
  - owl:sameAs
  - owl:equivalentClass ($C \equiv D$)
  - owl:equivalentProperty ($R \equiv S$)

```
<owl:Thing rdf:about="#MorningStar">
  <owl:sameAs rdf:resource="#EveningStar"/>
</owl:Thing>
```

Non-equivalence relations

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- owl:differentFrom
  - Can be used to specify a limited unique name assumption

```
<rdf:Description rdf:about="#HarryCorbett">
  <owl:differentFrom rdf:resource="#HarryHCorbett"/>
</rdf:Description>
```

- OWL (and DLs in general) make the Open World Assumption
  - Knowledge of world is incomplete
  - If something cannot be proven true, then it isn't assumed to be false

Non-equivalence relations

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- owl:AllDifferent and owl:distinctMembers
  - Used to specify a group of mutually distinct individuals

```
<owl:AllDifferent>
  <owl:distinctMembers rdf:parseType="Collection">
    <rdf:Description rdf:about="#John"/>
    <rdf:Description rdf:about="#Paul"/>
    <rdf:Description rdf:about="#George"/>
    <rdf:Description rdf:about="#Ringo"/>
  </owl:distinctMembers>
</owl:AllDifferent>
```

Class Definitions

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- Necessary Conditions ($\sqsubseteq$)
  - Primitive / partial classes
  - “If we know that something is a X, then it must fulfill the conditions...”
  - Defined using rdfs:subClassOf
- Necessary and Sufficient Conditions ($\equiv$)
  - Defined / complete classes
  - “If something fulfills the conditions..., then it is an X."
  - Defined using owl:equivalentClass

Property types - Inverse

- Defines a property as the inverse of another property ($R \equiv S^-$)

```
<owl:Property rdf:about="#hasAuthor">
  <owl:inverseOf rdf:resource="#wrote"/>
</owl:Property>
```

Property types - Symmetric

- Symmetric properties satisfy the axiom
  P(x,y) iff P(y,x)

```
<owl:SymmetricProperty rdf:about="#hasSibling"/>
```

Property types – Transitive

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- Transitive properties satisfy the axiom
  P(x,y) and P(y,z) implies P(x,z)

```
<owl:TransitiveProperty rdf:about="#hasAncestor"/>
```

Property types – Functional

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- Functional properties satisfy the axiom
  P(x,y) and P(x,z) implies y=z

```
<owl:FunctionalProperty rdf:about="#hasNINumber"/>
```

(everyone has only one NI number)

Property types – Inverse Functional

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- Inverse functional properties satisfy the axiom
  P(y,x) and P(z,x) implies y=z

```
<owl:InverseFunctionalProperty rdf:about="#hasNINumber"/>
```

(people with the same NI number are the same person)

- Cannot be used with owl:DatatypeProperty in OWL Lite/DL

Disjoint classes

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- owl:disjointWith
  - members of one class cannot also be members of some specified other class

```
<owl:Class rdf:about="#MaleHuman">
  <rdfs:subClassOf rdf:resource="#Human"/>
  <owl:disjointWith rdf:resource="#FemaleHuman"/>
</owl:Class>
```

- Cannot be used in OWL Lite

Enumerated classes

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- Defines a class as a direct enumeration of its members
  - owl:one of ($C \equiv \{a,b,c\}$)
- Cannot be extended (closed set)

- Cannot be used in OWL Lite

Enumerated classes example


```
<owl:Class rdf:about="#Continents">
  <owl:oneOf rdf:parseType="Collection">
    <owl:Thing rdf:about="#Africa"/>
    <owl:Thing rdf:about="#Antarctica"/>
    <owl:Thing rdf:about="#Oceania"/>
    <owl:Thing rdf:about="#Europe"/>
    <owl:Thing rdf:about="#North-America"/>
    <owl:Thing rdf:about="#South-America"/>
    <owl:Thing rdf:about="#Asia"/>
  </owl:oneOf>
</owl:Class>
```

Ontology modularisation

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- owl:imports mechanism for including other ontologies
- Also possible to use terms from other ontologies without explicitly importing them
- Importing requires certain entailments, whereas simple use does not require (but also does not prevent) those entailments

Ontology modularisation example

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- Ontology 1 (ont1) contains:
  BBB rdfs:subClassOf AAA
- Ontology-2 (ont2) contains:
  ont2 imports ont1
  CCC rdfs:subClassOf BBB

- Ontology-2 **must** entail
  CCC rdfs:subClassOf AAA

Ontology modularisation example

- Ontology 1 (ont1) contains:
  BBB rdfs:subClassOf AAA
- Ontology-3 (ont3) contains:
  CCC rdfs:subClassOf ont1:BBB

- Ontology-3 does **not necessarily** entail
  CCC rdfs:subClassOf ont1:AAA

OWL status

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- WebOnt working group formed Nov 2001
- OWL Recommendations published in Feb 2004

OWL references

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- Web Ontology Working Group homepage
  - http://www.w3.org/2001/sw/WebOnt/

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OWL 2

From OWL 1 to OWL 2

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- OWL 1 design based on contemporary understanding of techniques for decidable, sound and complete reasoning in description logics
- Our understanding has improved since 2004
  - Some things that looked intractable have been shown to be possible
- Changes between 1 and 2 fall into the following categories:
  - Syntactic sugar (making it easier to say things we could already say)
  - Constructs for increased expressivity
  - Datatype support
  - Metamodelling
  - Annotation

Syntactic Sugar: Disjoint Union

- Allows us to define a class as the union of a number of other classes, all of which are pairwise disjoint

$$C \equiv C_1 \sqcup C_2 \sqcup \ldots \sqcup C_n$$

$$C1 \sqcap C2 \equiv \bot$$

- We'll look at this modelling pattern more in later lectures

Syntactic Sugar: Disjoint Classes

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- OWL 1 lets us state that two classes are disjoint
- OWL 2 lets us state that a set of classes are pairwise disjoint

Syntactic Sugar: Negative Property Assertions

- OWL 1 lets us assert property values for an individual
- OWL 2 lets us assert that an individual does not have a particular property value

```
<owl:NegativePropertyAssertion>
        <owl:sourceIndividual rdf:resource="john"/>
        <owl:assertionProperty rdf:resource="hasChild"/>
        <owl:targetIndividual rdf:resource="susan"/>
</owl:NegativePropertyAssertion>
```

New Constructs: Self Restriction

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- Define a class of individuals which are related to to themselves by a given property

```
<owl:Restriction>
    <owl:onProperty rdf:resource="…"/>
    <owl:hasSelf rdf:datatype="&xsd;boolean">true</owl:hasSelf>
</owl:Restriction>
```

New Constructs: Qualified Cardinality Restrictions

- OWL 1 lets us either specify the local range of a property, or the number of values taken by the property
- OWL 2 lets us specify both together:

$$= 4\ hasPart.Wheel$$

```
<owl:Restriction>
        <owl:onProperty rdf:resource="hasPart"/>
        <owl:onClass rdf:resource="Wheel"/>
        <owl:cardinality rdf:datatype="&xsd;integer">4</owl:cardinality>
</owl:Restriction>
```

- Similar construct for datatype properties

New Constructs: Reflexive Properties

- Allows us to assert that a property is globally reflexive (relates every object to itself)

  <owl:ReflexiveProperty rdf:about="sameAgeAs"/>

New Constructs: Irreflexive Properties

- Allows us to assert that a property relates no object to itself

```
<owl:IrreflexiveProperty rdf:about="strictlyTallerThan"/>
```

New Constructs:
Asymmetric Properties

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- Allows us to assert that a property is asymmetric:
  - If p(x,y), then not p(y,x)

```
<owl:AsymmetricProperty rdf:about="strictlyTallerThan"/>
```

New Constructs: Disjoint Properties

- Allows us to state that two individuals cannot be related to each other by two different properties that have been declared disjoint

```
<owl:ObjectProperty rdf:about="connectedTo">
        <owl:propertyDisjointWith rdf:resource="contiguousWith"/>
</owl:ObjectProperty>
```

New Constructs:
Property Chain Inclusion

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- OWL 1 does not let us define a property as a composition of other properties
  - Example: hasUncle ≡ hasParent o hasBrother

- OWL 2 lets us define such property compositions

```
<owl:ObjectProperty rdf:about="hasUncle">
    <owl:propertyChainAxiom rdf:parseType="Collection">
        <owl:ObjectProperty rdf:about="hasParent"/>
        <owl:ObjectProperty rdf:about="hasBrother"/>
    </owl:propertyChainAxiom>
</owl:ObjectProperty>
```

New Constructs: Keys

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- OWL 1 lets us define a property to be functional, so that individuals can be uniquely identified by values of that property
- OWL 2 lets us define uniquely identifying keys that comprise several properties

```
<owl:Class rdf:about="Person">
    <owl:hasKey rdf:parseType="Collection">
        <owl:DatatypeProperty rdf:about="hasSSN"/>
        <owl:DatatypeProperty rdf:about="birthDate"/>
    </owl:hasKey>
</owl:Class>
```

Datatype Restrictions

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- Allows us to define subsets of datatypes that constrain the range of values allowed by a datatype
- For example, the datatype of integers greater than or equal to 5:

```
<owl:Datatype>
    <owl:onDatatype rdf:resource="&xsd;integer"/>
    <owl:withRestrictions rdf:parseType="Collection">
        <xsd:minInclusive
            rdf:datatype="&xsd;integer">5</xsd:minInclusive>
    </owl:withRestrictions>
</owl:Datatype>
```

Metamodelling: Punning

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- OWL 1 required the names used to identify classes, properties, individuals and datatypes to be disjoint
- OWL 2 relaxes this
  - The same name (URI) can be used for both a class and an individual
- However:
  - A name cannot be used for both a class and a datatype
  - A name cannot be used for more than one type of property (DataProperty vs ObjectProperty)

Language Profiles

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- OWL 1 has three dialects: OWL Lite, OWL DL and OWL Full

- OWL 2 introduces three profiles with useful computational properties (reasoning, conjunctive queries):
  - OWL 2 EL (PTIME-complete, PSPACE-complete)
  - OWL 2 QL (NLOGSPACE-complete, NP-complete)
  - OWL 2 RL (PTIME-complete, NP-complete)

  - OWL 1 DL (NEXPTIME-complete, decidability open)

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Manchester DL Syntax

A Plethora of Syntaxes

- The DL syntax we've used so far is a 'traditional' syntax for logical expressions

- Not well understood by non-logicians

- The Manchester DL syntax was introduced as a more user-friendly syntax for use in tools
  - Used in Protégé 4 – the subject of our next lecture

Manchester Syntax Summary

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Traditional DL Syntax	Manchester Syntax
$C \sqcap D$	C and D
$C \sqcup D$	C or D
$\neg C$	not C
$\exists R.C$	R some C
$\forall R.C$	R only C
$\geq n\ R$	R min n
$\leq n\ R$	R max n
$= n\ R$	R exactly n
$\exists R.\{x\}$	R value x
$\geq n\ R.C$	R min n C
Reflexive property	R Self
Datatype restrictions	int[>=2, <=15]

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The Protégé Ontology Editor

Protégé

- Leading ontology editor
- Early implementer of OWL (but was around before OWL)
- Thriving user community
    - Annual user conference
- Free and open source
    - http://protege.stanford.edu/
    - Many add-ons for visualisation, etc

Protégé and DL Reasoners

- Protégé integrates reasoning into the ontology design process
  - Checks your ontology for consistency, subsumption, etc
  - Uses DIG interface to communicate with the reasoner
- Pellet
  - http://pellet.owldl.com/
- FaCT++
  - http://owl.man.ac.uk/factplusplus/

ESSENTIAL READING!

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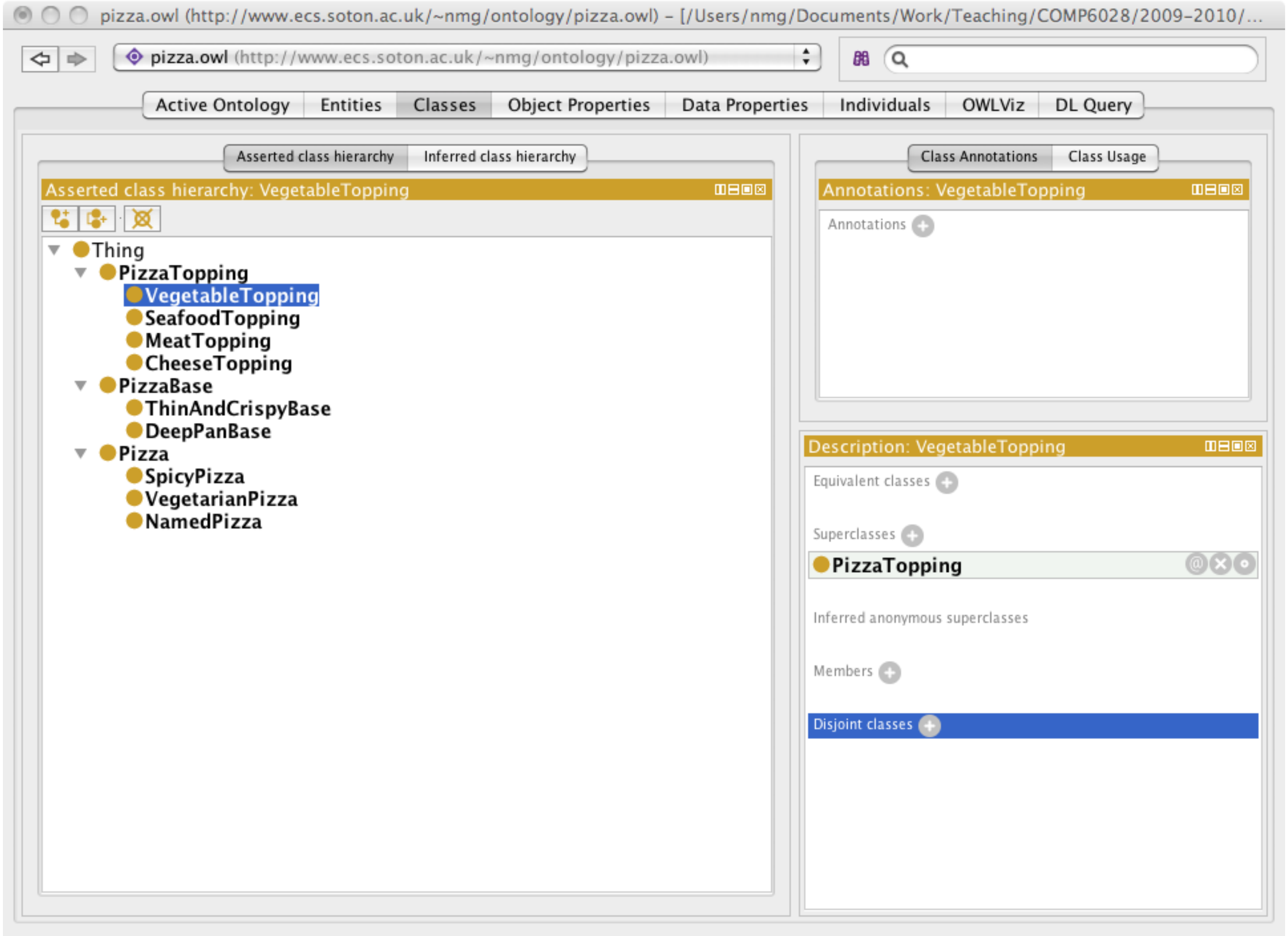
- Horridge et al, A Practical Guide to Building OWL Ontologies using the Protégé-OWL Plugin and CO-ODE Tools, 2007
- (available from COMP6028 website)


pizza.owl (http://www.ecs.soton.ac.uk/~nmg/ontology/pizza.owl) – [/Users/nmg/Documents/Work/Teaching/COMP6028/2009-2010/...
pizza.owl (http://www.ecs.soton.ac.uk/~nmg/ontology/pizza.owl)
Active Ontology
Entities
Classes
Object Properties
Data Properties
Individuals
OWLViz
DL Query
Asserted class hierarchy
Inferred class hierarchy
Asserted class hierarchy: VegetableTopping
Thing
PizzaTopping
VegetableTopping
SeafoodTopping
MeatTopping
CheeseTopping
PizzaBase
ThinAndCrispyBase
DeepPanBase
Pizza
SpicyPizza
VegetarianPizza
NamedPizza
Class Annotations
Class Usage
Annotations: VegetableTopping
Annotations
Description: VegetableTopping
Equivalent classes
Superclasses
PizzaTopping
Inferred anonymous superclasses
Members
Disjoint classes

Example ontology: OWL Pizzas

- Build an ontology for describing pizzas and their ingredients
- Must be able to determine whether pizzas are vegetarian, spicy, etc