

A Practical Guide To Building OWL Ontologies Using Protégé 4 and CO-ODE Tools

Edition 1.3

Matthew Horridge

Contributors

- v 1.0 Holger Knublauch , Alan Rector , Robert Stevens , Chris Wroe
- v 1.1 Simon Jupp, Georgina Moulton, Robert Stevens
- v 1.2 Nick Drummond, Simon Jupp, Georgina Moulton, Robert Stevens
- v 1.3 Sebastian Brandt

THE UNIVERSITY OF MANCHESTER

Copyright © The University Of Manchester

March 24, 2011

Contents

1	Introduction	7
1.1	Conventions	7
2	Requirements	9
3	What are OWL Ontologies?	10
3.1	Components of OWL Ontologies	10
3.1.1	Individuals	10
3.1.2	Properties	11
3.1.3	Classes	12
4	Building An OWL Ontology	13
4.1	Named Classes	15
4.2	Disjoint Classes	17
4.3	Using Create Class Hierarchy To Create Classes	19
4.4	OWL Properties	23
4.5	Inverse Properties	27
4.6	OWL Object Property Characteristics	29
4.6.1	Functional Properties	29
4.6.2	Inverse Functional Properties	29
4.6.3	Transitive Properties	29
4.6.4	Symmetric Properties	30

4.6.5	Asymmetric properties	32
4.6.6	Reflexive properties	32
4.6.7	Irreflexive properties	33
4.7	Property Domains and Ranges	33
4.8	Describing And Defining Classes	36
4.8.1	Property Restrictions	37
4.8.2	Existential Restrictions	40
4.9	Using A Reasoner	48
4.9.1	Invoking The Reasoner	48
4.9.2	Inconsistent Classes	49
4.10	Necessary And Sufficient Conditions (Primitive and Defined Classes)	53
4.10.1	Primitive And Defined Classes	57
4.11	Automated Classification	57
4.12	Universal Restrictions	59
4.13	Automated Classification and Open World Reasoning	62
4.13.1	Closure Axioms	63
4.14	Value Partitions	67
4.14.1	Covering Axioms	68
4.15	Adding Spiciness to Pizza Toppings	70
4.16	Cardinality Restrictions	73
4.17	Qualified Cardinality Restrictions	75
5	Datatype Properties	76
6	More On Open World Reasoning	83
7	Creating Other OWL Constructs In Protégé 4	89
7.1	Creating Individuals	89
7.2	hasValue Restrictions	91

7.3	Enumerated Classes	93
7.4	Annotation Properties	94
7.5	Multiple Sets Of Necessary & Sufficient Conditions	96
A	Restriction Types	97
A.1	Quantifier Restrictions	97
A.1.1	someValuesFrom – Existential Restrictions	98
A.1.2	allValuesFrom – Universal Restrictions	98
A.1.3	Combining Existential And Universal Restrictions in Class Descriptions	99
A.2	hasValue Restrictions	99
A.3	Cardinality Restrictions	100
A.3.1	Minimum Cardinality Restrictions	100
A.3.2	Maximum Cardinality Restrictions	100
A.3.3	Cardinality Restrictions	101
A.3.4	The Unique Name Assumption And Cardinality Restrictions	101
B	Complex Class Descriptions	102
B.1	Intersection Classes (\sqcap)	102
B.2	Union Classes (\sqcup)	102
C	Plugins	104
C.1	Installing Plugins	104
C.2	Useful Plugins	104
C.2.1	Matrix Plugin	104

Copyright

Copyright The University Of Manchester 2007

Acknowledgements

I would like to acknowledge and thank my colleagues at the University Of Manchester and also Stanford University for proof reading this tutorial/guide and making helpful comments and suggestions as to how it could be improved. In particular I would like to thank my immediate colleagues: Alan Rector, Nick Drummond, Hai Wang and Julian Seidenberg at the Univeristy Of Manchester, who suggested changes to early drafts of the tutorial in order to make things clearer and also ensure the technical correctness of the material. Alan was notably helpful in suggesting changes that made the tutorial flow more easily. I am grateful to Chris Wroe and Robert Stevens who conceived the original idea of basing the tutorial on an ontology about pizzas. Finally, I would also like to thank Natasha Noy from Stanford University for using her valuable experience in teaching, creating and giving tutorials about Protégé to provide detailed and useful comments about how initial drafts of the tutorial/guide could be made better.

This work was supported in part by the CO-ODE project funded by the UK Joint Information Services Committee and the HyOntUse Project (GR/S44686) funded by the UK Engineering and Physical Science Research Council and by 21XS067A from the National Cancer Institute.

<http://www.co-ode.org>



Chapter 1

Introduction

This guide introduces Protégé 4 for creating OWL ontologies. Chapter 3 gives a brief overview of the OWL ontology language. Chapter 4 focuses on building an OWL-DL ontology and using a Description Logic Reasoner to check the consistency of the ontology and automatically compute the ontology class hierarchy. Chapter 7 describes some OWL constructs such as hasValue Restrictions and Enumerated classes, which aren't directly used in the main tutorial.

1.1 Conventions

Class, property and individual names are written in a sans serif font **like this**.

Names for user interface views are presented in a style '**like this**'.

Where exercises require information to be typed into Protégé 4 a type writer font is used **like this**.

Exercises and required tutorial steps are presented like this:

Exercise 1: Accomplish this

- 
1. Do this.
 2. Then do this.
 3. Then do this.
-



Tips and suggestions related to using Protégé 4 and building ontologies are presented like this.

MEANING



Explanation as to what things mean are presented like this.



Potential pitfalls and warnings are presented like this.



NOTE

General notes are presented like this.

Vocabulary



Vocabulary explanations and alternative names are presented like this.

Chapter 2

Requirements

In order to follow this tutorial you must have Protégé 4, which is available from the Protégé website ¹, and the Protégé Plugins which are available via the CO-ODE web site ². It is also recommended (but not necessary) to use the OWLViz plugin, which allows the asserted and inferred classification hierarchies to be visualised, and is available from the CO-ODE web site, or can be installed when Protégé 4 is installed. For installation steps, please see the documentation for each component.

¹<http://protege.stanford.edu>

²<http://www.co-ode.org>

Chapter 3

What are OWL Ontologies?

Ontologies are used to capture knowledge about some domain of interest. An ontology describes the concepts in the domain and also the relationships that hold between those concepts. Different ontology languages provide different facilities. The most recent development in standard ontology languages is OWL from the World Wide Web Consortium (W3C)¹. Like Protégé, OWL makes it possible to describe concepts but it also provides new facilities. It has a richer set of operators - e.g. intersection, union and negation. It is based on a different logical model which makes it possible for concepts to be defined as well as described. Complex concepts can therefore be built up in definitions out of simpler concepts. Furthermore, the logical model allows the use of a reasoner which can check whether or not all of the statements and definitions in the ontology are mutually consistent and can also recognise which concepts fit under which definitions. The reasoner can therefore help to maintain the hierarchy correctly. This is particularly useful when dealing with cases where classes can have more than one parent.

3.1 Components of OWL Ontologies

OWL ontologies have similar components to Protégé frame based ontologies. However, the terminology used to describe these components is slightly different from that used in Protégé. An OWL ontology consists of Individuals, Properties, and Classes, which roughly correspond to Protégé frames Instances, Slots and Classes.

3.1.1 Individuals

Individuals, represent objects in the domain in which we are interested². An important difference between Protégé and OWL is that OWL does not use the Unique Name Assumption (UNA). This means that two different names could actually refer to the same individual. For example, “Queen Elizabeth”, “The Queen” and “Elizabeth Windsor” *might* all refer to the same individual. In OWL, it must be explicitly stated that individuals are the same as each other, or different to each other — otherwise they *might* be the same as each other, or they *might* be different to each other. Figure 3.1 shows a representation of some individuals in some domain—in this tutorial we represent individuals as diamonds in diagrams.

¹<http://www.w3.org/TR/owl-guide/>

²Also known as *the domain of discourse*.



Figure 3.1: Representation Of Individuals

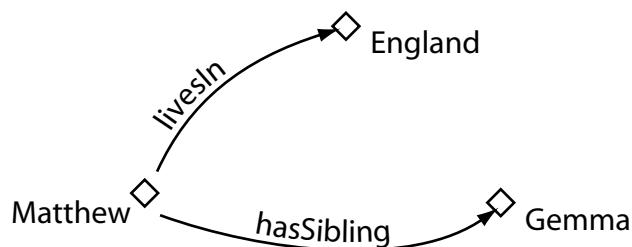


Figure 3.2: Representation Of Properties

Vocabulary



Individuals are also known as *instances*. Individuals can be referred to as being ‘instances of classes’.

3.1.2 Properties

Properties are *binary relations*³ on *individuals* - i.e. properties link *two* individuals together⁴. For example, the property **hasSibling** might link the individual **Matthew** to the individual **Gemma**, or the property **hasChild** might link the individual **Peter** to the individual **Matthew**. Properties can have inverses. For example, the inverse of **hasOwner** is **isOwnedBy**. Properties can be limited to having a single value – i.e. to being *functional*. They can also be either *transitive* or *symmetric*. These ‘property characteristics’ are explained in detail in Section 4.8. Figure 3.2 shows a representation of some properties linking some individuals together.

Vocabulary



Properties are roughly equivalent to *slots* in Protégé. They are also known as *roles* in description logics and *relations* in UML and other object oriented notions. In GRAIL and some other formalisms they are called *attributes*.

³A binary relation is a relation between *two* things.

⁴Strictly speaking we should speak of ‘instances of properties’ linking individuals, but for the sake of brevity we will keep it simple.

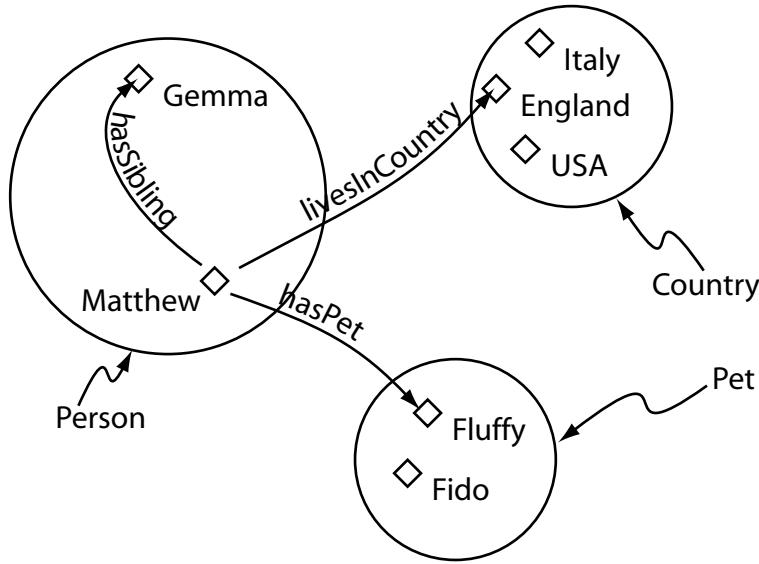


Figure 3.3: Representation Of Classes (Containing Individuals)

3.1.3 Classes

OWL classes are interpreted as *sets* that contain individuals. They are *described* using formal (mathematical) descriptions that state precisely the requirements for membership of the class. For example, the class **Cat** would contain all the individuals that are cats in our domain of interest.⁵ Classes may be organised into a superclass-subclass hierarchy, which is also known as a *taxonomy*. Subclasses specialise ('are subsumed by') their superclasses. For example consider the classes **Animal** and **Cat** – **Cat** might be a subclass of **Animal** (so **Animal** is the superclass of **Cat**). This says that, 'All cats are animals', 'All members of the class **Cat** are members of the class **Animal**', 'Being a **Cat** implies that you're an **Animal**', and '**Cat** is *subsumed* by **Animal**'. One of the key features of OWL-DL is that these superclass-subclass relationships (subsumption relationships) can be computed automatically by a *reasoner* – more on this later. Figure 3.3 shows a representation of some classes containing individuals – classes are represented as circles or ovals, rather like sets in Venn diagrams.



The word *concept* is sometimes used in place of class. Classes are a concrete representation of concepts.

In OWL classes are built up of descriptions that specify the conditions that must be satisfied by an individual for it to be a member of the class. How to formulate these descriptions will be explained as the tutorial progresses.

⁵Individuals may belong to more than one class.

Chapter 4

Building An OWL Ontology

This chapter describes how to create an ontology of Pizzas. We use Pizzas because we have found them to provide many useful examples.¹

Exercise 2: Create a new OWL Ontology

1. Start Protégé
 2. When the Welcome To Protégé dialog box appears, press the ‘Create New OWL Ontology’.
 3. A ‘Create Ontology URI Wizard will appear’. Every ontology is named using a Unique Resource Identifier (URI). Replace the default URI with <http://www.pizza.com/ontologies/pizza.owl> and press ‘Next’.
 4. You will also want to save your Ontology to a file on your PC. You can browse your hard disk and save your ontology to a new file, you might want to name your file ‘pizza.owl’. Once you choose a file press ‘Finish’.
-

After a short amount of time, a new empty Protégé file will have been created and the ‘Active Ontology Tab’ shown in Figure 4.1 will be visible. As can be seen from Figure 4.1, the ‘Active Ontology Tab’ allows information about the ontology to be specified. For example, the ontology URI can be changed, annotations on the ontology such as comments may be added and edited, and namespaces and imports can be set up via this tab.

¹The Ontology that we will create is based upon a Pizza Ontology that has been used as the basis for a course on editing DAML+OIL ontologies in OilEd (<http://oiled.man.ac.uk>), which was taught at the University Of Manchester.

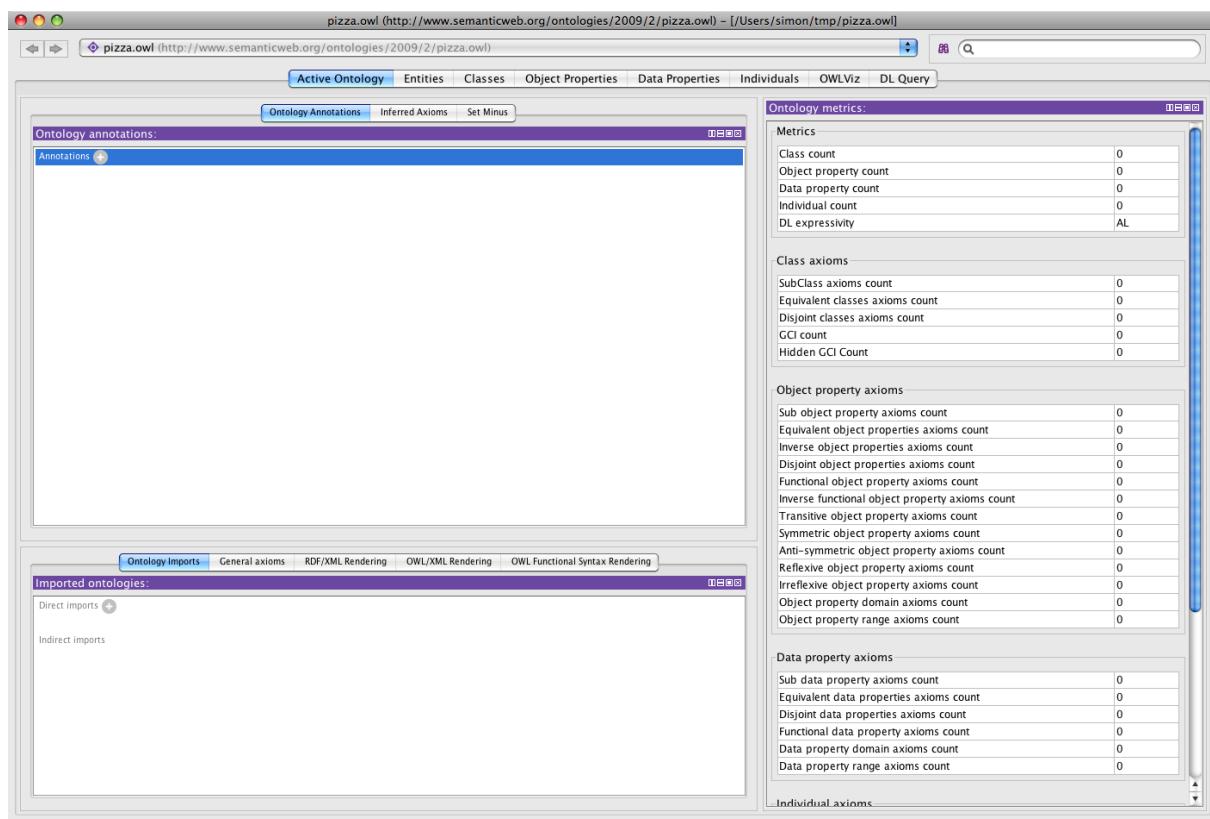


Figure 4.1: The Active Ontology Tab



Figure 4.2: The Ontology Annotations View – The ontology has a comment as indicated by the `comment` annotation

Exercise 3: Add a comment to the ontology

1. Ensure that the ‘Active Ontology Tab’ is selected.
2. In the ‘Ontology Annotations’ view, click the ‘Add’ icon (⊕) next to Annotations. An editing window will appear in the table. Select ‘comment’ from the list of built in annotation URIs and type your comment in the text box in the right hand pane.
3. Enter a comment such as `A pizza ontology that describes various pizzas based on their toppings.` and press OK to assign the comment. The annotations view on the ‘Active Ontology Tab’ should look like the picture shown in Figure 4.2

4.1 Named Classes

As mentioned previously, an ontology contains classes – indeed, the main building blocks of an OWL ontology are classes. In Protégé 4, editing of classes is carried out using the ‘Classes Tab’ shown in Figure 4.3. The initial class hierarchy tree view should resemble the picture shown in Figure 4.4. The empty ontology contains one class called `Thing`. As mentioned previously, OWL classes are interpreted as sets of *individuals* (or sets of objects). The class `Thing` is the class that represents the set containing *all* individuals. Because of this all classes are subclasses of `Thing`.²

Let’s add some classes to the ontology in order to define what we believe a pizza to be.

²Thing is part of the OWL Vocabulary, which is defined by the ontology located at <http://www.w3.org/2002/07/owl/\#>

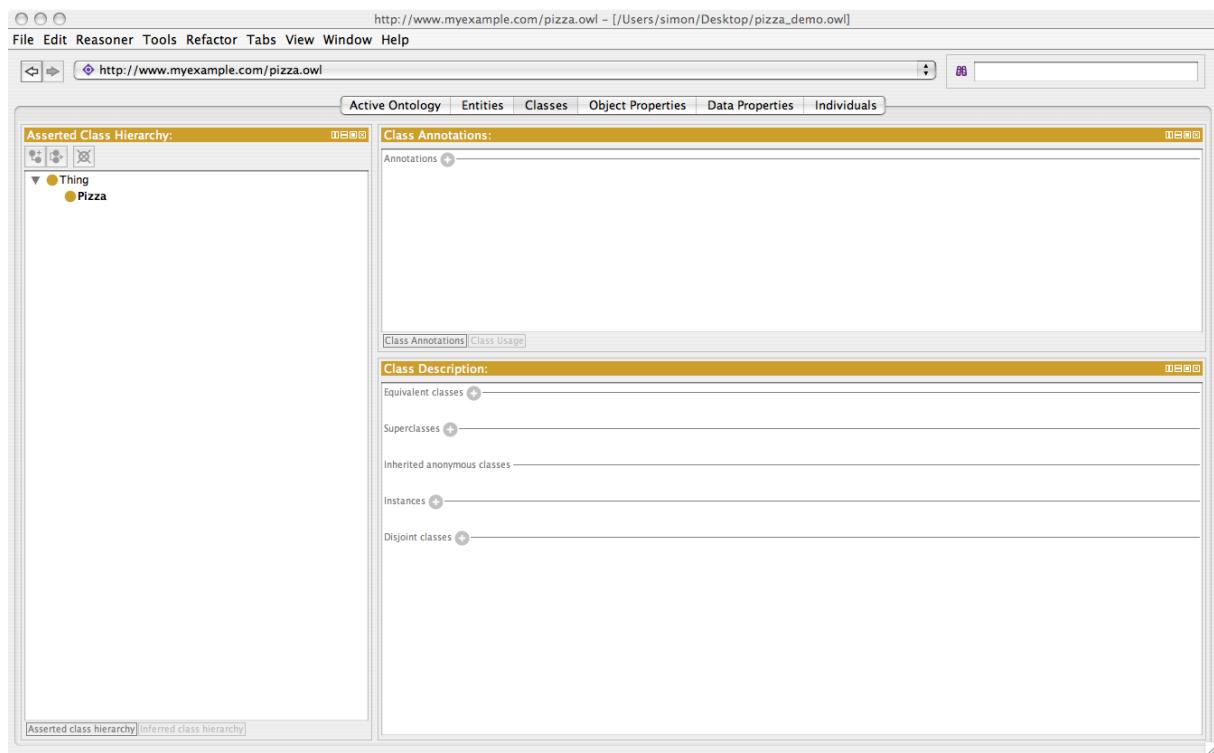


Figure 4.3: The Classes Tab

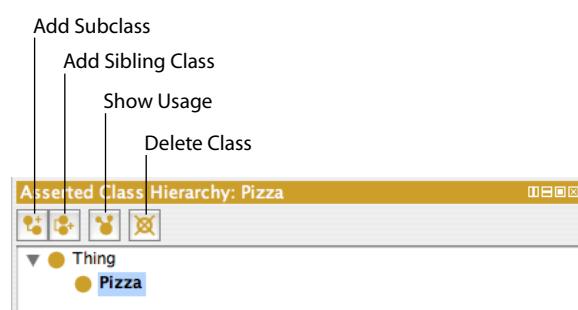


Figure 4.4: The Class Hierarchy Pane

Exercise 4: Create classes Pizza, PizzaTopping and PizzaBase

1. Ensure that the ‘**Classes Tab**’ is selected.
 2. Press the ‘**Add**’ icon (⊕) shown in Figure 4.4. This button creates a new class as a subclass of the selected class (in this case we want to create a subclass of **Thing**).
 3. A dialog will appear for you to name your class, enter **Pizza** (as shown in Figure 4.5) and hit return.
 4. Repeat the previous steps to add the classes **PizzaTopping** and also **PizzaBase**, ensuring that **Thing** is selected before the ‘**Add**’ icon (⊕) is pressed so that the classes are created as subclasses of **Thing**.
-

The class hierarchy should now resemble the hierarchy shown in Figure 4.6.



After creating **Pizza**, instead of re-selecting **Thing** and using the ‘**Create subclass**’ button to create **PizzaTopping** and **PizzaBase** as further subclasses of **Thing**, the ‘**Add sibling class**’ button (shown in Figure 4.4) can be used. While **Pizza** is selected, use the ‘**Create sibling class**’ button to create **PizzaTopping** and then use this button again (while **PizzaTopping** is selected) to create **PizzaBase** as sibling classes of **PizzaTopping** – these classes will of course still be created as subclasses of **Thing**, since **Pizza** is a subclass of **Thing**.

Vocabulary



A class hierarchy may also be called a taxonomy.



Although there are no mandatory naming conventions for OWL classes, we recommend that all class names should start with a capital letter and should not contain spaces. (This kind of notation is known as CamelBack notation and is the notation used in this tutorial). For example **Pizza**, **PizzaTopping**, **MargheritaPizza**. Alternatively, you can use underscores to join words. For example **Pizza_Topping**. Which ever convention you use, it is important to be consistent.

4.2 Disjoint Classes

Having added the classes **Pizza**, **PizzaTopping** and **PizzaBase** to the ontology, we now need to say these classes are *disjoint*, so that an individual (or object) cannot be an instance of more than one of these

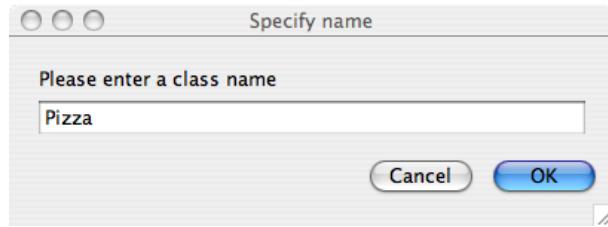


Figure 4.5: Class Name Dialog



Figure 4.6: The Initial Class Hierarchy

three classes. To specify classes that are disjoint from the selected class click the ‘**Disjoints classes**’ button which is located at the bottom of the ‘**Class Description**’ view.

Exercise 5: Make Pizza, PizzaTopping and PizzaBase disjoint from each other

1. Select the class **Pizza** in the class hierarchy.
2. Press the ‘**Disjoint classes**’ button in the ‘**class description**’ view, this will bring up a dialog where you can select multiple classes to be disjoint. This will make **PizzaBase** and **PizzaTopping** (the sibling classes of **Pizza**) disjoint from **Pizza**.

Notice that the disjoint classes view now displays **PizzaTopping** and **PizzaBase**. Select the class **PizzaBase**. Notice that the disjoint classes view displays the classes that are now disjoint to **PizzaBase**, namely **Pizza** and **PizzaTopping**.

MEANING



OWL Classes are assumed to ‘overlap’. We therefore cannot assume that an individual is not a member of a particular class simply because it has not been *asserted* to be a member of that class. In order to ‘separate’ a group of classes we must make them disjoint from one another. This ensures that an individual which has been asserted to be a member of one of the classes in the group cannot be a member of any other classes in that group. In our above example **Pizza**, **PizzaTopping** and **PizzaBase** have been made disjoint from one another. This means that it is not possible for an individual to be a member of a combination of these classes – it would not make sense for an individual to be a **Pizza** and a **PizzaBase**!

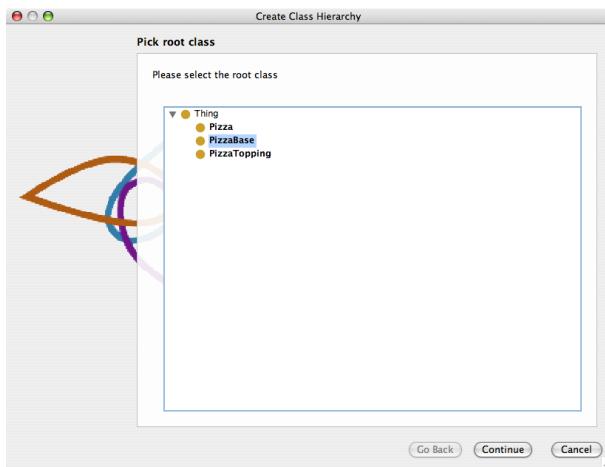


Figure 4.7: Create Class Hierarchy: Select class page

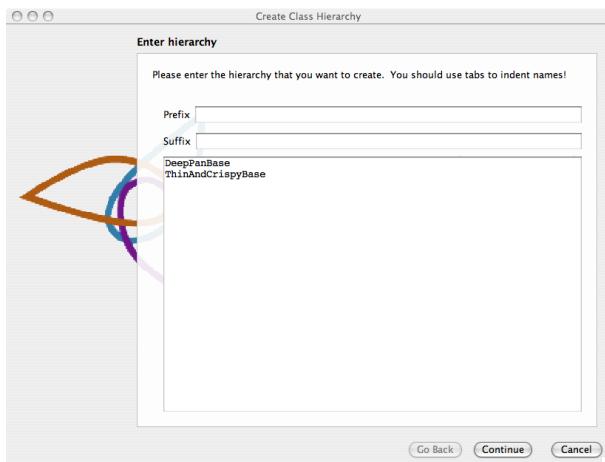


Figure 4.8: Create Class Hierarchy: Enter classes page

4.3 Using Create Class Hierarchy To Create Classes

In this section we will use the ‘Create Class Hierarchy’ tool to add some subclasses of the class `PizzaBase`.

Exercise 6: Use the ‘Create Class Hierarchy’ Tool to create ThinAndCrispy and DeepPan as subclasses of PizzaBase

1. Select the class **PizzaBase** in the class hierarchy.
 2. From the Tools menu on the Protégé menu bar select ‘**Create Class Hierarchy...**’.
 3. The tools shown in Figure 4.7 will appear. Since we preselected the **PizzaBase** class, the first radio button at the top of the tool should be prompting us to create the classes under the class **PizzaBase**. If we had not preselected **PizzaBase** before starting the tool, then the tree could be used to select the class.
 4. Press the ‘**Next**’ button on the tool—The page shown in Figure 4.8 will be displayed. We now need to tell the tool the subclasses of **PizzaBase** that we want to create. In the large text area, type in the class name **ThinAndCrispyBase** (for a thin based pizza) and hit return. Also enter the class name **DeepPanBase** so that the page resembles that shown in Figure 4.8 .
 5. Hit the ‘**Next**’ button on the tool. The tool checks that the names entered adhere to the naming styles that have previously been mentioned (No spaces etc.). It also checks for uniqueness – no two class names may be the same. If there are any errors in the class names, they will be presented on this page, along with suggestions for corrections.
 6. Hit the ‘**Next**’ button on the tool. Ensure the tick box ‘**Make all new classes disjoint**’ is *ticked* — instead of having to use the disjoint classes view, the tool will automatically make the new classes disjoint for us.
-

After the ‘**Next**’ button has been pressed, the tool creates the classes, makes them disjoint. Click ‘**Finish**’ to dismiss the tool. The ontology should now have **ThinAndCrispyBase** and also **DeepPanBase** as subclasses of **PizzaBase**. These new classes should be disjoint to each other. Hence, a pizza base cannot be both thin and crispy *and* deep pan. It isn’t difficult to see that if we had a lot of classes to add to the ontology, the tool would dramatically speed up the process of adding them.

TIP

On page one of the ‘**Create class hierarchy wizard**’ the classes to be created are entered. If we had a lot of classes to create that had the same prefix or suffix we could use the options to auto prepend and auto append text to the class names that we entered.

Creating Some Pizza Toppings

Now that we have some basic classes, let’s create some pizza toppings. In order to be useful later on the toppings will be grouped into various categories — meat toppings, vegetable toppings, cheese toppings

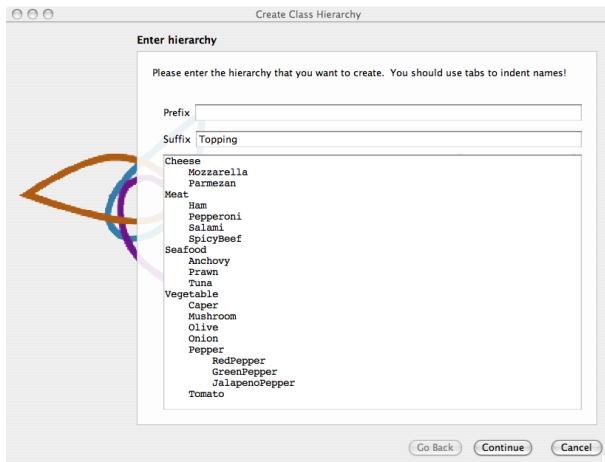


Figure 4.9: Topping Hierarchy

and seafood toppings.

Exercise 7: Create some subclasses of PizzaTopping

1. Select the class **PizzaTopping** in the class hierarchy.
2. Invoke the ‘**Create class hierarchy...**’ tool in the same way as the tool was started in the previous exercise.
3. Ensure **PizzaTopping** is selected and press the ‘**Next**’ button.
4. We want all our topping classes to end in **topping**, so in the ‘**Suffix all in list with**’ field, enter **Topping**. The tool will save us some typing by automatically appending **Topping** to all of our class names.
5. The tool allows a hierarchy of classes to be entered using a tab indented tree. Using the text area in the tool, enter the class names as shown in Figure 4.9. Note that class names must be indented using tabs, so for example **SpicyBeef**, which we want to be a subclass of **Meat** is entered under **Meat** and indented with a tab. Likewise, **Pepperoni** is also entered under **Meat** below **SpicyBeef** and also indented with a tab.
6. Having entered a tab indented list of classes, press the ‘**Next**’ button and then make sure that ‘**Make all primitive siblings disjoint**’ check box is ticked so that new *sibling* classes are made disjoint with each other.
7. Press the ‘**Finish**’ button to create the classes. Press ‘**Finish**’ again to close the tool.

The class hierarchy should now look similar to that shown in Figure 4.10 (the ordering of classes may be slightly different).

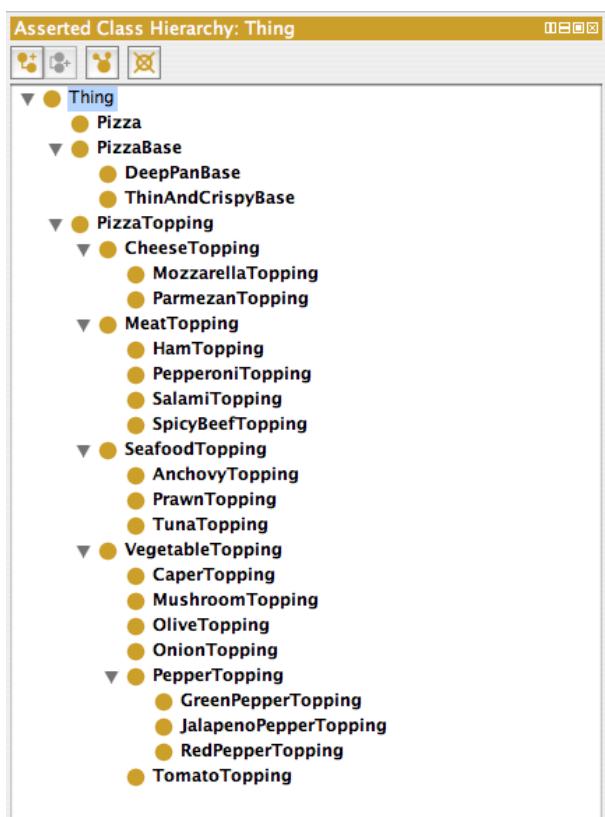


Figure 4.10: Class Hierarchy

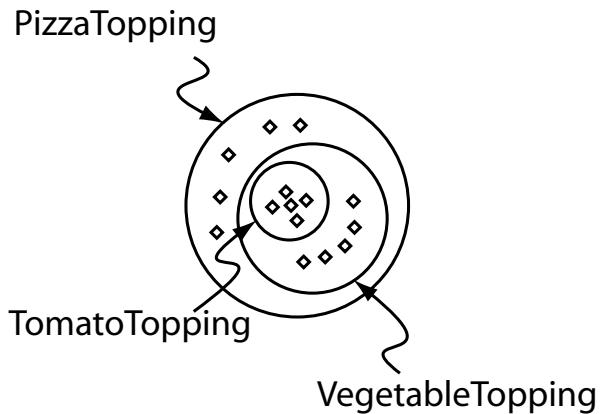


Figure 4.11: The Meaning Of Subclass — *All* individuals that are members of the class TomatoTopping are members of the class VegetableTopping and members of the class PizzaTopping as we have stated that TomatoTopping is a subclass of VegetableTopping which is a subclass of PizzaTopping

MEANING



Up to this point, we have created some simple named classes, some of which are *subclasses* of other classes. The construction of the class hierarchy may have seemed rather intuitive so far. However, what does it actually mean to be a *subclass* of something in OWL? For example, what does it mean for VegetableTopping to be a *subclass* of PizzaTopping, or for TomatoTopping to be a *subclass* of VegetableTopping? In OWL *subclass* means *necessary implication*. In other words, if VegetableTopping is a *subclass* of PizzaTopping then *ALL* instances of VegetableTopping are instances of PizzaTopping, *without exception* — if something is a VegetableTopping then this *implies* that it is also a PizzaTopping as shown in Figure 4.11.^a

^aIt is for this reason that we seemingly pedantically named all of our toppings with the suffix of ‘Topping’, for example, HamTopping. Despite the fact that class names themselves carry no formal semantics in OWL (and in other ontology languages), if we had named HamTopping Ham, then this could have implied to human eyes that anything that is a kind of ham is also a kind of MeatTopping and also a PizzaTopping.

4.4 OWL Properties

OWL Properties represent relationships. There are two main types of properties, *Object properties* and *Datatype properties*. Object properties are relationships between two individuals. In this chapter we will focus on *Object properties*; *datatype properties* are described in Chapter 5. Object properties link an individual to an individual. OWL also has a third type of property – *Annotation properties*³. Annotation properties can be used to add information (metadata — data about data) to classes, individuals and object/datatype properties. Figure 4.12 depicts an example of each type of property.

Properties may be created using the ‘**Object Properties**’ tab shown in Figure 4.13. Figure 4.14 shows the buttons located in the top left hand corner of the ‘**Object Properties**’ tab that are used for creating

³Object properties and Datatype properties may be marked as Annotation properties

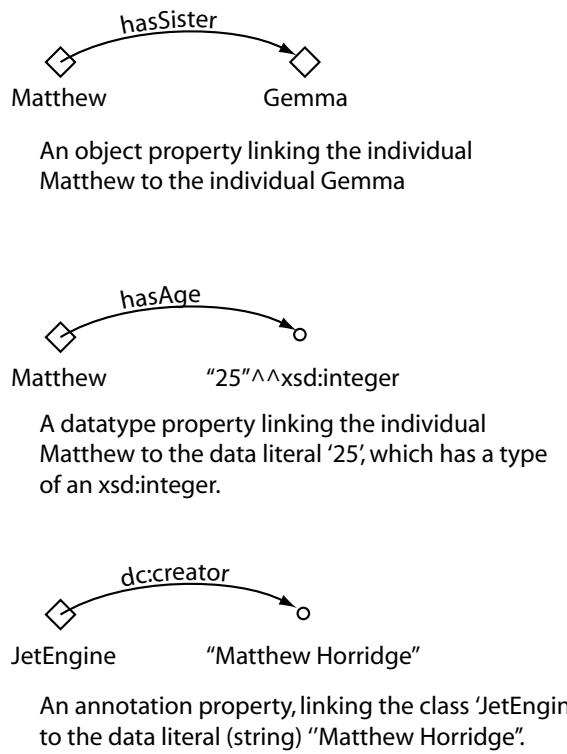


Figure 4.12: The Different types of OWL Properties

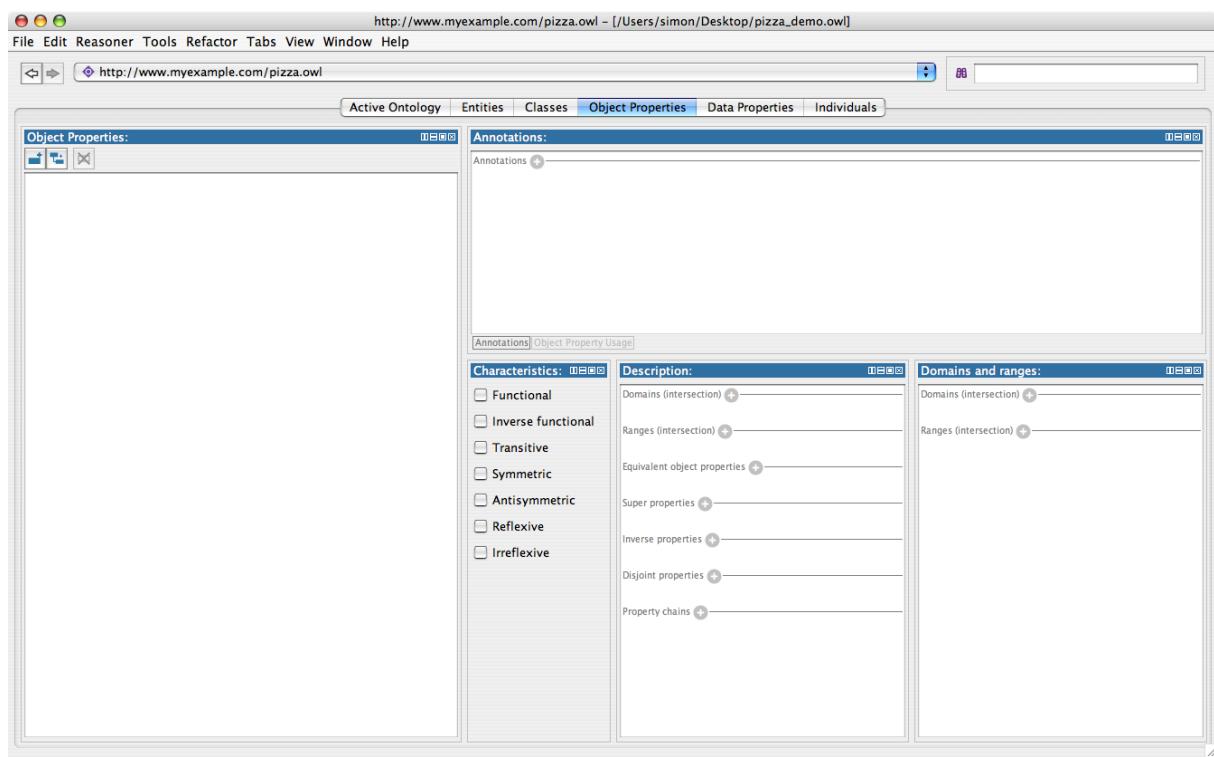


Figure 4.13: The PropertiesTab

OWL properties. As can be seen from Figure 4.14, there are buttons for creating Datatype properties, Object properties and Annotation properties. Most properties created in this tutorial will be **Object properties**.

Exercise 8: Create an object property called hasIngredient

1. Switch to the ‘Object Properties’ tab. Use the ‘Add Object Property’ button (see Figure 4.14) to create a new Object property.
2. Name the property to **hasIngredient** using the ‘Property Name Dialog’ that pops up, as shown in Figure 4.15 (The ‘Property Name Dialog’).

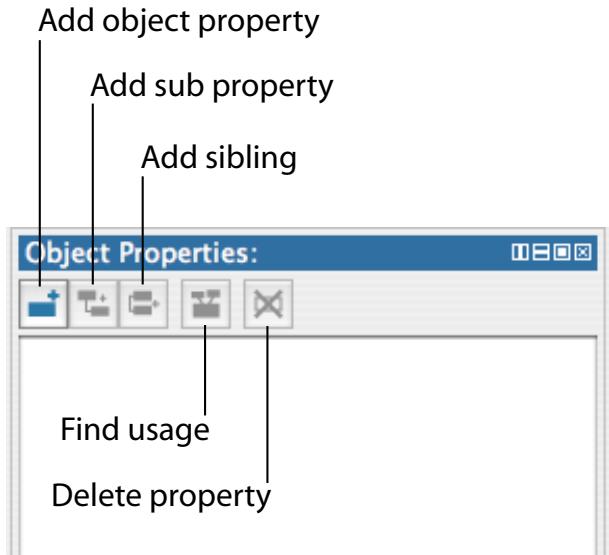


Figure 4.14: Property Creation Buttons — located on the Properties Tab above the property list/tree

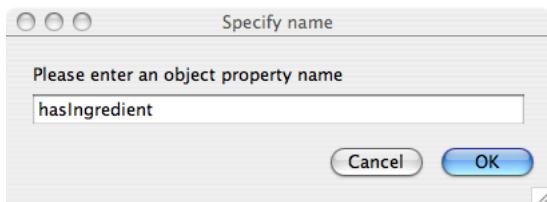


Figure 4.15: Property Name Dialog

TIP

Although there is no strict naming convention for properties, we recommend that property names start with a lower case letter, have no spaces and have the remaining words capitalised. We also recommend that properties are prefixed with the word ‘has’, or the word ‘is’, for example `hasPart`, `isPartOf`, `hasManufacturer`, `isProducerOf`. Not only does this convention help make the intent of the property clearer to humans, it is also taken advantage of by the ‘English Prose Tooltip Generator’^a, which uses this naming convention where possible to generate more human readable expressions for class descriptions.

^aThe English Prose Tooltip Generator displays the description of classes etc. in a more natural form of English, making it easy to understand a class description. The tooltips pop up when the mouse pointer is made to hover over a class description in the user interface.

Having added the `hasIngredient` property, we will now add two more properties — `hasTopping`, and `hasBase`. In OWL, properties may have sub properties, so that it is possible to form hierarchies of properties. Sub properties specialise their super properties (in the same way that subclasses specialise their superclasses). For example, the property `hasMother` might specialise the more general property of

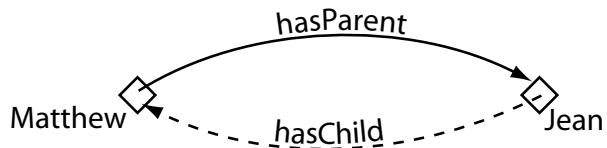


Figure 4.16: An Example Of An Inverse Property: `hasParent` has an inverse property that is `hasChild`

`hasParent`. In the case of our pizza ontology the properties `hasTopping` and `hasBase` should be created as sub properties of `hasIngredient`. If the `hasTopping` property (or the `hasBase` property) links two individuals this implies that the two individuals are related by the `hasIngredient` property.

Exercise 9: Create `hasTopping` and `hasBase` as sub-properties of `hasIngredient`

1. To create the `hasTopping` property as a sub property of the `hasIngredient` property, select the `hasIngredient` property in the property hierarchy on the ‘Object Properties’ tab.
 2. Press the ‘Add subproperty’ button. A new object property will be created as a sub property of the `hasIngredient` property.
 3. Name the new property to `hasTopping`.
 4. Repeat the above steps but name the property `hasBase`.
-

Note that it is also possible to create sub properties of datatype properties. However, it is not possible to mix and match object properties and datatype properties with regards to sub properties. For example, it is not possible to create an object property that is the sub property of a datatype property and vice-versa.

4.5 Inverse Properties

Each object property may have a corresponding inverse property. If some property links individual **a** to individual **b** then its inverse property will link individual **b** to individual **a**. For example, Figure 4.16 shows the property `hasParent` and its inverse property `hasChild` — if Matthew `hasParent` Jean, then because of the inverse property we can infer that Jean `hasChild` Matthew.

Inverse properties can be created/specified using the inverse property view shown in Figure 4.17. For

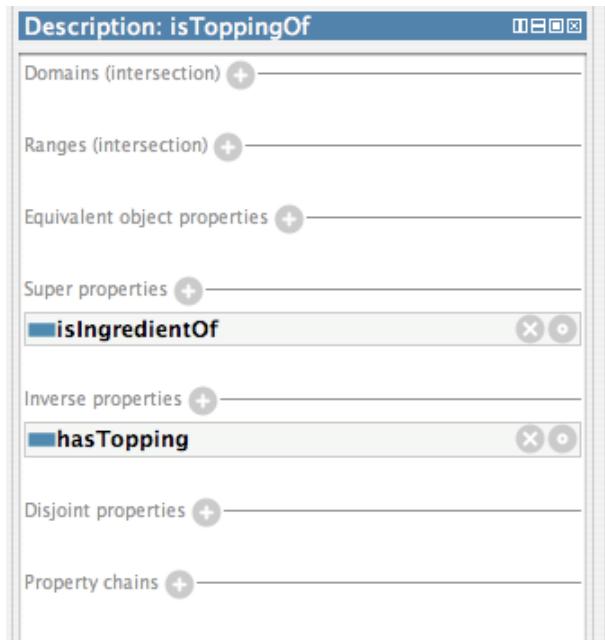


Figure 4.17: The Inverse Property View

completeness we will specify inverse properties for our existing properties in the Pizza Ontology.

Exercise 10: Create some inverse properties

1. Use the ‘Add object property’ button on the ‘Object Properties’ tab to create a new Object property called **isIngredientOf** (this will become the inverse property of **hasIngredient**).
2. Press the ‘Add’ icon (⊕) next to ‘Inverse properties’ button on the ‘Property Description’ view shown in Figure 4.17. This will display a dialog from which properties may be selected. Select the **hasIngredient** property and press ‘OK’. The property **hasIngredient** should now be displayed in the ‘Inverse Property’ view.
3. Select the **hasBase** property.
4. Press the ‘Add’ icon (⊕) next to ‘Inverse properties’ on the ‘Property Description’ view. Create a new property in this dialog called **isBaseOf**. Select this property and click ‘OK’. Notice that **hasBase** now has a inverse property assigned called **isBaseOf**. You can optionally place the new **isBaseOf** property as a sub-property of **isIngredientOf** (N.B This will get inferred later anyway when you use the reasoner).
5. Select the **hasTopping** property.
6. Press the ‘Add’ icon (⊕) next to ‘Inverse properties’ on the ‘Property Description’ view. Use the property dialog that pops up to create the property **isToppingOf** and press ‘OK’.

4.6 OWL Object Property Characteristics

OWL allows the meaning of properties to be enriched through the use of *property characteristics*. The following sections discuss the various characteristics that properties may have:

4.6.1 Functional Properties

If a property is functional, for a given individual, there can be at most one individual that is related to the individual via the property. Figure 4.18 shows an example of a functional property `hasBirthMother` — something can only have *one* birth mother. If we say that the individual **Jean** `hasBirthMother` **Peggy** and we also say that the individual **Jean** `hasBirthMother` **Margaret**⁴, then because `hasBirthMother` is a functional property, we can infer that **Peggy** and **Margaret** must be the same individual. It should be noted however, that if **Peggy** and **Margaret** were explicitly stated to be two different individuals then the above statements would lead to an inconsistency.

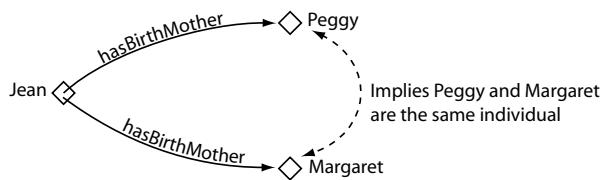


Figure 4.18: An Example Of A Functional Property: `hasBirthMother`

Vocabulary



Functional properties are also known as *single valued properties* and also *features*.

4.6.2 Inverse Functional Properties

If a property is inverse functional then it means that the *inverse* property is *functional*. For a given individual, there can be at most one individual related to that individual via the property. Figure 4.19 shows an example of an inverse functional property `isBirthMotherOf`. This is the inverse property of `hasBirthMother` — since `hasBirthMother` is functional, `isBirthMotherOf` is inverse functional. If we state that **Peggy** is the birth mother of **Jean**, and we also state that **Margaret** is the birth mother of **Jean**, then we can infer that **Peggy** and **Margaret** are the same individual.

4.6.3 Transitive Properties

If a property is transitive, and the property relates individual **a** to individual **b**, and also individual **b** to individual **c**, then we can infer that individual **a** is related to individual **c** via property **P**. For example, Figure 4.20 shows an example of the transitive property `hasAncestor`. If the individual **Matthew** has an ancestor that is **Peter**, and **Peter** has an ancestor that is **William**, then we can infer that **Matthew** has an ancestor that is **William** – this is indicated by the dashed line in Figure 4.20.

⁴The name Peggy is a diminutive form for the name Margaret

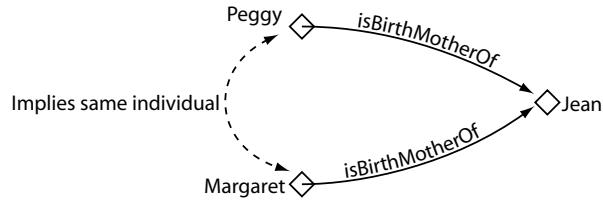


Figure 4.19: An Example Of An Inverse Functional Property: `isBirthMotherOf`

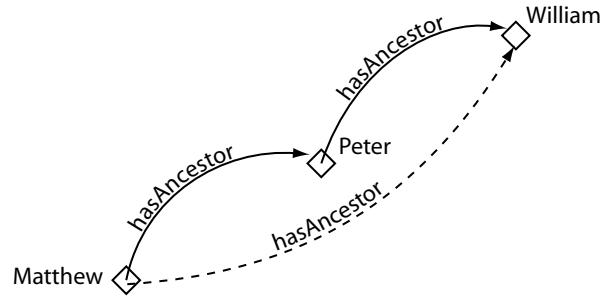


Figure 4.20: An Example Of A Transitive Property: `hasAncestor`

4.6.4 Symmetric Properties

If a property P is symmetric, and the property relates individual a to individual b then individual b is also related to individual a via property P . Figure 4.21 shows an example of a symmetric property. If the individual **Matthew** is related to the individual **Gemma** via the `hasSibling` property, then we can infer that **Gemma** must also be related to **Matthew** via the `hasSibling` property. In other words, if **Matthew** has a sibling that is **Gemma**, then **Gemma** must have a sibling that is **Matthew**. Put another way, the property is its own inverse property.

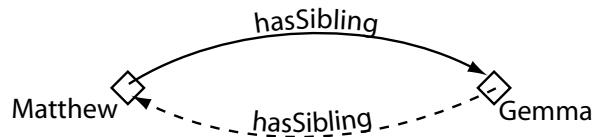


Figure 4.21: An Example Of A Symmetric Property: `hasSibling`

We want to make the `hasIngredient` property transitive, so that for example if a pizza topping has an ingredient, then the pizza itself also has that ingredient. To set the property characteristics of a property the property characteristics view shown in Figure 4.22 which is located in the lower right hand corner of

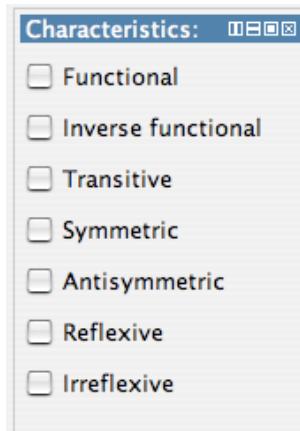


Figure 4.22: Property Characteristics Views

the properties tab is used.

Exercise 11: Make the hasIngredient property transitive

1. Select the `hasIngredient` property in the property hierarchy on the ‘Object Properties’ tab.
2. Tick the ‘Transitive’ tick box on the ‘Property Characteristics View’.
3. Select the `isIngredientOf` property, which is the inverse of `hasIngredient`. Ensure that the transitive tick box is ticked.



NOTE

If a property is transitive then its inverse property should also be transitive.^a

^aAt the time of writing this must be done manually in Protégé 4. However, the reasoner *will* assume that if a property is transitive, its inverse property is also a transitive.



Note that if a property is transitive then it cannot be functional.^a

^aThe reason for this is that transitive properties, by their nature, may form ‘chains’ of individuals. Making a transitive property functional would therefore not make sense.

We now want to say that our pizza can only have one base. There are numerous ways that this could be accomplished. However, to do this we will make the `hasBase` property *functional*, so that it may have

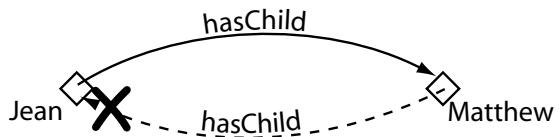


Figure 4.23: An example of the asymmetric property hasChildOf

only one value for a given individual.

Exercise 12: Make the hasBase property functional

1. Select the **hasBase** property.
2. Click the ‘Functional’ tick box on the ‘Property Characteristics View’ so that it is ticked.



If a datatype property is selected, the property characteristics view will be reduced so that only options for ‘Allows multiple values’ and ‘Inverse Functional’ will be displayed. This is because OWL-DL does not allow datatype properties to be transitive, symmetric or have inverse properties.

4.6.5 Asymmetric properties

If a property **P** is asymmetric, and the property relates individual **a** to individual **b** then individual **b** cannot be related to individual **a** via property **P**. Figure 4.23 shows an example of a asymmetric property. If the individual **Robert** is related to the individual **David** via the **isChildOf** property, then it can be inferred that **David** is not related to **Robert** via the **isChildOf** property. It is, however, reasonable to state that **David** could be related to another individual **Bill** via the **isChildOf** property. In other words, if **Robert** is a child of **David**, then **David** cannot be a child of **Robert**, but **David** can be a child of **Bill**.

4.6.6 Reflexive properties

A property **P** is said to be reflexive when the property must relate individual **a** to itself. In Figure 4.24 we can see an example of this: using the property **knows**, an individual **George** must have a relationship to itself using the property **knows**. In other words, **George** must know herself. However, in addition, it is possible for **George** to know other people; therefore the individual **George** can have a relationship with individual **Simon** along the property **knows**.

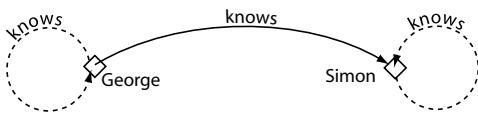


Figure 4.24: An example of a Reflexive Property: `knows`

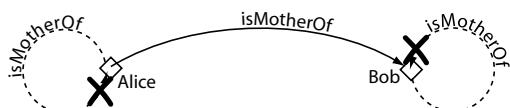


Figure 4.25: An example of an Irreflexive Property: `isMotherOf`

4.6.7 Irreflexive properties

If a property P is *irreflexive*, it can be described as a property that relates an individual a to individual b , where individual a and individual b are not the same. An example of this would be the property `motherOf`: an individual **Alice** can be related to individual **Bob** along the property `motherOf`, but **Alice** cannot be `motherOf` herself (Figure 4.25).

4.7 Property Domains and Ranges

Properties may have a *domain* and a *range* specified. Properties link individuals from the *domain* to individuals from the *range*. For example, in our pizza ontology, the property `hasTopping` would probably link individuals belonging to the class **Pizza** to individuals belonging to the class of **PizzaTopping**. In this case the *domain* of the `hasTopping` property is **Pizza** and the *range* is **PizzaTopping** — this is depicted in Figure 4.26.



Property Domains And Ranges In OWL — It is important to realise that in OWL domains and ranges should *not* be viewed as constraints to be checked. They are used as ‘axioms’ in reasoning. For example if the property `hasTopping` has the domain set as **Pizza** and we then applied the `hasTopping` property to **IceCream** (individuals that are members of the class **IceCream**), this would generally not result in an error. It would be used to infer that the class **IceCream** must be a subclass of **Pizza**!^a.

^aAn error will only be generated (by a reasoner) if **Pizza** is disjoint to **IceCream**

We now want to specify that the `hasTopping` property has a *range* of **PizzaTopping**. To do this the range

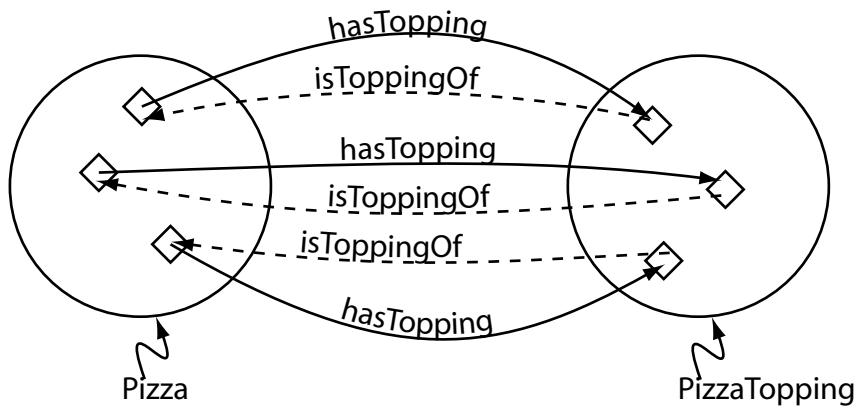


Figure 4.26: The domain and range for the `hasTopping` property and its inverse property `isToppingOf`. The domain of `hasTopping` is `Pizza` the range of `hasTopping` is `PizzaTopping` — the domain and range for `isToppingOf` are the domain and range for `hasTopping` swapped over



Figure 4.27: Property Range View (For Object Properties)

view shown in Figure 4.27 is used.

Exercise 13: Specify the range of `hasTopping`

1. Make sure that the `hasTopping` property is selected in the property hierarchy on the ‘Object Properties’ tab.
2. Press the ‘Add’ icon (\oplus) next to ‘Ranges’ on the ‘Property Description’ view (Figure 4.27). A dialog will appear that allows a class to be selected from the ontology class hierarchy.
3. Select `PizzaTopping` and press the ‘OK’ button. `PizzaTopping` should now be displayed in the range list.

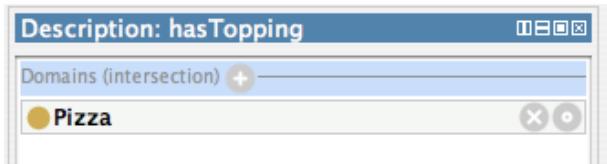


Figure 4.28: Property Domain View



NOTE

It is possible to specify multiple classes as the range for a property. If multiple classes are specified in Protégé 4 the range of the property is interpreted to be the *intersection* of the classes. For example, if the range of a property has the classes **Man** and **Woman** listed in the range view, the range of the property will be interpreted as **Man intersection Woman**.

To specify the domain of a property the domain view shown in Figure 4.28 is used.

Exercise 14: Specify Pizza as the domain of the hasTopping property

1. Make sure that the **hasTopping** property is selected in the property hierarchy on the '**Object Properties**' tab.
2. Press the '**Add**' icon (+) next to '**Domains**' on the '**Property Description**' view . A dialog will appear that allows a class to be selected from the ontology class hierarchy.
3. Select **Pizza** and press the OK button. **Pizza** should now be displayed in the domain list.

MEANING



This means that individuals that are used 'on the left hand side' of the **hasTopping** property will be inferred to be members of the class **Pizza**. Any individuals that are used 'on the right hand side' of the **hasTopping** property will be inferred to be members of the class **PizzaTopping**. For example, if we have individuals **a** and **b** and an assertion of the form **a hasTopping b** then it will be inferred that **a** is a member of the class **Pizza** and that **b** is a member of the class **PizzaTopping**^a.

^aThis will be the case even if **a** has not been asserted to be a member of the class **Pizza** and/or **b** has not been asserted to be a member of the class **PizzaTopping**.



Take a look at the `isToppingOf` property, which is the inverse property of `hasTopping`. Notice that Protégé has automatically filled in domain and range of the `isToppingOf` property because the domain and range of the inverse property were specified. The range of `isToppingOf` is the domain of the inverse property `hasTopping`, and the domain of `isToppingOf` is the range of the inverse property `hasTopping`. This is depicted in Figure 4.26.

Exercise 15: Specify the domain and range for the `hasBase` property and its inverse property `isBaseOf`

1. Select the `hasBase` property.
 2. Specify the domain of the `hasBase` property as `Pizza`.
 3. Specify the range of the `hasBase` property as `PizzaBase`.
 4. Select the `isBaseOf` property. Notice that the domain of `isBaseOf` is the range of the inverse property `hasBase` and that the range of `isBaseOf` is the domain of the inverse property `hasBase`.
 5. Make the domain of the `isBaseOf` property `PizzaBase`.
 6. Make the range of the `isBaseOf` property `Pizza`.
-



In the previous steps we have ensured that the domains and ranges for properties are also set up for inverse properties in a correct manner. In general, domain for a property is the range for its inverse, and the range for a property is the domain for its inverse — Figure 4.26 illustrates this for the `hasTopping` and `isToppingOf`.



Although we have specified the domains and ranges of various properties for the purposes of this tutorial, we generally advise *against* doing this. The fact that domain and range conditions do not behave as constraints and the fact that they can cause ‘unexpected’ classification results can lead problems and unexpected side effects. These problems and side effects can be particularly difficult to track down in a large ontology.

4.8 Describing And Defining Classes

Having created some properties we can now use these properties to describe and define our Pizza Ontology classes.

4.8.1 Property Restrictions

Recall that in OWL, properties describe binary relationships. Datatype properties describe relationships between individuals and data values. Object properties describe relationships between two individuals. For example, in Figure 3.2 the individual **Matthew** is related to the individual **Gemma** via the **hasSibling** property. Now consider all of the individuals that have a **hasSibling** relationship to some other individual. We can think of these individuals as belonging *the class of individuals* that have some **hasSibling** relationship. The key idea is that a class of individuals is described or defined by the relationships that these individuals participate in. In OWL we can define such classes by using *restrictions*.

Vocabulary



A *restriction* describes a class of individuals based on the relationships that members of the class participate in. In other words a *restriction* is a kind of *class*, in the same way that a named class is a kind of class.

Restriction Examples

Let's take a look at some examples to help clarify the kinds of classes of individuals that we might want to describe based on their properties.

- The class of individuals that have at least one **hasSibling** relationship.
- The class of individuals that have at least one **hasSibling** relationship to members of **Man** – i.e. things that have at least one sibling that is a man.
- The class of individuals that only have **hasSibling** relationships to individuals that are **Women** – i.e. things that only have siblings that are women (sisters).
- The class of individuals that have more than three **hasSibling** relationships.
- The class of individuals that have at least one **hasTopping** relationship to individuals that are members of **MozzarellaTopping** – i.e. the class of things that have at least one kind of mozzarella topping.
- The class of individuals that only have **hasTopping** relationships to members of **VegetableTopping** – i.e. the class of individuals that only have toppings that are vegetable toppings.

In OWL we can describe all of the above classes of individuals using *restrictions*. OWL restrictions in OWL fall into three main categories:

- Quantifier Restrictions
- Cardinality Restrictions
- **hasValue** Restrictions.

We will initially use quantifier restrictions, which can be further categorised into *existential* restrictions and *universal* restrictions. Both types of restrictions will be illustrated with examples throughout the tutorial.

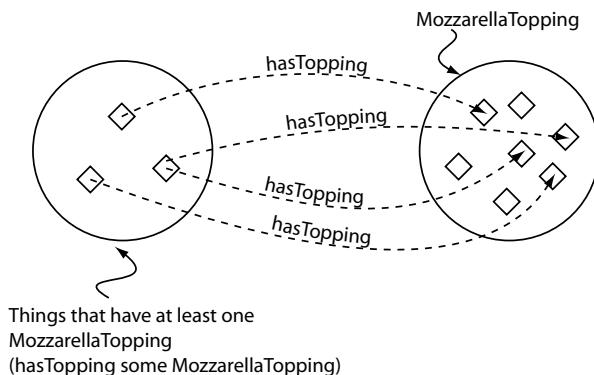


Figure 4.29: The Restriction **hasTopping some Mozzarella**. This restriction describes the class of individuals that have *at least one* topping that is **Mozzarella**

Existential and Universal Restrictions

- Existential restrictions describe classes of individuals that participate in *at least one* relationship along a specified property to individuals that are members of a specified class. For example, “the class of individuals that have *at least one* (some) **hasTopping** relationship to members of **MozzarellaTopping**”. In Protégé 4 the keyword ‘**some**’ is used to denote existential restrictions.⁵.
- Universal restrictions describe classes of individuals that for a given property only have relationships along this property to individuals that are members of a specified class. For example, “the class of individuals that *only* have **hasTopping** relationships to members of **VegetableTopping**”. In Protégé 4 the keyword ‘**only**’ is used.⁶.

Let’s take a closer look at the example of an existential restriction. The restriction **hasTopping some MozzarellaTopping** is an existential restriction (as indicated by the **some** keyword), which acts along the **hasTopping** property, and has a *filler* **MozzarellaTopping**. This restriction describes *the class* of individuals that have *at least one* **hasTopping** relationship to an individual that is a member of the class **MozzarellaTopping**. This restriction is depicted in Figure 4.29 — The diamonds in the Figure represent individuals. As can be seen from Figure 4.29, the restriction is a class which contains the individuals that satisfy the restriction.

MEANING



A restriction describes an *anonymous class* (an unnamed class). The anonymous class contains all of the individuals that satisfy the restriction – i.e. all of the individuals that have the relationships required to be a member of the class.

The restrictions for a class are displayed and edited using the ‘**Class Description View**’ shown in Figure 4.30. The ‘**Class Description View**’ is the ‘heart of’ the ‘**Classes**’ tab in protege, and holds virtually all of the information used to describe a class. At first glance, the ‘**Class Description View**’ may seem complicated, however, it will become apparent that it is an incredibly powerful way of describing and defining classes.

⁵ Existential restrictions may be denoted by the *existential quantifier* (\exists). They are also known as ‘**someValuesFrom**’ restrictions in OWL speak.

⁶ Universal restrictions may be denoted by the *universal quantifier* (\forall), which can be read as *only*. They are also known as ‘**allValuesFrom**’ restrictions in OWL speak.

"Equivalent class header" A list of equivalent classes appear here. The classes are sometimes referred to as Necessary & sufficient criteria.

Delete

Edit

Create restriction

The screenshot shows the Class Description View for the class MargheritaPizza. The top bar has three icons and the title "Class Description: MargheritaPizza". On the right are "Delete" and "Edit" buttons. Below the title are sections for "Equivalent classes", "Superclasses", "Inherited anonymous classes", "Instances", and "Disjoint classes". Each section contains a list of items with a delete icon on the right. The "Equivalent classes" section lists: NamedPizza, hasTopping some MozzarellaTopping, hasTopping some TomatoTopping, and hasTopping only (TomatoTopping or MozzarellaTopping). The "Inherited anonymous classes" section lists: hasBase some PizzaBase. The "Disjoint classes" section lists: AmericanaPizza, AmericanHotPizza, and SohoPizza.

Equivalent classes +

Superclasses +

NamedPizza
hasTopping some MozzarellaTopping
hasTopping some TomatoTopping
hasTopping only (TomatoTopping or MozzarellaTopping)

Inherited anonymous classes

hasBase some PizzaBase

Instances +

Disjoint classes +

AmericanaPizza
AmericanHotPizza
SohoPizza

"Subclass of header" A list of subclasses appear here. These classes are sometimes referred to as Necessary criteria.

"Inferred/Inherited header" A list of conditions that have been inherited from superclasses will be displayed here.

Figure 4.30: The Class Description View

Restrictions are used in OWL class descriptions to specify anonymous superclasses of the class being described.

4.8.2 Existential Restrictions

Existential restrictions are by far the most common type of restrictions in OWL ontologies. An existential restriction describes a class of individuals that have *at least one* (some) relationship along a specified property to an individual that is a member of a specified class. For example, **hasBase some PizzaBase** describes all of the individuals that have *at least one* relationship along the **hasBase** property to an individual that is a member of the class **PizzaBase** — in more natural English, all of the individuals that have at least one pizza base.

Vocabulary



Existential restrictions are also known as *Some Restrictions*, or as *some values from* restrictions.

TIP

Other tools, papers and presentations might write the restriction **hasBase some PizzaBase** as $\exists \text{ hasBase } \text{PizzaBase}$ — this alternative notation is known as DL Syntax (Description Logics Syntax), which is a more formal syntax.

Exercise 16: Add a restriction to Pizza that specifies a Pizza must have a PizzaBase

1. Select **Pizza** from the class hierarchy on the ‘Classes’ tab.
 2. Select the ‘Add’ icon (+) next to ‘Superclasses’ header in the ‘Class Description View’ shown in Figure 4.31 in order to create a necessary condition.
 3. Press the ‘Add Class’ button shown in Figure 4.31. This will open a text box in the Class Description view where we can enter our restrictions as shown in Figure 4.32
-

The create restriction text box allows you construct restrictions using class, property and individual names. You can drag and drop classes, properties and individuals into the text box or type them in, the text box with check all the values you enter and alert you to any errors. To create a restriction we have to do three things:

- Enter the property to be restricted from the property list.
- Enter a type of restriction from the restriction types e.g. ‘**some**’ for an existential restriction.
- Specify a filler for the restriction



Figure 4.31: Creating a Necessary Restriction

Exercise 17: Add a restriction to Pizza that specifies a Pizza must have a PizzaBase (Continued...)

1. You can either drag and drop **hasBase** from the property list into the create restriction text box, or type it in.
2. Now add the type or restriction, we will use an existential restriction so type '**some**'.
3. Specify that the filler is **PizzaBase** — to do this either: type **PizzaBase** into the filler edit box, or drag and drop **PizzaBase** into the text box as show in Figure 4.32
4. Press '**Enter**' to create the restriction and close the create restriction text box. If all information was entered correctly the dialog will close and the restriction will be displayed in the '**Class Description View**'. If there were errors they will be underlined in red in the text box, o popup will give some hints to the cause of the error — if this is the case, recheck that the type of restriction, the property and filler have been specified correctly.

TIP

A very useful feature of the expression builder is the ability to 'auto complete' class names, property names and individual names. Auto completion is activated by pressing '**alt tab**' or '**Ctrl-Space**' on the keyboard. In the above example if we had typed **Pi** into the expression editor and pressed the tab key, the choices to complete the word **Pi** would have popped up in a list as shown in Figure 4.32. The up and down arrow keys could then have been used to select **PizzaBase** and pressing the Enter key would complete the word for us.

The class description view should now look similar to the picture shown in Figure 4.33.

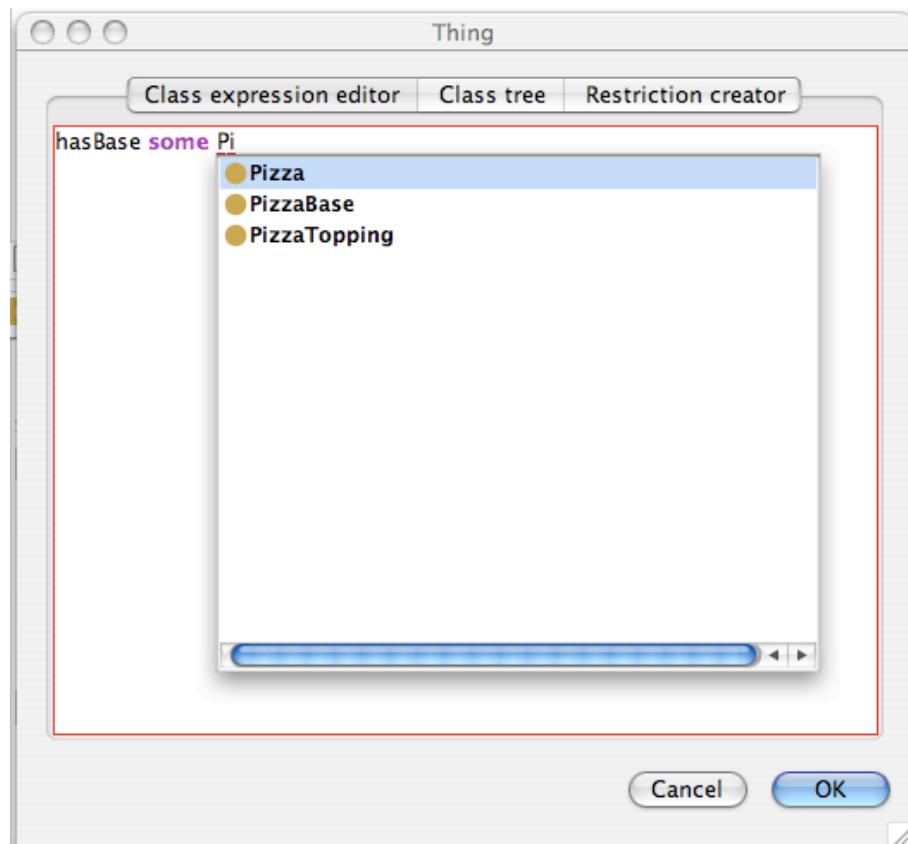


Figure 4.32: Creating a restriction in the text box, with auto-complete



Figure 4.33: class description view: Description of a Pizza

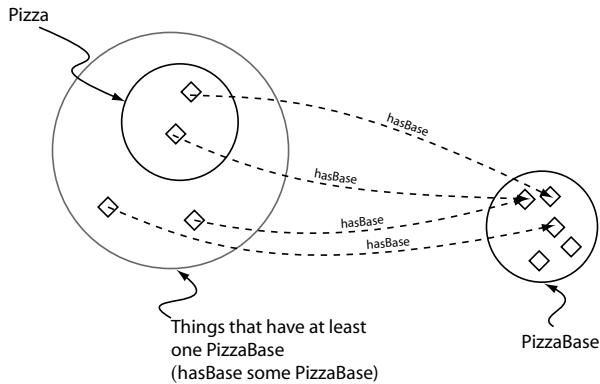


Figure 4.34: A Schematic Description of a **Pizza** — In order for something to be a **Pizza** it is *necessary* for it to have a (*at least one*) **PizzaBase** — A **Pizza** is a *subclass* of the things that have *at least one* **PizzaBase**

MEANING



We have described the class **Pizza** to be a subclass of **Thing** and a subclass of the things that have a base which is some kind of **PizzaBase**.

Notice that these are *necessary* conditions — if something is a **Pizza** it is *necessary* for it to be a member of the class **Thing** (in OWL, everything is a member of the class **Thing**) and necessary for it to have a kind of **PizzaBase**.

More formally, for something to be a **Pizza** it is *necessary* for it to be in a relationship with an individual that is a member of the class **PizzaBase** via the property **hasBase** — This is depicted in Figure 4.34.

MEANING



When restrictions are used to describe classes, they actually specify anonymous superclasses of the class being described. For example, we could say that **MargheritaPizza** is a subclass of, amongst other things, **Pizza** and also a subclass of the things that have *at least one* topping that is **MozzarellaTopping**.

Creating Some Different Kinds Of Pizzas

It's now time to add some different kinds of pizzas to our ontology. We will start off by adding a 'MargheritaPizza', which is a pizza that has toppings of mozzarella and tomato. In order to keep our

ontology tidy, we will group our different pizzas under the class ‘NamedPizza’:

Exercise 18: Create a subclass of Pizza called NamedPizza, and a subclass of NamedPizza called MargheritaPizza

1. Select the class **Pizza** from the class hierarchy on the ‘**Classes**’ tab.
 2. Press the ‘**Add**’ icon (⊕) to create a new subclass of **Pizza**, and name it **NamedPizza**.
 3. Create a new subclass of **NamedPizza**, and name it **MargheritaPizza**.
 4. Add a comment to the class **MargheritaPizza** using the ‘**Annotations**’ view that is located next to the class hierarchy view: **A pizza that only has Mozzarella and Tomato toppings** – it’s always a good idea to document classes, properties etc. during ontology editing sessions in order to communicate intentions to other ontology builders.
-

Having created the class **MargheritaPizza** we now need to specify the toppings that it has. To do this we will add two restrictions to say that a **MargheritaPizza** has the toppings **MozzarellaTopping** and **TomatoTopping**.

Exercise 19: Create an existential (some) restriction on MargheritaPizza that acts along the property hasTopping with a filler of MozzarellaTopping to specify that a MargheritaPizza has at least one MozzarellaTopping

1. Make sure that **MargheritaPizza** is selected in the class hierarchy.
 2. Use the ‘**Add**’ icon (⊕) on the ‘**Superclasses**’ section of the ‘**Class Description view**’ (Figure 4.30) to open a text box.
 3. Type **hasTopping** as the property to be restricted in the text box.
 4. Type ‘**some**’ to create the existential restriction.
 5. Type the class **MozzarellaTopping** as the filler for the restriction — remember that this can be achieved by typing the class name **MozzarellaTopping** into the filler edit box, or by using drag and drop from the class hierarchy.
 6. Press ‘**Enter**’ to create the restriction — if there are any errors, the restriction will not be created, and the error will be highlighted in red.
-



Figure 4.35: The Class Description View Showing A Description Of A MargheritaPizza

Now specify that MargheritaPizzas also have TomatoTopping.

Exercise 20: Create a existential restriction (some) on MargheritaPizza that acts along the property hasTopping with a filler of TomatoTopping to specify that a MargheritaPizza has at least one TomatoTopping

1. Ensure that MargheritaPizza is selected in the class hierarchy.
2. Use the ‘Add’ icon (+) on the ‘Superclasses’ section of the ‘Class Description View’ (Figure 4.30) to display open the text box.
3. Type hasTopping as the property to be restricted.
4. Type ‘some’ to create the existential restriction.
5. Type the class TomatoTopping as the filler for the restriction.
6. Click ‘Enter’ to create restriction dialog to create the restriction.

The ‘Class Description View’ should now look similar to the picture shown in Figure 4.35.

MEANING



We have added restrictions to MargheritaPizza to say that a MargheritaPizza is a NamedPizza that has at least one kind of MozzarellaTopping and at least one kind of TomatoTopping.

More formally (reading the class description view line by line), if something is a member of the class MargheritaPizza it is *necessary* for it to be a member of the class NamedPizza and it is *necessary* for it to be a member of the anonymous class of things that are linked to at least one member of the class MozzarellaTopping via the property hasTopping, and it is *necessary* for it to be a member of the anonymous class of things that are linked to at least one member of the class TomatoTopping via the property hasTopping.

Now create the class to represent an Americana Pizza, which has toppings of pepperoni, mozzarella



Figure 4.36: The Class Description View displaying the description for **AmericanaPizza**

and tomato. Because the class **AmericanaPizza** is very similar to the class **MargheritaPizza** (i.e. an Americana pizza is almost the same as a Margherita pizza but with an extra topping of pepperoni) we will make a *clone* of the **MargheritaPizza** class and then add an extra restriction to say that it has a topping of pepperoni.

Exercise 21: Create AmericanaPizza by cloning and modifying the description of MargheritaPizza

1. Select the class **MargheritaPizza** in the class hierarchy on the Classes tab.
 2. Select “”Duplicate selected class from the ‘Edit’ menu. A dialog will appear for you to name the new class, this will be created with exactly the same conditions (restrictions etc.) as **AmericanaPizza**.
 3. Ensuring that **AmericanaPizza** is still selected, select the ‘Add’ icon (+) next to the ‘Superclasses’ header in the class description view, as we want to add a new restriction to the necessary conditions for **AmericanaPizza**.
 4. Type the property **hasTopping** as the property to be restricted.
 5. Type ‘**some**’ to create the existential restriction.
 6. Specify the restriction filler as the class **PepperoniTopping** by either typing **PepperoniTopping** into the text box, or by using drag and drop from the class hierarchy.
 7. Press **OK** to create the restriction.
-



Figure 4.37: The Class Description View displaying the description for AmericanHotPizza

The ‘Class Description View’ should now look like the picture shown in Figure 4.36.

Exercise 22: Create an AmericanHotPizza and a SohoPizza

1. An **AmericanHotPizza** is almost the same as an **AmericanaPizza**, but has Jalapeno peppers on it — create this by cloning the class **AmericanaPizza** and adding an existential restriction along the **hasTopping** property with a filler of **JalapenoPepperTopping**.
2. A **SohoPizza** is almost the same as a **MargheritaPizza** but has additional toppings of olives and parmezian cheese — create this by cloning **MargheritaPizza** and adding two existential restrictions along the property **hasTopping**, one with a filler of **OliveTopping**, and one with a filler of **ParmezanTopping**.

For **AmericanHot** pizza the class description view should now look like the picture shown in Figure 4.37. For **SohoPizza** the class description view should now look like the picture shown in 4.38.

Having created these pizzas we now need to make them disjoint from one another:

Exercise 23: Make subclasses of NamedPizza disjoint from each other

1. Select the class **MargheritaPizza** in the class hierarchy on the ‘Classes’ tab.
2. Select the ‘Make primitive siblings disjoint’ option in the ‘Edit’ menu to make the pizzas disjoint from each other.



Figure 4.38: The Class Description View displaying the description for SohoPizza

4.9 Using A Reasoner

One of the key features of ontologies that are described using OWL-DL is that they can be processed by a *reasoner*. One of the main services offered by a reasoner is to test whether or not one class is a subclass of another class⁷. By performing such tests on the classes in an ontology it is possible for a reasoner to compute the *inferred* ontology class hierarchy. Another standard service that is offered by reasoners is *consistency* checking. Based on the description (conditions) of a class the reasoner can check whether or not it is possible for the class to have any instances. A class is deemed to be inconsistent if it cannot possibly have any instances.

Vocabulary



Reasoners are sometimes called *classifiers*. Classification, however, is not the only inference service provided by reasoners. For instance, a reasoner also performs consistency checking which is different from classification. Hence, the preferred term is *reasoner*.

4.9.1 Invoking The Reasoner

Protégé 4 allows different OWL reasoners to be plugged in, the reasoner shipped with Protégé is called Fact++. The ontology can be ‘sent to the reasoner’ to automatically compute the classification hierarchy, and also to check the logical consistency of the ontology. In Protégé 4 the ‘manually constructed’ class hierarchy is called the *asserted hierarchy*. The class hierarchy that is automatically computed by the reasoner is called the *inferred hierarchy*. To automatically classify the ontology (and check for inconsistencies) the ‘**Classify...**’ action should be used. This can be invoked via the ‘**Classify...**’ button in the Reasoner drop down menu shown in Figure 4.39. When the inferred hierarchy has been computed, an *inferred hierarchy* window will pop open on top the existing *asserted hierarchy* window as shown in Figure 4.40. If a class has been reclassified (i.e. if its superclasses have changed) then the class name

⁷Known as subsumption testing — the descriptions of the classes (conditions) are used to determine if a superclass/subclass relationship exists between them.

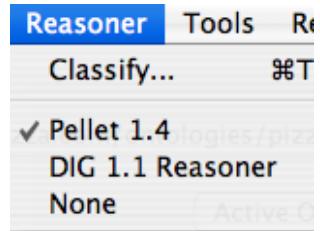


Figure 4.39: Classify the ontology from the reasoner menu

will appear in a blue colour in the *inferred hierarchy*. If a class has been found to be inconsistent its icon will be highlighted in red.



The task of computing the inferred class hierarchy is also known as *classifying the ontology*.

4.9.2 Inconsistent Classes

In order to demonstrate the use of the reasoner in detecting inconsistencies in the ontology we will create a class that is a subclass of both **CheeseTopping** and also **VegetableTopping**. This strategy is often used as a check so that we can see that we have built our ontology correctly. Classes that are added in order to test the integrity of the ontology are sometimes known as *Probe Classes*.

Exercise 24: Add a Probe Class called ProbelnconsistentTopping which is a subclass of both CheeseTopping and VegetableTopping

1. Select the class **CheeseTopping** from the class hierarchy on the Classes tab.
 2. Create a subclass of **CheeseTopping** named **ProbelnconsistentTopping**.
 3. Add a comment to the **ProbelnconsistentTopping** class that is something along the lines of, “This class should be inconsistent when the ontology is classified.” This will enable anyone who looks at our pizza ontology to see that we deliberately meant the class to be inconsistent.
 4. Ensure that the **ProbelnconsistentTopping** class is selected in the class hierarchy, and then select the ‘Superclass’ header in the ‘Class Description View’.
 5. Click on the ‘superclasses’ button on the ‘Class Description View’. This will display a dialog containing the class hierarchy from which a class may be selected. Select the class **VegetableTopping** and then press the ‘OK’ button. The class **VegetableTopping** will be added as a superclass, so that the class description view should look like the picture in Figure 4.41.
-

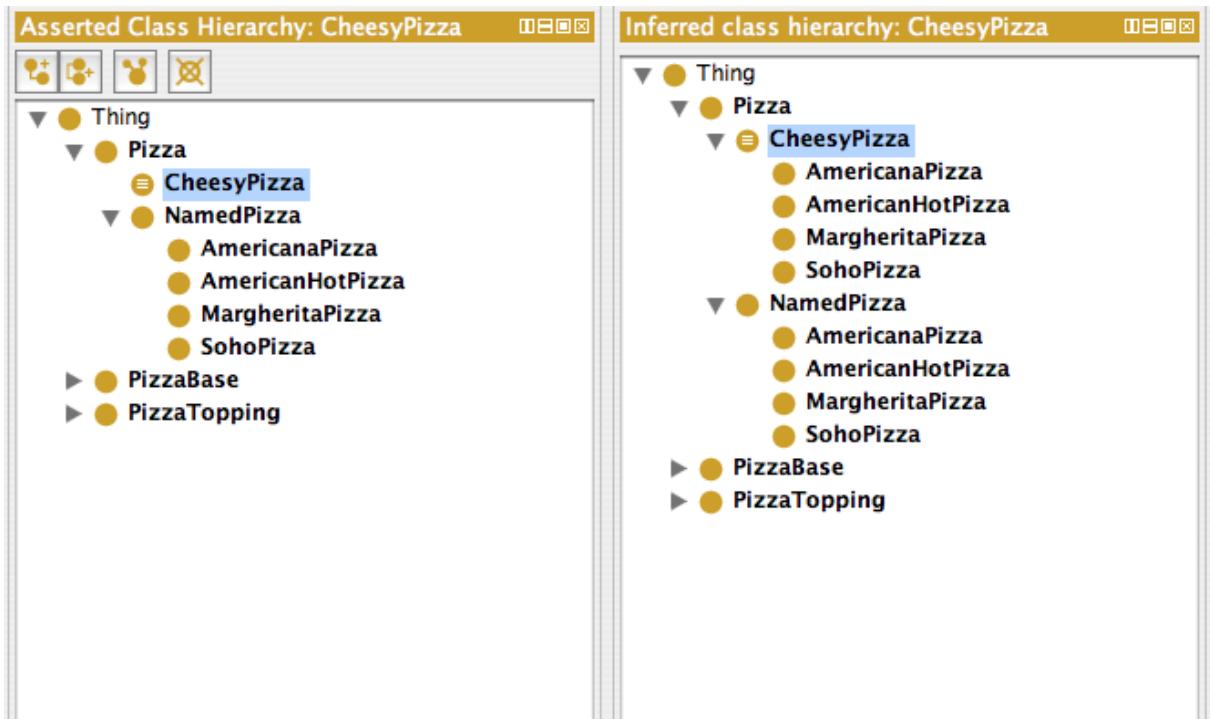


Figure 4.40: The Inferred Hierarchy Pane alongside the Asserted Hierarchy Pane after classification has taken place. Note the inferred subclasses of CheesyPizza



Figure 4.41: The Class Description View Displaying ProbInconsistentTopping

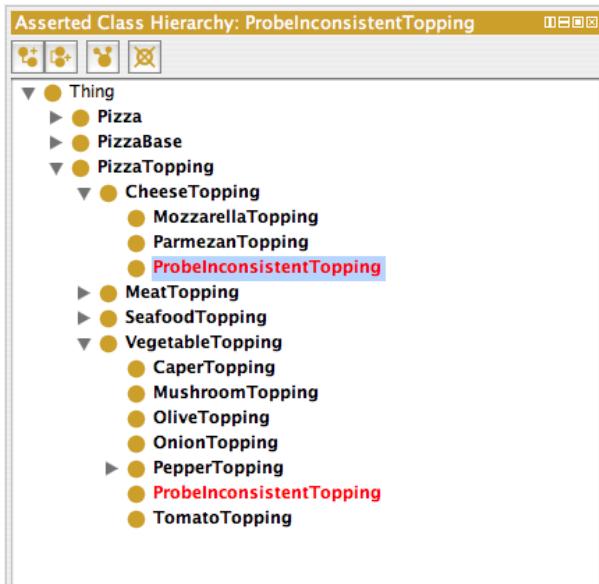


Figure 4.42: The Class `ProbelInconsistentTopping` found to be inconsistent by the reasoner

MEANING



If we study the class hierarchy, `ProbelInconsistentTopping` should appear as a subclass of `CheeseTopping` and as a subclass of `VegetableTopping`. This means that `ProbelInconsistentTopping` is a `CheeseTopping` *and* a `VegetableTopping`. More formally, all individuals that are members of the class `ProbelInconsistentTopping` are also (necessarily) members of the class `CheeseTopping` and (necessarily) members of the class `VegetableTopping`. Intuitively this is incorrect since something can not simultaneously be both cheese and a vegetable!

Exercise 25: Classify the ontology to make sure `ProbelInconsistentTopping` is inconsistent

1. Press the ‘Classify...’ button on the Reasoner drop down menu to classify the ontology.
-

After a few seconds the inferred hierarchy will have been computed and the *inferred hierarchy* window will pop open (if it was previously closed). The hierarchy should resemble that shown in Figure 4.42 — notice that the class `ProbelInconsistentTopping` is highlighted in red, indicating that the reasoner has found this class to be inconsistent (i.e. it cannot possibly have any individuals as members).

MEANING

Why did this happen? Intuitively we know something cannot at the same time be both cheese and a vegetable. Something should not be both an instance of **CheeseTopping** and an instance of **VegetableTopping**. However, it must be remembered that we have chosen the names for our classes. As far as the reasoner is concerned names have no meaning. The reasoner cannot determine that something is inconsistent based on names. The actual reason that **ProbeInconsistentTopping** has been detected to be inconsistent is because its superclasses **VegetableTopping** and **CheeseTopping** are *disjoint from each other* — remember that earlier on we specified that the four categories of topping were disjoint from each other. Therefore, individuals that are members of the class **CheeseTopping** cannot be members of the class **VegetableTopping** and vice-versa.

TIP

To close the inferred hierarchy use the small white cross on a red background button on the top right of the inferred hierarchy window.

Exercise 26: Remove the disjoint statement between CheeseTopping and VegetableTopping to see what happens

1. Select the class **CheeseTopping** using the class hierarchy.
 2. The ‘**Disjoints view**’ should contain **CheeseTopping**’s sibling classes: **VegetableTopping**, **SeafoodTopping** and **MeatTopping**. Select **VegetableTopping** in the Disjoints view.
 3. Press the ‘**Delete selected row**’ button on the Disjoints view to remove the disjoint axiom that states **CheeseTopping** and **VegetableTopping** are disjoint.
 4. Press ‘**Classify...**’ on the Reasoner drop down menu to send the ontology to the reasoner. After a few seconds the ontology should have been classified and the results displayed.
-

MEANING

It should be noticeable that `ProbelnconsistentTopping` is no longer inconsistent! This means that individuals which are members of the class `ProbelnconsistentTopping` are also members of the class `CheeseTopping` and `VegetableTopping` — something can be both cheese and a vegetable!

This clearly illustrates the importance of the careful use of disjoint axioms in OWL. OWL classes ‘overlap’ until they have been stated to be disjoint from each other. If certain classes are not disjoint from each other then unexpected results can arise. Accordingly, if certain classes have been incorrectly made disjoint from each other then this can also give rise to unexpected results.

Exercise 27: Fix the ontology by making `CheeseTopping` and `Vegetable` disjoint from each other

1. Select the class `CheeseTopping` using the class hierarchy.
 2. The ‘Disjoint classes’ section of the ‘Class Description’ view should contain `MeatTopping` and `SeafoodTopping`.
 3. Press the ‘Add’ icon (+) on the ‘Disjoint classes’ to display a dialog in which classes may be picked from. Select the class `VegetableTopping` and press the ‘OK’ button. `CheeseTopping` should once again be disjoint from `VegetableTopping`.
 4. Test that the disjoint axiom has been added correctly — Press ‘Classify...’ on the Reasoner drop down menu to send the ontology to the reasoner. After a few seconds the ontology should have been classified, and `ProbelnconsistentTopping` should be highlighted in red indicating that it is once again inconsistent.
-

4.10 Necessary And Sufficient Conditions (Primitive and Defined Classes)

All of the classes that we have created so far have only used *necessary* conditions to describe them. *Necessary* conditions can be read as, “If something is a member of this class then it is *necessary* to fulfil these conditions”. With *necessary* conditions alone, we cannot say that, “If something fulfils these conditions then it *must* be a member of this class”.

Vocabulary



A class that only has *necessary* conditions is known as a **Primitive Class**.

Let’s illustrate this with an example. We will create a subclass of `Pizza` called `CheesyPizza`, which will



Figure 4.43: The Description of CheesyPizza (Using Necessary Conditions)

be a **Pizza** that has at least one kind of **CheeseTopping**.

Exercise 28: Create a subclass of Pizza called CheesyPizza and specify that it has at least one topping that is a kind of CheeseTopping

1. Select **Pizza** in the class hierarchy on the ‘Classes’ tab.
2. Press the ‘Add’ icon (⊕) to create a subclass of **Pizza**. Name it **CheesyPizza**.
3. Make sure that **CheesyPizza** is selected in the class hierarchy. Select the ‘Add’ icon (⊕) next to the ‘Superclasses’ header in the class description view.
4. Type **hasTopping** as the property to be restricted.
5. Type ‘**some**’ to create the existential restriction.
6. Finally type **CheeseTopping** and press ‘Enter’ to close the dialog and create the restriction.

The ‘Class Description View’ should now look like the picture shown in Figure 4.43.

MEANING



Our description of **CheesyPizza** states that if something is a member of the class **CheesyPizza** it is *necessary* for it to be a member of the class **Pizza** and it is *necessary* for it to have *at least one* topping that is a member of the class **CheeseTopping**.

Our current description of **CheesyPizza** says that if something is a **CheesyPizza** it is necessarily a **Pizza** and it is *necessary* for it to have *at least one* topping that is a kind of **CheeseTopping**. We have used *necessary* conditions to say this. Now consider some (random) individual. Suppose that we know that this individual is a member of the class **Pizza**. We also know that this individual has at least one kind of **CheeseTopping**. However, given our current description of **CheesyPizza** this knowledge is not *sufficient* to determine that the individual is a member of the class **CheesyPizza**. To make this possible we need to change the conditions for **CheesyPizza** from *necessary* conditions to *necessary AND sufficient* conditions. This means that not only are the conditions *necessary* for membership of the class **CheesyPizza**, they



Figure 4.44: The Description of CheesyPizza (Using Necessary AND Sufficient Conditions)

are also *sufficient* to determine that any (random) individual that satisfies them must be a member of the class **CheesyPizza**.

Vocabulary



A class that has at least one set of *necessary and sufficient* conditions is known as a **Defined Class**.

Vocabulary



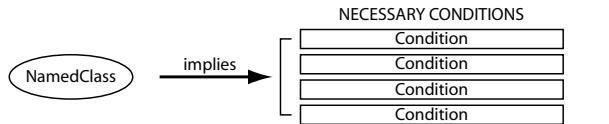
Necessary conditions are simply called Superclasses in Protégé 4. Necessary and sufficient condition are called Equivalent classes.

In order to convert *necessary* conditions to *necessary and sufficient* conditions, the conditions must be moved from under the ‘**Superclasses**’ header in the class description view to be under the ‘**Equivalent classes**’ header. This can be done with the ‘**Convert to defined class**’ option in the ‘**Edit**’ menu.

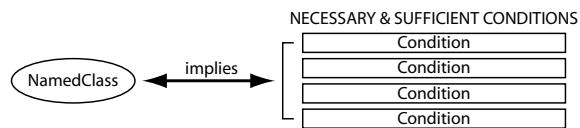
Exercise 29: Convert the necessary conditions for CheesyPizza into necessary & sufficient conditions

- 1. Ensure that **CheesyPizza** is selected in the class hierarchy.
 - 2. In the ‘**Edit**’ menu select ‘**Convert to defined class**’.
-

The ‘**Class Description View**’ should now look like the picture shown in Figure 4.44.



If an individual is a member of 'NamedClass' then it must satisfy the conditions. However if some individual satisfies these necessary conditions, we cannot say that it is a member of 'Named Class' (the conditions are not 'sufficient' to be able to say this) - this is indicated by the direction of the arrow.



If an individual is a member of 'NamedClass' then it must satisfy the conditions. If some individual satisfies the conditions then the individual must be a member of 'NamedClass' - this is indicated by the double arrow.

Figure 4.45: Necessary And Sufficient Conditions

MEANING



We have converted our description of **CheesyPizza** into a *definition*. If something is a **CheesyPizza** then it is *necessary* that it is a **Pizza** and it is also *necessary* that *at least one* topping that is a member of the class **CheeseTopping**. Moreover, if an individual is a member of the class **Pizza** and it has at least one topping that is a member of the class **CheeseTopping** then these conditions are *sufficient* to determine that the individual *must* be a member of the class **CheesyPizza**. The notion of *necessary and sufficient* conditions is illustrated in Figure 4.45.

To summarise: If class **A** is described using *necessary* conditions, then we can say that if an individual is a member of class **A** it must satisfy the conditions. We cannot say that *any* (random) individual that satisfies these conditions must be a member of class **A**. However, if class **A** is now *defined* using *necessary and sufficient* conditions, we can say that if an individual is a member of the class **A** it must satisfy the conditions *and* we can now say that if any (random) individual satisfies these conditions then it must be a member of class **A**. The conditions are not only *necessary* for membership of **A** but also *sufficient* to determine that something satisfying these conditions is a member of **A**.

How is this useful in practice? Suppose we have another class **B**, and we know that any individuals that are members of class **B** also satisfy the conditions that define class **A**. We can determine that class **B** is *subsumed by* class **A** — in other words, **B** is a subclass of **A**. Checking for class subsumption is a key task of a description logic reasoner and we will use the reasoner to automatically compute a classification hierarchy in this way.



NOTE

In OWL it is possible to have multiple sets of necessary & sufficient conditions. This is discussed later in section 7.5

4.10.1 Primitive And Defined Classes

Classes that have at least one set of necessary and sufficient conditions are known as *defined* classes — they have a definition, and any individual that satisfies the definition will belong to the class. Classes that do not have any sets of necessary and sufficient conditions (only have necessary conditions) are known as *primitive* classes. In Protégé 4 *defined* classes have a class icon with three *horizontal* white lines in them. *Primitive* classes have a class icon that has a plain *yellow* background. It is also important to understand that the reasoner can only automatically classify classes under *defined* classes - i.e. classes with at least one set of necessary and sufficient conditions.

4.11 Automated Classification

Being able to use a reasoner to automatically compute the class hierarchy is one of the major benefits of building an ontology using the OWL-DL sub-language. Indeed, when constructing very large ontologies (with upwards of several thousand classes in them) the use of a reasoner to compute subclass-superclass relationships between classes becomes almost vital. Without a reasoner it is very difficult to keep large ontologies in a maintainable and logically correct state. In cases where ontologies can have classes that have many superclasses (multiple inheritance) it is nearly always a good idea to construct the class hierarchy as a simple tree. Classes in the asserted hierarchy (manually constructed hierarchy) therefore have no more than one superclass. Computing and maintaining multiple inheritance is the job of the reasoner. This technique⁸ helps to keep the ontology in a maintainable and modular state. Not only does this promote the reuse of the ontology by other ontologies and applications, it also minimises human errors that are inherent in maintaining a multiple inheritance hierarchy.

Having created a definition of a **CheesyPizza** we can use the reasoner to automatically compute the subclasses of **CheesyPizza**.

Exercise 30: Use the reasoner to automatically compute the subclasses of CheesyPizza

- 1. Press the ‘Classify...’ button on the Reasoner drop down menu (See Figure 4.39).
-

After a few seconds the inferred hierarchy should have been computed and the inferred hierarchy window will pop open (if it was previously closed). The inferred hierarchy should appear similar to the picture shown in Figure 4.46. Figures 4.47 and 4.48 show the OWLViz display of the asserted and inferred hierarchies respectively. Notice that classes which have had their superclasses changed by the reasoner are shown in blue.

⁸Sometimes known as ontology normalisation.

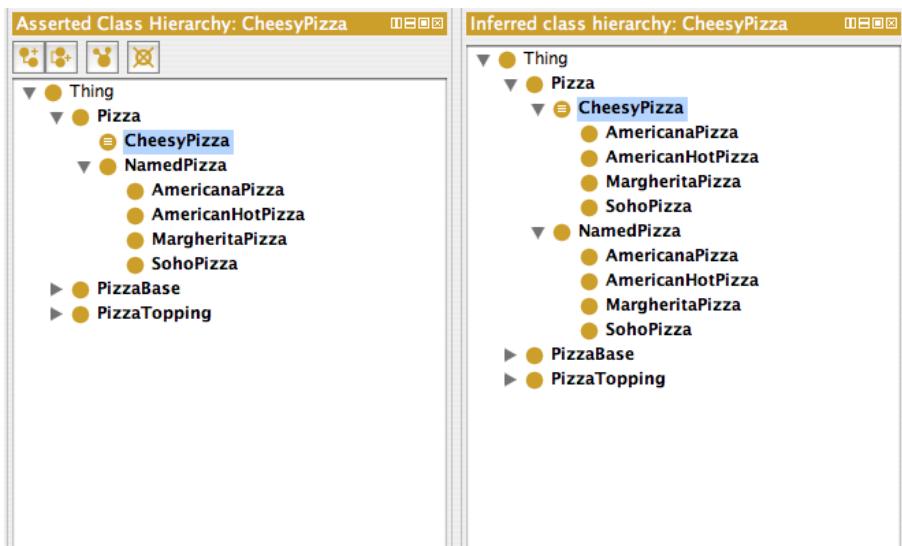


Figure 4.46: The Asserted and Inferred Hierarchies Displaying The Classification Results For `CheesyPizza`

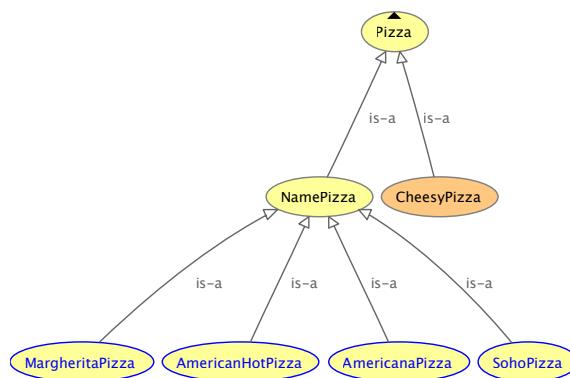


Figure 4.47: OWLViz Displaying the Asserted Hierarchy for `CheesyPizza`

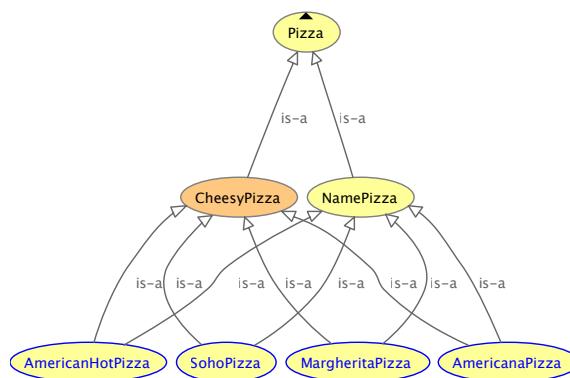


Figure 4.48: OWLViz Displaying the Inferred Hierarchy for `CheesyPizza`

MEANING

The reasoner has determined that **MargheritaPizza**, **AmericanaPizza**, **AmericanHotPizza** and **SohoPizza** are subclasses of **CheesyPizza**. This is because we *defined* **CheesyPizza** using necessary and sufficient conditions. Any individual that is a **Pizza** and has *at least one* topping that is a **CheeseTopping** is a member of the class **CheesyPizza**. Due to the fact that all of the individuals that are described by the classes **MargheritaPizza**, **AmericanaPizza**, **AmericanHotPizza** and **SohoPizza** are **Pizzas** and they have *at least one* topping that is a **CheeseTopping**^a the reasoner has determined that these classes must be subclasses of **CheeseTopping**.

^aOr toppings that belong to the subclasses of **CheeseTopping**



It is important to realise that, in general, classes will never be placed as subclasses of *primitive* classes (i.e. classes that only have necessary conditions) by the reasoner^a.

^aThe exception to this is when a property has a domain that is a primitive class. This can *coerce* classes to be reclassified under the primitive class that is the domain of the property — the use of property domains to cause such effects is strongly discouraged.

4.12 Universal Restrictions

All of the restrictions we have created so far have been existential restrictions (some). Existential restrictions specify the existence of *at least one* relationship along a given property to an individual that is a member of a specific class (specified by the filler). However, existential restrictions do not mandate that the *only* relationships for the given property that can exist must be to individuals that are members of the specified filler class.

For example, we could use an existential restriction **hasTopping some MozzarellaTopping** to describe the individuals that have *at least one* relationship along the property **hasTopping** to an individual that is a member of the class **MozzarellaTopping**. This restriction does *not* imply that all of the **hasTopping** relationships must be to a member of the class **MozzarellaTopping**. To restrict the relationships for a given property to individuals that are members of a specific class we must use a *universal restriction*.

Universal restrictions are given the symbol \forall . They *constrain* the relationships along a given property to individuals that are members of a specific class. For example the universal restriction $\forall \text{ hasTopping MozzarellaTopping}$ describes the individuals all of whose **hasTopping** relationships are to members of the class **MozzarellaTopping** — the individuals do not have a **hasTopping** relationships to individuals that aren't members of the class **MozzarellaTopping**.

Vocabulary



Universal restrictions are also known as *AllValuesFrom Restrictions*.



The above universal restriction $\forall \text{ hasTopping MozzarellaTopping}$ also describes the individuals that *do not participate in any hasTopping relationships*. An individual that does not participate in any **hasTopping** relationships whatsoever, by definition does not have any **hasTopping** relationships to individuals that aren't members of the class **MozzarellaTopping** and the restriction is therefore satisfied.



For a given property, universal restrictions do *not* specify the existence of a relationship. They merely state that *if* a relationship exists for the property then it must be to individuals that are members of a specific class.

Suppose we want to create a class called **VegetarianPizza**. Individuals that are members of this class can *only* have toppings that are **CheeseTopping** or **VegetableTopping**. To do this we can use a *universal restriction*.

Exercise 31: Create a class to describe a VegetarianPizza

1. Create a subclass of **Pizza**, and name it **VegetarianPizza**.
2. Making sure that **VegetarianPizza** is selected, click on the '**Add**' icon (+) next to the '**Superclasses**' header in the '**Class Description View**'.
3. Type **hasTopping** as the property to be restricted.
4. Type '**only**' in order to create a universally quantified restriction.
5. For the filler we want to say **CheeseTopping** *or* **VegetableTopping**. We place this inside brackets so write an open bracket followed by the class **CheeseTopping** either by typing **CheeseTopping** into the filler box. We now need to use the *unionOf* operator between the class names. We can add this operator by simply typing *or*. Next insert the class **VegetableTopping** by typing it. You should now have **hasTopping only (CheeseTopping or VegetableTopping)** in the text box.
6. Press '**OK**' to close the dialog and create the restriction — if there are any errors (due to typing errors etc.) they will be underlined in red.

At this point the class description view should look like the picture shown in Figure 4.49.

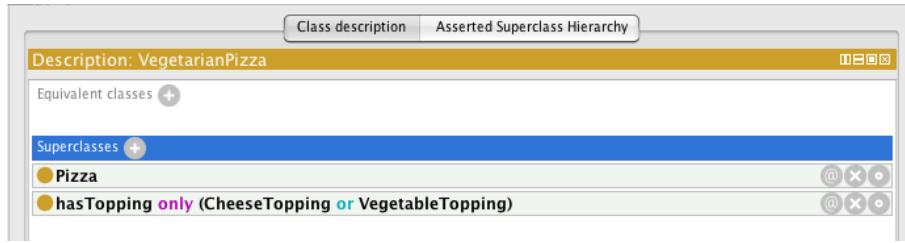


Figure 4.49: The Description of `VegetarianPizza` (Using Necessary Conditions)

MEANING



This means that if something is a member of the class `VegetarianPizza` it is *necessary* for it to be a kind of `Pizza` and it is *necessary* for it to *only* (\forall universal quantifier) have toppings that are kinds of `CheeseTopping` *or* kinds of `VegetableTopping`.

In other words, all `hasTopping` relationships that individuals which are members of the class `VegetarianPizza` participate in must be to individuals that are either members of the class `CheeseTopping` or `VegetableTopping`.

The class `VegetarianPizza` also contains individuals that are `Pizzas` and do not participate in *any* `hasTopping` relationships.



In situations like the above example, a common mistake is to use an *intersection* instead of a *union*. For example, `CheeseTopping` \sqcap `VegetableTopping`. This reads, `CheeseTopping and VegetableTopping`. Although “CheeseTopping and Vegetable” might be a natural thing to say in English, this logically means something that is *simultaneously* a kind of `CheeseTopping` and `VegetableTopping`. This is obviously incorrect as demonstrated in section 4.9.2. If the classes `CheeseTopping` and `VegetableTopping` were not disjoint, this would have been a logically legitimate thing to say – it would not be inconsistent and therefore would not be ‘spotted’ by the reasoner.



In the above example it might have been tempting to create two universal restrictions — one for `CheeseTopping` (\forall `hasTopping CheeseTopping`) and one for `VegetableTopping` (\forall `hasTopping VegetableTopping`). However, when multiple restrictions are used (for any type of restriction) the total description is taken to be the intersection of the individual restrictions. This would have therefore been equivalent to one restriction with a filler that is the *intersection* of `MozarellaTopping` and `TomatoTopping` — as explained above this would have been logically incorrect.

Currently `VegetarianPizza` is described using *necessary* conditions. However, our description of a `VegetarianPizza` could be considered to be *complete*. We know that any individual that satisfies these conditions must be a `VegetarianPizza`. We can therefore convert the *necessary* conditions for `Vegetarian-`

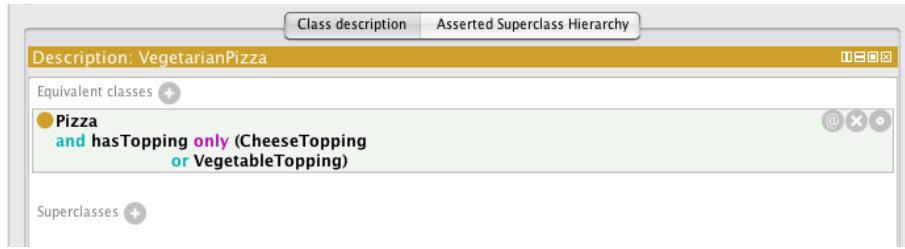


Figure 4.50: The Class Description View Displaying the Definition of `VegetarianPizza` (Using Necessary and Sufficient Conditions)

an `Pizza` into *necessary and sufficient* conditions. This will also enable us to use the reasoner to determine the subclasses of `VegetarianPizza`.

Exercise 32: Convert the necessary conditions for `VegetarianPizza` into necessary & sufficient conditions

1. Ensure that `VegetarianPizza` is selected in the class hierarchy.
2. In the ‘Edit’ menu select ‘Convert to defined class’.

The ‘Class Description View’ should now look like the picture shown in Figure 4.50.

MEANING



We have converted our description of `VegetarianPizza` into a *definition*. If something is a `VegetarianPizza`, then it is *necessary* that it is a `Pizza` and it is also *necessary* that *all* toppings belong to the class `CheeseTopping` or `VegetableTopping`. Moreover, if something is a member of the class `Pizza` and all of its toppings are members of the class `CheeseTopping` or the class `VegetableTopping` then these conditions are *sufficient* to recognise that it *must* be a member of the class `VegetarianPizza`. The notion of *necessary and sufficient* conditions is illustrated in Figure 4.45.

4.13 Automated Classification and Open World Reasoning

We want to use the reasoner to automatically compute the superclass-subclass relationship (subsumption relationship) between `MargheritaPizza` and `VegetarianPizza` and also, `SohoPizza` and `VegetarianPizza`. Recall that we believe that `MargheritaPizza` and `SohoPizza` should be vegetarian pizzas (they should be subclasses of `VegetarianPizza`). This is because they have toppings that are essentially vegetarian toppings — by our definition, vegetarian toppings are members of the classes `CheeseTopping` or `VegetableTopping` and their subclasses. Having previously created a definition for `VegetarianPizza` (using a set of *necessary and sufficient* conditions) we can use the reasoner to perform automated classification

and determine the vegetarian pizzas in our ontology.

Exercise 33: Use the reasoner to classify the ontology

1. Press the ‘Classify...’ button in the Reasoner Drop Down menu.
-

You will notice that **MargheritaPizza** and also **SohoPizza** have *not* been classified as subclasses of **VegetarianPizza**. This may seem a little strange, as it appears that both **MargheritaPizza** and **SohoPizza** have ingredients that are vegetarian ingredients, i.e. ingredients that are kinds of **CheeseTopping** or kinds of **VegetableTopping**. However, as we will see, **MargheritaPizza** and **SohoPizza** have something missing from their definition that means they cannot be classified as subclasses of **VegetarianPizza**.

Reasoning in OWL (Description Logics) is based on what is known as the *open world assumption* (OWA). It is frequently referred to as *open world reasoning* (OWR). The *open world assumption* means that we cannot assume something doesn’t exist until it is explicitly stated that it does not exist. In other words, because something hasn’t been stated to be true, it cannot be assumed to be false — it is assumed that ‘the knowledge just hasn’t been added to the knowledge base’. In the case of our pizza ontology, we have stated that **MargheritaPizza** has toppings that are kinds of **MozzarellaTopping** and also kinds of **TomatoTopping**. Because of the *open world assumption*, until we explicitly say that a **MargheritaPizza** *only* has these kinds of toppings, it is assumed (by the reasoner) that a **MargheritaPizza** could have other toppings. To specify explicitly that a **MargheritaPizza** has toppings that are kinds of **MozzarellaTopping** or kinds of **MargheritaTopping** and *only* kinds of **MozzarellaTopping** or **MargheritaTopping**, we must add what is known as a *closure axiom*⁹ on the **hasTopping** property.

4.13.1 Closure Axioms

A *closure axiom* on a property consists of a universal restriction that acts along the property to say that it can *only* be filled by the specified fillers. The restriction has a filler that is the *union* of the fillers that occur in the existential restrictions for the property¹⁰. For example, the closure axiom on the **hasTopping** property for **MargheritaPizza** is a universal restriction that acts along the **hasTopping** property, with a filler that is the *union of MozzarellaTopping* and also **TomatoTopping**. i.e. $\forall \text{ hasTopping } (\text{Mozzarell}$

⁹Also referred to as a closure restriction.

¹⁰And technically speaking the classes for the values used in any **hasValue** restrictions (see later).



Figure 4.51: Class Description View: Margherita Pizza With a Closure Axiom for the `hasTopping` property

`laTopping ⊑ TomatoTopping).`

Exercise 34: Add a closure axiom on the `hasTopping` property for MargheritaPizza

1. Make sure that **MargheritaPizza** is selected in the class hierarchy on the ‘Classes’ tab.
2. Press the ‘Add’ icon (⊕) next to the ‘Superclasses’ section of the ‘Class Description’ view to open the edit text box.
3. Type `hasTopping` as the property to be restricted.
4. Type ‘only’ to create the universal restriction.
5. Open brackets and type `MozzarellaTopping` or `TomatoTopping` close bracket.
6. Press ‘OK’ to create the restriction and add it to the class **MargheritaPizza**.

The class description view should now appear as shown in Figure 4.51.

MEANING

This now says that if an individual is a member of the class **MargeritaPizza** then it must be a member of the class **Pizza**, *and* it must have at least one topping that is a kind of **MozzarellaTopping** *and* it must have at least one topping that is a member of the class **TomatoTopping** *and* the toppings must *only* be kinds of **MozzarellaTopping** *or* **TomatoTopping**.



A common error in situations such as above is to only use universal restrictions in descriptions. For example, describing a **MargheritaPizza** by making it a subclass of **Pizza** and then only using $\forall \text{ hasTopping } (\text{MozzarellaTopping} \sqcup \text{ TomatoTopping})$ without any existential restrictions. However, because of the semantics of the universal restriction, this actually means either: things that are **Pizzas** and only have toppings that are **MozzarellaTopping** or **TomatoTopping**, OR, things that are **Pizzas** and *do not have any* toppings at all.

Exercise 35: Add a closure axiom on the hasTopping property for SohoPizza

1. Make sure that **SohoPizza** is selected in the class hierarchy on the ‘Classes’ tab.
2. Press the ‘Add’ icon (+) on the ‘Superclasses’ section of the ‘Class Description’ view to open the edit text box.
3. Type **hasTopping** as the property to be restricted.
4. Type ‘**only**’ to create the universal restriction.
5. Open brackets and type **MozzarellaTopping** or **TomatoTopping** or **ParmezanTopping** or **OliveTopping** close bracket.
6. Press ‘**OK**’ to create the restriction and add it to the class **SohoPizza**.

For completeness, we will add closure axioms for the **hasTopping** property to **AmericanaPizza** and also **AmericanHotPizza**. At this point it may seem like tedious work to enter these closure axioms by hand.

Fortunately Protégé 4 has the capability of creating closure axioms for us.

Exercise 36: Automatically create a closure axiom on the hasTopping property for AmericanaPizza

1. Select **AmericanaPizza** in the class hierarchy on the Classes tab.
 2. In the class description view, select one of the restrictions on the hasTopping property, e.g., **hasTopping some TomatoTopping**.
 3. Right click the restriction and select '**Create closure axiom**'.
 4. A new closure axiom is created.
-

Exercise 37: Automatically create a closure axiom on the hasTopping property for AmericanHot-Pizza

1. Select **AmericanHotPizza** in the class hierarchy on the Classes tab.
 2. In the class description view, select one of the restrictions on the hasTopping property, e.g., **hasTopping some TomatoTopping**.
 3. Right click the restriction and select '**Create closure axiom**'.
 4. A new closure axiom is created.
-

Having added closure axioms on the **hasTopping** property for our pizzas, we can now used the reasoner to automatically compute classifications for them.

Exercise 38: Use the reasoner to classify the ontology

1. Press the '**Classify...**' button on the reasoner drop down menu. to invoke the reasoner.
-

After a short amount of time the ontology will have been classified and the '**Inferred Hierarchy**' pane will pop open (if it is not already open). This time, **MargheritaPizza** and also **SohoPizza** will have been classified as subclasses of **VegetarianPizza**. This has happened because we specifically 'closed' the **hasTopping** property on our pizzas to say *exactly* what toppings they have and **VegetarianPizza** was *defined* to be a **Pizza** with only kinds of **CheeseTopping** and only kinds of **VegetableTopping**. Figure 4.52 shows the current asserted and inferred hierarchies. It is clear to see that the asserted hierarchy is simpler and 'cleaner' than the 'tangled' inferred hierarchy. Although the ontology is only very simple at this stage, it should be becoming clear that the use of a reasoner can help (especially in the case of large ontologies) to maintain a multiple inheritance hierarchy for us.

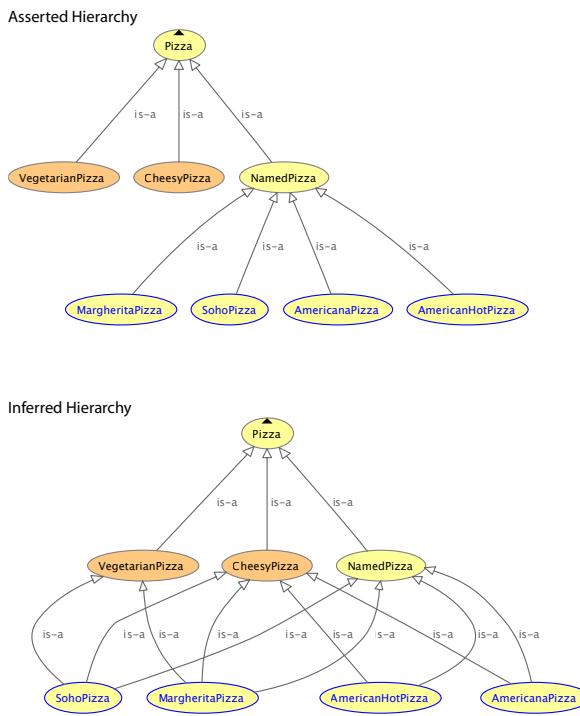


Figure 4.52: The asserted and inferred hierarchies showing the “before and after” classification of `Pizzas` into `CheesyPizzas` and `VegetarianPizzas`.

4.14 Value Partitions

In this section we create some *Value Partitions*, which we will use to refine our descriptions of various classes. *Value Partitions* are not part of OWL, or any other ontology language, they are a ‘design pattern’. Design patterns in ontology design are analogous to design patterns in object oriented programming — they are solutions to modelling problems that have occurred over and over again. These design patterns have been developed by experts and are now recognised as proven solutions for solving common modelling problems. As mentioned previously, Value Partitions can be created to refine our class descriptions, for example, we will create a Value Partition called ‘SpicinessValuePartition’ to describe the ‘spiciness’ of `PizzaToppings`. Value Partitions restrict the range of possible values to an *exhaustive list*, for example, our ‘SpicinessValuePartition’ will restrict the range to ‘Mild’, ‘Medium’, and ‘Hot’. Creating a ValuePartition in OWL consists of several steps:

1. Create a class to represent the ValuePartition. For example to represent a ‘spiciness’ ValuePartition we might create the class `SpicinessValuePartition`.
2. Create subclasses of the ValuePartition to represent the possible options for the ValuePartition. For example we might create the classes `Mild`, `Medium` and `Hot` as subclasses of the `SpicinessValuePartition` class.
3. Make the subclasses of the ValuePartition class disjoint.
4. Provide a *covering axiom* to make the list of value types *exhaustive* (see below).

5. Create an object property for the ValuePartition. For example, for our spiciness ValuePartition, we might create the property **hasSpiciness**.
6. Make the property *functional*.
7. Set the range of the property as the ValuePartition class. For example for the **hasSpiciness** property the range would be set to **SpicinessValuePartition**.

Let's create a ValuePartition that can be used to describe the spiciness of our pizza toppings. We will then be able to classify our pizzas into spicy pizzas and non-spicy pizzas. We want to be able to say that our pizza toppings have a spiciness of either 'mild', 'medium' or 'hot'. Note that these choices are mutually exclusive – something cannot be both 'mild' and 'hot', or a combination of the choices.

Exercise 39: Create a ValuePartition to represent the spiciness of pizza toppings

1. Create a new class as a sub class of **Thing** called **ValuePartition**.
 2. Create a sub class of **ValuePartition** called **SpicinessValuePartition**.
 3. Create three new classes as subclasses of **SpicinessValuePartition**. Name these classes **Hot**, **Medium**, and **Mild**.
 4. Make the classes **Hot**, **Medium**, and **Mild** disjoint from each other. You can do this by selecting the class **Hot**, and selecting '**Make all primitive siblings disjoint**' from the '**Edit**' menu.
 5. In the '**Object Property Tab**' create a new Object Property called **hasSpiciness**. Set the range of this property to **SpicinessValuePartition**. Make this new property functional by ticking the functional box.
 6. Add a covering axiom to the **SpicinessValuePartition**. Highlight **SpicinessValuePartition** in the class hierarchy, in the '**Equivalent classes**' section of the class description view select the '**Add**' icon () and type **Hot** or **Medium** or **Mild** in the dialog box.
-

Let's look at the SpicinessValuePartitionClass (refer to Figure 4.53 and Figure 4.54):

4.14.1 Covering Axioms

As part of the ValuePartition pattern we use a *covering axiom*. A covering axiom consists of two parts: The class that is being 'covered', and the classes that form the covering. For example, suppose we have three classes **A**, **B** and **C**. Classes **B** and **C** are subclasses of class **A**. Now suppose that we have a covering axiom that specifies class **A** is *covered* by class **B** and also class **C**. This means that a member of class **A** *must* be a member of **B** and/or **C**. If classes **B** and **C** are disjoint then a member of class **A** *must* be a member of *either* class **B** *or* class **C**. Remember that ordinarily, although **B** and **C** are subclasses of **A** an individual may be a member of **A** without being a member of either **B** or **C**.

In Protégé 4 a covering axiom manifests itself as a class that is the *union* of the classes being covered, which forms a superclass of the class that is being covered. In the case of classes **A**, **B** and **C**, class **A** would have a superclass of **B** \sqcup **C**. The effect of a covering axiom is depicted in Figure 4.55.

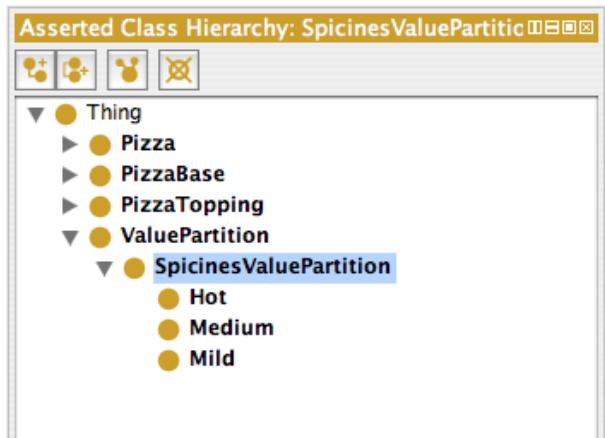


Figure 4.53: Classes Added by the ‘Create ValuePartition’ Wizard

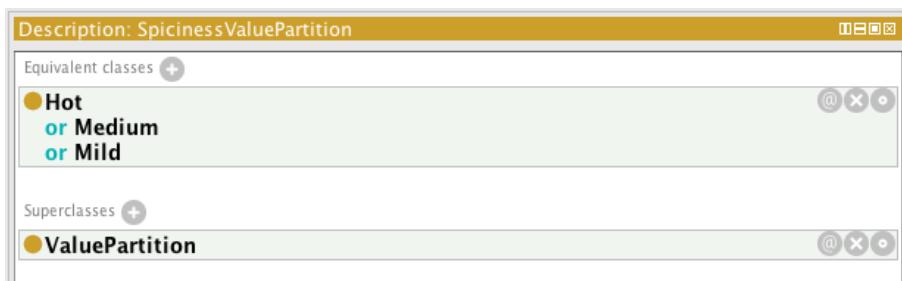


Figure 4.54: The Class Description View Displaying the Description of the **SpicinessValuePartition** Class

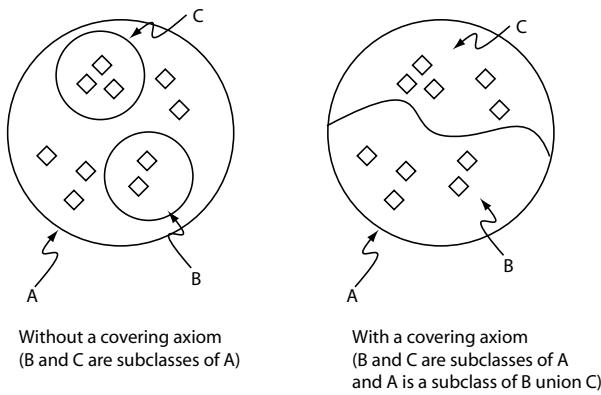


Figure 4.55: A schematic diagram that shows the effect of using a Covering Axiom to cover class **A** with classes **B** and **C**

Our **SpicinessValuePartition** has a covering axiom to state that **SpicinessValuePartition** is *covered* by the classes **Mild**, **Medium** and **Hot** — **Mild**, **Medium** and **Hot** are disjoint from each other so that an individual cannot be a member of more than one of them. The class **SpicinessValuePartition** has a superclass that is **Mild** \sqcup **Medium** \sqcup **Hot**. This covering axiom means that a member of **SpicinessValuePartition** *must* be a member of either **Mild** or **Medium** or **Hot**.

The difference between not using a covering axiom, and using a covering axiom is depicted in Figure 4.56. In both cases the classes **Mild**, **Medium** and **Hot** are disjoint — they do not overlap. It can be seen that in the case without a covering axiom an individual may be a member of the class **SpicinessValuePartition** and still not be a member of **Mild**, **Medium** or **Hot** — **SpicinessValuePartition** is *not* covered by **Mild**, **Medium** and **Hot**. Contrast this with the case when a covering axiom *is* used. It can be seen that if an individual is a member of the class **SpicinessValuePartition**, it *must* be a member of one of the three subclasses **Mild**, **Medium** or **Hot** — **SpicinessValuePartition** is *covered* by **Mild**, **Medium** and **Hot**.

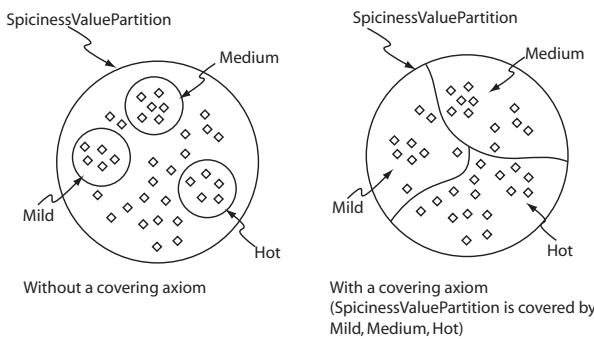


Figure 4.56: The effect of using a covering axiom on the **SpicinessValuePartition**

4.15 Adding Spiciness to Pizza Toppings

We can now use the **SpicinessValuePartition** to describe the spiciness of our pizza toppings. To do this we will add an existential restriction to each kind of **PizzaTopping** to state its spiciness. Restrictions

will take the form, `hasSpiciness some SpicinessValuePartition`, where `SpicinessValuePartition` will be one of `Mild`, `Medium` or `Hot`.

We can do this for each topping as we have already done when describing pizzas or we can use the *Matrix Plugin* (see Section C.2.1 in the Appendix) to speed up the process.

Exercise 40: Specify hasSpiciness restrictions on PizzaToppings

1. Make sure that `JalapenoPepperTopping` is selected in the class hierarchy.
 2. Use the ‘Add’ icon () on the ‘Superclasses’ section of the ‘Class Description view’ which opens a dialog.
 3. Select the ‘Class expression editor’ tab.
 4. Type `hasSpiciness some Hot` to create the existential restriction. Remember you can use autocomplete to speed up the process.
 5. Press ‘OK’ to create the restriction — if there are any errors, the restriction will not be created, and the error will be highlighted in red.
 6. Repeat this for each of the bottom level `PizzaToppings` (those that have no subclasses).
-

To complete this section, we will create a new class `SpicyPizza`, which should have pizzas that have spicy toppings as its subclasses. In order to do this we want to define the class `SpicyPizza` to be a `Pizza` that has *at least* one topping (`hasTopping`) that has a spiciness (`hasSpiciness`) that is `Hot`. This can be accomplished in more than one way, but we will create a restriction on the `hasTopping` property, that has a restriction on the `hasSpiciness` property as its filler.

Exercise 41: Create a SpicyPizza as a subclass of Pizza

1. Create a subclass of `Pizza` called `SpicyPizza`.
 2. Ensure `SpicyPizza` is selected.
 3. Press the ‘Add’ icon () on the ‘Superclasses’ section of the class description view
 4. Type `hasTopping` as the property to be restricted.
 5. Type ‘`some`’ as the type of restriction.
 6. The filler should be: `PizzaTopping and hasSpiciness some Hot`. This filler describes an anonymous class, which contains the individuals that are members of the class `PizzaTopping` and also members of the class of individuals that are related to the members of class `Hot` via the `hasSpiciness` property. In other words, the things that are `PizzaToppings` and have a spiciness that is `Hot`. To create this restriction in the text box type, ‘`(PizzaTopping and (hasSpiciness some Hot))`’, including the brackets.
 7. Finally, select the ‘Convert to defined class’ option in the ‘Edit’ menu.
-

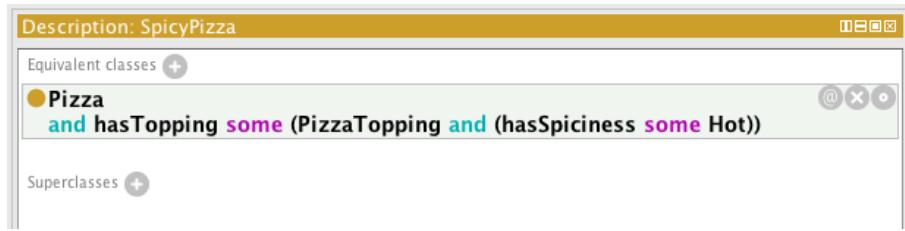


Figure 4.57: The definition of SpicyPizza

The class description view should now look like the picture shown in Figure 4.57

MEANING



Our description of a **SpicyPizza** above says that all members of **SpicyPizza** are **Pizzas** and have at least one topping that has a Spiciness of **Hot**. It also says that *anything* that is a **Pizza** and has *at least* one topping that has a spiciness of **Hot** is a **SpicyPizza**.



In the final step of Exercise 41 we created a restriction that had the *class expression* (**PizzaTopping** and **hasSpiciness some Hot**) rather than a named class as its filler. This filler was made up of an intersection between the named class **PizzaTopping** and the restriction **hasSpiciness some Hot**. Another way to do this would have been to create a subclass of **PizzaTopping** called **HotPizzaTopping** and define it to be a hot topping by having a necessary condition of **hasSpiciness some Hot**. We could have then used **hasTopping some HotPizzaTopping** in our definition of **SpicyPizza**. Although this alternative way is simpler, it is more verbose. OWL allows us to essentially shorten class descriptions and definitions by using class expressions in place of named classes as in the above example.

We should now be able to invoke the reasoner and determine the spicy pizzas in our ontology.

Exercise 42: Use the reasoner to classify the ontology

1. Press ‘Classify...’ in the Reasoner drop down menu to invoke the reasoner and classify the ontology.

After the reasoner has finished, the ‘Inferred Hierarchy’ class pane will pop open, and you should find that **AmericanHotPizza** has been classified as a subclass of **SpicyPizza** — the reasoner has automatically computed that any individual that is a member of **AmericanHotPizza** is also a member of **SpicyPizza**.

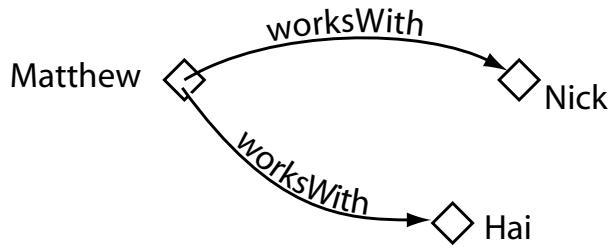


Figure 4.58: Cardinality Restrictions: Counting Relationships

4.16 Cardinality Restrictions

In OWL we can describe the class of individuals that have *at least*, *at most* or *exactly* a specified number of relationships with other individuals or datatype values. The restrictions that describe these classes are known as *Cardinality Restrictions*. For a given property P , a *Minimum Cardinality Restriction* specifies the minimum number of P relationships that an individual must participate in. A *Maximum Cardinality Restriction* specifies the maximum number of P relationships that an individual can participate in. A *Cardinality Restriction* specifies the *exact* number of P relationships that an individual must participate in.

Relationships (for example between two individuals) are only counted as separate relationships if it can be determined that the individuals that are the *fillers* for the relationships are *different* to each other. For example, Figure 4.58 depicts the individual **Matthew** related to the individuals **Nick** and the individual **Hai** via the **worksWith** property. The individual **Matthew** satisfies a *minimum cardinality* restriction of 2 along the **worksWith** property if the individuals **Nick** and **Hai** are distinct individuals i.e. they are different individuals.

Let's add a cardinality restriction to our Pizza Ontology. We will create a new subclass of **Pizza** called



Figure 4.59: The Class Description View Displaying the Description of an InterestingPizza

InterestingPizza, which will be defined to have three or more toppings.

Exercise 43: Create an InterestingPizza that has at least three toppings

1. Switch to the Classes tab and make sure that the Pizza class is selected.
2. Create a subclass of Pizza called InterestingPizza.
3. Press the ‘Add’ icon (⊕) on the ‘Superclasses’ section of the class description view.
4. Type hasTopping as a property to be restricted.
5. Type ‘min’ to create a minimum cardinality restriction.
6. Specify a minimum cardinality of three by typing 3 into the text box.
7. Press the ‘Enter’ to close the dialog and create the restriction. The class description view should now show Pizza and hasTopping min 3 under ‘Superclasses’. The ‘Equivalent classes’ section should be empty.
8. Select the ‘Convert to defined class’ option in the ‘Edit’ menu. The ‘Superclasses’ section should be empty now while the ‘Equivalent classes’ section should show Pizza and hasTopping min 3.

The class description view should now appear like the picture shown in Figure 4.59.

MEANING



What does this mean? Our definition of an InterestingPizza describes the set of individuals that are members of the class Pizza and that have *at least* three hasTopping relationships with other (distinct) individuals.

Exercise 44: Use the reasoner to classify the ontology

1. Press ‘Classify...’ in the Reasoner drop down menu.

Figure 4.60: Describing a FourCheesePizza using a Qualified Cardinality Restriction

After the reasoner has classified the ontology, the ‘**Inferred Hierarchy**’ window will pop open. Expand the hierarchy so that **InterestingPizza** is visible. Notice that **InterestingPizza** now has subclasses **AmericanaPizza**, **AmericanHotPizza** and **SohoPizza** — notice **MargheritaPizza** has *not* been classified under **InterestingPizza** because it only has two distinct kinds of topping.

4.17 Qualified Cardinality Restrictions

In the previous section we described cardinality restrictions - specifies the *exact* number of **P** relationships that an individual must participate in. In this section we focus on *Qualified* Cardinality Restrictions (QCR), which are more specific than cardinality restrictions in that they state the class of objects within the restriction. Let’s add a Qualified Cardinality Restriction to our pizza ontology. To do this, we will create a subclass of **NamedPizza**, called **Four Cheese Pizza**, which will be defined as having exactly four cheese toppings.

Exercise 45: Create a Four Cheese Pizza that has exactly four cheese toppings (Figure 4.60)

1. Create a subclass of **Pizza** called **FourCheesePizza**
 2. Select the ‘**Superclasses**’ header in the class description view
 3. Press the ‘**Add**’ icon () to open a text box
 4. Type **hasTopping** for the property
 5. Type **exactly** to create an exact cardinality restriction
 6. Specify a QCR of four by typing **4** into the text box
 7. Type **CheeseTopping** to specify the type of topping
 8. Click OK and create the restriction
-

Our definition of a **FourCheesePizza** describes the set of individuals that are members of the class **NamedPizza** and that have exactly *four* **hasTopping** relationships with individuals of the **CheeseTopping** class. With this description a **FourCheesePizza** can still also have other relationships to other kinds of toppings. In order for us to say that we just want it to have four cheese toppings and no other toppings we must add the keyword ‘*only*’ (the universal quantifier). This means that the only kinds of topping allowed are cheese toppings.



An unqualified cardinality restriction is exactly the same as a qualified cardinality restriction with a filler of **Thing**.
eg. **hasTopping min 3** is the same as **hasTopping min 3 Thing**.

Chapter 5

Datatype Properties

In Section 4.4 of Chapter 4 we introduced properties in OWL, but only described object properties—that is, relationships between individuals. In this chapter we will discuss and show examples of Datatype properties. Datatype properties link an individual to an XML Schema Datatype value or an rdf literal. In other words, they describe relationships between an individual and data values. Most of the property characteristics described in Chapter 4 cannot be used with datatype properties. We will describe those characteristics of properties that are applicable to data properties later in this chapter.

Datatype properties can be created using the ‘**Datatype Properties view**’ in either the ‘**Entities**’ or ‘**Datatype Properties tab**’ shown in Figure 5.1.

We will use datatype properties to describe the calorie content of pizzas. We will then use some numeric ranges to broadly classify particular pizzas as high or low calorie. In order to do this we need to complete the following steps:

- Create a datatype property `hasCalorificContentValue`, which will be used to state the calorie content of particular pizzas.
- Create several example pizza individuals with specific calorie contents.
- Create two classes broadly categorising pizzas as low or high calorie.

Now let us do this in Protégé.

A datatype property can be used to relate an individual to a concrete data value that may be typed or untyped.

Exercise 46: Create a datatype property called `hasCalorificContentValue`

1. Switch to the ‘**Datatype Properties**’ tab. Use the ‘**Add Datatype Property**’ button to create a new Datatype property called `hasCalorificContentValue`.
-

There is nothing intrinsic to data properties to prevent us from performing class-level classification, but

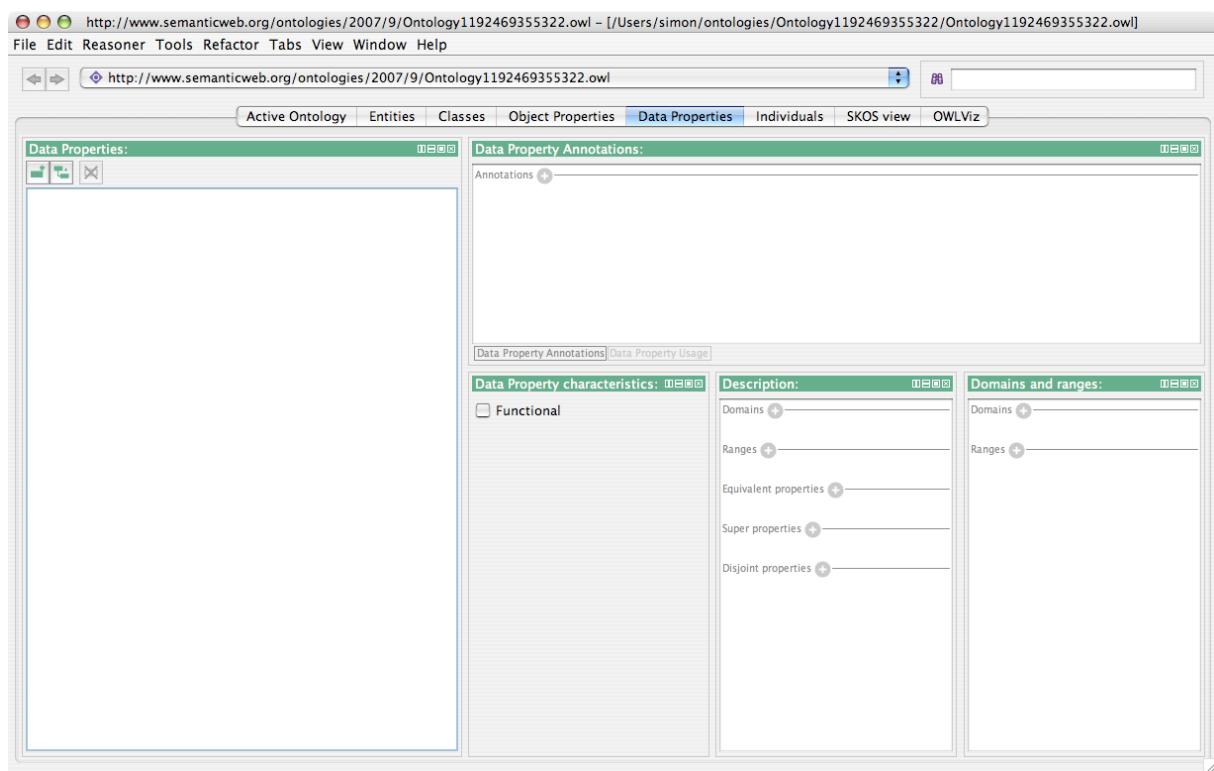


Figure 5.1: A snapshot of the Datatype Properties tab in Protégé

we will create some individuals as examples for classification as it is probably too strong to say that all `MargheritaPizzas` have exactly 263 calories.

Exercise 47: Create example pizza individuals

1. Ensure the ‘Entities Tab’ or ‘Individuals Tab’ is selected and that the ‘Individuals view’ is visible (by default in the entities tab it will be one of the views stacked at the bottom left of the tab).
2. Press the ‘Add individual’ button and create an individual called `Example-Margherita`
3. In the ‘Individual Description view’ add a type of `MargheritaPizza`. In the dialog that appears you can do this with either the ‘Class hierarchy’ or the ‘Class expression editor’.
4. In the ‘Property assertions view’ add a ‘Data property assertion’ and in the dialog shown in Figure 5.2 ensure `hasCalorificContentValue` is selected as the property, `integer` is selected as the type and a value of `263` is entered.
5. Create several more example pizza individuals with different calorie contents including an instance of `QuattroFormaggio` with `723` calories.

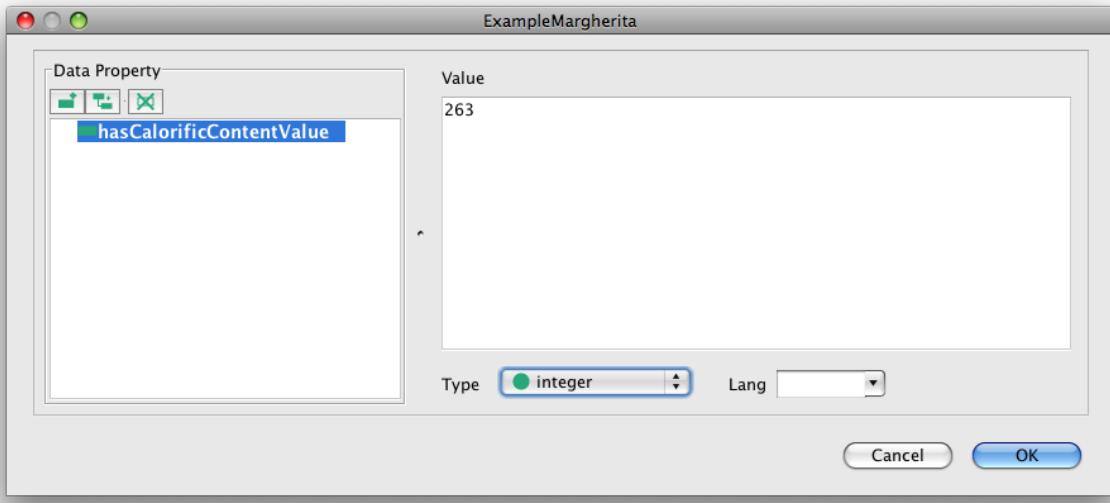


Figure 5.2: Creating a data property assertion

A datatype property can also be used in a restriction to relate individuals to members of a given datatype. Built in datatypes are specified in the XML schema vocabulary and include integers, floats, strings, booleans etc.

Exercise 48: Create a datatype restriction to state that all Pizzas have a calorific value

1. Ensure the ‘Entities’ or ‘Classes’ Tab is selected
2. Select **Pizza** and in the ‘Class Description view’ and add a superclass. This brings up the editor dialog.
3. In the dialog select the ‘**Data restriction creator**’ shown in Figure 5.3. This operates in the same way as the object restriction creator, but the filler is a named datatype.
4. Make sure the type of restriction is set to ‘**some**’.
5. select **hasCalorificContentValue** as the property being restricted.
6. Finally, choose the datatype **integer**
7. press ‘**OK**’. The restriction **hasCalorificContentValue some integer** is now shown in the superclasses.

MEANING



We have now stated that all pizzas have at least one calorific value (and that value must be an integer).

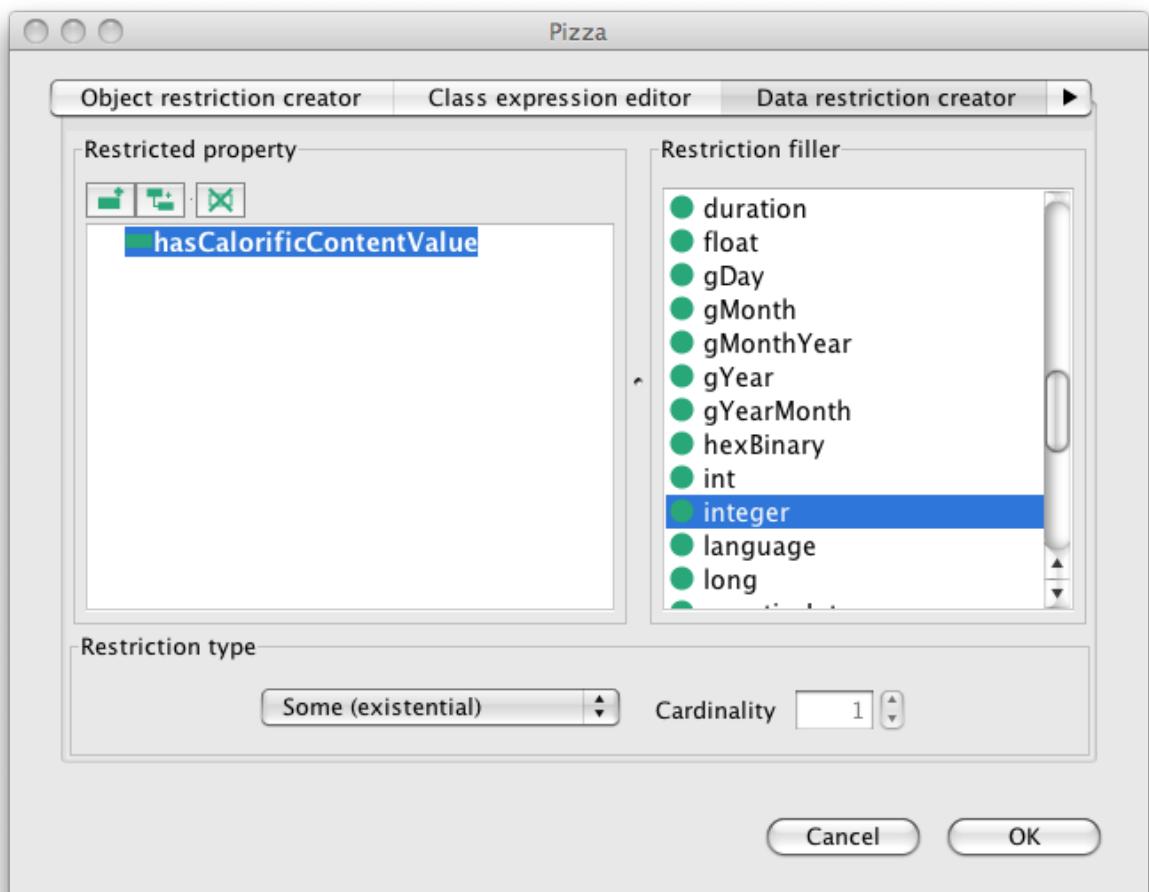


Figure 5.3: Creating a some restriction using a data property

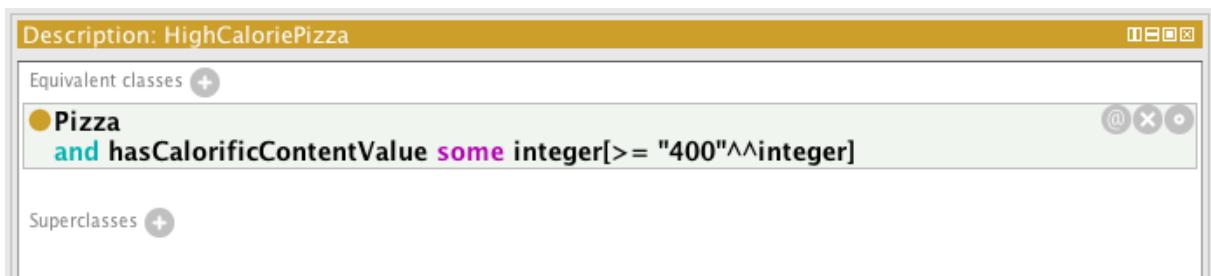


Figure 5.4: Using datatype restrictions to define ranges for HighCaloriePizza

In addition to using the predefined set of datatypes we can further specialise the use of a datatype by specifying restrictions on the possible values. For example, it is easy to specify a range of values for a number.

Using the datatype property we have created, we will now create defined classes that specify a range of interesting values. We will create definitions that use the `minInclusive` and `maxExclusive` facets that can be applied to numeric datatypes. **HighCaloriePizza** will be defined to be *any pizza that has a calorific value equal to or higher than 400*.

Exercise 49: Create a HighCaloriePizza that has a calorific value higher than or equal to 400

1. Ensure the ‘Classes Tab’ or ‘Entities Tab’ is selected.
2. Create a subclass of **Pizza** called **HighCaloriePizza**.
3. In the ‘Class Description view’ click the ‘Add’ icon (+) in the ‘Superclasses’ section to add a new restriction
4. In the ‘Class expression editor’, type ‘`hasCalorificContentValue some integer[>= 400]`’ and click ‘OK’
5. Convert the class to a defined class (‘Ctrl-D’, or ‘Command-D’ on a Mac). You should now have a class defined as in Figure 5.4.
6. Create a **LowCaloriePizza** in the same way, but define it as being equivalent to **Pizza** and `hasCalorificContentValue some integer[< 400]` (any pizza that has a calorific value less than 400). Notice that the definition does not overlap with **HighCaloriePizza**.

You now have two categories of pizza that should cover any individual that has had its calorie content specified. We should now be able to test if the classification holds for the example individuals we created.

Description: HighCaloriePizza

Equivalent classes +

Pizza
and hasCalorificContentValue some integer[>= "400"^^integer]

Superclasses +

Pizza

Inherited anonymous classes

hasCalorificContentValue some integer
hasBase some PizzaBase

Members +

ExampleAmericanHot
ExampleFruttiDiMare
ExampleQuattroFormaggio

Disjoint classes +

Figure 5.5: Individuals classified as being members of HighCaloriePizza

We will use the reasoner to perform instance classification.

Exercise 50: Classify pizza individuals based on their hasCalorificContentValue

1. Select a reasoner from the ‘Reasoner menu’ or press ‘Classify’ if one is already selected. The reasoner should classify and show the inferred class hierarchy.
2. Select **HighCaloriePizza**. You should be able to see inferences shown in the ‘Class Description view’ in yellow with a dashed border.
3. Check the ‘Members’ section (see Figure 5.5). It should include your instance of ‘QuattroFormaggio’ and perhaps other individuals which you specified as having a calorie value equal to or over 400.
4. Select **LowCaloriePizza**. Check the ‘Members’ section. It should include your instance of ‘ExampleMargherita’ and perhaps other individuals which you specified as having a calorie value lower than 400.

Finally, think about how many different calorie values can be held by an individual pizza. Of course, the answer is only one. Remember that there is a property characteristic that states that a property with that characteristic can only be held by an individual once. By describing an object property as *functional* we state that any given individual can be related to *at most* one other individual along that property. We can also use the functional characteristic on data properties (This is currently the only characteristic

it is possible to use on data properties) By making `hasCalorificContentValue` functional we are saying that any one pizza can only ever have one calorie value.

Exercise 51: Making the `hasCalorificContentValue` datatype property functional

1. Go to the ‘Datatype Properties’ tab and select `hasCalorificContentValue`
 2. In the ‘Data Type Characteristics’ pane, click the ‘functional’ radio button.
 3. Test that this works by creating a pizza individual that has two calorie values. This should cause the ontology to become inconsistent.
-



NOTE

There are several ways to model units in OWL, but we will not be reasoning about them so have chosen to keep the example simple. In this example the units are implicit in the name of the property (calories) and are used universally throughout our ontology.

Chapter 6

More On Open World Reasoning

The examples in this chapter demonstrate the nuances of Open World Reasoning.

We will create a **NonVegetarianPizza** to complement our categorisation of pizzas into **VegetarianPizzas**. The **NonVegetarianPizza** should contain all of the **Pizzas** that are *not* **VegetarianPizzas**. To do this we will create a class that is the *complement* of **VegetarianPizza**. A *complement* class contains all of the individuals that are *not* contained in the class that it is the complement to. Therefore, if we create **NonVegetarianPizza** as a subclass of **Pizza** *and* make it the *complement* of **VegetarianPizza** it should contain all of the **Pizzas** that are *not* members of **VegetarianPizza**.

Exercise 52: Create NonVegetarianPizza as a subclass of Pizza and make it disjoint to Vegetarian-Pizza

1. Select **Pizza** in the class hierarchy on the ‘Classes’ tab. Press the ‘Add’ icon (⊕) to create a new class as the subclass of **Pizza**.
 2. Name the new class **NonVegetarianPizza**.
 3. Make **NonVegetarianPizza** disjoint with **VegetarianPizza** — while **NonVegetarian-Pizza** is selected, go to the ‘Class description’ view and press the ‘Add’ icon (⊕) on the ‘Disjoint classes’ section.
-

We now want to define a **NonVegetarianPizza** to be a **Pizza** that is not a **VegetarianPizza**.

Exercise 53: Make VegetarianPizza the complement of VegetarianPizza

1. Make sure that **NonVegetarianPizza** is selected in the class hierarchy on the '**Classes tab**'.
 2. Double click on **Pizza** in the '**Superclasses**' section of the '**Class Description View**', and edit to create **Pizza** and not **VegetarianPizza**.
 3. Press OK to create and assign the expression. If everything was entered correctly then the expression editor will close and the expression will have been created. (If there are errors, check the spelling of **VegetarianPizza**).
-

TIP

A very useful feature of the expression editor is the ability to 'auto complete' class names, property names and individual names. The auto completion for the inline expression editor is activated using the tab key. In the above example if we had typed **Vege** into the inline expresion editor and pressed the tab key, the choices to complete the word **Vege** would have poped up in a list as shown in Figure 6.1. The up and down arrow keys could then have been used to select **VegetarianPizza** and pressing the Enter key would complete the word for us.

The class description view should now resemble the picture shown in 6.2. However, we need to add **Pizza** to the *necessary and sufficient* conditions as at the moment our definition of **NonVegetarianPizza** says that an individual that is not a member of the class **VegetarianPizza** (everything else!) is a **NonVegetarianPizza**.

Exercise 54: Add Pizza to the necessary and sufficient conditions for NonVegetarianPizza

1. Make sure **NonVegetarianPizza** is selected in the class hierarchy on the '**Clases**' tab.
 2. Convert the superclass to an equivalent class. Either select '**Edit — Convert to defined class**' or copy and paste the superclass you just edited from the superclasses to the equivalent classes section. Note that before pasting you should select the '**Equivalent classes**' header.
-

The '**Class Description View**' should now look like the picture shown in Figure 6.3.

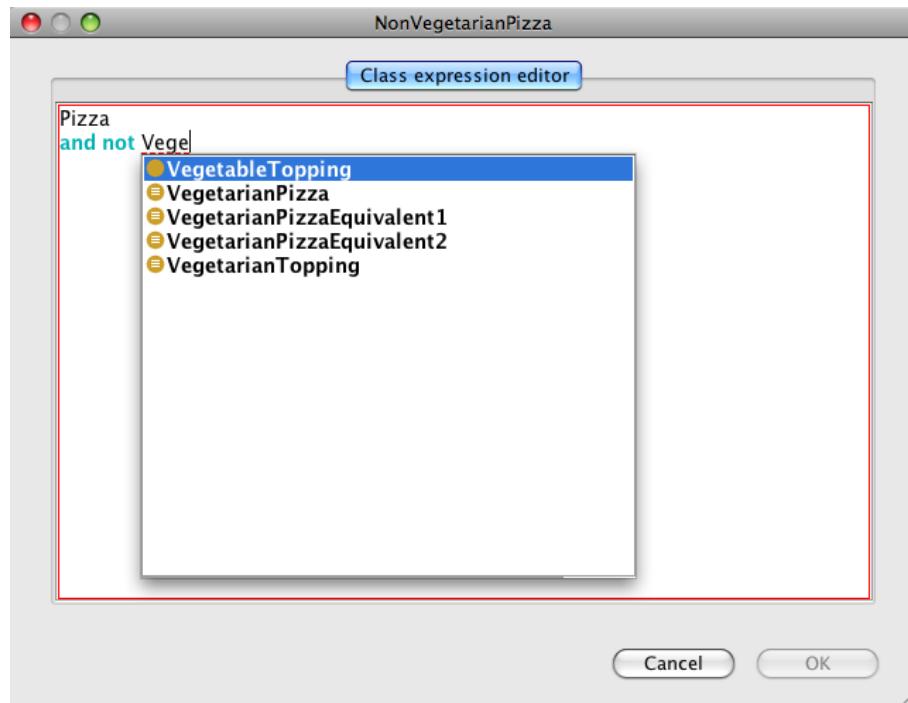


Figure 6.1: Class Description View: Expression Editor Auto Completion

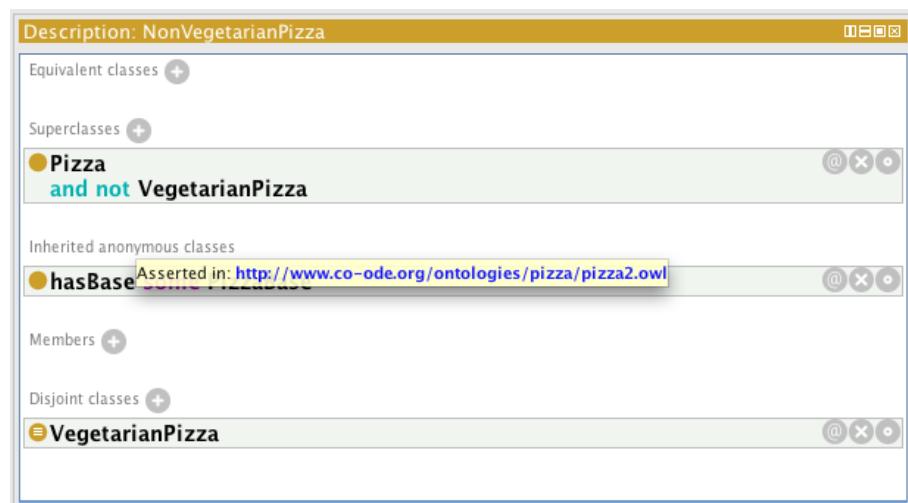


Figure 6.2: The Class Description View Displaying NonVegetarianPizza as a primitive class



Figure 6.3: The Class Description View Displaying the Definition for `NonVegetarianPizza`

MEANING



The complement of a class includes all of the individuals that are not members of the class. By making `NonVegetarianPizza` a subclass of `Pizza` and the complement of `VegetarianPizza` we have stated that individuals that are `Pizzas` and are *not* members of `VegetarianPizza` must be members of `NonVegetarianPizza`. Note that we also made `VegetarianPizza` and `NonVegetarianPizza` disjoint so that if an individual is a member of `VegetarianPizza` it cannot be a member of `NonVegetarianPizza`.

Exercise 55: Use the reasoner to classify the ontology

1. Press the ‘Classify...’ button in the Reasoner toolbar. After a short time the reasoner will have computed the inferred class hierarchy, and the inferred class hierarchy pane will pop open.

The inferred class hierarchy should resemble the picture shown in Figure 6.4. As can be seen, `MargheritaPizza` and `SohoPizza` have been classified as subclasses of `VegetarianPizza`. `AmericanaPizza` and `AmericanHotPizza` have been classified as `NonVegetarianPizza`. Things *seemed* to have worked. How-

ever, let's add a pizza that does not have a closure axiom on the `hasTopping` property.

Exercise 56: Create a subclass of NamedPizza with a topping of Mozzarella

1. Create a subclass of `NamedPizza` called `UnclosedPizza`.
 2. Making sure that `UnclosedPizza` is selected in the 'Class Description View' select the 'Superclasses' header.
 3. Press the 'Add class' button to display restriction text box.
 4. Type `hasTopping` as the property to be restricted.
 5. Type '`some`' in order to create an existential restriction.
 6. Type `MozzarellaTopping` into text box to specify that the toppings must be individuals that are members of the class `MozzarellaTopping`.
 7. Press 'Enter' to close the dialog and create the restriction.
-

MEANING



If an individual is a member of `UnclosedPizza` it is necessary for it to be a `NamedPizza` and have *at least one* `hasTopping` relationship to an individual that is a member of the class `MozzarellaTopping`. Remember that because of the Open World Assumption and the fact that we have not added a closure axiom on the `hasTopping` property, an `UnclosedPizza` *might* have additional toppings that are not kinds of `MozzarellaTopping`.

Exercise 57: Use the reasoner to classify the ontology

1. Press 'Classify...' in the Reasoner drop down menu.
-

Examine the class hierarchy. Notice that `UnclosedPizza` is neither a `VegetarianPizza` or `NonVegetarianPizza`.

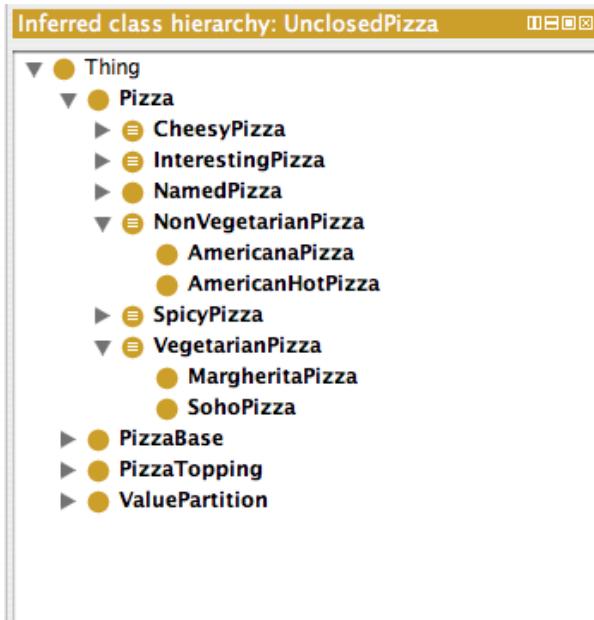


Figure 6.4: The Inferred Class Hierarchy Showing Inferred Subclasses of `VegetarianPizza` and `NonVegetarianPizza`

MEANING



As expected (because of Open World Reasoning) `UnclosedPizza` has *not* been classified as a `VegetarianPizza`. The reasoner cannot determine `UnclosedPizza` is a `VegetarianPizza` because there is no closure axiom on the `hasTopping` and the pizza *might* have other toppings. We therefore might have expected `UnclosedPizza` to be classified as a `NonVegetarianPizza` since it has not been classified as a `VegetarianPizza`. However, Open World Reasoning does not dictate that because `UnclosedPizza` cannot be determined to be a `VegetarianPizza` it is *not* a `VegetarianPizza` — it *might* be a `VegetarianPizza` and also it *might not* be a `VegetarianPizza`! Hence, `UnclosePizza` cannot be classified as a `NonVegetarianPizza`.

Chapter 7

Creating Other OWL Constructs In Protégé 4

This chapter discusses how to create some other OWL constructs using Protégé 4. These constructs are not part of the main tutorial and may be created in a new Protégé 4 project if desired. This chapter is best followed using the pizza ontology already built.

7.1 Creating Individuals

OWL allows us to define individuals and to assert properties about them. Individuals can also be used in class descriptions, namely in hasValue restrictions and enumerated classes which will be explained in section 7.2 and section 7.3 respectively. To create individuals in Protégé 4 the '**Individuals Tab**' is used.

Suppose we wanted to describe the country of origin of various pizza toppings. We would first need to add various ‘countries’ to our ontology. Countries, for example, ‘England’, ‘Italy’, ‘America’, are typically thought of as being individuals (it would be incorrect to have a class **England** for example, as it’s members would be deemed to be, ‘things that are instances of **England**’). To create this in our Pizza Ontology we

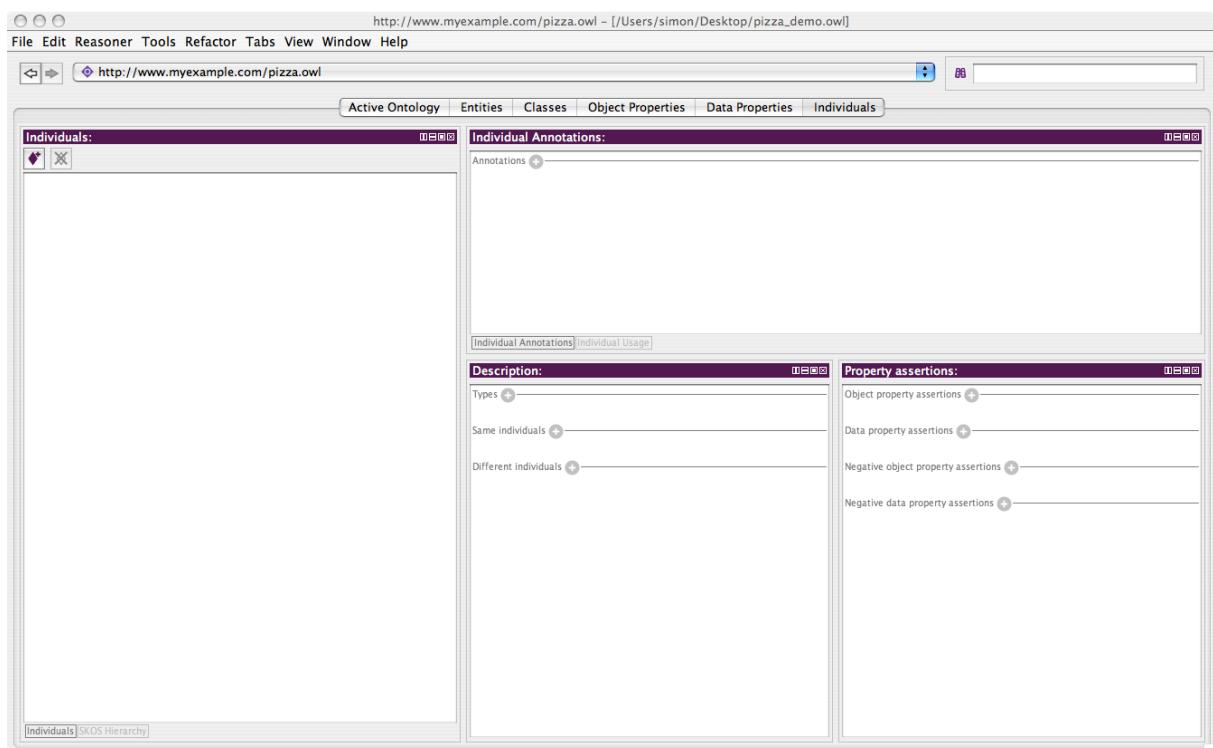


Figure 7.1: The Individuals Tab

will create a class **Country** and then ‘populate’ it with individuals:

Exercise 58: Create a class called Country and populate it with some individuals

1. Create **Country** as a subclass of **Thing**.
2. Switch to the ‘**Individuals Tab**’ shown in Figure 7.1.
3. Press the ‘**Add individual**’ button shown in Figure 7.2. (Remember that ‘Individual’ is another name for ‘Instance’ in ontology terminology).
4. Name the new Individual **Italy**.
5. Select the ‘**Add**’ icon (+) next to the ‘**Types**’ header from the ‘**Individual Types View**’ located in the centre of the Individual tab. Choose **Country** from the class hierarchy, this will make **Italy** an individual of the class **Country**.
6. Use the above steps to create some more individuals that are members of the class **Country** called **America**, **England**, **France**, and **Germany**.

Recall from section 3.1.1 that OWL does not use the Unique Name Assumption (UNA). Individuals can therefore be asserted to be the ‘Same As’ or ‘Different From’ other individuals. In Protégé 4 these assertions can be made using the ‘**SameAs**’ and ‘**DifferentFrom**’ sections of the ‘**Individual Description**

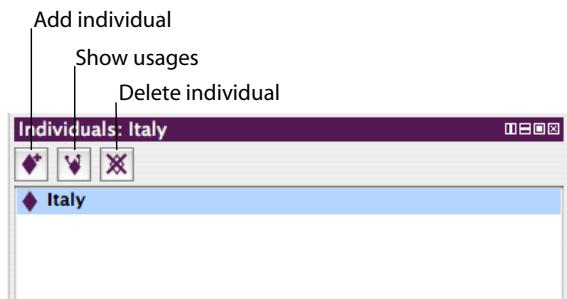


Figure 7.2: Instances Manipulation Buttons

view’.

Having created some individuals we can now use these individuals in class descriptions as described in section 7.2 and section 7.3.

7.2 hasValue Restrictions

A hasValue restriction, denoted by the symbol \exists , describes the set of individuals that have *at least one* relationship along a specified property to a *specific individual*. For example, the hasValue restriction `hasCountryOfOrigin \exists Italy` (where `Italy` is an individual) describes the set of individuals (the anonymous class of individuals) that have *at least* one relationship along the `hasCountryOfOrigin` property to the *specific* individual `Italy`. For more information about hasValue restrictions please see Appendix A.2.

Suppose that we wanted to specify the origin of ingredients in our pizza ontology. For example, we might want to say that mozzarella cheese (`MozzarellaTopping`) is from `Italy`. We already have some countries in our pizza ontology (including `Italy`), which are represented as individuals. We can use a hasValue



Figure 7.3: The Class Description View Displaying The hasValue Restriction for MozzarellaTopping

restriction along with these individuals to specify the county of origin of MozzarellaTopping as Italy.

Exercise 59: Create a hasValue restriction to specify that MozzarellaTopping has Italy as its country of origin.

1. Switch to the ‘Object Properties’ tab. Create a new object property and name it **hasCountryOfOrigin**.
2. Switch to the ‘Classes’ tab and select the class **MozzarellaTopping**.
3. Select the ‘Add’ icon (⊕) on the ‘Superclasses’ section of the ‘Class Description View’ to open the editor.
4. Type **hasCountryOfOrigin** as the property to be restricted.
5. Type **value** as the type of restriction to be created.
6. Enter **Italy** as the individual to complete the restriction. You can either type this in or drag and drop from the individuals window.
7. Press ‘Enter’ to close the dialog and create the restriction.

The ‘Class Description View’ should now look similar to the picture shown in Figure 7.3.

MEANING



The conditions that we have specified for **MozzarellaTopping** now say that: individuals that are members of the class **MozzarellaTopping** are also members of the class **CheeseTopping** and are related to the individual **Italy** via the **hasCountryOfOrigin** property and are related to at least one member of the class **Mild** via the **hasSpiciness** property. In more natural English, things that are kinds of mozzarella topping are also kinds of cheese topping and come from Italy and are mildly spicy.



With current reasoners the classification is *not complete* for individuals. Use individuals in class descriptions with care — unexpected results may be caused by the reasoner.

7.3 Enumerated Classes

As well as describing classes through named superclasses and anonymous superclasses such as restrictions, OWL allows classes to be defined by precisely listing the individuals that are the members of the class. For example, we might define a class `DaysOfTheWeek` to contain the individuals (and only the individuals) `Sunday`, `Monday`, `Tuesday`, `Wednesday`, `Thursday`, `Friday` and `Saturday`. Classes such as this are known as *enumerated* classes.

In Protégé 4 enumerated classes are defined using the ‘**Class Description View**’ expression editor – the individuals that make up the enumerated class are listed (separated by spaces) inside curly brackets. For example `{Sunday Monday Tuesday Wednesday Thursday Friday Saturday}`. The individuals must first have been created in the ontology. Enumerated classes described in this way are anonymous classes – they are the class of the individuals (and only the individuals) listed in the enumeration. We can attach these individuals to a named class in Protégé 4 by creating the enumeration as an equivalent class.

Exercise 60: Convert the class `Country` into an enumerated class

1. Switch the ‘**Classes**’ tab and select the class `Country`.
 2. Select the ‘**Equivalent classes**’ section in the ‘**Class Description**’ view.
 3. Press the ‘**Add**’ icon () of the ‘**Equivalent classes**’ section. A text box will appear.
 4. Type `{America, England, France, Germany, Italy}` into the text box. (Remember to surround the items with curly brackets). Remember that the auto complete function is available — to use it type the first few letters of an individual and press the tab key to get a list of possible choices.
 5. Press the enter key to accept the enumeration and close the expression editor.
-

The ‘**Class Description View**’ should now look similar to the picture shown in Figure 7.4.



Figure 7.4: The Class Description View Displaying An Enumeration Class

MEANING



This means that an individual that is a member of the **Country** class must be one of the listed individuals (i.e one of **America** **England** **France** **Germany** **Italy**).^a More formally, the class **country** is equivalent to (contains the same individuals as) the anonymous class that is defined by the enumeration — this is depicted in Figure 7.5.

^aThis is obviously not a complete list of countries, but for the purposes of this ontology (and this example!) it meets our needs.

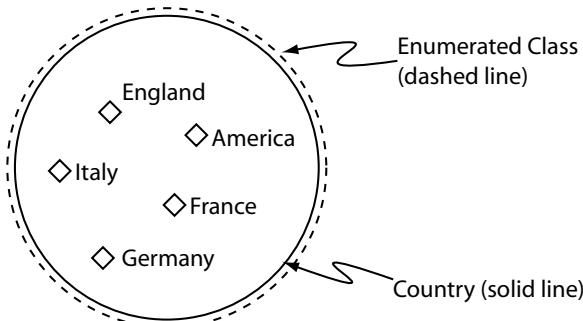


Figure 7.5: A Schematic Diagram Of The **Country** Class Being Equivalent to an Enumerated Class

7.4 Annotation Properties

OWL allows classes, properties, individuals and the ontology itself (technically speaking the ontology header) to be annotated with various pieces of information/meta-data. These pieces of information may take the form of auditing or editorial information. For example, comments, creation date, author, or, references to resources such as web pages etc. OWL-Full does not put any constraints on the usage of annotation properties. However, OWL-DL does put several constraints on the usage of annotation properties — two of the most important constraints are:

- The filler for annotation properties must either be a data literal¹, a URI reference or an individual.
- Annotation properties cannot be used in property axioms — for example they may not be used in the property hierarchy, so they cannot have sub properties, or be the sub property of another property. They also must not have a domain and a range set for them.

¹A data literal is the character representation of a datatype value, for example, “Matthew”, 25, 3.11.

OWL has five pre-defined annotation properties that can be used to annotate classes (including anonymous classes such as restrictions), properties and individuals:

1. **owl:versionInfo** — in general the range of this property is a string.
2. **rdfs:label** — has a range of a string. This property may be used to add meaningful, human readable names to ontology elements such as classes, properties and individuals. **rdfs:label** can also be used to provide multi-lingual names for ontology elements.
3. **rdfs:comment** — has a range of a string.
4. **rdfs:seeAlso** — has a range of a URI which can be used to identify related resources.
5. **rdfs:isDefinedBy** — has a range of a URI reference which can be used to reference an ontology that defines ontology elements such as classes, properties and individuals.

For example the annotation property **rdfs:comment** is used to store the comment for classes in Protégé 4. The annotation property **rdfs:label** could be used to provide alternative names for classes, properties etc.

There are also several annotation properties which can be used to annotate an ontology. The ontology annotation properties (listed below) have a range of a URI reference which is used to refer to another ontology. It is also possible to the use the **owl:VersionInfo** annotation property to annotate an ontology.

- **owl:priorVersion** — identifies prior versions of the ontology.
- **owl:backwardsCompatibleWith** — identifies a prior version of an ontology that the current ontology is compatible with. This means that all of the identifiers from the prior version have the same intended meaning in the current version. Hence, any ontologies or applications that reference the prior version can safely switch to referencing the new version.
- **owl:incompatibleWith** — identifies a prior version of an ontology that the current ontology is *not* compatible with.

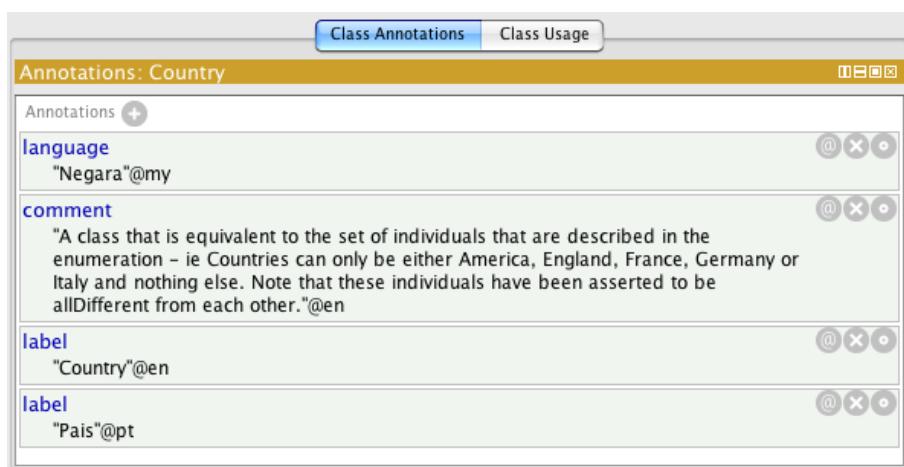


Figure 7.6: An annotations view

To create annotation properties use the appropriate annotation property view in each of the ‘**Active Ontology**’, ‘**Classes**’, ‘**Object Property**’ and ‘**Datatype Property**’ Tabs. You can manage your annotation using the ‘**Annotations Properties**’ Tab, new annotation properties can be created by pressing the ‘**create Annotation Property**’ button on the ‘**Annotation Property**’ Tab. To use annotation properties the annotations views shown in Figure 7.6 is used. An annotations view is located on the Classes, Properties, Individuals and Active Ontology tab for annotation classes, properties, individuals and the ontology respectively. Annotations can also be added to restrictions and other anonymous classes by right clicking (ctrl click on a Mac) in the class description view and selecting ‘**Edit annotation properties...**’.

7.5 Multiple Sets Of Necessary & Sufficient Conditions

In OWL it is possible to have multiple sets of necessary and sufficient conditions (Equivalent classes) as depicted in Figure 7.7. In the ‘**Class Description View**’, multiple sets of necessary and sufficient conditions are represented using multiple ‘**Equivalent class**’ headers with necessary and sufficient conditions listed under each header as shown in Figure 7.7. To create a *new* set of necessary and sufficient conditions, use the ‘**Add**’ icon (⊕) next to the ‘**Equivalent class**’ header. The Equivalent classes can then be written into the ‘**Class description**’ dialog box that appears.

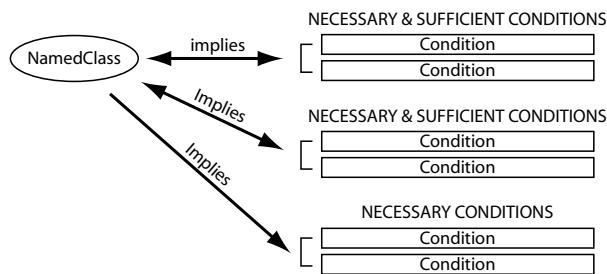


Figure 7.7: Necessary Conditions, and Multiple Sets of Necessary And Sufficient Conditions

Appendix A

Restriction Types

This appendix contains further information about the types of property restrictions in OWL. It is intended for readers who aren't too familiar with the notions of logic that OWL is based upon.

All types of restrictions describe an unnamed set that could contain some individuals. This set can be thought of as an *anonymous class*. Any individuals that are members of this anonymous class satisfy the restriction that describes the class (Figure A.1). Restrictions describe the constraints on relationships that the individuals participate in for a given property.

When we describe a named class using restrictions, what we are effectively doing is describing anonymous superclasses of the named class.

A.1 Quantifier Restrictions

Quantifier restrictions consist of three parts:

1. A quantifier, which is either the existential quantifier (some), or the universal quantifier (only).
2. A property, along which the restriction acts.
3. A filler that is a class description.

For a given individual, the quantifier effectively puts constraints on the relationships that the individual participates in. It does this by either specifying that *at least one* kind of relationship must exist, or by specifying the *only* kinds of relationships that can exist (if they exist).

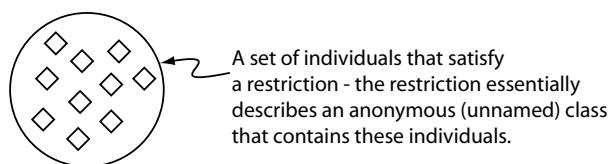


Figure A.1: Restrictions Describe Anonymous Classes Of Individuals

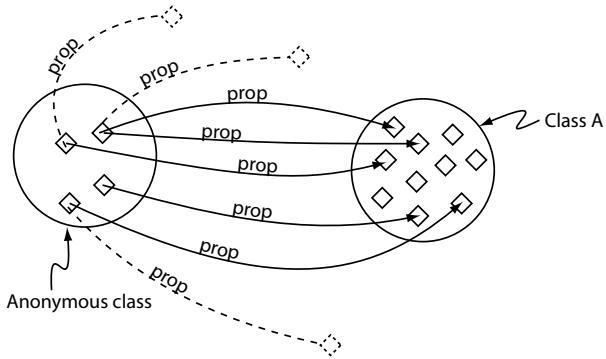


Figure A.2: A Schematic Of An Existential Restriction (`prop some ClassA`)

A.1.1 `someValuesFrom` – Existential Restrictions

Existential restrictions, also known as ‘`someValuesFrom`’ restrictions, or ‘`some`’ restrictions are denoted in DL-syntax using \exists – a backwards facing E. Existential restrictions describe the set of individuals that have *at least one* specific kind of relationship to individuals that are members of a specific class. Figure A.2 shows an abstracted schematic view of an existential restriction, $\exists \text{ prop ClassA}$ – i.e. a restriction along the property `prop` with a filler of `ClassA`. Notice that all the individuals in the anonymous class that the restriction defines have *at least one* relationship along the property `prop` to an individual that is a member of the class `ClassA`. The dashed lines in Figure A.2 represent the fact that the individuals *may* have other `prop` relationships with other individuals that are *not* members of the class `ClassA` even though this has not been explicitly stated — The existential restriction does not constrain the `prop` relationship to members of the class `ClassA`, it just states that every individual must have *at least one* `prop` relationship with a member of `ClassA` — this is the *open world assumption* (OWA).

For a more concrete example, the existential restriction, $\exists \text{ hasTopping MozzarellaTopping}$, describes the set of individuals that take place in *at least one* `hasTopping` relationship with an other individual that is a member of the class `MozzarellaTopping` — in more natural English this restriction could be viewed as describing the things that ‘have a Mozzarella topping’. The fact that we are using an existential restriction to describe the group of individuals that have *at least one* relationship along the `hasTopping` property with an individual that is a member of the class `MozzarellaTopping` does *not* mean that these individuals *only* have a relationship along the `hasTopping` property with an individual that is a member of the class `MozzarellaTopping` (there could be other `hasTopping` relationships that just haven’t been explicitly specified).

A.1.2 `allValuesFrom` – Universal Restrictions

Universal restrictions are also known as ‘`allValuesFrom`’ restrictions, or ‘`only`’ restrictions since they *constrain* the filler for a given property to a *specific* class. Universal restrictions are given the symbol \forall – i.e. an upside down A. Universal restrictions describe the set of individuals that, for a given property, *only* have relationships to other individuals that are members of a specific class. A feature of universal restrictions, is that for the given property, the set of individuals that the restriction describes will also contain the individuals that *do not have any* relationship along this property to any other individuals. A universal restriction along the property `prop` with a filler of `ClassA` is depicted in Figure A.3. Once again, an important point to note is that universal restrictions do not ‘guarantee’ the existence of a relationship for a given property. They merely state that if such a relationship for the given property exists, then it

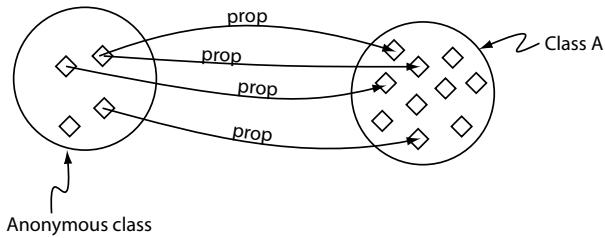


Figure A.3: A Schematic View Of The Universal Restriction, `prop` only `ClassA`

must be with an individual that is a member of a specified class.

Let's take a look at an example of a universal restriction. The restriction, $\forall \text{ hasTopping TomatoTopping}$ describes the anonymous class of individuals that *only* have `hasTopping` relationships to individuals that are members of the class `TomatoTopping`, OR, individuals that definitely *do not* participate in any `hasTopping` relationships at all.

A.1.3 Combining Existential And Universal Restrictions in Class Descriptions

A common ‘pattern’ is to combine existential and universal restrictions in class definitions for a given property. For example the following two restrictions might be used together, $\exists \text{ hasTopping MozzarellaTopping}$, and also, $\forall \text{ hasTopping MozzarellaTopping}$. This describes the set of individuals that have *at least* one `hasTopping` relationship to an individual from the class `MozzarellaTopping`, *and only* `hasTopping` relationships to individuals from the class `MozzarellaTopping`.

It is worth noting that is particularly unusual (and probably an error), if when describing a class, a universal restriction along a given property is used *without* using a ‘corresponding’ existential restriction along the same property. In the above example, if we had only used the universal restriction $\forall \text{ hasTopping Mozzarella}$, then we would have described the set of individuals that *only* participate in the `hasTopping` relationship with members of the class `Mozzarella`, *and also* those individuals that *do not participate in any* `hasTopping` relationships – probably a mistake.

A.2 hasValue Restrictions

A `hasValue` restriction, denoted by the symbol \exists , describes an anonymous class of individuals that are related to another *specific individual* along a specified property. Contrast this with a quantifier restriction where the individuals that are described by the quantifier restriction are related to *any* individual from a *specified* class along a specified property. Figure A.4 shows a schematic view of the `hasValue` restriction `prop` \exists `abc`. This restriction describes the anonymous class of individuals that have at least one relationship along the `prop` property to the specific individual `abc`. The dashed lines in Figure A.4 represent the fact that for a given individual the `hasValue` restriction does not constrain the property used in the restriction to a relationship with the individual used in the restriction i.e. there could be other relationships along the `prop` property. It should be noted that `hasValue` restrictions are semantically equivalent to an existential restriction along the same property as the `hasValue` restriction, which has a filler that is an enumerated class that contains the individual (and only the individual) used in the `hasValue` restriction.

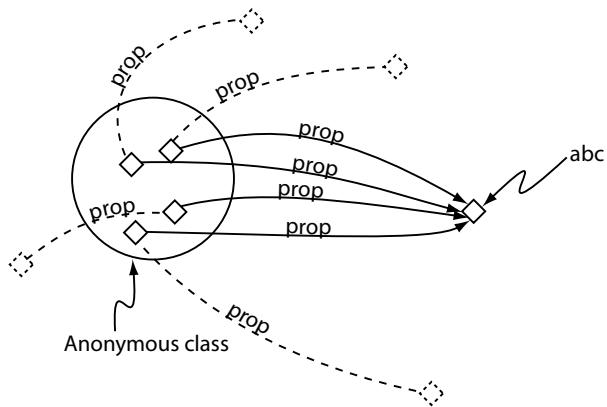


Figure A.4: A Schematic View Of The hasValue Restriction, $\text{prop} \ni \text{abc}$ — dashed lines indicate that this type of restriction does not constrain the property used in the hasValue restriction solely to the individual used in the hasValue restriction

A.3 Cardinality Restrictions

Cardinality restrictions are used to talk about the number of relationships that an individual may participate in for a given property. Cardinality restrictions are conceptually easier to understand than quantifier restrictions, and come in three flavours: Minimum cardinality restrictions, Maximum cardinality restrictions, and Cardinality restrictions.

A.3.1 Minimum Cardinality Restrictions

Minimum cardinality restrictions specify the *minimum* number of relationships that an individual must participate in for a given property. The symbol for a minimum cardinality restriction is the ‘greater than or equal to’ symbol (\geq). For example the minimum cardinality restriction, $\geq \text{hasTopping} 3$, describes the individuals (an anonymous class containing the individuals) that participate in *at least* three `hasTopping` relationships. Minimum cardinality restrictions place no maximum limit on the number of relationships that an individual can participate in for a given property.

A.3.2 Maximum Cardinality Restrictions

Maximum cardinality restrictions specify the *maximum* number of relationships that an individual can participate in for a given property. The symbol for maximum cardinality restrictions is the ‘less than or equal to’ symbol (\leq). For example the maximum cardinality restriction, $\leq \text{hasTopping} 2$, describes the class of individuals that participate in at most two `hasTopping` relationships. Note that maximum cardinality restrictions place no minimum limit on the number of relationships that an individual must participate in for a specific property.

A.3.3 Cardinality Restrictions

Cardinality restrictions specify the *exact* number of relationships that an individual must participate in for a given property. The symbol for a cardinality restriction is the ‘equals’ symbol (=). For example, the cardinality restriction, = **hasTopping** 5, describes the set of individuals (the anonymous class of individuals) that participate in *exactly* five **hasTopping** relationships. Note that a cardinality restriction is really a syntactic short hand for using a combination of a minimum cardinality restriction and a maximum cardinality restriction. For example the above cardinality restriction could be represented by using the intersection of the two restrictions: \leq **hasTopping** 5, and, \geq **hasTopping** 5.

A.3.4 The Unique Name Assumption And Cardinality Restrictions

OWL does *not* use the Unique Name Assumption (UNA)¹. This means that different names *may* refer to the same individual, for example, the names “Matt” and “Matthew” may refer to the same individual (or they may not). Cardinality restrictions rely on ‘counting’ *distinct* individuals, therefore it is important to specify that either “Matt” and “Matthew” are the same individual, or that they are different individuals. Suppose that an individual “Nick” is related to the individuals “Matt”, “Matthew” and “Matthew Horridge”, via the **worksWith** property. Imagine that it has also been stated that the individual “Nick” is a member of the class of individuals that work with at the most two other individuals (people). Because OWL does not use the Unique Name Assumption, rather than being viewed as an error, it will be inferred that two of the names refer to the same individual².

¹Confusingly, some reasoners (such as RACER) *do* use the Unique Name Assumption!

²If “Matt”, “Matthew” and “Matthew Horridge” have been asserted to be different individuals, then this will make the knowledge base inconsistent.

Appendix B

Complex Class Descriptions

An OWL class is specified in terms of its superclasses. These superclasses are typically named classes and restrictions that are in fact anonymous classes. Superclasses may also take the form of ‘complex descriptions’. These complex descriptions can be built up using simpler class descriptions that are cemented together using logical operators. In particular:

- AND (\sqcap) — a class formed by using the AND operator is known as an *intersection* class. The class is the *intersection* of the individual classes.
- OR (\sqcup) — A class formed by using the OR operator is known as a *union* class. The class formed is the *union* of the individual classes.

B.1 Intersection Classes (\sqcap)

An intersection class is described by combining two or more classes using the AND operator (\sqcap). For example, consider the intersection of **Human** and **Male** — depicted in Figure B.1. This describes an *anonymous* class that contains the individuals that are members of the class **Human** and the class **Male**. The semantics of an intersection class mean that the anonymous class that is described is a subclass of **Human** and a subclass of **Male**.

The anonymous intersection class above can be used in another class description. For example, suppose we wanted to build a description of the class **Man**. We might specify that **Man** is a subclass of the anonymous class described by the intersection of **Human** and **Male**. In other words, **Man** is a subclass of **Human** and **Male**.

B.2 Union Classes (\sqcup)

A union class is created by combining two or more classes using the OR operator (\sqcup). For example, consider the union of **Man** and ‘**Woman**’ — depicted in Figure B.2. This describes an anonymous class that contains the individuals that belong to either the class **Man** or the class **Woman** (or both).

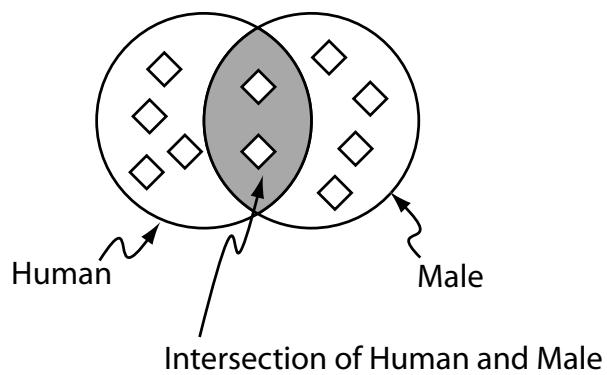


Figure B.1: The intersection of **Human** and **Male** ($\text{Human} \sqcap \text{Male}$) — The shaded area represents the intersection

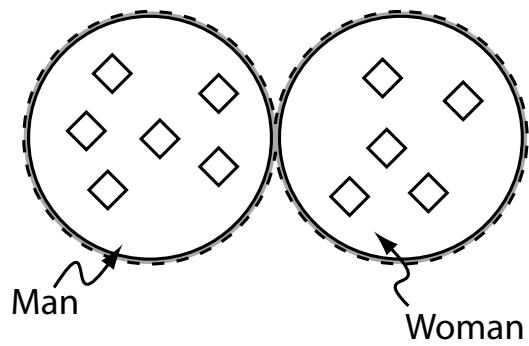


Figure B.2: The union of **Man** and **Woman** ($\text{Man} \sqcup \text{Woman}$) — The shaded area represents the union

The anonymous class that is described can be used in another class description. For example, the class **Person** might be equivalent of the union of **Man** and **Woman**.

Appendix C

Plugins

C.1 Installing Plugins

The installation of plugins to Protégé 4 is managed from within the preferences dialog. Selecting the ‘**Preferences**’ option in the ‘**File**’ menu brings up the main preferences dialog of Protégé. Clicking on the ‘**Plugins**’ tab in that dialog brings up the plugins panel shown in Figure C.1. This panel has three purposes: specifying the plugin registry, updating plugins already installed, and installing new plugins. The current plugin registry is shown in the ‘**Plugin registry**’ box. Updates for existing plugins can be installed by clicking on the ‘**Check for updates now**’ button in the ‘**Auto update**’ box.

In order to install new plugins, click on the ‘**Check for downloads now**’ button which opens the dialog shown in Figure C.2. Under ‘**Downloads**’, this dialog lists all plugins that are available in the plugin registry and are not yet installed. In order to install new plugins, just locate the names of the plugins in the list, check the checkboxes at the beginning of the relevant lines, and confirm the dialog by clicking on the ‘**Install**’ button.

In addition to this automatic registry-based plugin installation, plugins may also be installed by hand. In the most common case, Protégé plugins are packaged as Java *.jar* files. These can be installed by moving them into the *plugins* folder in your Protégé installation.

Note that independently of the installation mechanism plugins will be ready to use only after a restart (remember to save your work before re-starting Protégé).

C.2 Useful Plugins

C.2.1 Matrix Plugin

Adding existential restrictions on many classes can be very time consuming.

Fortunately, the *Matrix Plugin* can help to speed things up. Once installed (see Section C.1), the matrix plugin provides several table-style views of the ontology and some default tabs to get you started. One of these views (the *Class Matrix*) can be used to add existential restrictions along specified properties to



Figure C.1: The Plugins Tab in the Preferences Dialog

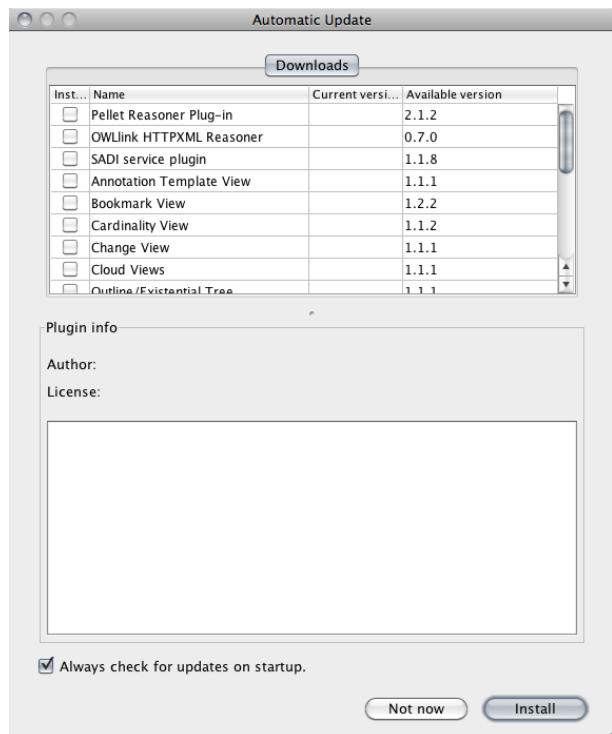


Figure C.2: The Downloads Dialog for Plugins

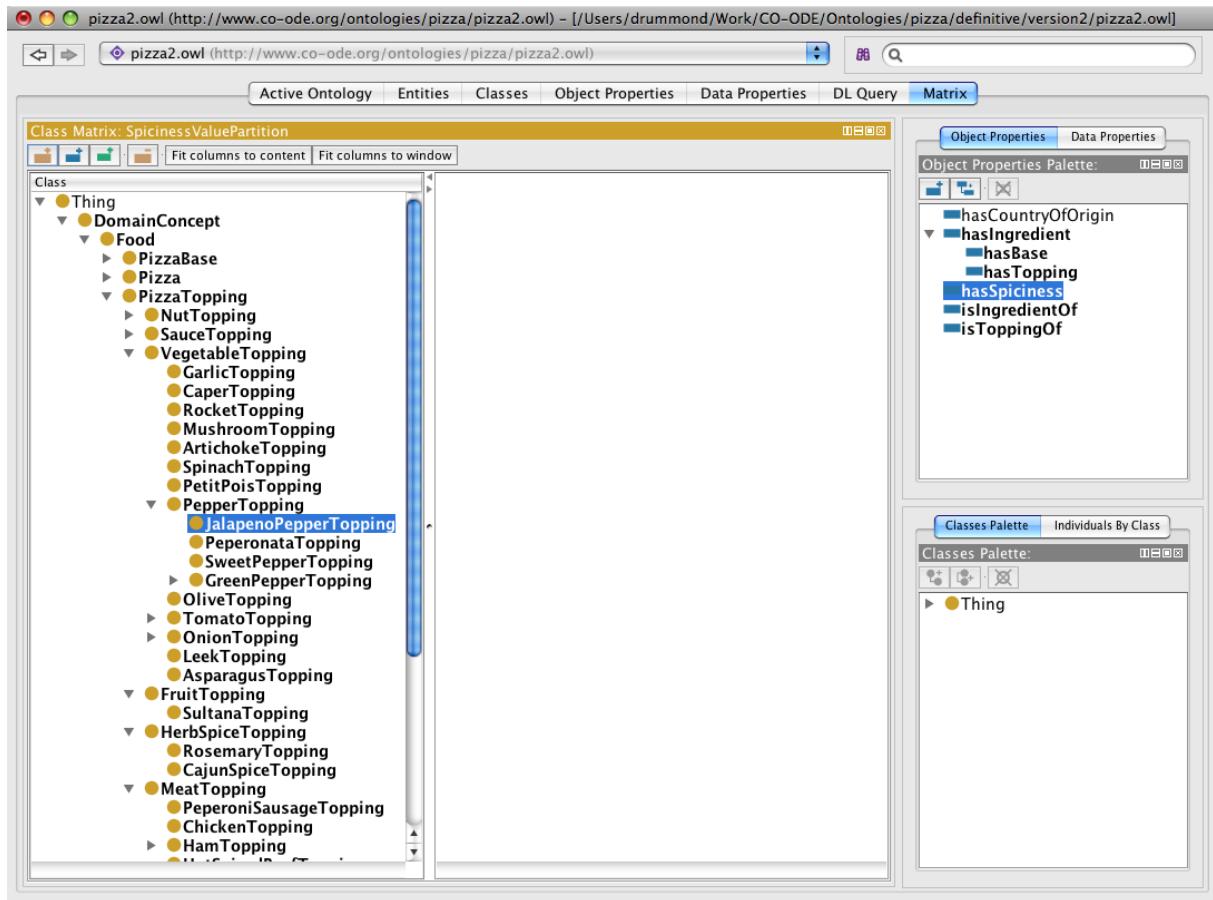


Figure C.3: Matrix Tab

many classes in a quick and efficient manner.

As an example this is how you would use the *Class Matrix* to add spiciness to **PizzaToppings**

1. In the ‘Window’ menu, click on the ‘Tabs’ item and select the ‘Matrix’ tab.
2. In the Matrix Tab the ‘Class Matrix’ view is shown on the left by default. This is shown in figure C.3. You should also be able to see a class hierarchy and property view on the right.
3. Drag and drop the **hasSpiciness** property from the ‘properties palette’ into the empty pane of the ‘Class Matrix’ view. You should see a new column created with the title ‘**hasSpiciness (some)**’.
4. For each pizza topping in the class hierarchy enter a spiciness value. You can do this using drag and drop from the ‘Classes palette’ view or by typing directly into the appropriate cell. Remember you can use the auto completion to help fill in the values for you. You should end up with values for your **PizzaToppings** as shown in Figure C.4.
5. If you return to the ‘EntitiesTab’ or ‘Classes Tab’ you will see each topping now has an existential superclass filled in.

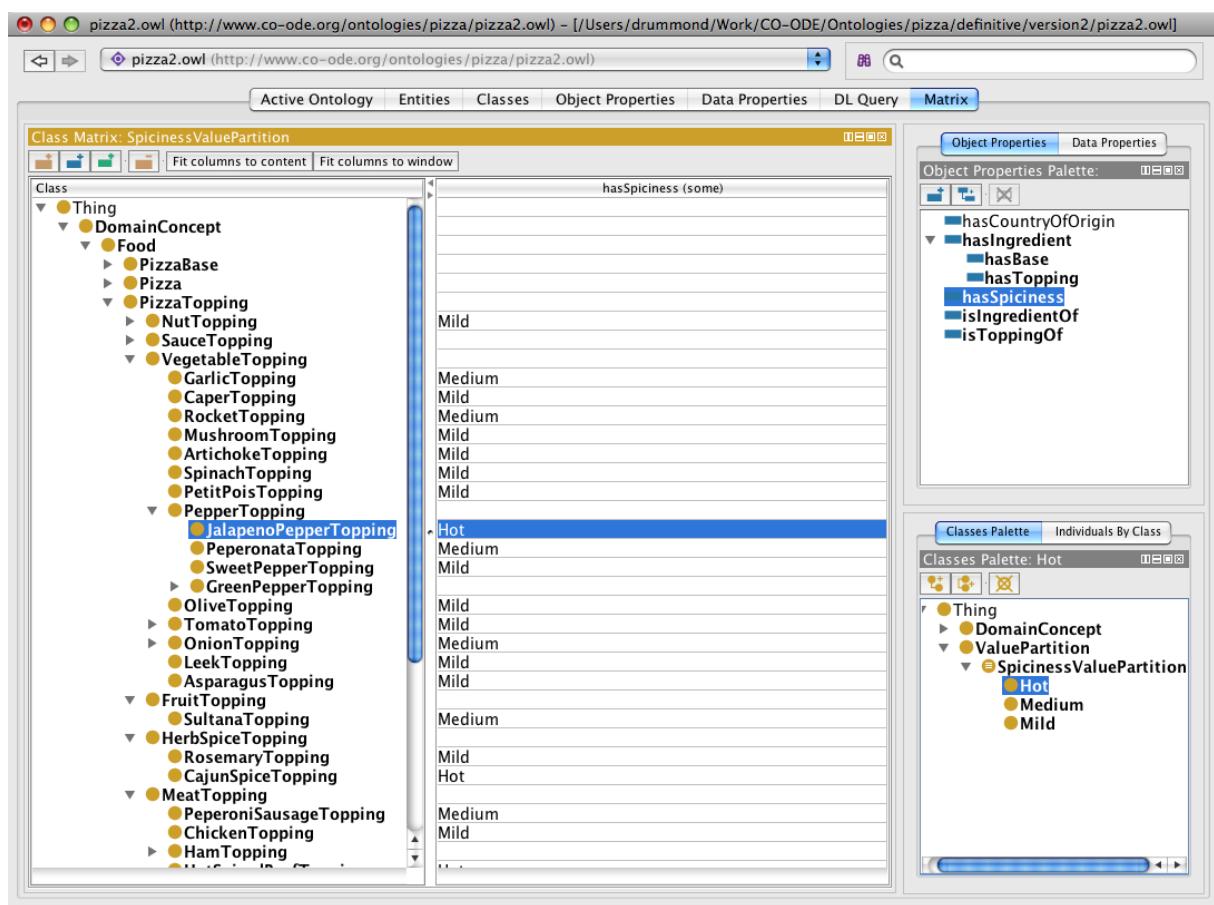


Figure C.4: Matrix Tab: With restrictions entered