Department of
Engineering
Ferrara

Introduction to Semantic Web and Description Logics: Protégé and Pellet

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Outline

Outline

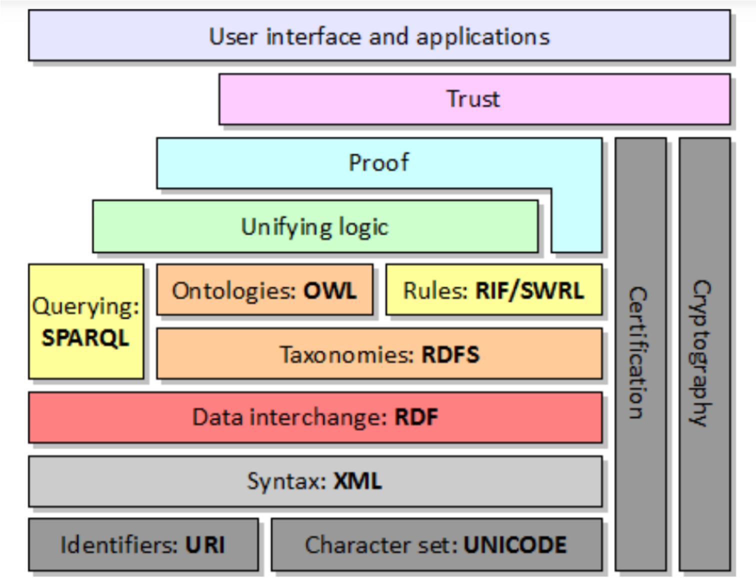
Summing up...

Until now, we have spoken about

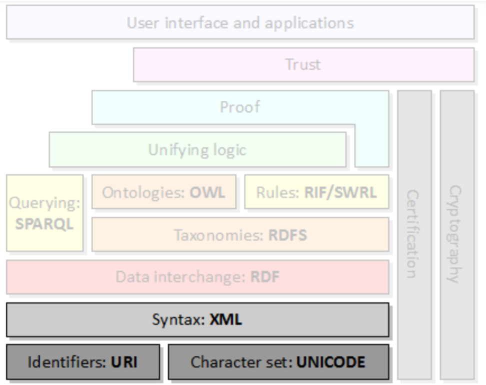
- Description Logics, starting from a simple logic and finishing with an introduction of $\mathcal{ALC}$
- Semantic Web, with some applications and tools, standards, problems

Outline

The Semantic Web Cake

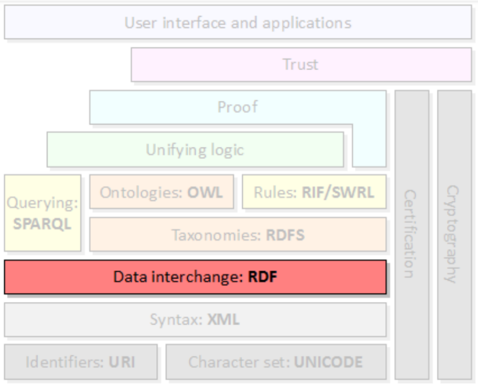


The Basis



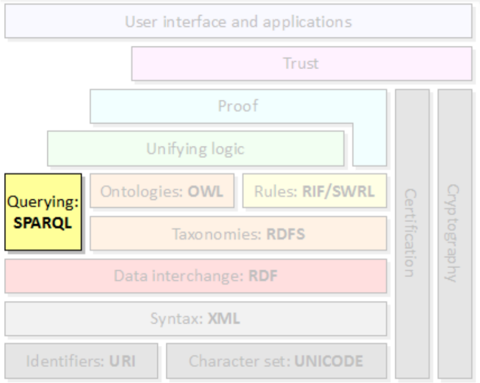
At the base there are the naming mechanism (URI) and the basic language, which specifies the elemental syntax (XML)

Resource Description Framework



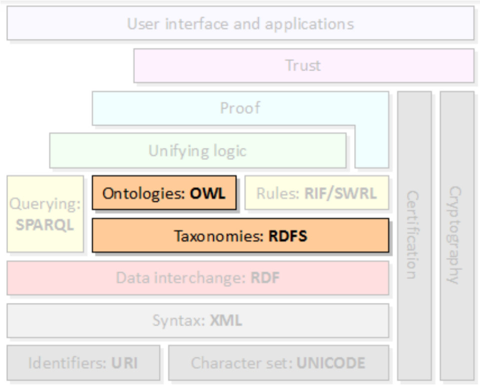
Describes the information of the domain by means of triples
<subject, predicate, object> or <resource, attribute, value>

Querying at a low level



SPARQL can be used to express queries across diverse data sources, whether the data is stored natively as RDF or viewed as RDF via middleware.
Extracts data, does not infers new information

Knowledge Representation



RDFS extends RDF with type, subclassOf, ...
OWL extends RDFS, with different level of expressivity

OWL

- Three level of expressivity/complexity
  - OWL-Lite, decidable, based on $\mathcal{SHIF}(\mathbf{D})$
  - OWL DL, decidable and more expressive, based on $\mathcal{SHOIN}(\mathbf{D})$
  - OWL Full, not decidable, highly expressive
- OWL 2 based on $\mathcal{SROIQ}(\mathbf{D})$
- Permits the use of many features:
  - Classes (categories): subClassOf, intersectionOf, unionOf, complementOf, enumeration, equivalence, disjoint
  - Properties (Roles, Relations): symmetric, transitive, functional, inverse Functional, range, domain, subPropertyOf, inverseOf, equivalentProperty
  - Instances (Individuals): sameIndividualAs, differentFrom, allDifferent

Ontology

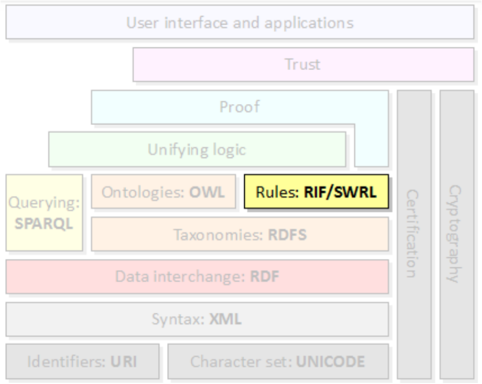
A **formal**, **explicit description** of a **domain** of interest

- Classes (Concepts)
- Semantic relation between classes (roles)
- Properties associated to a concept (restrictions, ...)
- Logic (axioms, inference rules)

Knowledge Base

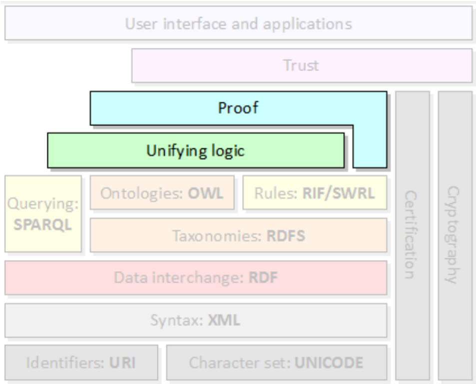
Knowledge Base = **Ontology** + **Instances**

Knowledge Representation



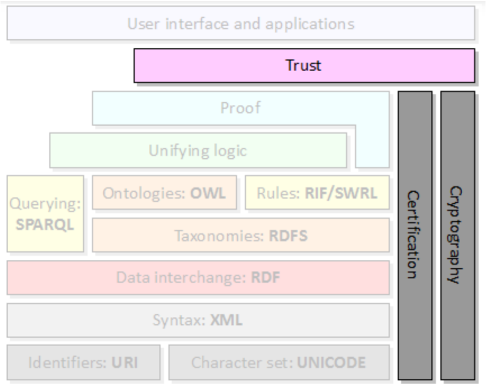
Allows to add rules to data, e.g., **If-then**
Note, one can use OWL 2 RL Profile

Reasoning



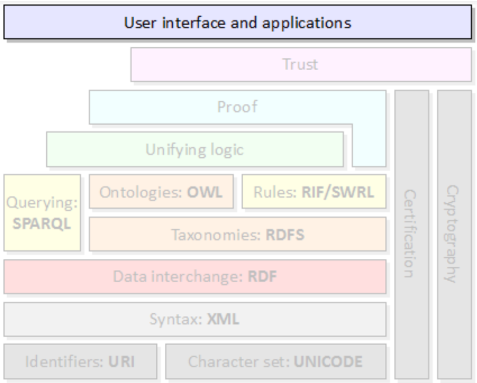
Allows to find new implicit information from the explicit ones, also providing proofs for the inferred new knowledge

Trust



Ensures privacy of the data

UI and Applications



Provides an environment to present application to final users

Outline

Ontologies and Semantic Web

As seen in the Semantic Web Cake, there are two ways for defining ontologies for the Semantic Web

- RDF Schema, that extends RDF with basic element for the description of ontologies (type, subClassOf, subPropertyOf, range, domain), good for taxonomies
- OWL, extends on RDFS, based on Description Logics. Defines three different sublanguages of increasing complexity:
  - OWL-Lite: limited support for certain features (ex.: cardinality), good for thesauri or hierarchies
  - OWL DL: good expressiveness, based on Description Logics, suited for modeling knowledge bases
  - OWL Full: minimal compatibility with RDFS

OWL and Description Logics

- Description Logics is a family of logics
- Each logic is distinguished from the other depending on which operators are supported
- The more supported operators, the higher the complexity

OWL and Description Logics

OWL DL supports the following operators

Axiom	DL Syntax	Example
subClassOf	$C_1 \sqsubseteq C_2$	$Human \sqsubseteq Animal \sqcap Biped$
equivalentClasses	$C_1 \sqsubseteq C_2$	$Man \sqsubseteq Human \sqcap Male$
disjointWith	$C_1 \sqsubseteq \neg C_2$	$Male \sqsubseteq \neg Female$
sameIndividualAs	$\{x_1\} \equiv \{x_2\}$	$\{President\_Bush\} \equiv \{G\_W\_Bush\}$
differentFrom	$\{x_1\} \sqsubseteq \neg\{x_2\}$	$\{robb\} \sqsubseteq \neg\{tony\}$
subPropertyOf	$R_1 \sqsubseteq R_2$	$hasDaughter \sqsubseteq hasChild$
equivalentPropertyOf	$R_1 \equiv R_2$	$cost \equiv price$
inverseOf	$R_1 \equiv R_2^-$	$hasChild \equiv hasParent^-$
transitiveProperty	R^+	$ancestor^+$
functionalProperty	$\top \sqsubseteq \leq 1 P$	$\top \sqsubseteq \leq 1 hasMother$
inverseFunctionalProperty	$\top \sqsubseteq \leq 1 P^-$	$\top \sqsubseteq \leq 1 hasSSN^-$

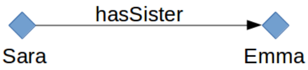
Note: all the operators that combines properties are applicable also to those that involve datatypes

A few of terminology

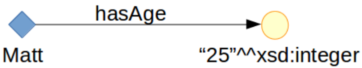
OWL	$\Leftrightarrow$	DL
Class	$\Leftrightarrow$	Concept
Property	$\Leftrightarrow$	Role
Instance	$\Leftrightarrow$	Individual

A few of terminology

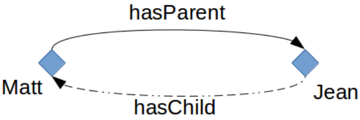
Object Property



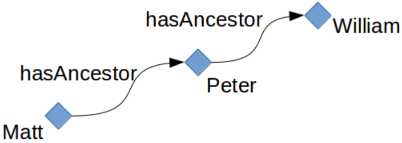
Datatype Property



Inverse Property

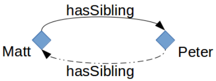


Transitive Property

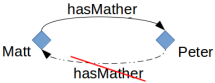


A few of terminology

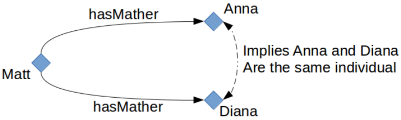
Symmetric Property



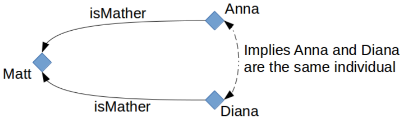
Antisymmetric Property



Functional Property



Inverse Functional Property



Reflexive Property

If r is reflexive, then

$\forall a \in Individuals | r(a, a)$

Irreflexive Property

If r is irreflexive, then

there cannot exists $r(a, a)$

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Ontology Editors

There are many editor for developing ontologies

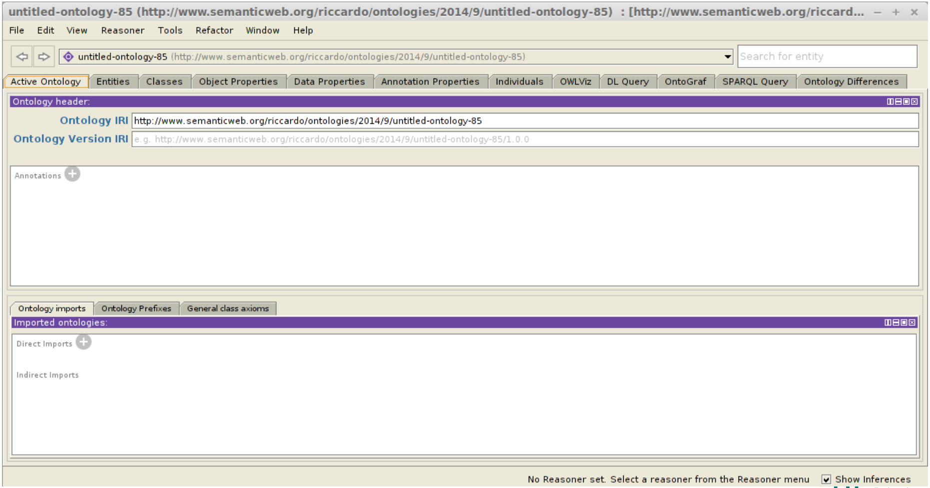
- WebODE, http://mayor2.dia.fi.upm.es/oeg-upm/index.php/en/old-technologies/60-webode
- ICOM, http://www.inf.unibz.it/~franconi/icom/
- Protégé, http://protege.stanford.edu/
- much more, some of them listed at http://www.w3.org/2001/sw/wiki/Category:Editor

Protégé

- Graphical editor
- Developed at the Stanford Center fo Biomedical Informatics Research (US)
- Open Source, Java based, highly extensible
- Plug-in environment, with a very large number of available plug-ins
- Can export ontologies in several different formats (OWL, RDFS, Turtle, ...)
- A web interface is also available at `http://webprotege.stanford.edu/`

Protégé 5.0

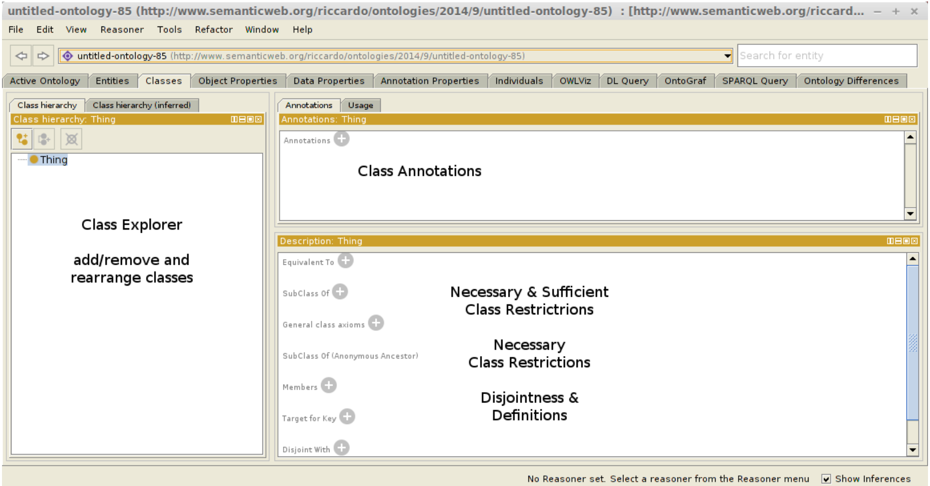
Protégé presents several tabs



Protégé 5.0

- Active Ontology, shows information about the open ontology
- Entities, gives a centralized place where the user can modify quite all the information of the ontology
- Classes, classes editor
- Object Properties
- Data Properties
- Annotation Properties (metadata...)
- Indididuals
- SPARQL Query, SPARQL engine

Protégé - Classes Editor



Protégé - Classes Editor

For each class, is possible to specify

- The hierarchy
- General information (annotations)
- Necessary and Sufficient conditions ($\equiv$)
- Necessary conditions ($\sqsubseteq$)
- Disjointness conditions with other classes (by default, in OWL all the classes can overlap with each others)

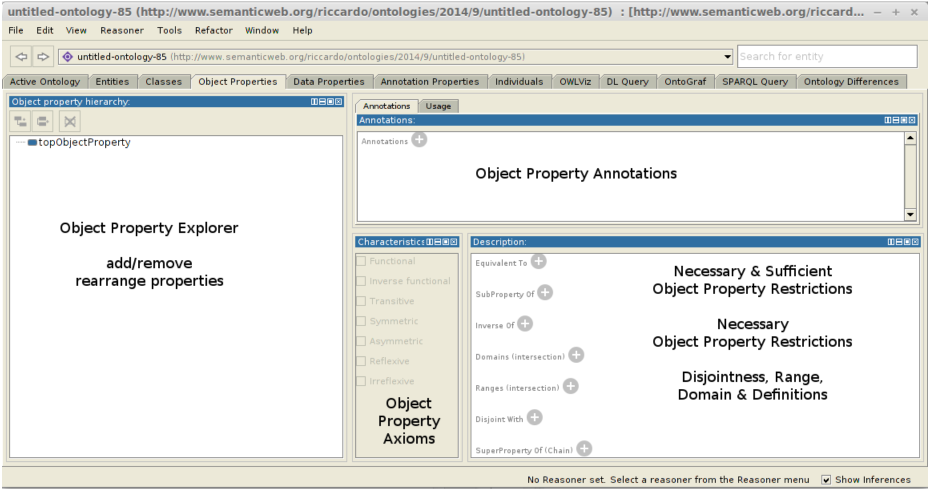
Class Definition

A class can be modeled by defining its necessary and sufficient conditions, by specifying expressions (subClassOf relation with conjunction/disjunction between concepts) or by specifying restrictions on properties

Class Definition Using Restrictions

- **Quantifier Restrictions**
  - **Existential Restriction**: $\exists r.C$, `:someValuesFrom`, keyword **some**
    class whose individuals are r-related with at least one individuals of C
  - **Universal Restriction**: $\forall r.C$, `:allValuesFrom`, keyword **only**
    class whose individuals are r-related with only individuals of C
- **Cardinality Restrictions (possibly qualified)**
  - **Minimun Cardinality Restriction**: $\geq nr(.C)$, `:minCardinality`, keyword **min**
    class whose individuals are r-related with at least n individuals (of C)
  - **Exact Cardinality Restriction**: $= nr(.C)$, `:exactCardinality`, keyword **exactly**
    class whose individuals are r-related with exactly n individuals (of C)
  - **Maximum Cardinality Restriction**: $\leq nr(.C)$, `:maxCardinality`, keyword **max**
    class whose individuals are r-related with at most n individuals (of C)

Protégé - Object Properties Editor

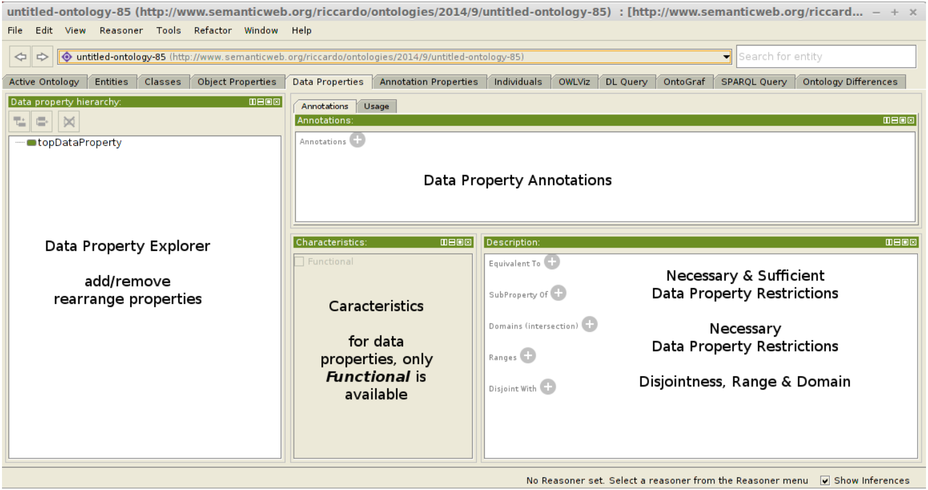


Protégé - Object Properties Editor

For each object property, is possible to specify

- The hierarchy
- General information (annotations)
- Characteristics (Functional Property, Transitive Property, ...)
- Necessary and Sufficient conditions ($\equiv$)
- Necessary conditions ($\sqsubseteq$)
- Disjointness conditions with other properties
- Domain
- Range

Protégé - Data Properties Editor



Protégé - Data Properties Editor

For each object property, is possible to specify

- The hierarchy
- General information (annotations)
- Characteristics (Functional Property only)
- Necessary and Sufficient conditions ($\equiv$)
- Necessary conditions ($\sqsubseteq$)
- Disjointness conditions with other properties
- Domain
- Range

Domain & Range

Properties link individuals from a **domain** with individuals from a **range**

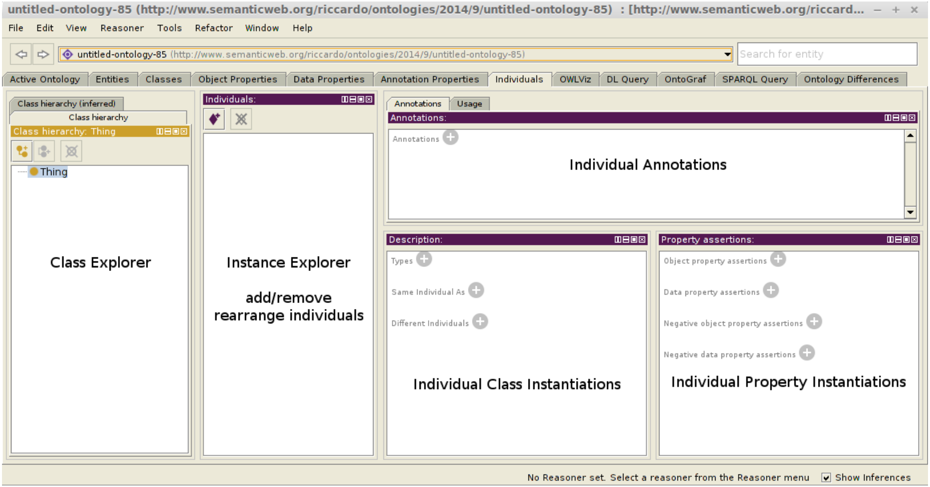
The definition of a domain or a range is used during the inference process to infer new knowledge
E.g.: given the classes Pizza and PizzaTopping, the relation hasTopping has:

- Pizza as domain
- PizzaTopping as range

If I model that iceCream hasTopping chocolate, then the fact that iceCream is a Pizza can be inferred

Note: domain and range are inverted with inverse properties

Protégé - Individuals Editor



Protégé - Individuals Editor

For each individual, it is possible to specify

- The type (classes)
- Relationship with other individuals (equality, disequality)
- Property assertions

Inferred Knowledge Base

Inferred ontology

- Protégé infers the **inferred hierarchy** or classes and properties by means of the subsumption mechanism (use of reasoners, e.g., FACT++)

Inferred classification of individuals

Consistency checking: check whether each class can have at least one individual that belongs to it

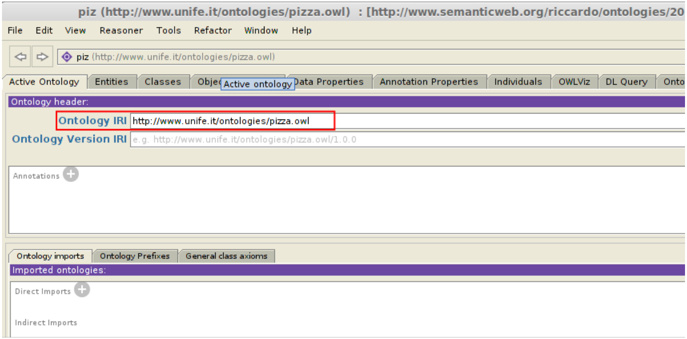
Exercise

A simplified and updated version of the step-by-step exercise from “Protégé OWL Tutorial”

`http://mowl-power.cs.man.ac.uk/protegeowltutorial/resources/ProtegeOWLTutorialP4_v1_3.pdf`

Exercise - Step 1

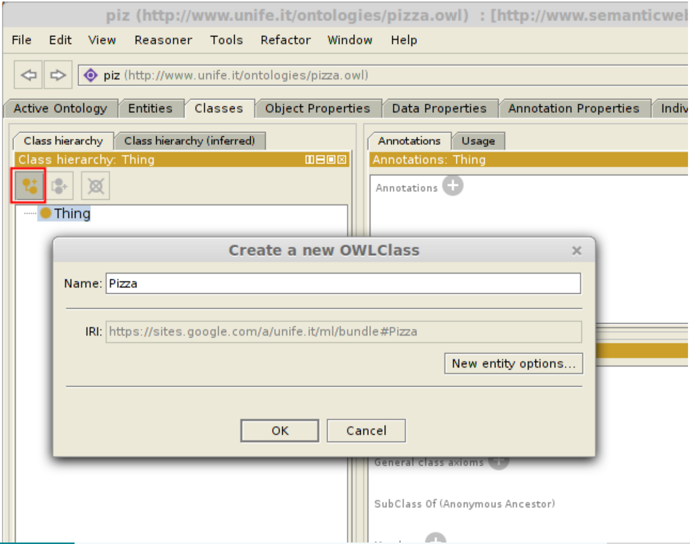
- Start Protégé and you will see the *main tab*. Replace the *IRI* with `http://www.unife.it/ontologies/pizza.owl`



- Now our ontology has a significant IRI. In *Annotation* we can add a comment (e.g., what the ontology models)

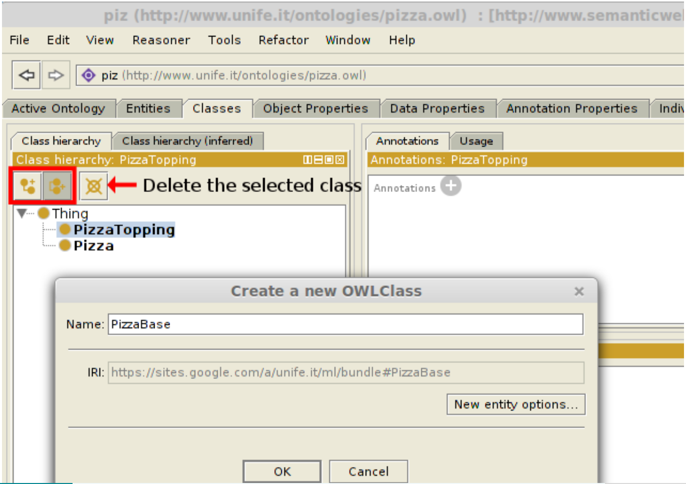
Exercise - Step 2

- Go to *Classes* tab and create a subclass of `Thing`, called `Pizza`



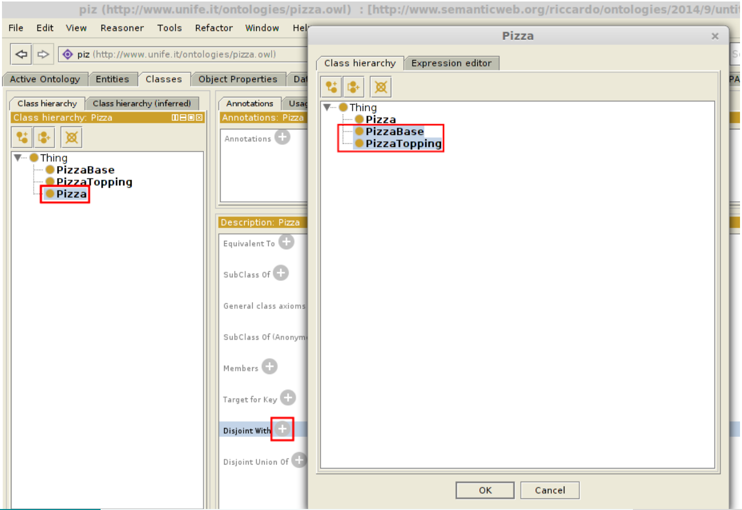
Exercise - Step 3

- Create two sibling classes of `Pizza`, called `PizzaTopping` and `PizzaBase` TIP: You can create a subclass of `Thing` or a sibling of the other classes



Exercise - Step 4

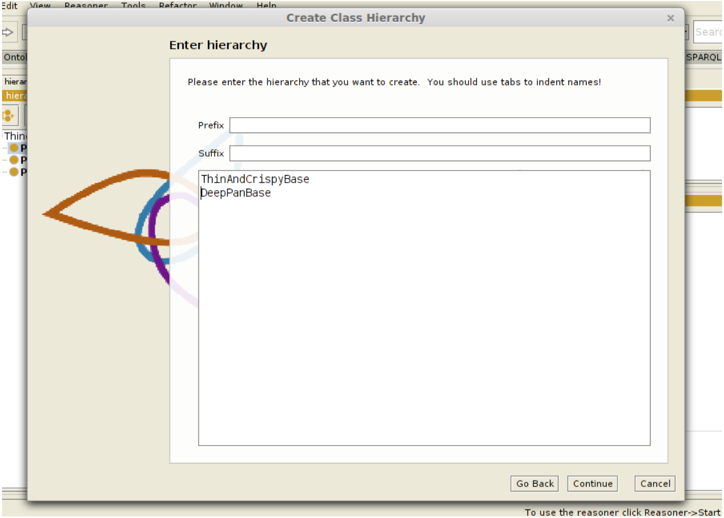
- Make the created classes disjoint from each other. Select `Pizza`, press *Disjoint With* in *Description* and select the other classes



Exercise - Step 5

- Create a class hierarchy for `PizzaBase`
- From the *Tools* menu select *Create Class Hierarchy...*
- Select `PizzaBase`
- Type in the class name the two names `ThinAndCrispyBase` and `DeepPanBase`, and click *Continue*
- After the tool have checked the entered names, tick *Make sibling classes disjoint* and click *Finish*

Exercise - Step 5



Exercise - Step 6

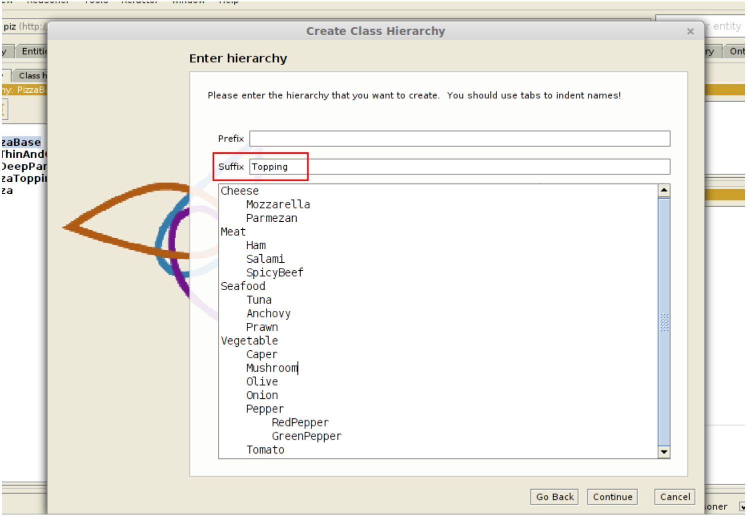
- Create a class hierarchy for `PizzaTopping`, usign *Create Class Hierarchy...* tool
- Select `PizzaTopping`
- Type in the class name text you find in the next step, set `Topping` in *Suffix* (the tool automatically appends `Topping` at the end of all the created classes) and click *Continue*
- After the tool have checked the entered names, tick *Make sibling classes disjoint* and click *Finish*

Exercise - Step 6

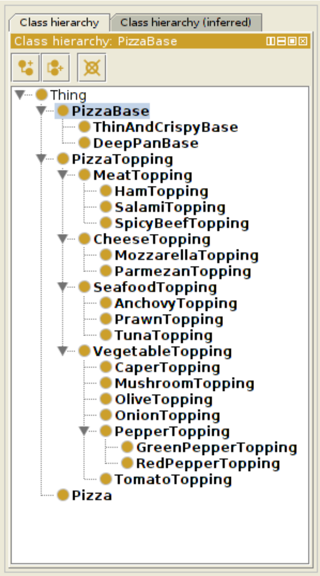
The tool allows a hierarchy of classes to be entered using a *tab indented tree*. Class names must be indented using tabs, so for example `SpicyBeef`, which we want to be a subclass of Meat is entered under Meat and indented with a tab.

```
Cheese
	Mozzarella
	Parmezan
Meat
	Ham
	Salami
	SpicyBeef
Seafood
	Tuna
	Anchovy
	Prawn
Vegetable
	Caper
	Mushroom
	Olive
	Onion
	Pepper
		RedPepper
		GreenPepper
	Tomato
```

Exercise - Step 6

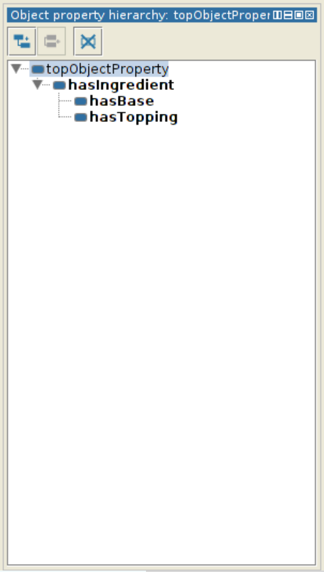


Exercise - Step 6



Exercise - Step 7

- Go to *Object Properties* tab and create a property, called `hasIngredient`
- Create two subproperty of `hasIngredient`, called `hasTopping` and `hasBase`

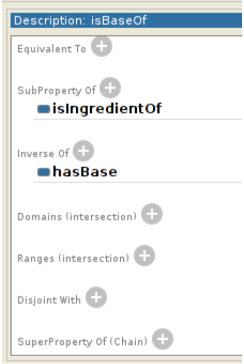


Exercise - Step 8

- Create inverse properties of the properties just defined
- Select the property and click on *InverseOf*, here create the corresponding property

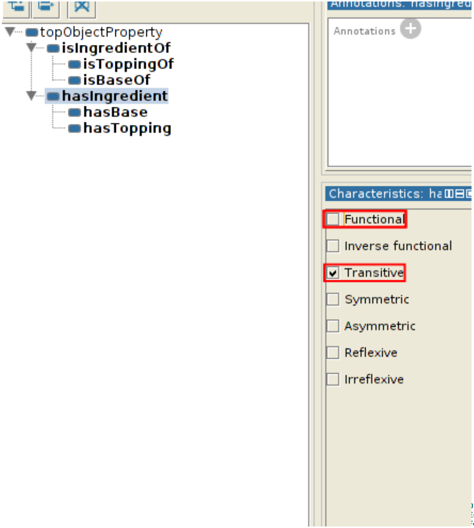
`hasIngredient`	⇔	`isIngredientOf`
`hasTopping`	⇔	`isToppingOf`
`hasBase`	⇔	`isBaseOf`

- 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).



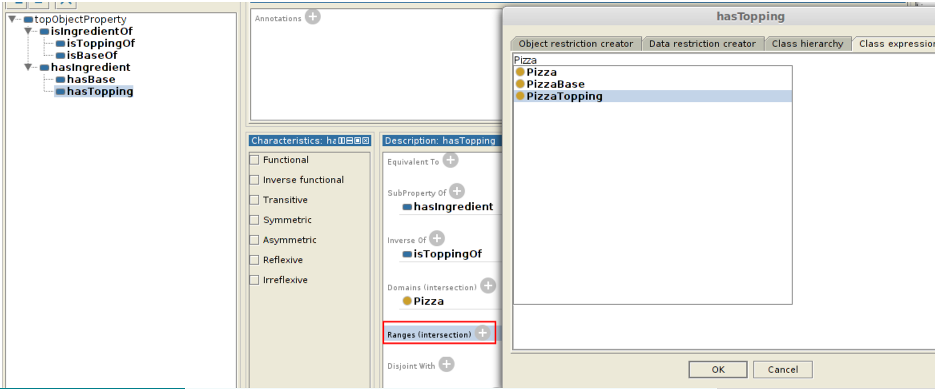
Exercise - Step 9

- Make `hasIngredient` property *transitive*
- Make `hasBase` property *functional*



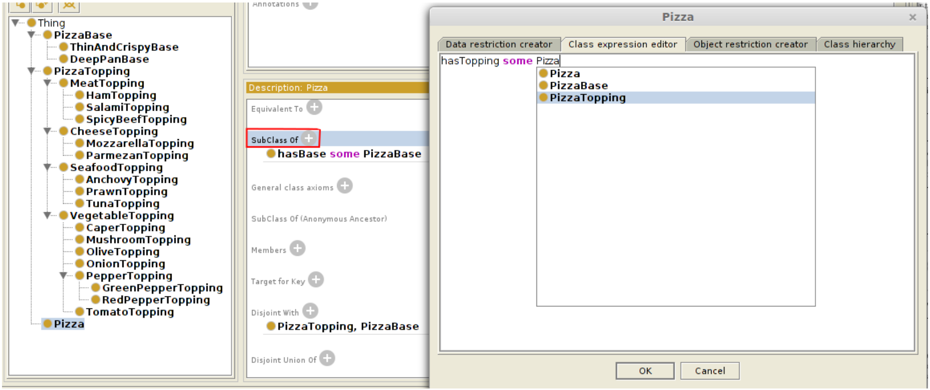
Exercise - Step 10

- Specify the the domain (`Pizza`) and range (`PizzaTopping`) for `hasTopping`) property
- Specify the the domain (`Pizza`) and range (`PizzaBase`) for `hasBase`) property
- Do the inverse for `isToppingOf` and `isBaseOf`



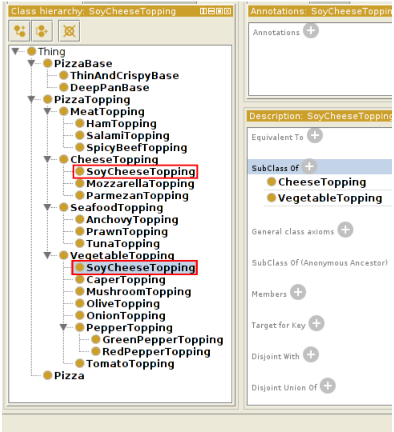
Exercise - Step 11

- Add that the class `Pizza` is a subclass of $\exists hasBase.PizzaBase$ (hasBase **some** PizzaBase)
- Add that the class `Pizza` is a subclass of $\exists hasTopping.PizzaTopping$ (hasTopping **some** PizzaTopping)



Exercise - Step 12

- Add the class `SoyCheeseTopping` as a subclass of `VegetableTopping` and of `CheeseTopping`



Exercise - Step 13

Add some individuals

- `chiliPepper`
  - types `RedPepperTopping`
- `spicyTomato`
  - types `TomatoTopping`
  - Object property assertions `hasIngredient chiliPepper`
- `spicyRedDeepPizza`
  - types `Pizza`, `hasBase some DeepPanBase`
  - Object property assertions `hasTopping spicyTomato`
- `tunaOnionThinPizza`
  - types `hasBase some ThinAndCrispyBase`, `hasTopping some OnionTopping`, `hasTopping some TunaTopping`

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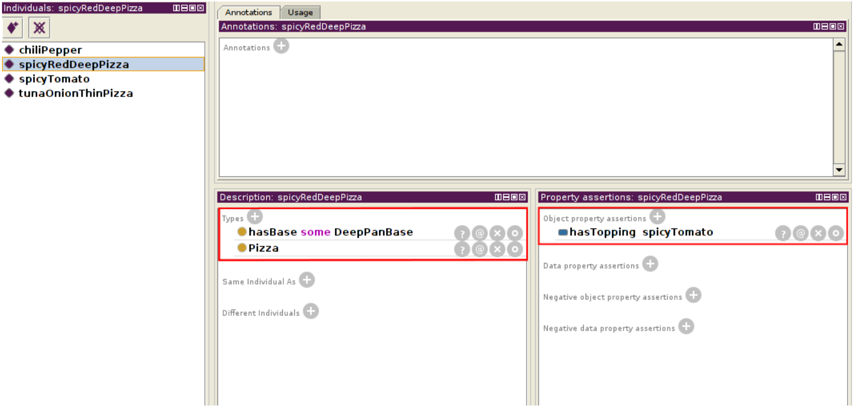
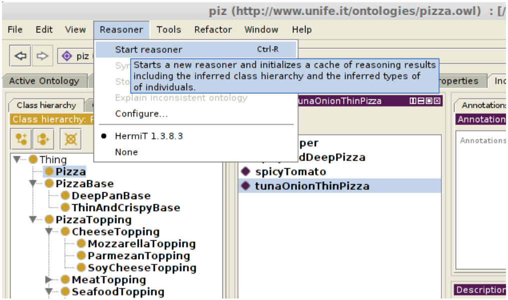
Exercise - Step 13



Exercise - Step 14

Start the internal reasoner and see what happens



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Reasoners

There are many reasoners available

- FaCT++ `http://owl.man.ac.uk/factplusplus/`
- Hermit `http://www.hermit-reasoner.com/`
- Pellet `https://github.com/stardog-union/pellet`
- much more, some of them listed at `http://www.w3.org/2001/sw/wiki/Category:Reasoner`

Pellet

- Developed by Clark & Parsia LLC
- Open Source, Java based
- Can import ontologies in several different formats (OWL, RDFS, Turtle, ...)
- Can import ontologies from several different sources (local file, remote ontology, ...)

Pellet

"Pellet is an OWL 2 reasoner. [...] Pellet provides functionality to check consistency of ontologies, compute the classification hierarchy, explain inferences, and answer SPARQL queries."

SOURCE: Pellet Documentation
`https://github.com/stardog-union/pellet`

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Features

Pellet can execute several different tasks:

- **classify**: classifies the ontology and display the hierarchy
- **consistency**: checks the consistency of an ontology
- **entail**: checks if all axioms are entailed by the ontology
- **explain**: explains one or more inferences in a given ontology including ontology inconsistency
- **extract**: extract a set of (specified) inferences from an ontology
- **info**: displays information and statistics about 1 or more ontologies

Features

- **lint**: shows problems contained in the ontology (warnings, errors)
- **modularity**: extracts from the ontology information about given classes
- **query**: executes SPARQL queries
- **realize**: computes and displays the most specific instances for each class
- **trans-tree**: computes a transitive-tree closure, reporting the hierarchy of the classes which use the given transitive property
- **unsat**: finds the unsatisfiable classes in the ontology

Entail - Query Types

Entail computes one ore more explanations for the given query

- **unsat**: Explain why the given class is unsatisfiable
- **all-unsat**: Explain all unsatisfiable classes
- **inconsistent**: Explain why the ontology is inconsistent
- **hierarchy**: Print all explanations for the class hierarchy
- **subclass**: Explain why C is a subclass of D, where C and D are given classes
- **instance**: Explain why i is an instance of C, where i is an individual and C a class
- **property-value**: Explain why s has value o for property p, where s is an individual, o an individual or a value of a certain datatype and p is a property

Explanation

Roughly: an explanation is a set of axioms from the KB which entail (is a model) for the given query

There could be many different explanations for a given query, depending on the KB

Tableau Algorithm

All the commands of Pellet exploit the Tableau Algorithm for doing inference
The algorithm builds a graph (also called **tableau**)

- A tableau is an ABox represented as a graph in which:
  - Each node represents an individual *a* and is labeled with the set of concepts it belongs to;
  - Each edge between two individuals *a* and *b* is labeled with the set of roles to which the couple (a, b) belongs.

Tableau Algorithm

- A tableau algorithm proves an axiom by refutation
  - Axiom E is entailed if $\neg E$ has no model in the KB.
  - Example 1: to test a class assertion axiom $C(a)$, it adds $\neg C$ to the label of a.
  - Example 2: to test the inconsistency of a concept C, it adds a new anonymous node a to the tableau and adds $\neg C$ to the label of a.

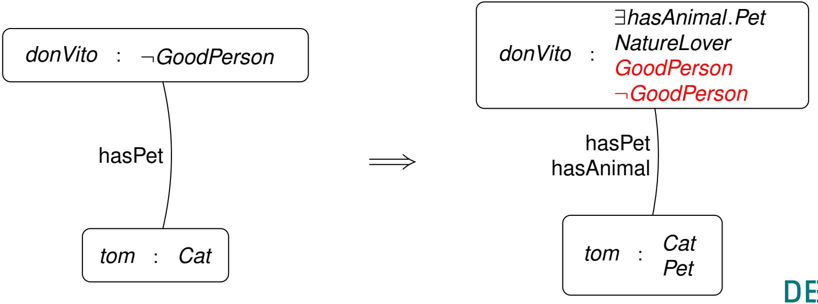
Tableau Algorithm

- A tableau algorithm repeatedly applies a set of consistency preserving tableau expansion rules until a clash is detected or a clash-free graph is found to which no more rules are applicable.
  - there are several expansion rules, often a rule correspond to one concept-froming operator
  - A clash (contradiction) is either:
    - a couple (C, a) where C and $\neg C$ are present in the label of a node;
    - a couple $(a = b, a \neq b)$, where a and b are individuals.
- If the expansion of the tableau with the query leads to at least one clash the query is entailed w.r.t. the KB.

The Tableau Algorithm

$tom : Cat$
$(donVito, tom) : hasPet$
$Cat \sqsubseteq Pet$
$\exists hasAnimal.Pet \sqsubseteq NatureLover$
$NatureLover \sqsubseteq GoodPerson$
$hasPet \sqsubseteq hasAnimal$

$Q = donVito : GoodPerson$



Inference with Pellet

- The tableau algorithm finds a single explanation
- Pellet implement also a backtracking algorithm to find all the possible explanations
  - uses an hitting set algorithm that repeatedly removes an axiom from the KB and then computes again a new explanation.
- Some expansion rules are non-deterministic, the tableau algorithm has to handle non-determinism

Why use reasoners?

Reasoners such as Pellet can help also the debug of an knowledge base

The explanations can highlight part of the ontology that contains inconsistent information

Exercise

Try some commands:

- information regarding the knowledge base

```
info file:<path-to-pizza-owl>/pizza.owl
```

- hierarchy of the knowledge base

```
classify file:<path-to-pizza-owl>/pizza.owl
```

Note: `SoyCheeseTopping` ≡ `Nothing`!

- check if two individuals are linked together

```
explain -max 100 --property-value
spicyRedDeepPizza,hasIngredient,chiliPepper
file:<path-to-pizza-owl>/pizza.owl
```

Exercise

Run the following queries:

- check the unsatisfiability of a class

```
explain -max 100 --unsat SoyCheeseTopping
file:<path-to-pizza-owl>/pizza.owl
```

- check why an individual belongs to a class

```
explain -max 100 --instance spicyRedDeepPizza,Pizza
file:<path-to-pizza-owl>/pizza.owl
```

- check if two individuals are linked together

```
explain -max 100 --property-value
spicyRedDeepPizza,hasIngredient,chiliPepper
file:<path-to-pizza-owl>/pizza.owl
```

Exercise

```
Terminal
riccardo@riccardo ~/src/pellet-2.3.1 $ ./pellet.sh explain -max 100 --property-v
alue https://sites.google.com/a/unife.it/ml/bundle#spicyRedDeepPizza,https://sit
es.google.com/a/unife.it/ml/bundle#hasIngredient,https://sites.google.com/a/unif
e.it/ml/bundle#chiliPepper file:/home/riccardo/papers/seminariosw/Ontology/pizza
.owl
Axiom: spicyRedDeepPizza hasIngredient chiliPepper

Explanation(s):
1)   Transitive hasIngredient
     spicyTomato hasIngredient chiliPepper
     spicyRedDeepPizza hasTopping spicyTomato
     hasTopping subPropertyOf hasIngredient


2)   hasTopping inverseOf isToppingOf
     Transitive hasIngredient
     spicyTomato hasIngredient chiliPepper
     isIngredientOf inverseOf hasIngredient
     isToppingOf subPropertyOf isIngredientOf
     spicyRedDeepPizza hasTopping spicyTomato


riccardo@riccardo ~/src/pellet-2.3.1 $ 
```

Thanks.

Questions?

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