Reasoning with OWL

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2) The University of Manchester, United Kingdom

Credits:

- Matthew Horridge, Holger Knublauch et al.

  A Practical guide to building OWL ontologies using the Protégé-OWL plugin and CO-ODE tools

- Natasha Noy, Alan Rector

  W3C “Semantic Web Best Practice” Working Group

Objective

Acquiring an in-depth understanding of the OWL-DL semantics in order to perform advanced reasoning tasks

- We will rely on the pizza example for:
  - a better formalization of the domain knowledge
  - leveraging OWL-DL reasoning capabilities for an easier curation of the ontology
  - an overview of some good practice

Outline

- OWL semantics
- Open world assumption
- Reasoning with individuals

Getting started

1. Getting Protégé
   - version 4.0
   - http://protege.stanford.edu
2. Getting some documentation
   - http://protege.stanford.edu/doc/users.html
   - OWL Tutorial : http://www.co-ode.org
   - Wiki: http://protege.cim3.net/cgi-bin/wiki.pl
   - Mailing lists

Getting started

1. Use the protege2007owlTutorial-01.owl ontology from: http://www.ea3888.univ-rennes1.fr/dameron/protege2007/
2. Launch Protégé
3. Select “Open OWL ontology”
4. Retrieve your local copy of the ontology

OWL Semantics

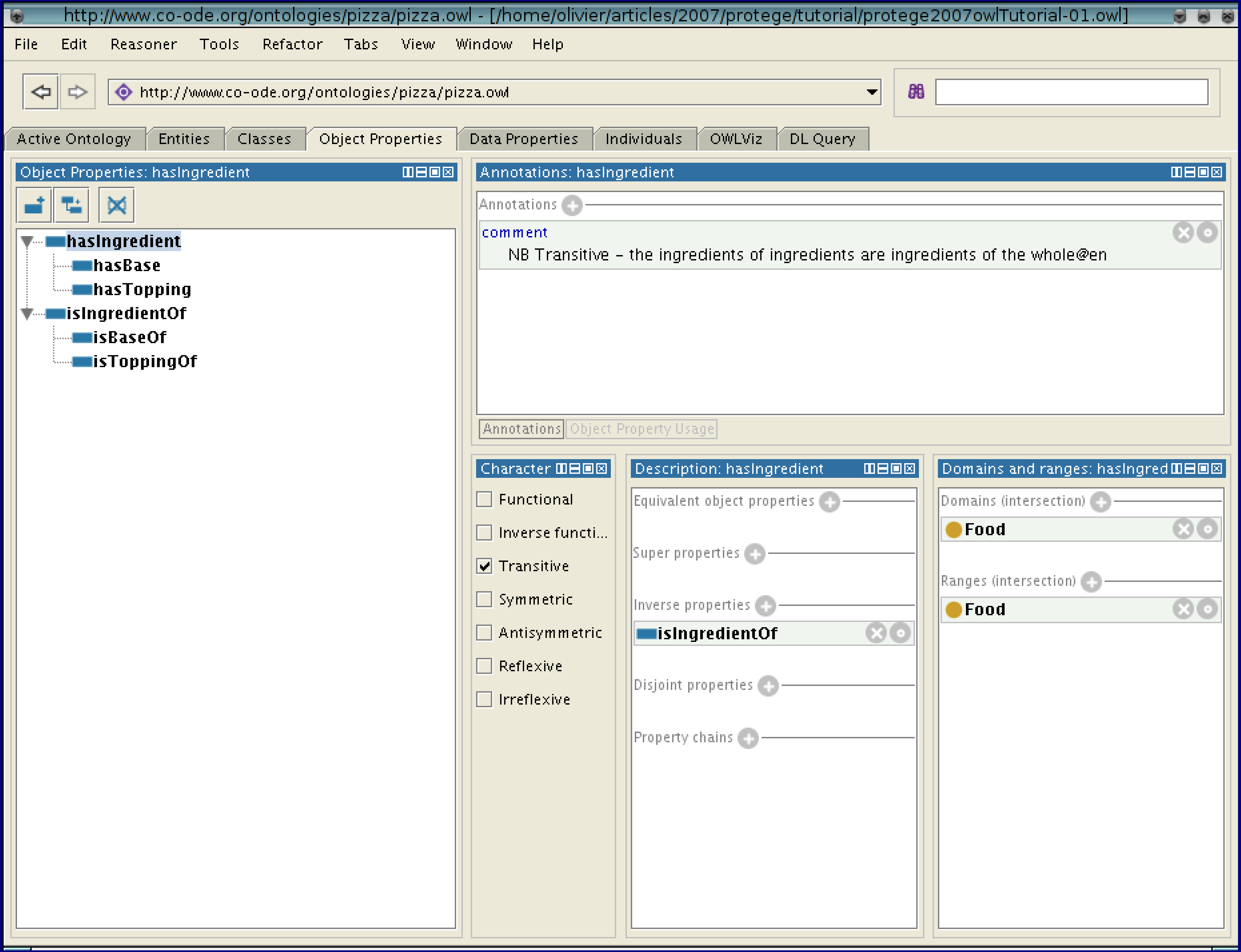
(the theoretical part)

Individuals

- Atoms
- Individuals have an identity and can be counted
- They are fundamental for understanding the semantics of DL...
- ... but you hardly use them when building ontologies

Properties

- A property = binary relationships btw individuals
- Domain, Range
  - Used as axioms (e.g. *hasTopping* and ice creams)
- Subproperties
- Characteristics
  - Transitive: e.g. *hasPart*, *hasAncestor*...
  - Symmetric: e.g. *isSiblingOf*...
  - Functional: e.g. *hasSSN*, *hasMother*...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Object Properties: hasIngredient
Annotations: hasIngredient
Annotations
Object Property Usage
Character
Description: hasIngredient
Domains and ranges: hasIngred

hasIngredient
- hasBase
- hasTopping

isIngredientOf
- isBaseOf
- isToppingOf

Annotations

comment
NB Transitive – the ingredients of ingredients are ingredients of the whole@en

□ Functional
□ Inverse functi...
☑ Transitive
□ Symmetric
□ Antisymmetric
□ Reflexive
□ Irreflexive

Equivalent object properties

Super properties

Inverse properties
isIngredientOf

Disjoint properties

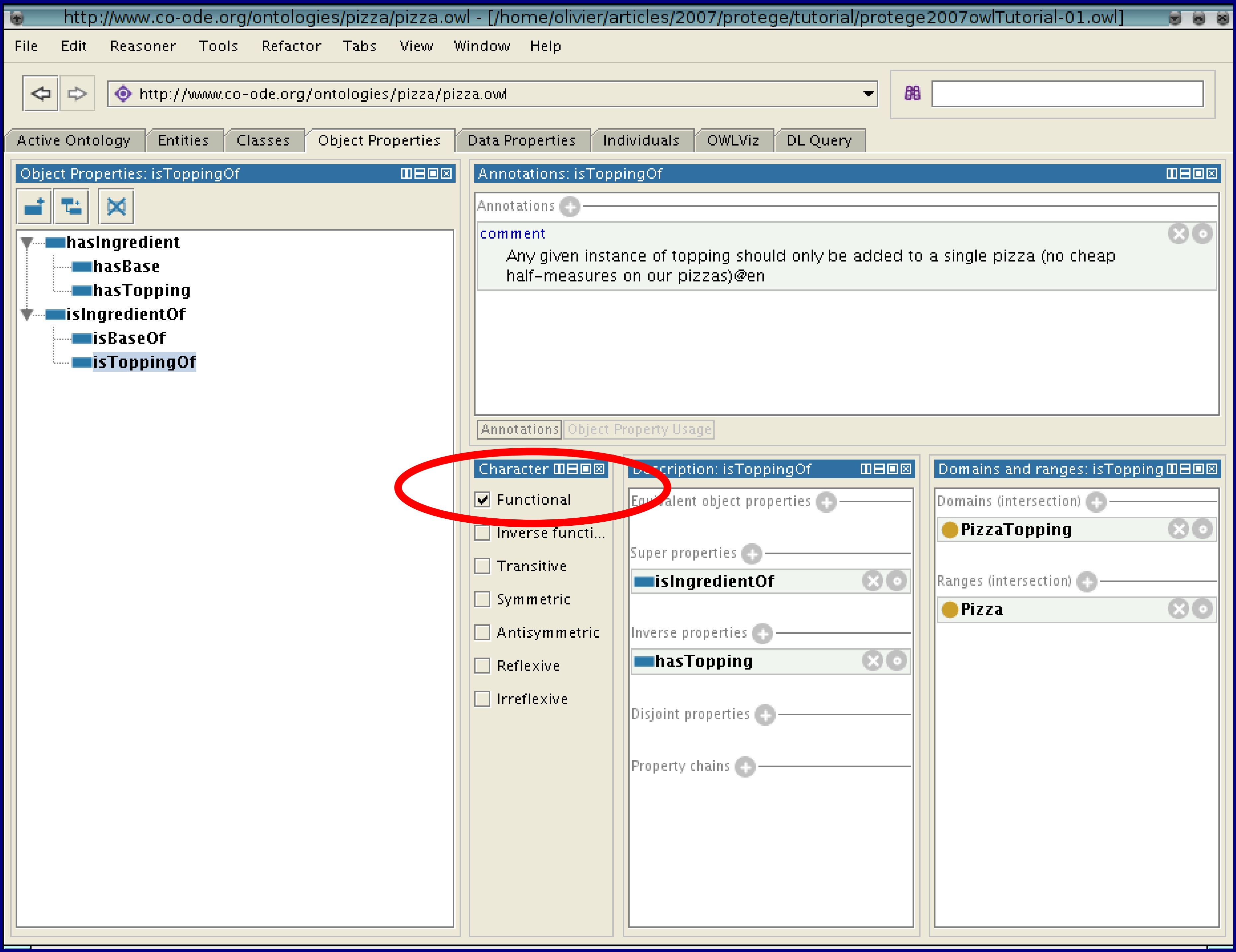
Property chains

Domains (intersection)
● Food

Ranges (intersection)
● Food

Functional Properties

- Functional property: each element of the domain can have 0 or 1 image in the range
  - ex: *hasBiologicalMother*, *isToppingOf*, *isBaseOf*,...
- If a property is functional, then its inverse is inverse functional
  - ex: *hasTopping*
- A property can be both functional and inv.-functional
  - ex: *hasSSN*, *hasBase*
  - not all do! -> *hasBiologicalMother*



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Object Properties: isToppingOf
Annotations: isToppingOf
Annotations
Object Property Usage
Character
Description: isToppingOf
Domains and ranges: isTopping

- hasIngredient
  - hasBase
  - hasTopping
- isIngredientOf
  - isBaseOf
  - isToppingOf

Annotations

comment
Any given instance of topping should only be added to a single pizza (no cheap half-measures on our pizzas)@en

☑ Functional
☐ Inverse functi...
☐ Transitive
☐ Symmetric
☐ Antisymmetric
☐ Reflexive
☐ Irreflexive

Equivalent object properties

Super properties
isIngredientOf

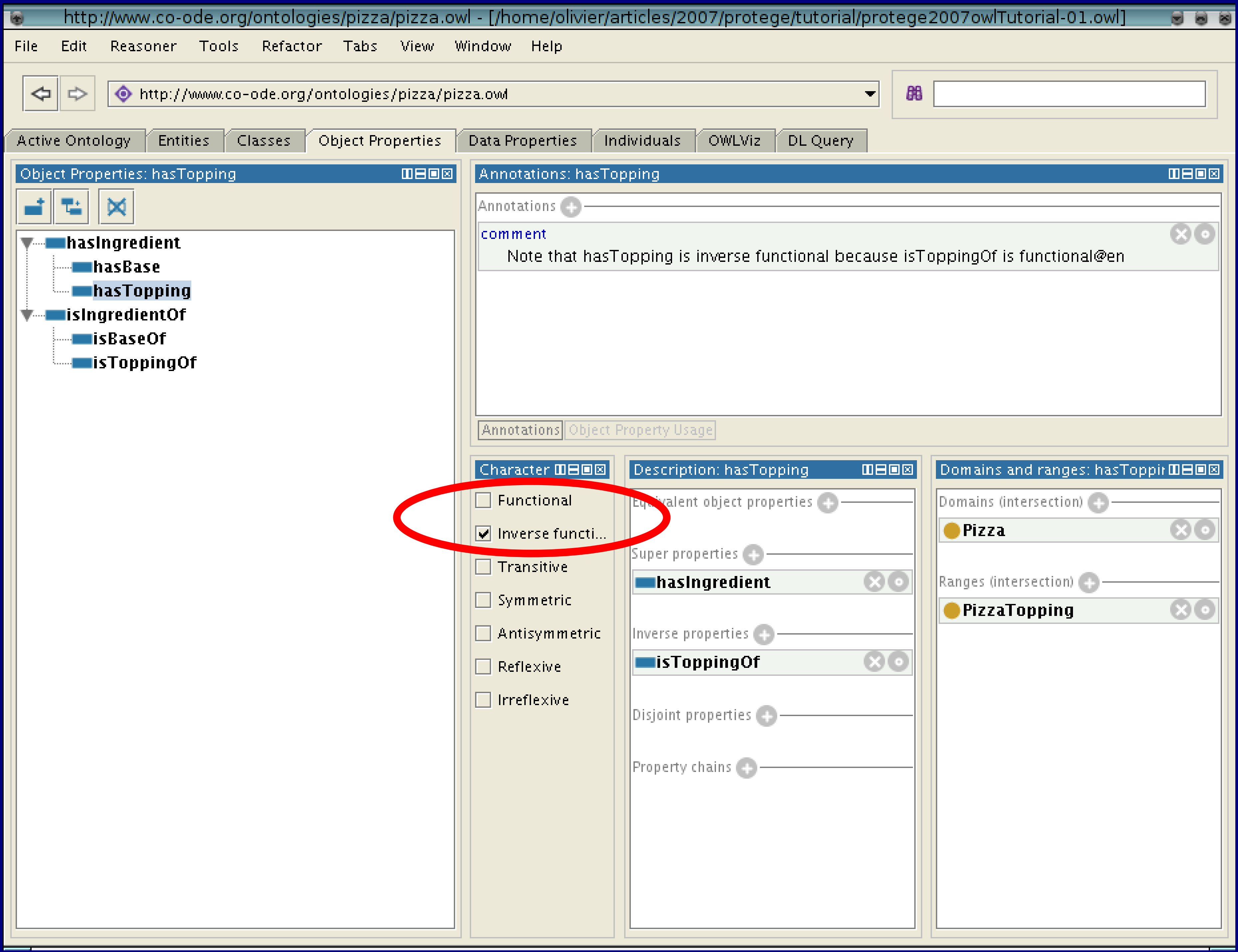
Inverse properties
hasTopping

Disjoint properties

Property chains

Domains (intersection)
PizzaTopping

Ranges (intersection)
Pizza



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Object Properties: hasTopping

- hasIngredient
  - hasBase
  - hasTopping
- isIngredientOf
  - isBaseOf
  - isToppingOf

Annotations: hasTopping

comment
Note that hasTopping is inverse functional because isToppingOf is functional@en

Character

□ Functional
☑ Inverse functi...
□ Transitive
□ Symmetric
□ Antisymmetric
□ Reflexive
□ Irreflexive

Description: hasTopping

Equivalent object properties

Super properties
hasIngredient

Inverse properties
isToppingOf

Disjoint properties

Property chains

Domains and ranges: hasToppir

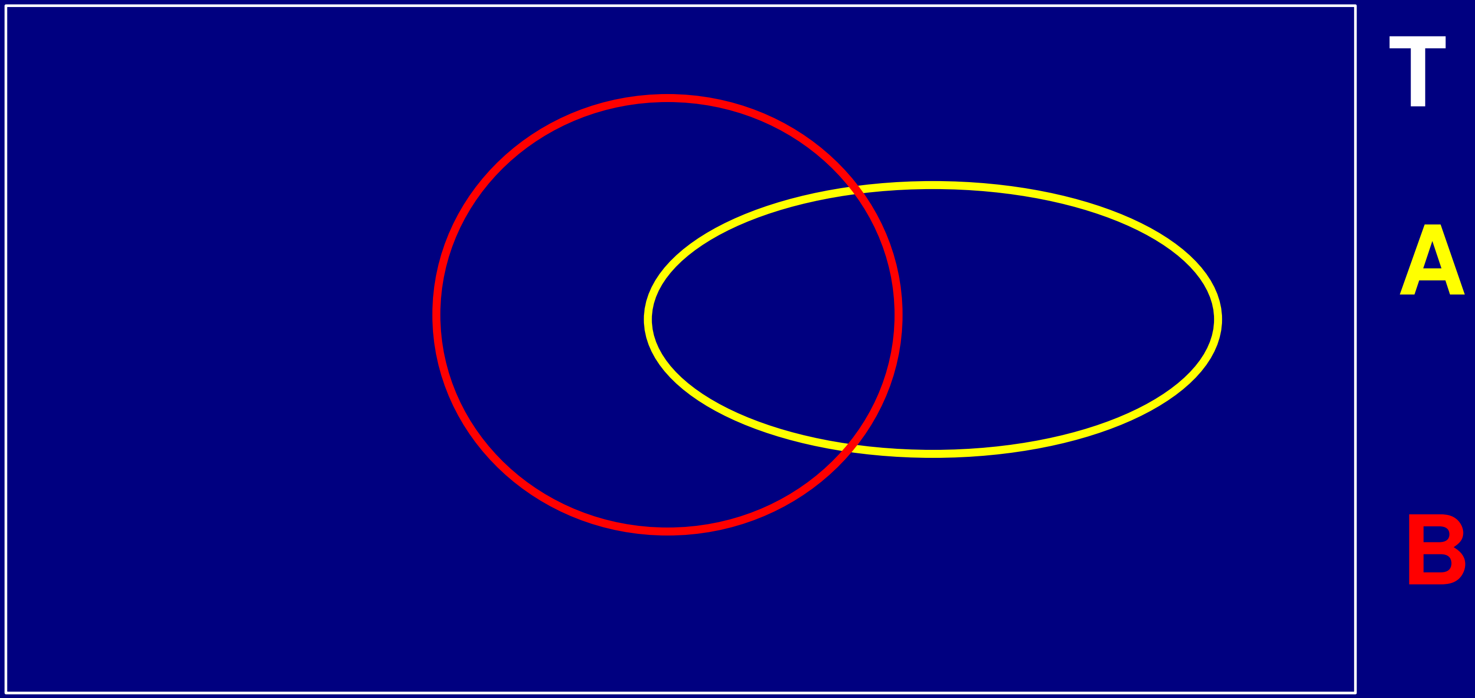
Domains (intersection)
Pizza

Ranges (intersection)
PizzaTopping

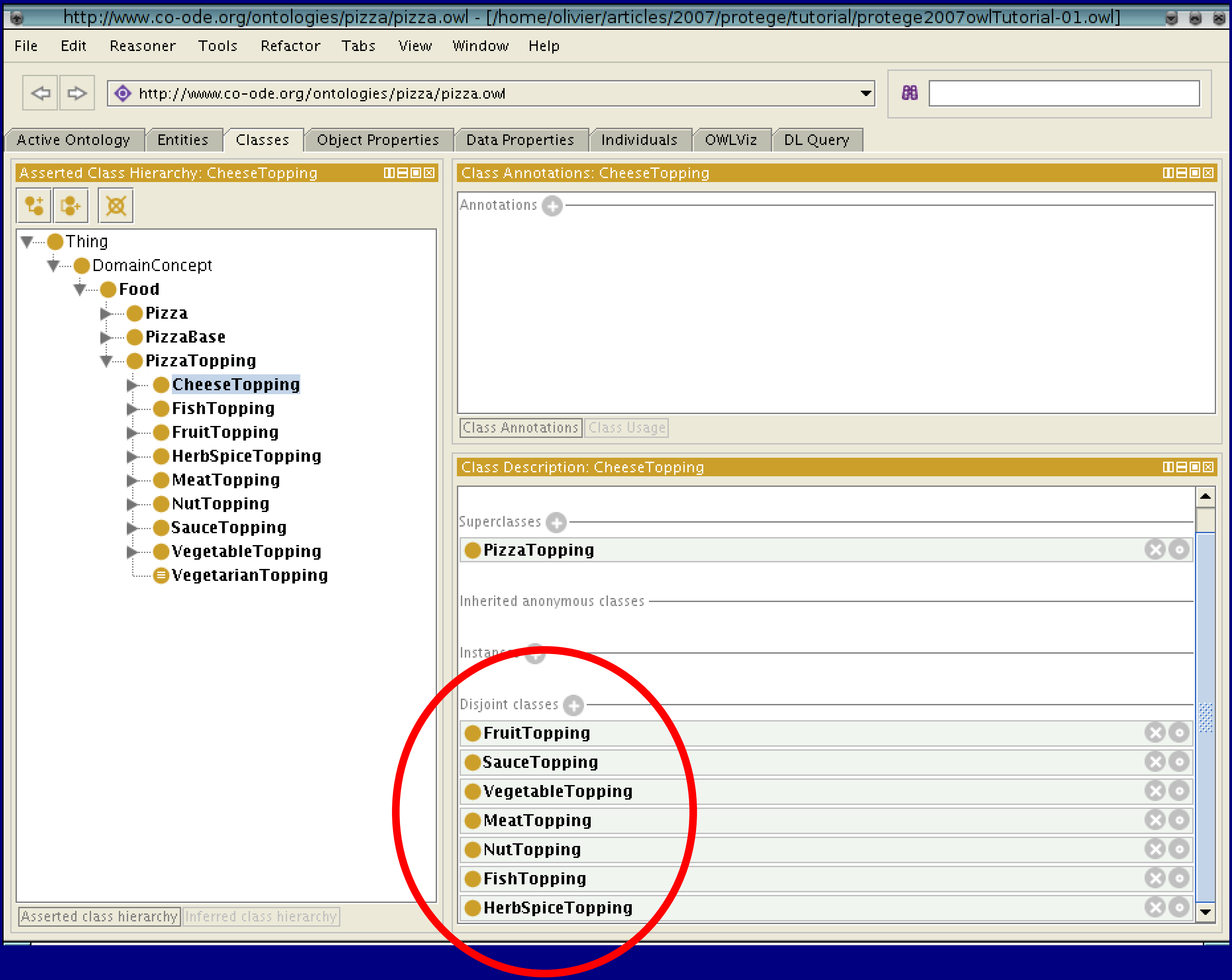
Classes

- A class is a set of individuals
  - Special classes:
    - top ($\top$) = owl:Thing i.e. set of all the individuals
    - bottom ($\bot$) = empty set
  - Can be combined using set operators
    - subset (subsumption)
    - disjoint sets
    - union
    - intersection
    - complement

Classes: Disjointness



By default, any individual MAY be an instance of any classes => **partial overlap of classes is assumed**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Asserted Class Hierarchy: CheeseTopping
Class Annotations: CheeseTopping
Annotations
Class Annotations
Class Usage
Class Description: CheeseTopping
Asserted class hierarchy
Inferred class hierarchy

- Thing
  - DomainConcept
    - Food
      - Pizza
      - PizzaBase
      - PizzaTopping
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping
        - VegetarianTopping

Superclasses

- PizzaTopping

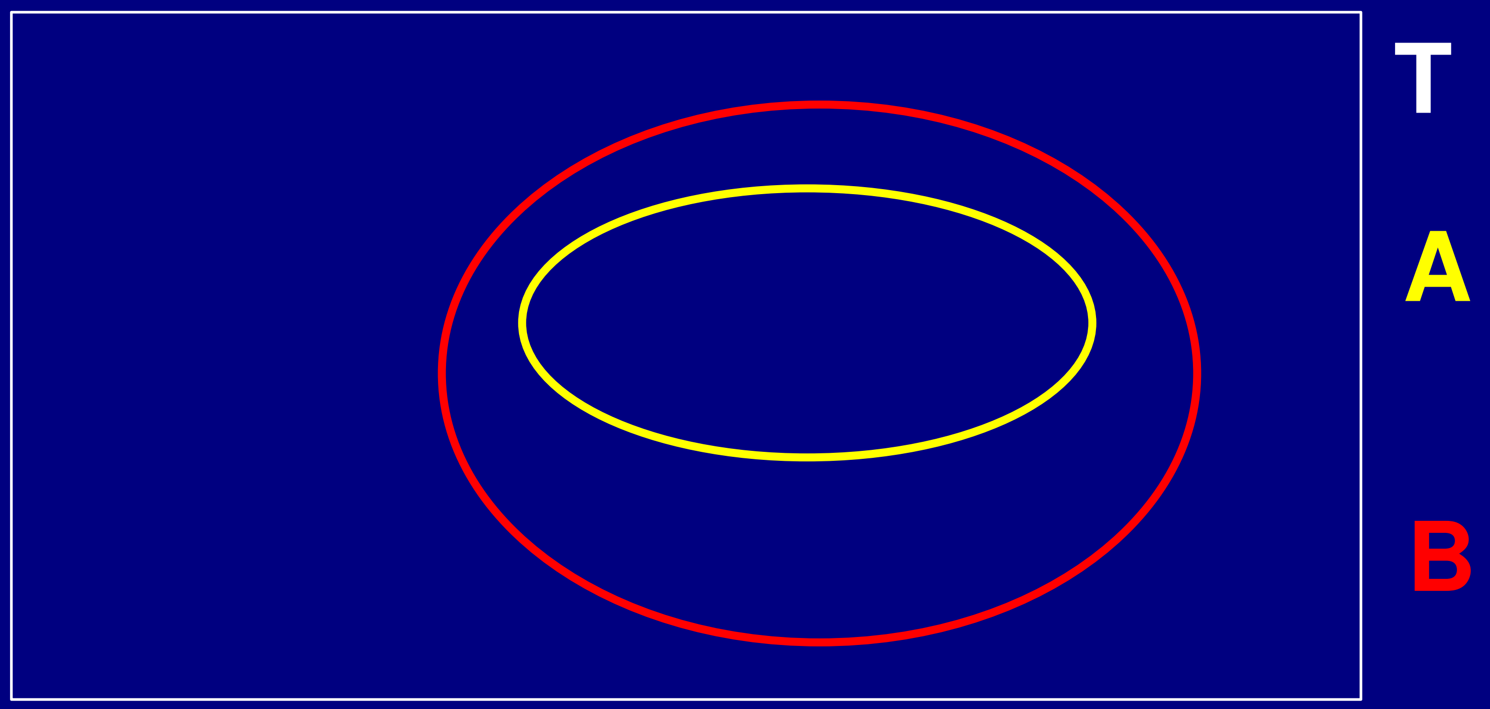
Inherited anonymous classes

Instances

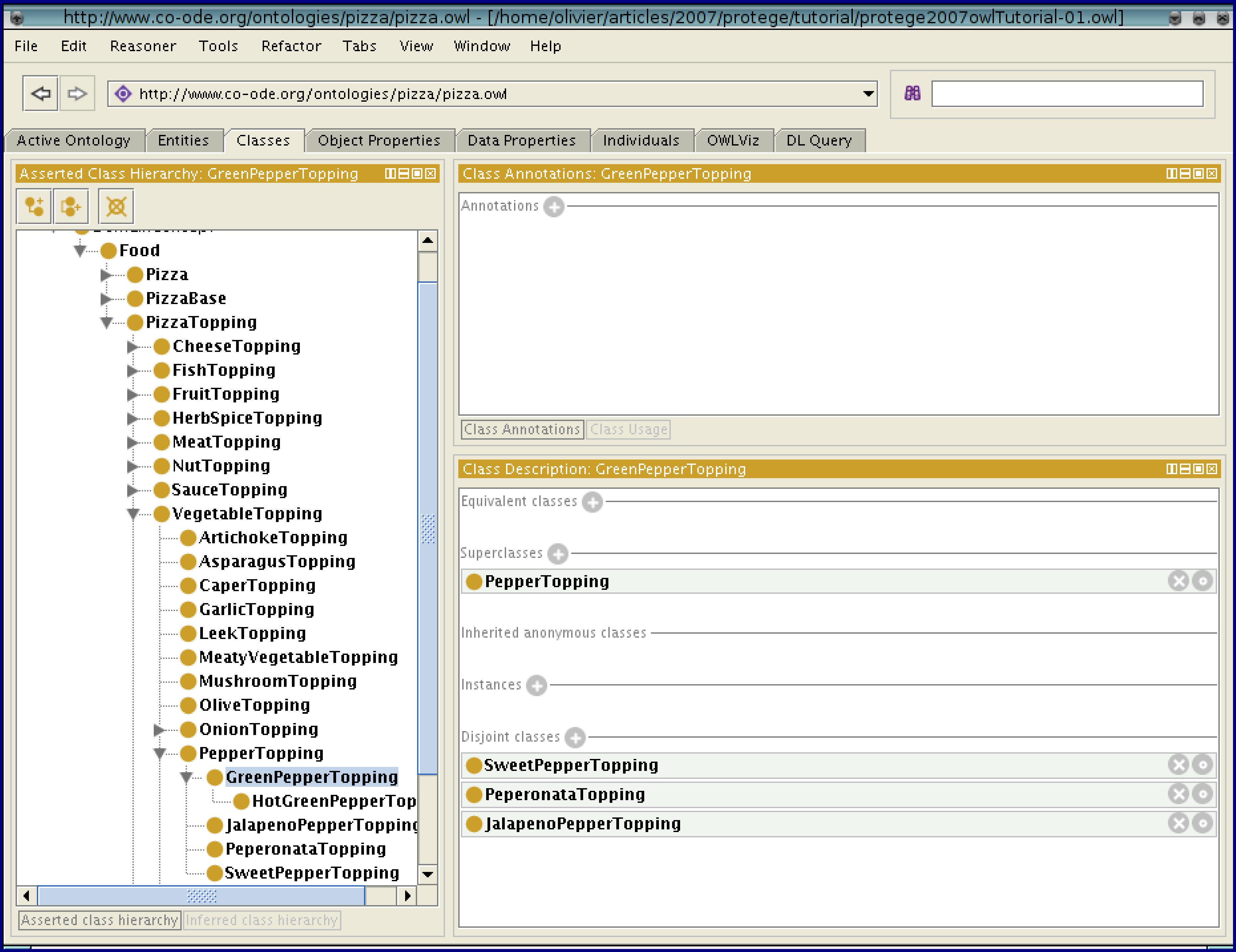
Disjoint classes

- FruitTopping
- SauceTopping
- VegetableTopping
- MeatTopping
- NutTopping
- FishTopping
- HerbSpiceTopping

Classes: subsumption



A ⊑ B : all the instances of A are instances of B (A is subClass of B)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Asserted Class Hierarchy: GreenPepperTopping
Class Annotations: GreenPepperTopping
Annotations
Class Annotations
Class Usage
Class Description: GreenPepperTopping
Equivalent classes
Superclasses
Inherited anonymous classes
Instances
Disjoint classes
Asserted class hierarchy
Inferred class hierarchy

```
Food
    Pizza
    PizzaBase
    PizzaTopping
        CheeseTopping
        FishTopping
        FruitTopping
        HerbSpiceTopping
        MeatTopping
        NutTopping
        SauceTopping
        VegetableTopping
            ArtichokeTopping
            AsparagusTopping
            CaperTopping
            GarlicTopping
            LeekTopping
            MeatyVegetableTopping
            MushroomTopping
            OliveTopping
            OnionTopping
            PepperTopping
                GreenPepperTopping
                    HotGreenPepperTop
                JalapenoPepperToppin
                PeperonataTopping
                SweetPepperTopping
```

Superclasses

- PepperTopping

Disjoint classes

- SweetPepperTopping
- PeperonataTopping
- JalapenoPepperTopping

Classes

- Cumulative approach: combine classes
  - using set operators (union, intersection, complement)
  - express constraints
  - define complex concepts
- Intensional approach: describe the characteristics of a class and the system will automatically:
  - recognize that an individual is an instance of it
  - recognize that it is a subclass or a superclass of another class

Combining Classes

Objective

- Combine classes using the OR, AND and NOT operators
- Refer to the semantics of these operators (and avoid some basic mistakes)

=> find out which pizze are:

  - Cheesy and vegetarian
  - Cheesy or vegetarian
  - vegetarian and not vegetarian

Prerequisite

- Pizza
  - VegetarianPizza
  - CheesyPizza

  NOT DISJOINTS

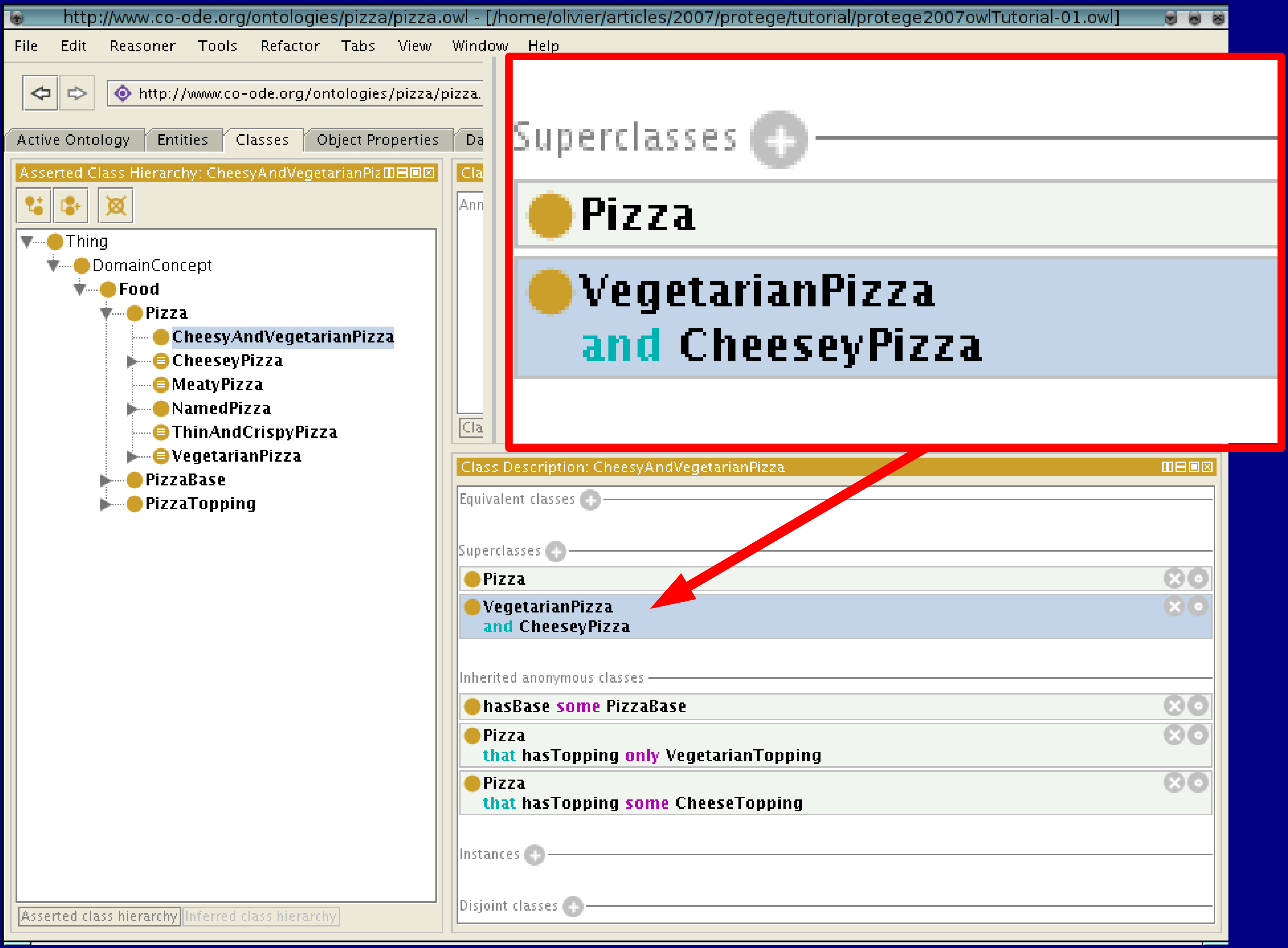
  - NamedPizza
    - MargheritaPizza
    - AmericanPizza
    - CaprinaPizza

    DISJOINTS

Don't worry about the toppings, this is the next step!

AND (Intersection)

- Create CheesyAndVegetarianPizza as a subclass of Pizza
  - so far, except for the name, we have not provided any meaning
  - we have not exploited the cumulative approach
- Add the necessary condition: VegetarianPizza ⊓ CheesyPizza
- Classify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Asserted class hierarchy
Inferred class hierarchy
Class Description: CheesyAndVegetarianPizza

Asserted Class Hierarchy: CheesyAndVegetarianPiz

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheesyAndVegetarianPizza
        - CheeseyPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping

Superclasses

Pizza

VegetarianPizza
and CheeseyPizza

Class Description: CheesyAndVegetarianPizza

Equivalent classes

Superclasses

Pizza

VegetarianPizza
and CheeseyPizza

Inherited anonymous classes

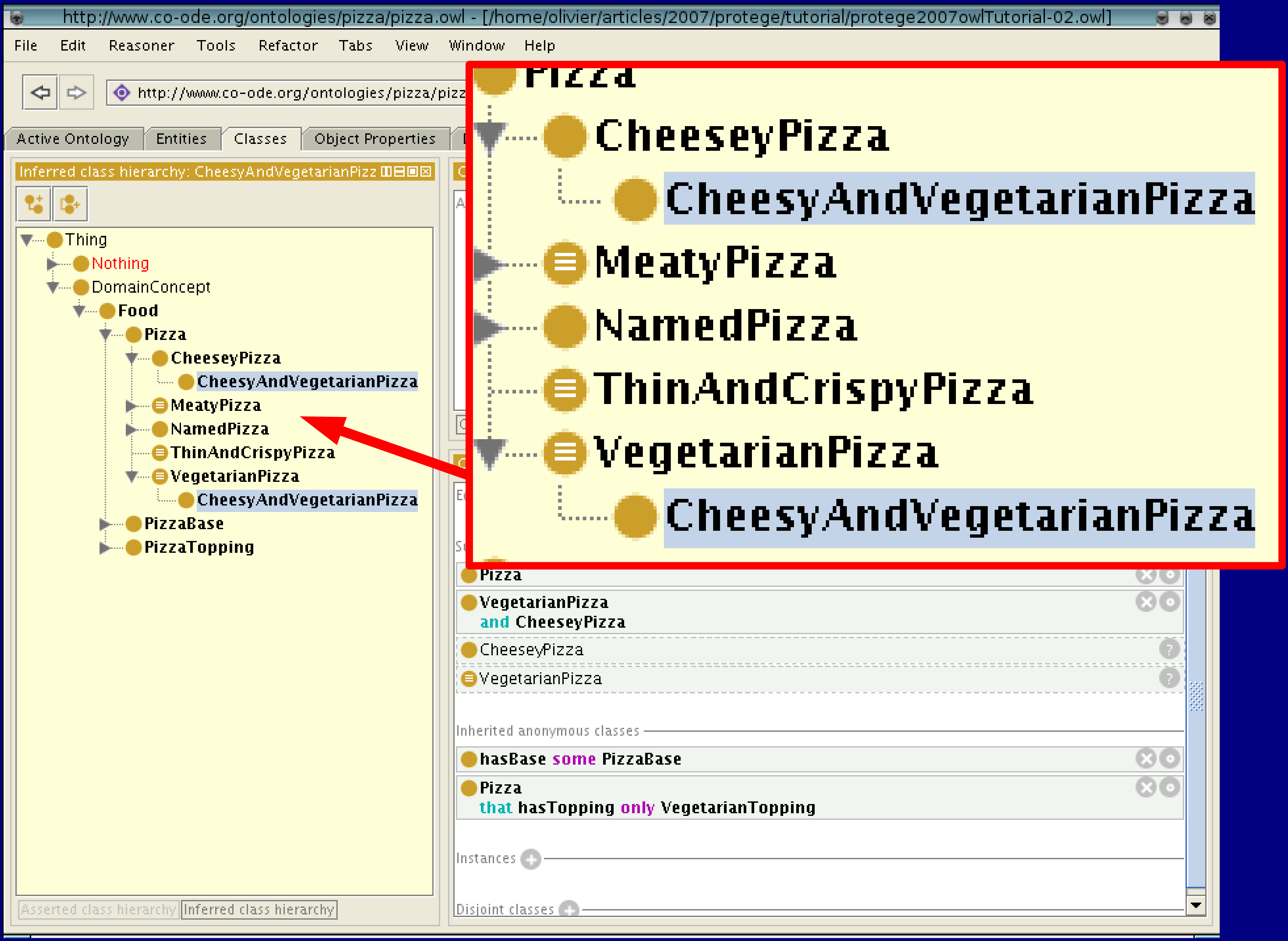
hasBase some PizzaBase

Pizza
that hasTopping only VegetarianTopping

Pizza
that hasTopping some CheeseTopping

Instances

Disjoint classes



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http://www.co-ode.org/ontologies/pizza/pizz

Inferred class hierarchy: CheesyAndVegetarianPizz

- Thing
  - Nothing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyPizza
          - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
          - CheesyAndVegetarianPizza
      - PizzaBase
      - PizzaTopping

Pizza

VegetarianPizza
and CheeseyPizza

CheeseyPizza

VegetarianPizza

Inherited anonymous classes

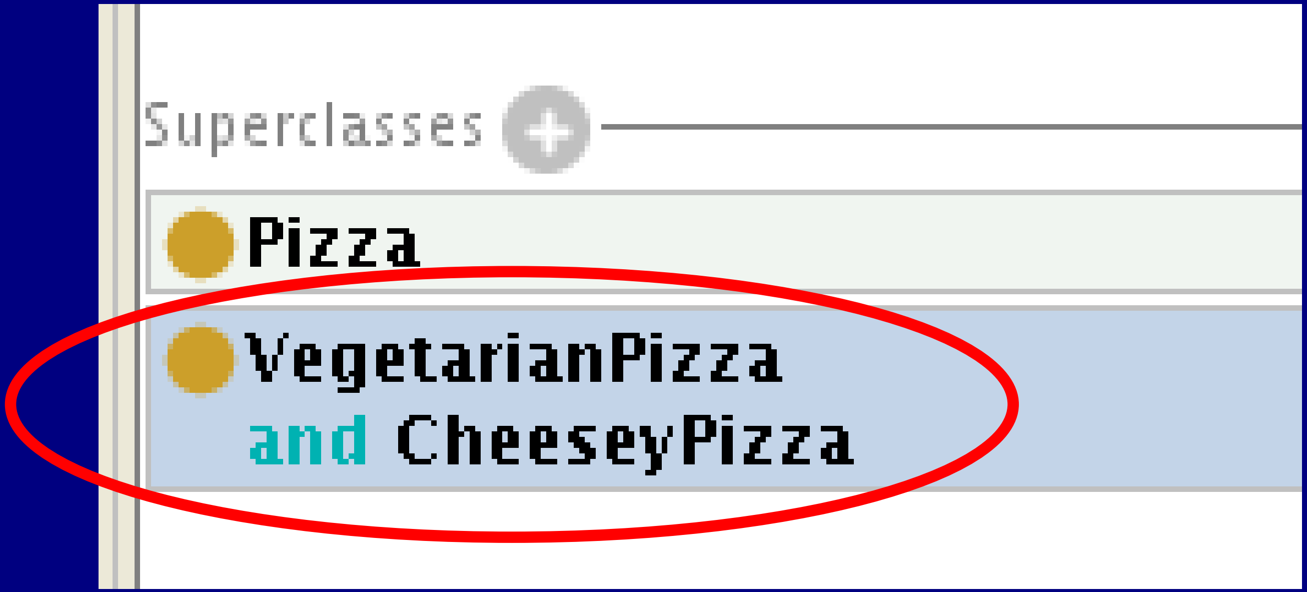
hasBase some PizzaBase

Pizza
that hasTopping only VegetarianTopping

Instances

Disjoint classes

- Pizza
  - CheeseyPizza
    - CheesyAndVegetarianPizza
  - MeatyPizza
  - NamedPizza
  - ThinAndCrispyPizza
  - VegetarianPizza
    - CheesyAndVegetarianPizza

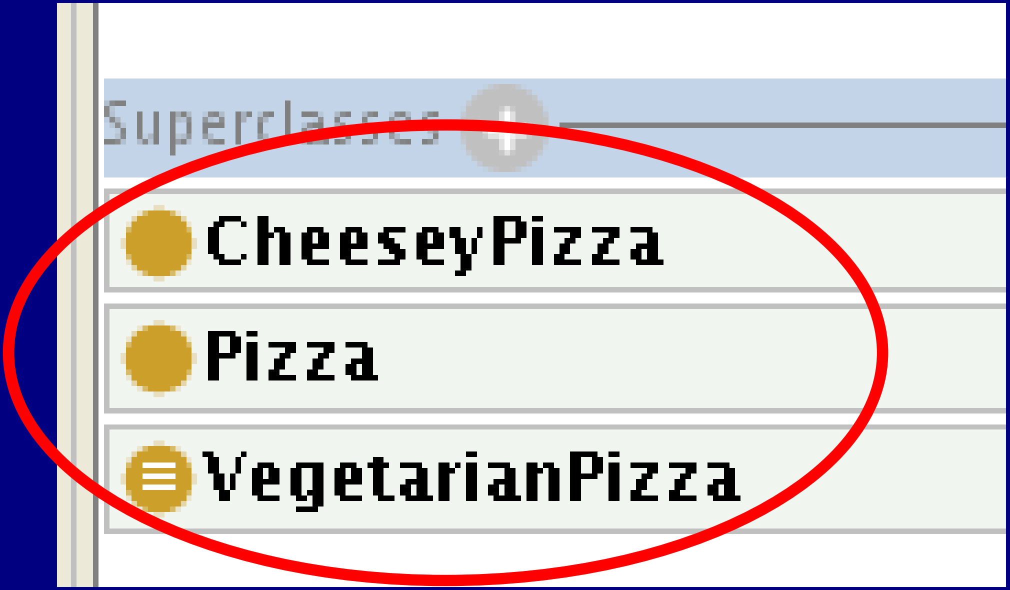


Superclasses

Pizza

VegetarianPizza
and CheeseyPizza

is equivalent to:



Superclasses

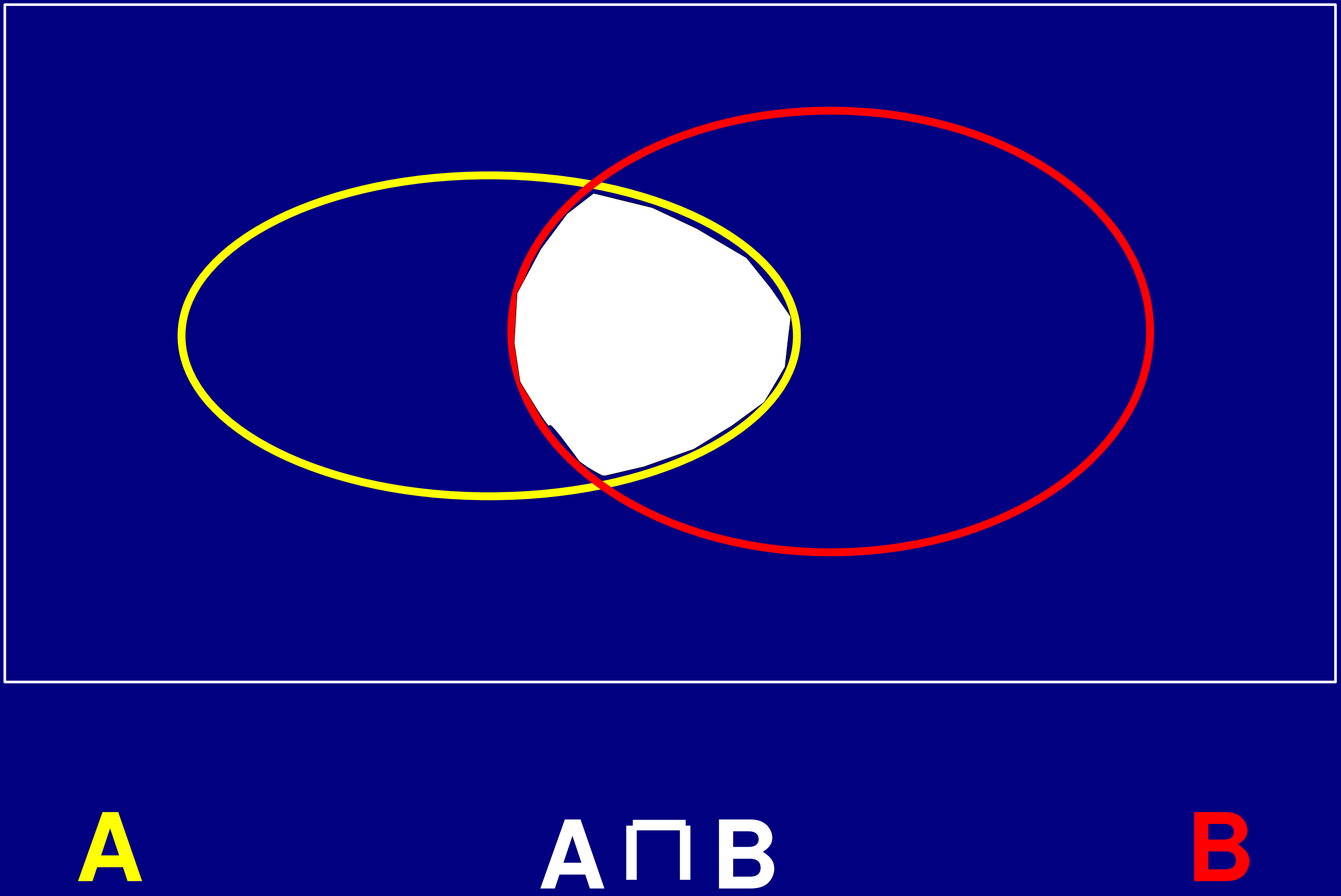
CheeseyPizza

Pizza

VegetarianPizza

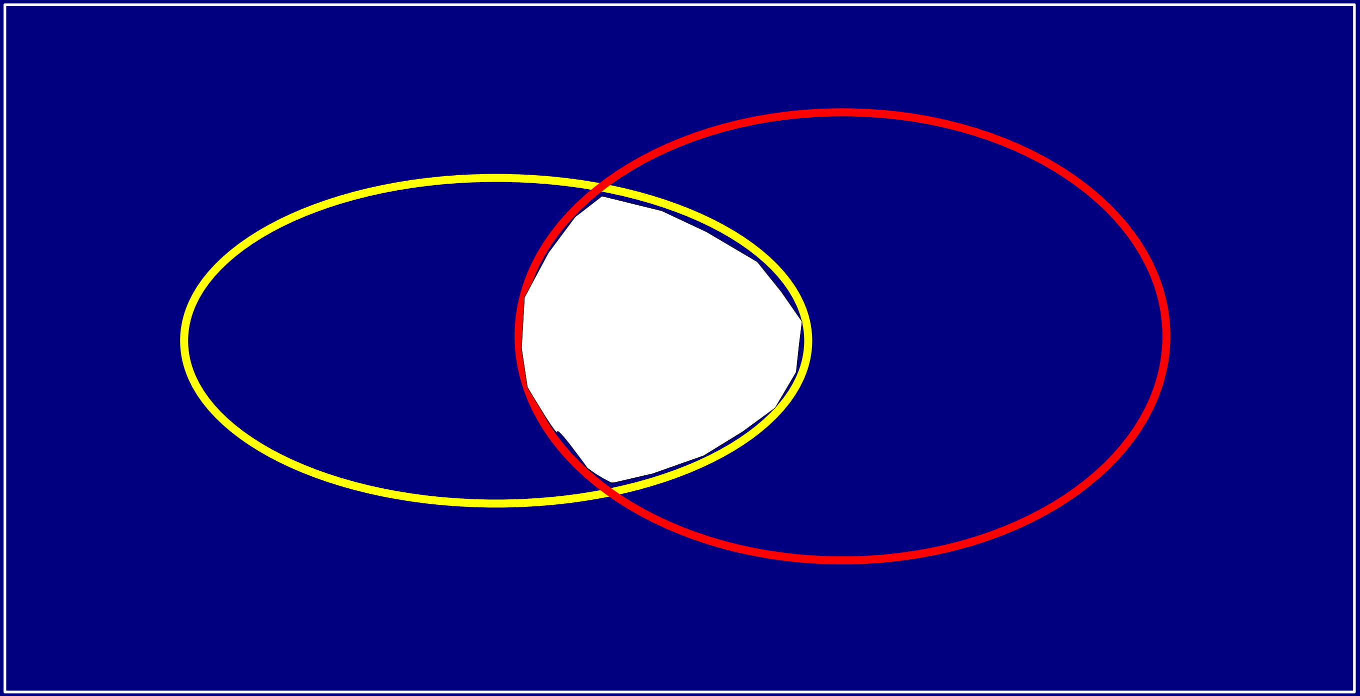
... but the reasoning would have been trivial :-)

AND (Intersection)



$A \sqcap B$ = set of indiv. instances of A and of B

AND (Intersection)



A

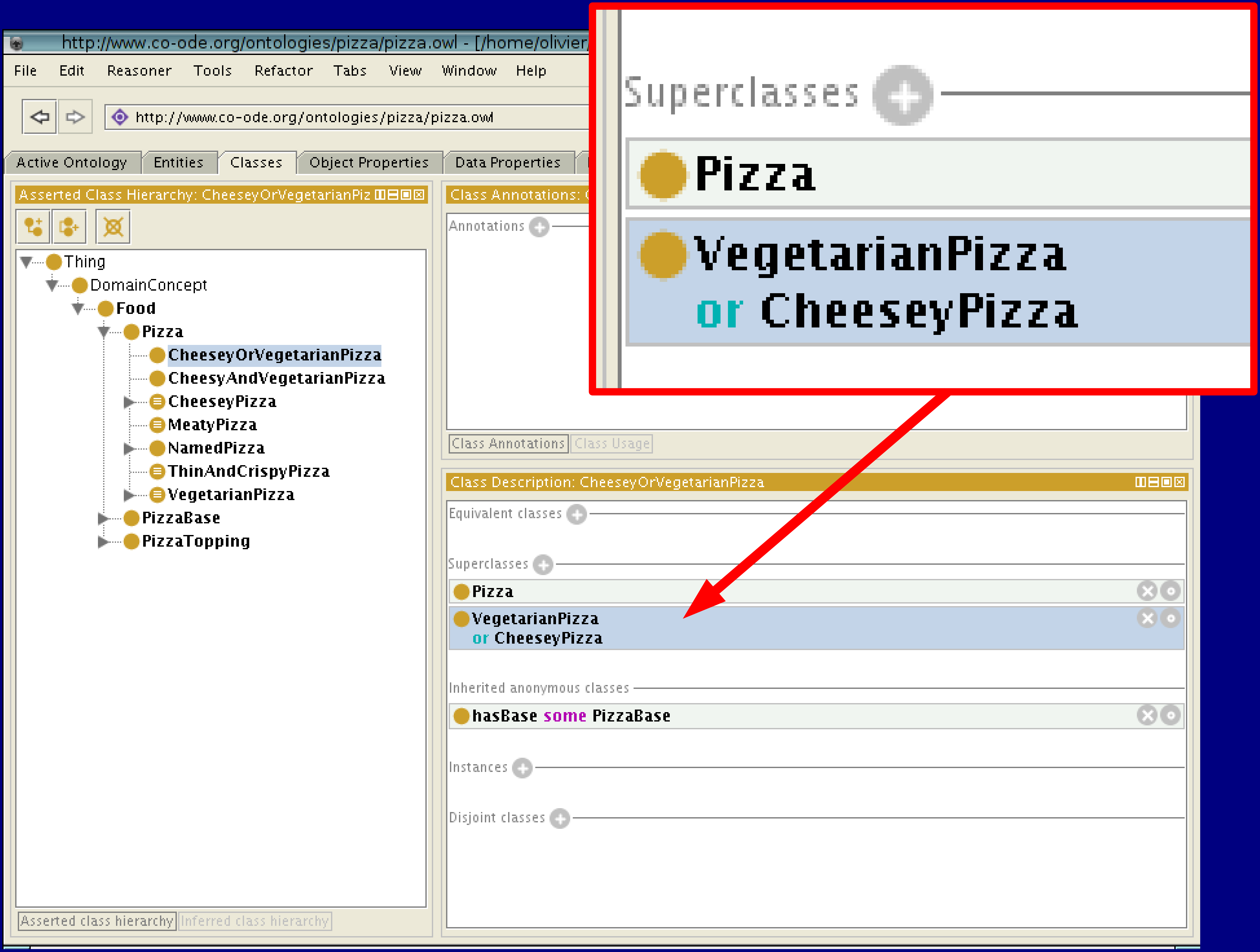
A ⊓ B

B

Ex: VegetarianPizza ⊓ CheesyPizza

OR (Union)

- Create CheesyOrVegetarianPizza as a subclass of Pizza
- Add the necessary condition: VegetarianPizza ⊔ CheesyPizza
- Classify :-(



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Asserted Class Hierarchy: CheeseyOrVegetarianPiz

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheesyAndVegetarianPizza
        - CheeseyPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping

Class Annotations: C

Annotations

Class Description: CheeseyOrVegetarianPizza

Equivalent classes

Superclasses

Pizza

VegetarianPizza
or CheeseyPizza

Inherited anonymous classes

hasBase some PizzaBase

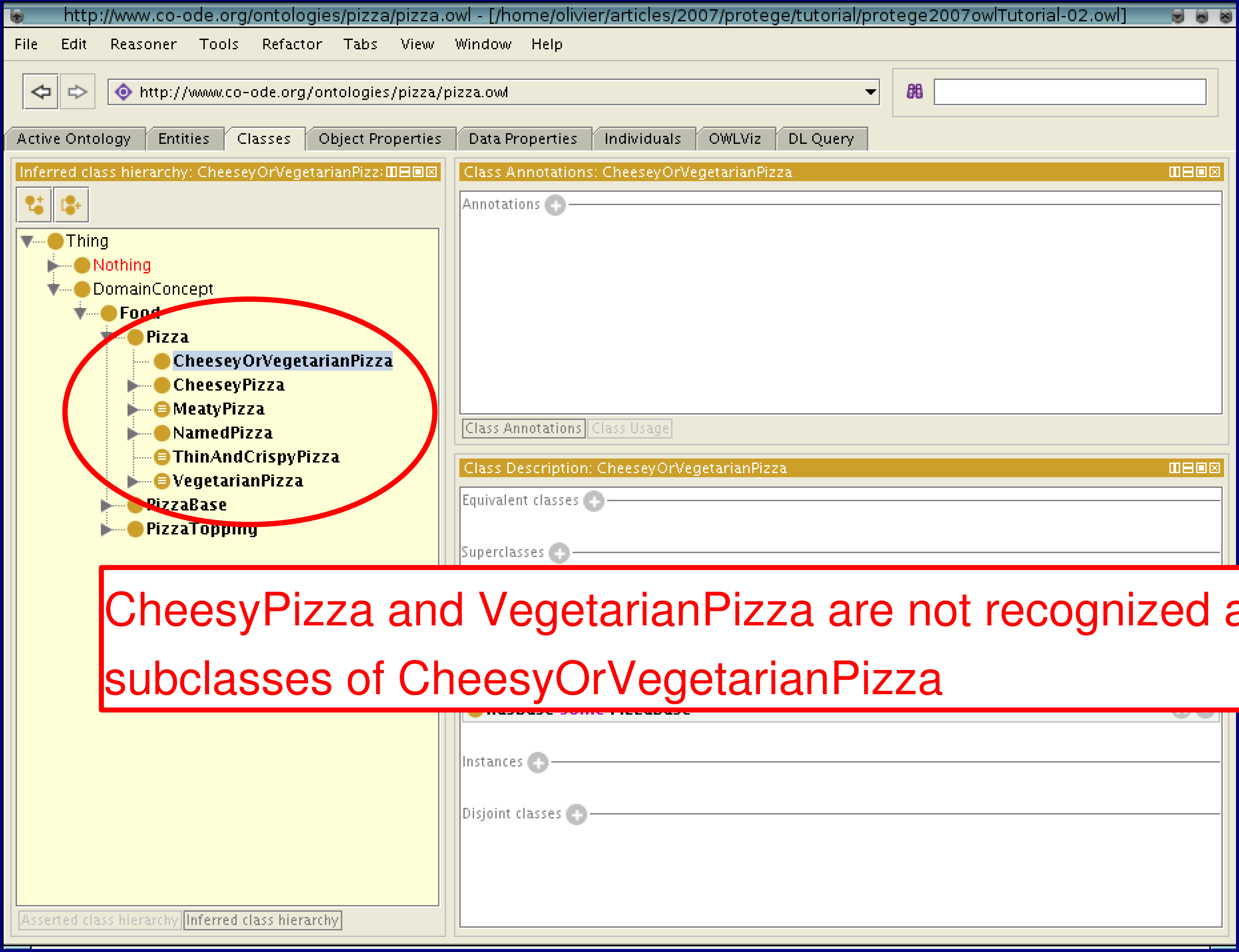
Instances

Disjoint classes

Superclasses

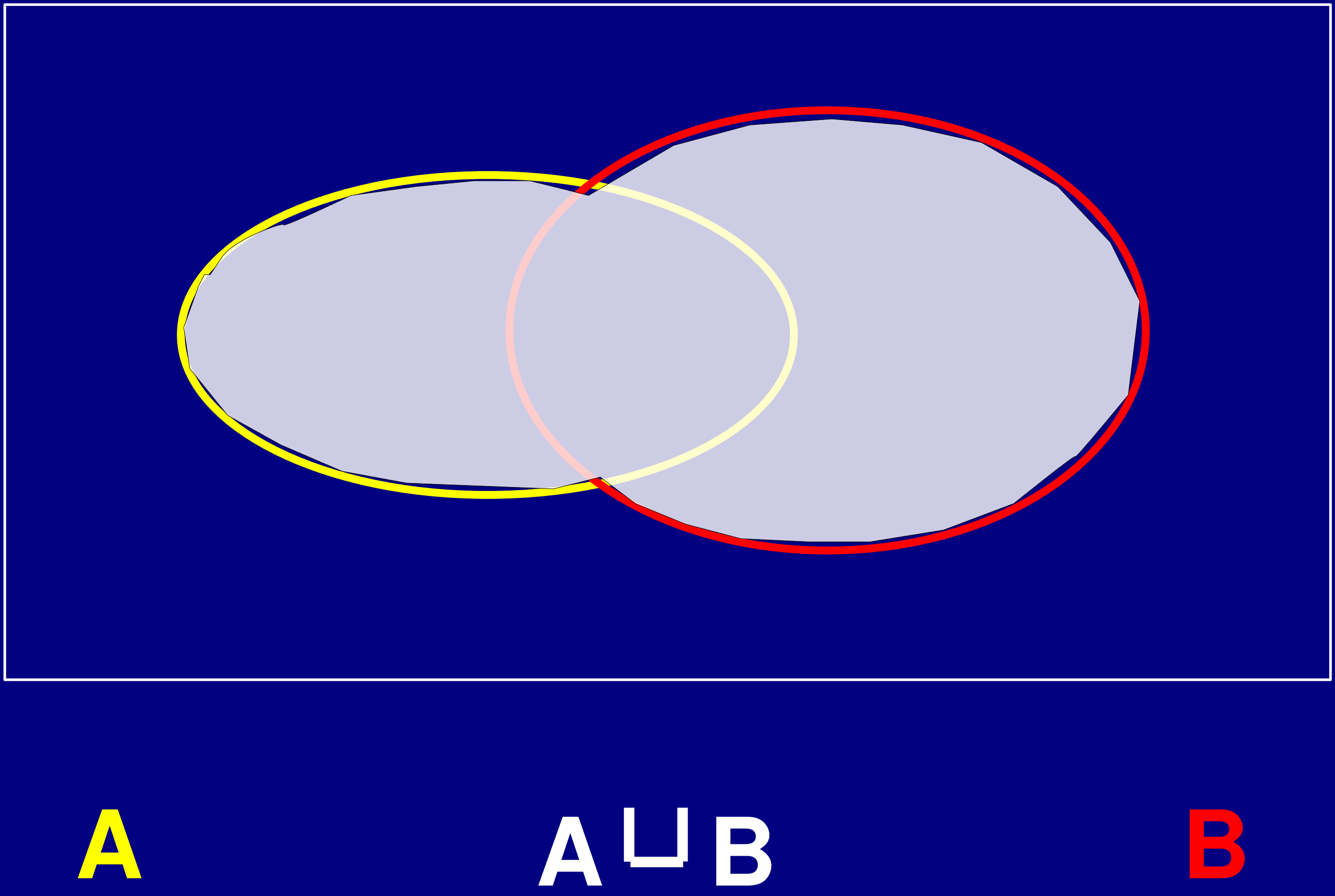
Pizza

VegetarianPizza
or CheeseyPizza



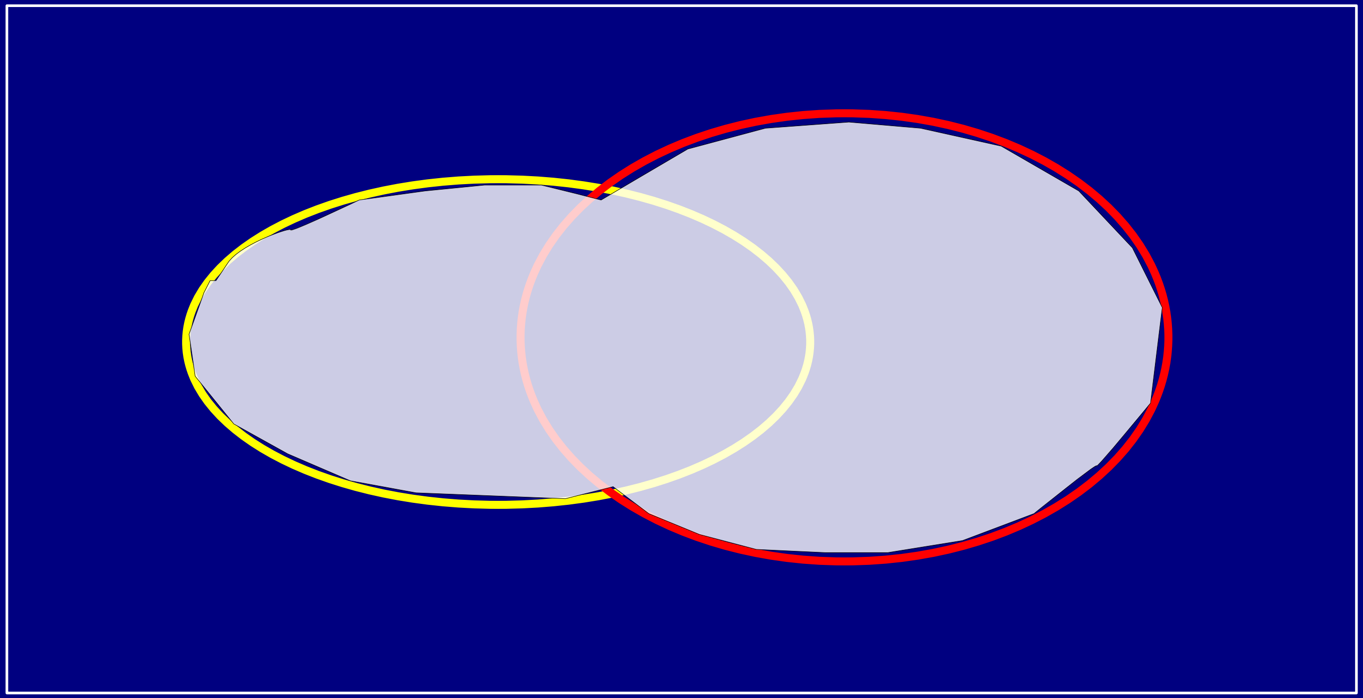
CheesyPizza and VegetarianPizza are not recognized as subclasses of CheesyOrVegetarianPizza

OR (Union)



$A \sqcup B$ = set of indiv. instances of A or of B

OR (Union)

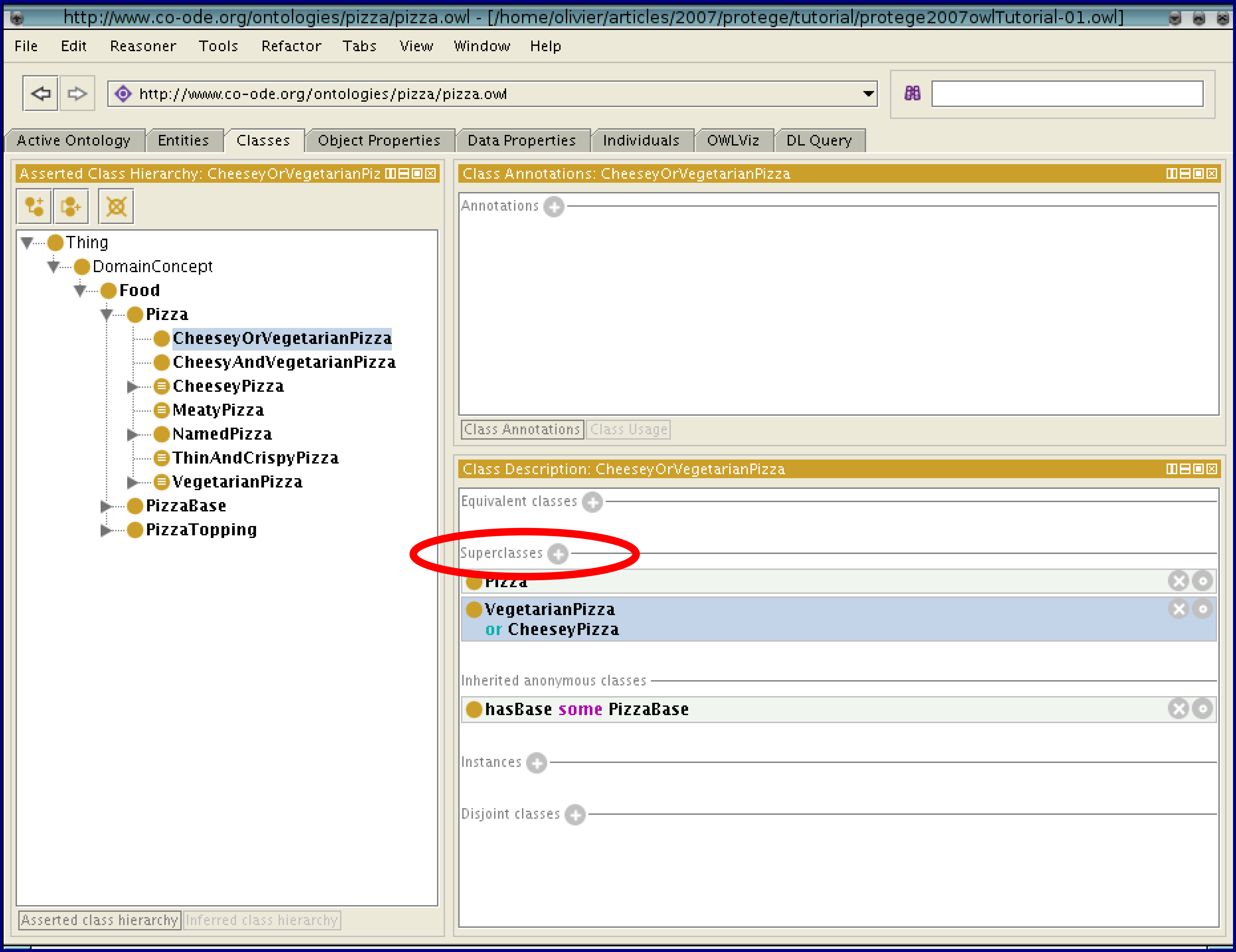


A

A ⊔ B

B

Ex: VegetarianPizza ⊔ CheesyPizza



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Class Annotations: CheeseyOrVegetarianPizza
Annotations
Class Annotations
Class Usage
Class Description: CheeseyOrVegetarianPizza
Asserted class hierarchy
Inferred class hierarchy

```
Thing
  DomainConcept
    Food
      Pizza
        CheeseyOrVegetarianPizza
        CheesyAndVegetarianPizza
        CheeseyPizza
        MeatyPizza
        NamedPizza
        ThinAndCrispyPizza
        VegetarianPizza
      PizzaBase
      PizzaTopping
```

Equivalent classes

Superclasses

- Pizza
- VegetarianPizza
  or CheeseyPizza

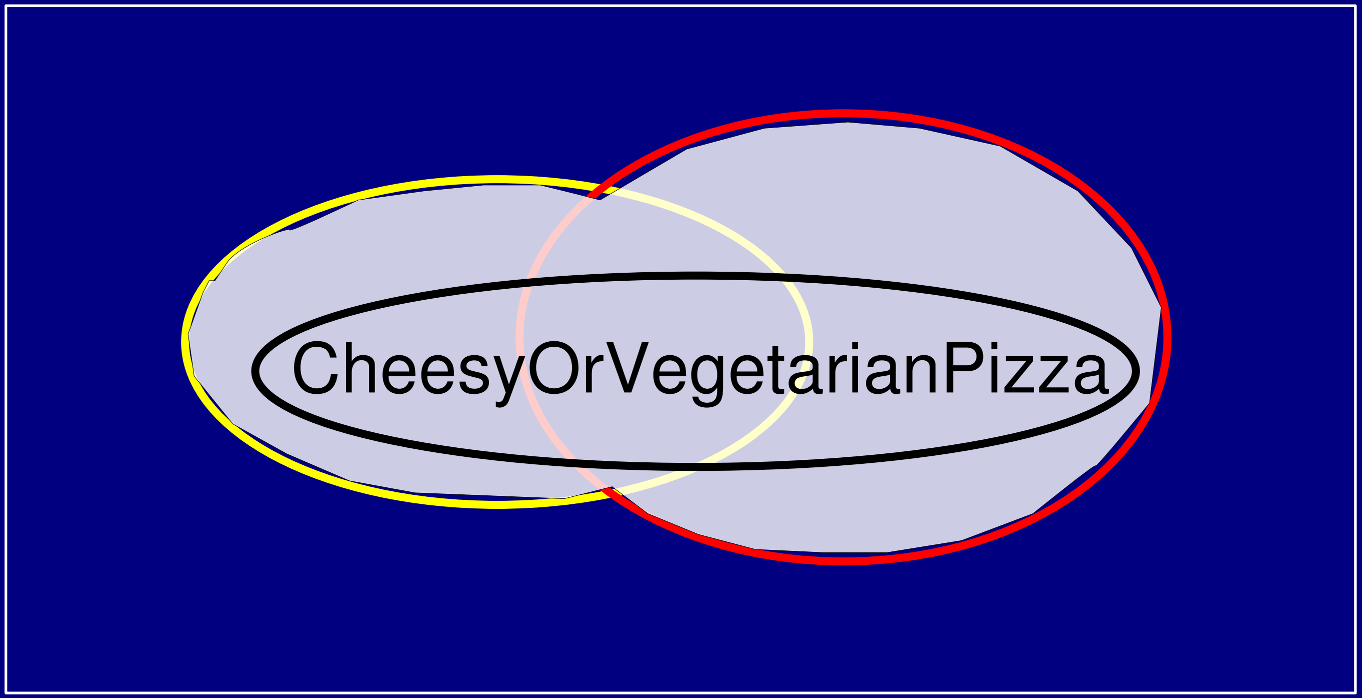
Inherited anonymous classes

- hasBase some PizzaBase

Instances

Disjoint classes

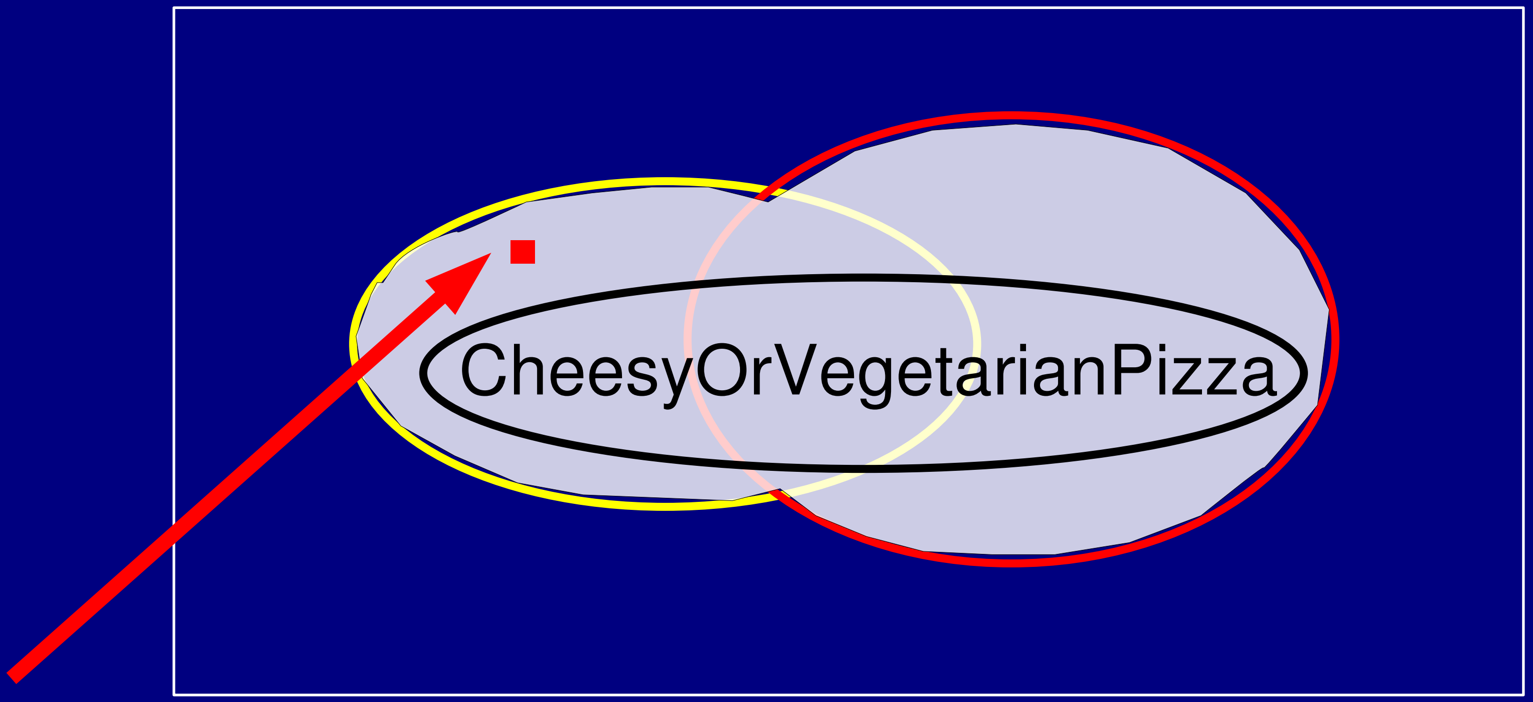
OR (Union)



A **A ⊔ B** **B**

CheesyOrVegie ⊏ VegetarianPizza ⊔ CheesyPizza

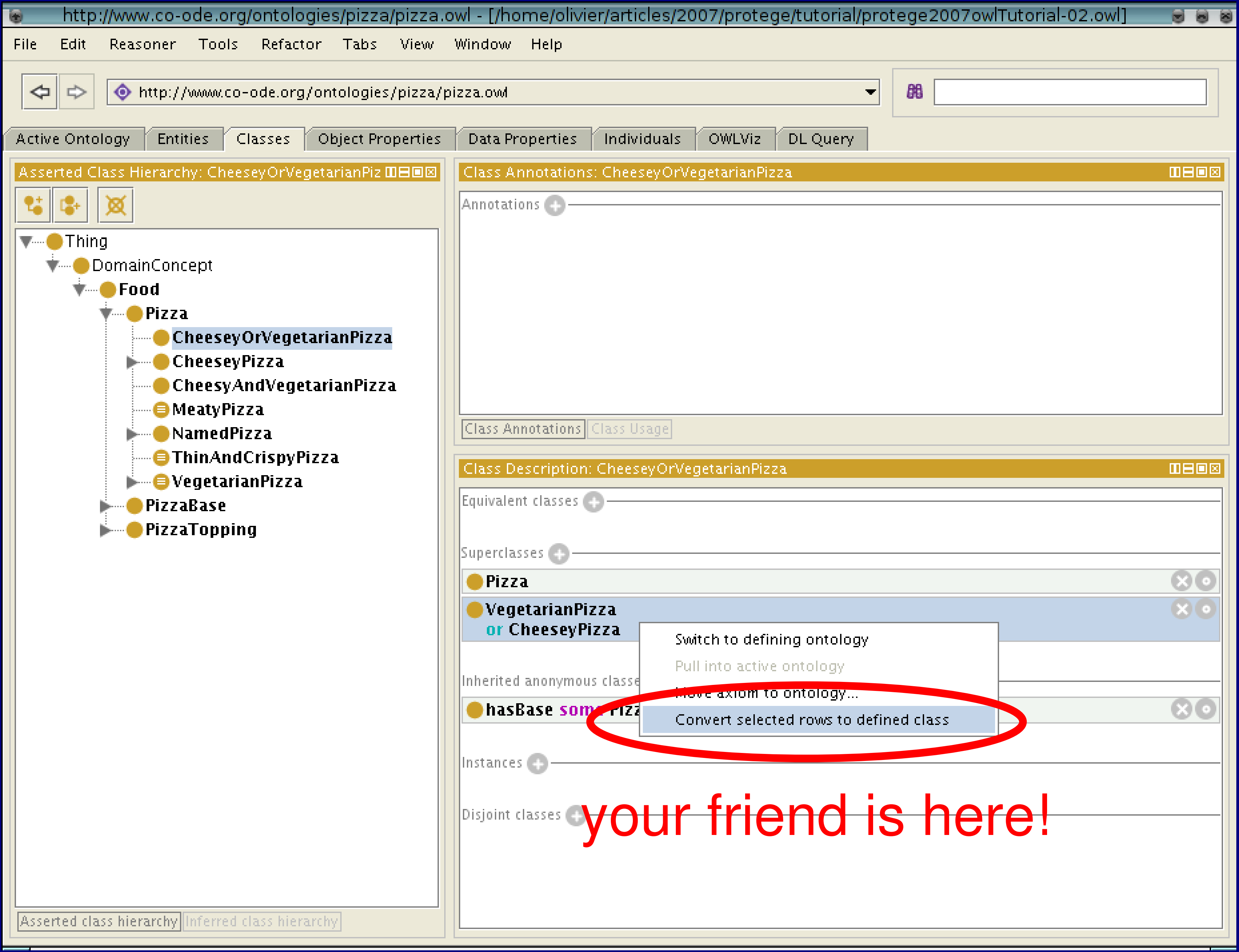
OR (Union)



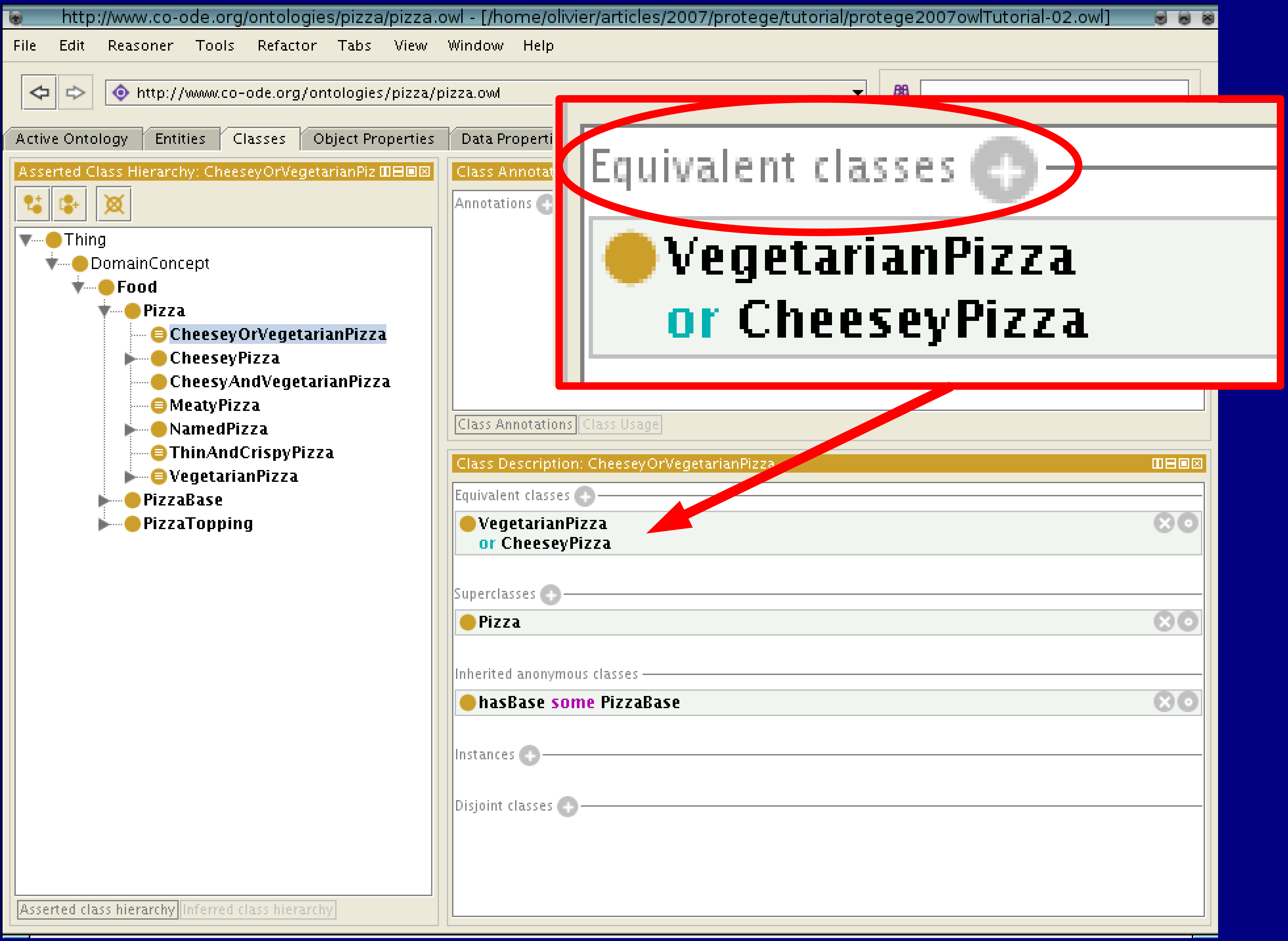
- There could be instances of CheesyPizza (red dot) that are not instances of CheesyOrVegetarianPizza...
- ... therefore, CheesyPizza is not subclass of CheesyOrVeggie

OR (Union)

- Now, use a definition for CheesyOrVegetarianPizza (tip: right-click is your friend)



your friend is here!



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http://www.co-ode.org/ontologies/pizza/pizza.owl

Asserted Class Hierarchy: CheeseyOrVegetarianPiz

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping

Class Description: CheeseyOrVegetarianPizza

Equivalent classes

VegetarianPizza
or CheeseyPizza

Superclasses

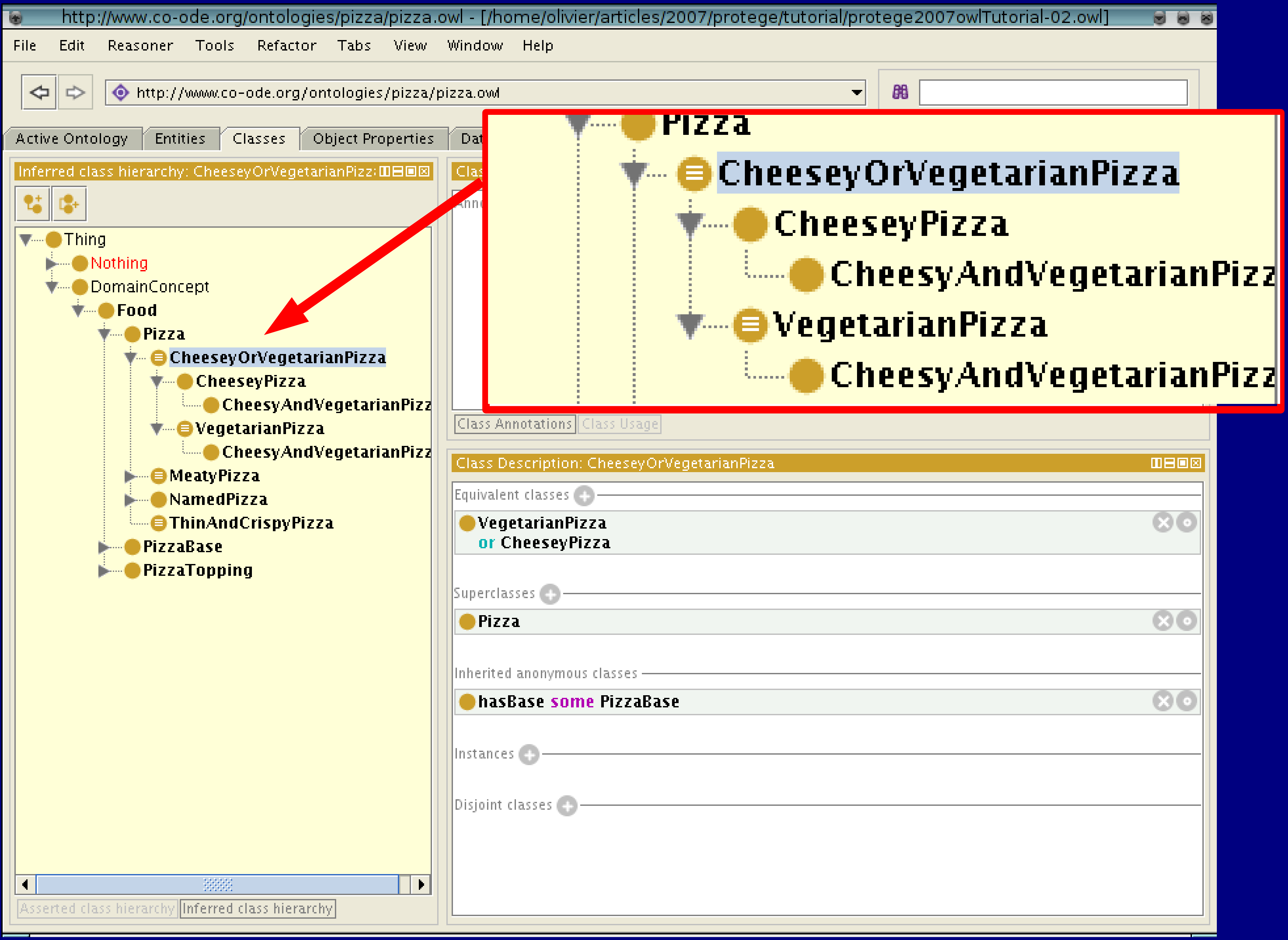
Pizza

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes



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Inferred class hierarchy: CheeseyOrVegetarianPizz

- Thing
  - Nothing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
          - CheeseyPizza
            - CheesyAndVegetarianPizz
          - VegetarianPizza
            - CheesyAndVegetarianPizz
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
      - PizzaBase
      - PizzaTopping

- Pizza
  - CheeseyOrVegetarianPizza
    - CheeseyPizza
      - CheesyAndVegetarianPizz
    - VegetarianPizza
      - CheesyAndVegetarianPizz

Class Description: CheeseyOrVegetarianPizza

Equivalent classes

VegetarianPizza
or CheeseyPizza

Superclasses

Pizza

Inherited anonymous classes

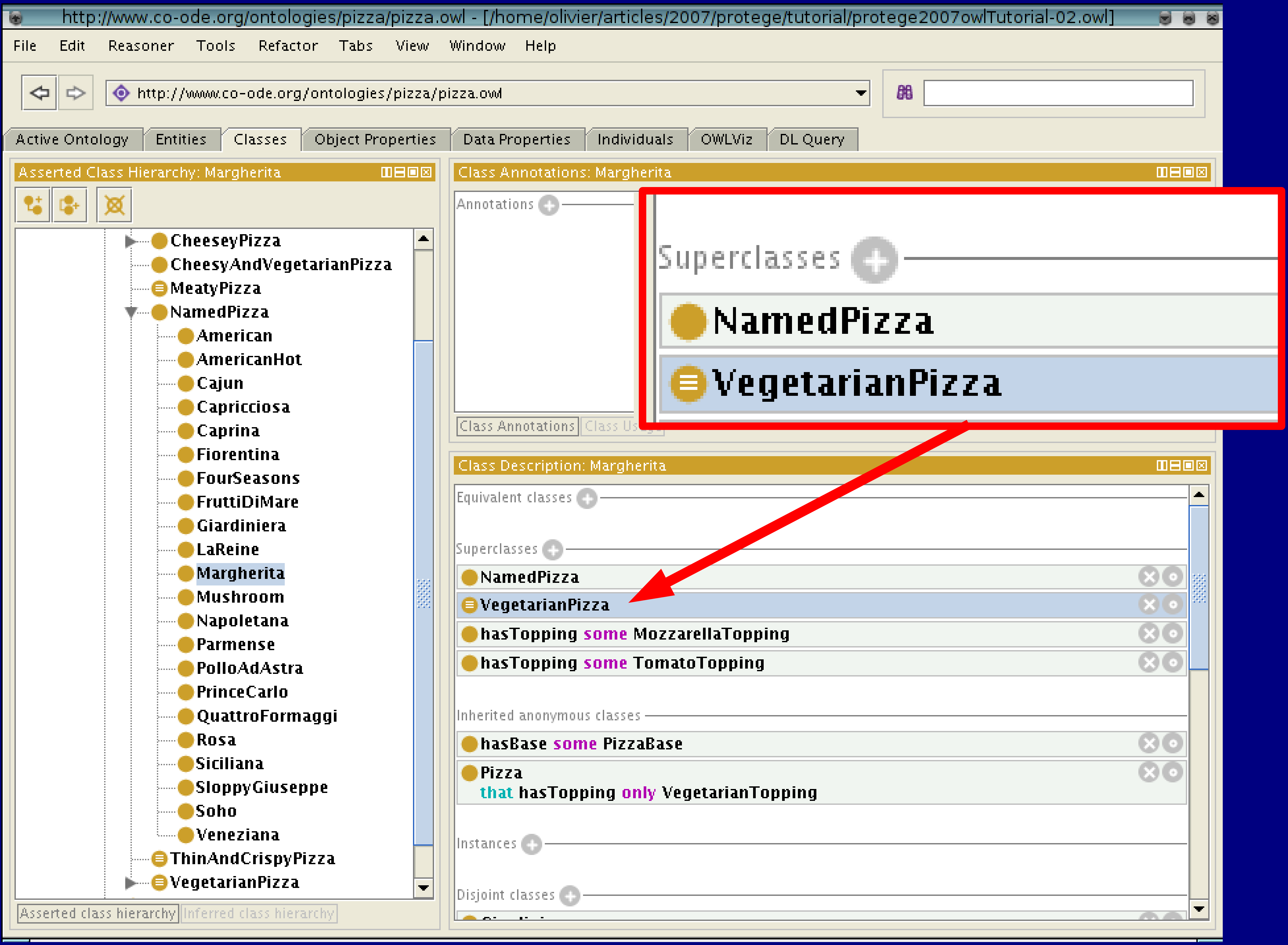
hasBase some PizzaBase

Instances

Disjoint classes

Examples

- Declare MargheritaPizza to be a VegetarianPizza
- Declare AmericanPizza to be a CheesyPizza
- Declare CaprinaPizza to be both CheesyPizza and VegetarianPizza
- Classify
  - :-)
  - why isn't CaprinaPizza classified as expected ?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DL Query
Asserted Class Hierarchy: Margherita
Class Annotations: Margherita
Annotations
Class Annotations
Class Usage
Class Description: Margherita
Asserted class hierarchy
Inferred class hierarchy

Superclasses
- NamedPizza
- VegetarianPizza

Asserted Class Hierarchy: Margherita

- CheeseyPizza
- CheesyAndVegetarianPizza
- MeatyPizza
- NamedPizza
  - American
  - AmericanHot
  - Cajun
  - Capricciosa
  - Caprina
  - Fiorentina
  - FourSeasons
  - FruttiDiMare
  - Giardiniera
  - LaReine
  - Margherita
  - Mushroom
  - Napoletana
  - Parmense
  - PolloAdAstra
  - PrinceCarlo
  - QuattroFormaggi
  - Rosa
  - Siciliana
  - SloppyGiuseppe
  - Soho
  - Veneziana
- ThinAndCrispyPizza
- VegetarianPizza

Class Description: Margherita

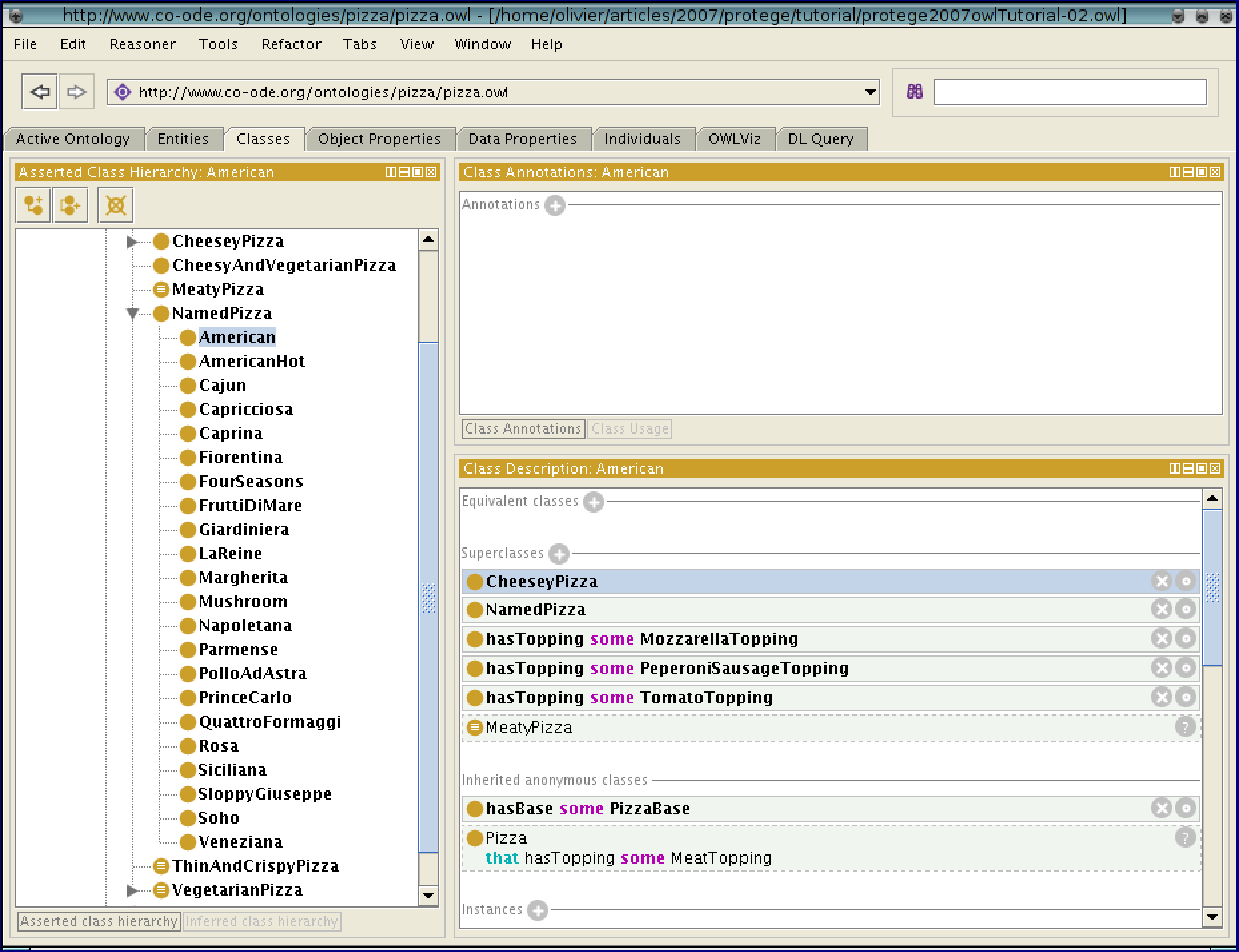
Equivalent classes

Superclasses
- NamedPizza
- VegetarianPizza
- hasTopping some MozzarellaTopping
- hasTopping some TomatoTopping

Inherited anonymous classes
- hasBase some PizzaBase
- Pizza
  that hasTopping only VegetarianTopping

Instances

Disjoint classes



http://www.co-ode.org/ontologies/pizza/pizza.owl - [/home/olivier/articles/2007/protege/tutorial/protege2007owlTutorial-02.owl]

http://www.co-ode.org/ontologies/pizza/pizza.owl

Asserted Class Hierarchy: American

- CheeseyPizza
- CheesyAndVegetarianPizza
- MeatyPizza
- NamedPizza
  - American
  - AmericanHot
  - Cajun
  - Capricciosa
  - Caprina
  - Fiorentina
  - FourSeasons
  - FruttiDiMare
  - Giardiniera
  - LaReine
  - Margherita
  - Mushroom
  - Napoletana
  - Parmense
  - PolloAdAstra
  - PrinceCarlo
  - QuattroFormaggi
  - Rosa
  - Siciliana
  - SloppyGiuseppe
  - Soho
  - Veneziana
- ThinAndCrispyPizza
- VegetarianPizza

Class Annotations: American

Annotations

Class Description: American

Equivalent classes

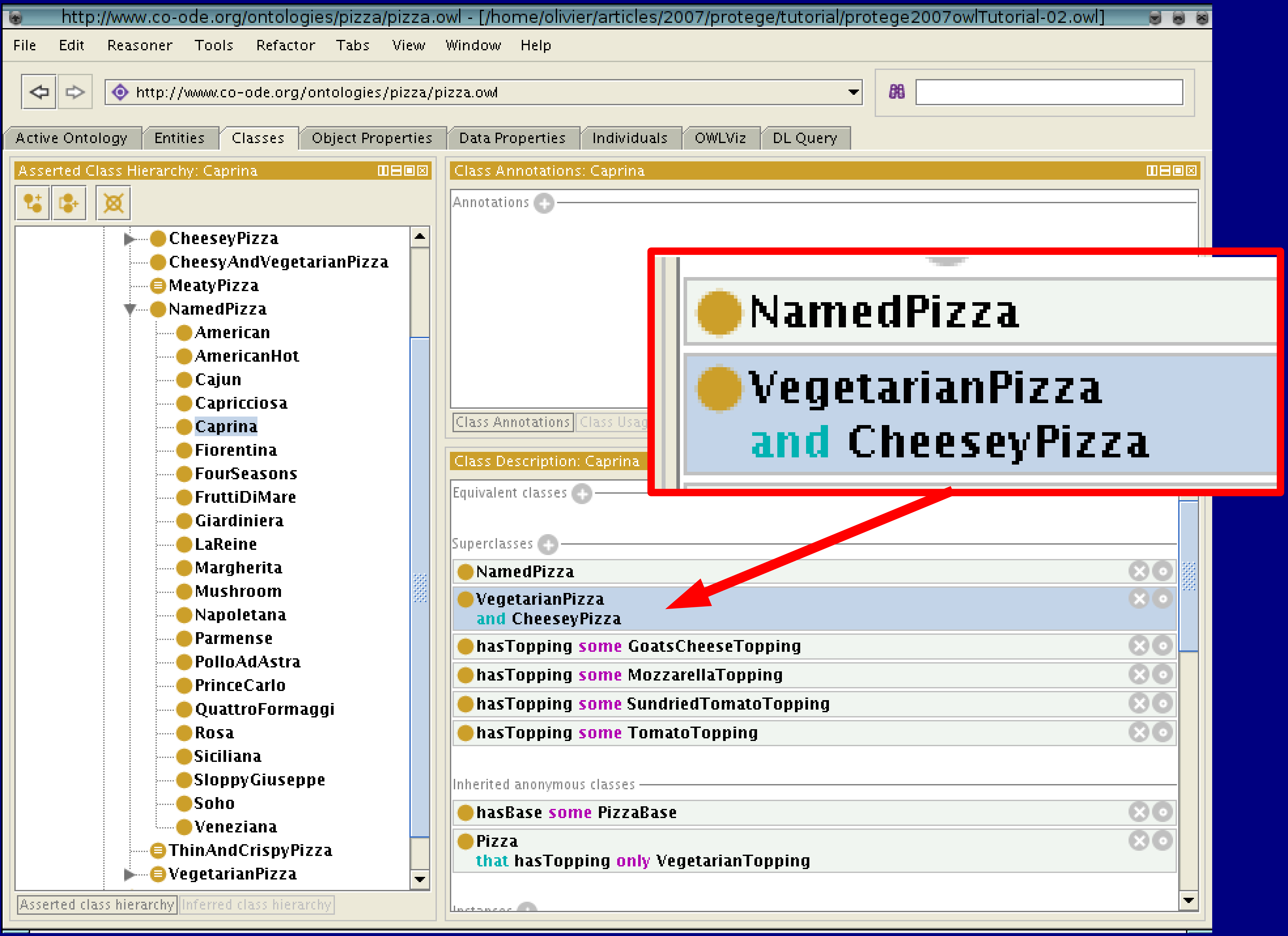
Superclasses

CheeseyPizza
NamedPizza
hasTopping some MozzarellaTopping
hasTopping some PeperoniSausageTopping
hasTopping some TomatoTopping
MeatyPizza

Inherited anonymous classes

hasBase some PizzaBase
Pizza
that hasTopping some MeatTopping

Instances



Asserted Class Hierarchy: Caprina

- CheeseyPizza
- CheesyAndVegetarianPizza
- MeatyPizza
- NamedPizza
  - American
  - AmericanHot
  - Cajun
  - Capricciosa
  - Caprina
  - Fiorentina
  - FourSeasons
  - FruttiDiMare
  - Giardiniera
  - LaReine
  - Margherita
  - Mushroom
  - Napoletana
  - Parmense
  - PolloAdAstra
  - PrinceCarlo
  - QuattroFormaggi
  - Rosa
  - Siciliana
  - SloppyGiuseppe
  - Soho
  - Veneziana
- ThinAndCrispyPizza
- VegetarianPizza

Class Annotations: Caprina

Annotations

Class Description: Caprina

Equivalent classes

Superclasses

NamedPizza

VegetarianPizza
and CheeseyPizza

hasTopping some GoatsCheeseTopping

hasTopping some MozzarellaTopping

hasTopping some SundriedTomatoTopping

hasTopping some TomatoTopping

Inherited anonymous classes

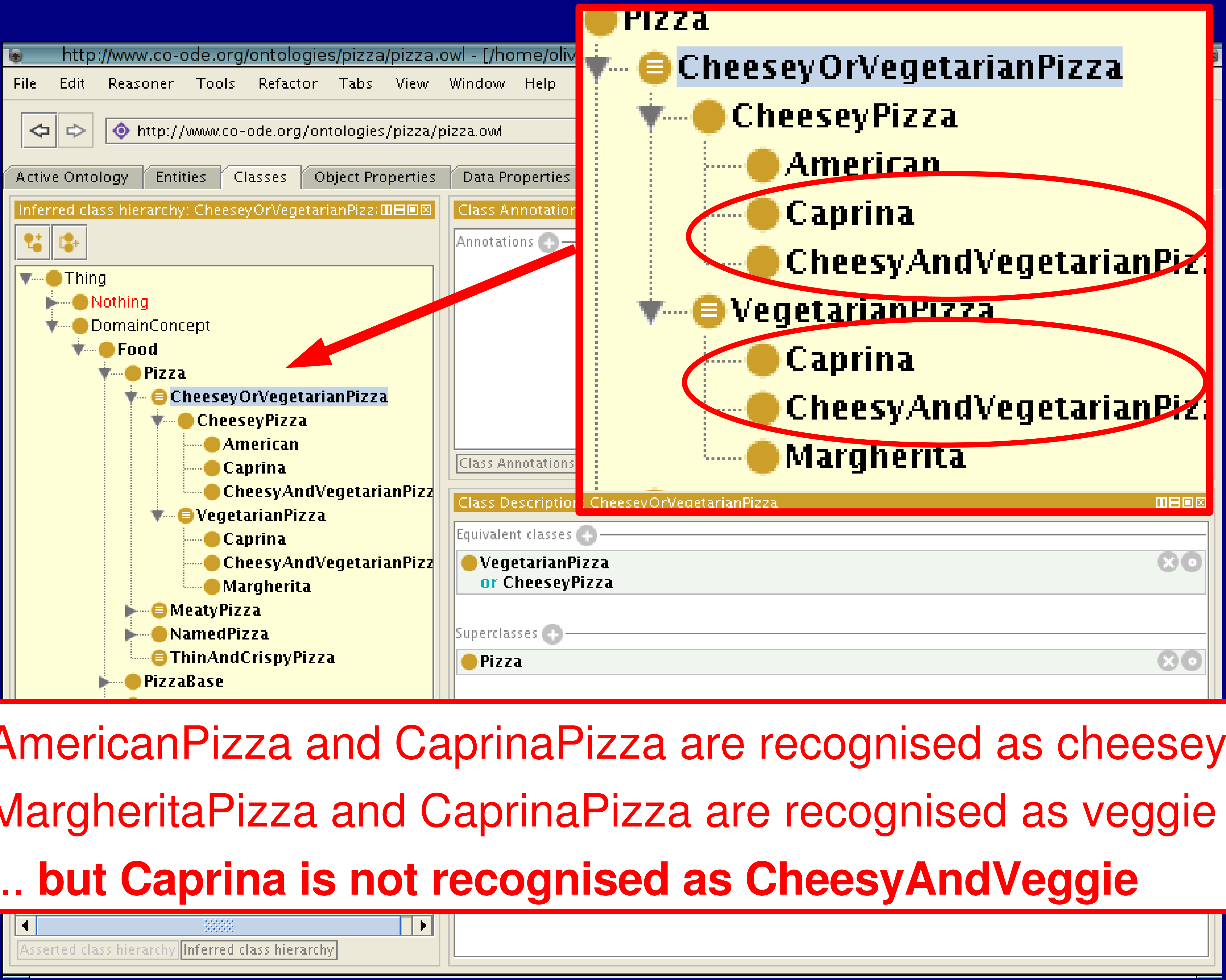
hasBase some PizzaBase

Pizza
that hasTopping only VegetarianTopping

Instances

NamedPizza

VegetarianPizza
and CheeseyPizza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File Edit Reasoner Tools Refactor Tabs View Window Help
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Active Ontology
Entities
Classes
Object Properties
Data Properties
Class Annotation
Annotations
Class Annotations
Asserted class hierarchy
Inferred class hierarchy

Inferred class hierarchy: CheeseyOrVegetarianPizz:

```
Thing
  Nothing
  DomainConcept
    Food
      Pizza
        CheeseyOrVegetarianPizza
          CheeseyPizza
            American
            Caprina
            CheesyAndVegetarianPizz
          VegetarianPizza
            Caprina
            CheesyAndVegetarianPizz
            Margherita
        MeatyPizza
        NamedPizza
        ThinAndCrispyPizza
      PizzaBase
```

```
Pizza
  CheeseyOrVegetarianPizza
    CheeseyPizza
      American
      Caprina
      CheesyAndVegetarianPiz
    VegetarianPizza
      Caprina
      CheesyAndVegetarianPiz
      Margherita
```

Class Description: CheeseyOrVegetarianPizza

Equivalent classes

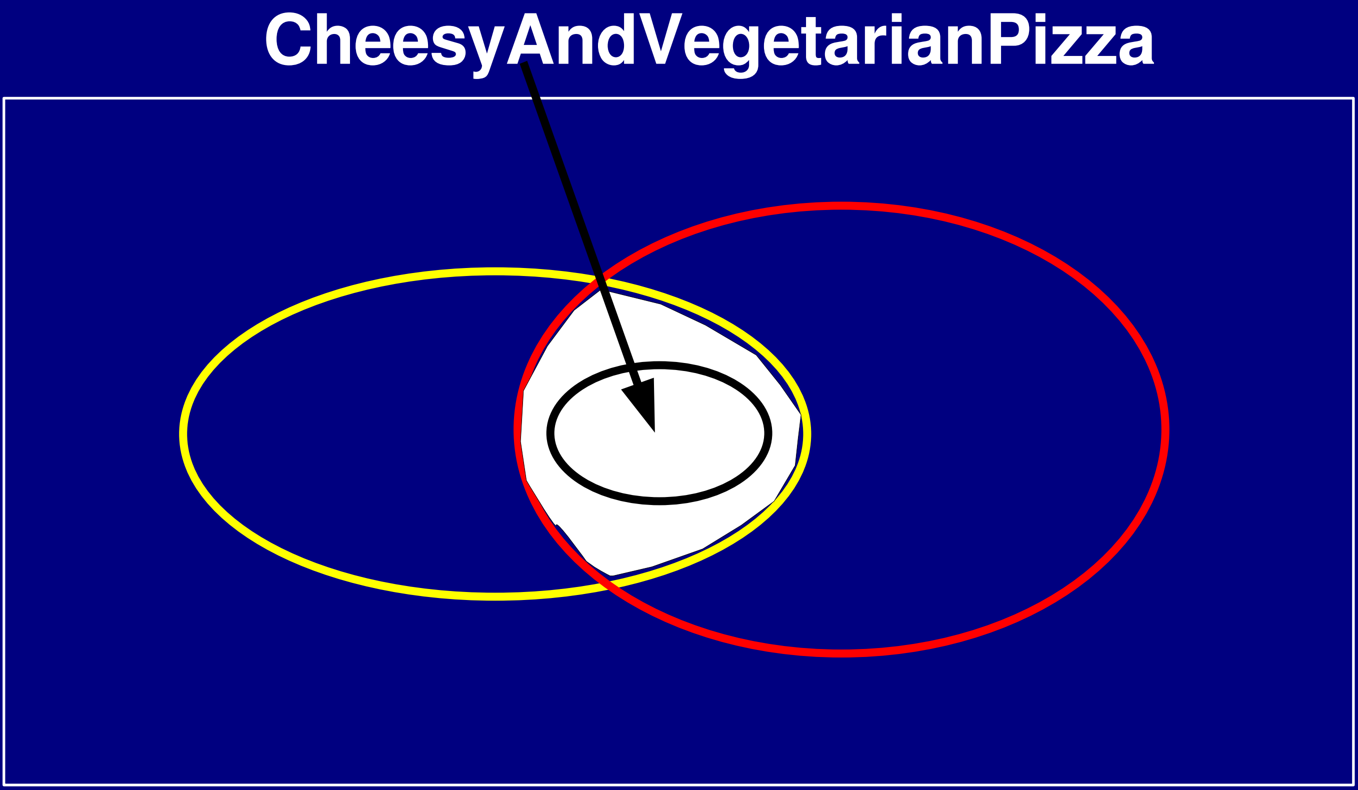
VegetarianPizza
or CheeseyPizza

Superclasses

Pizza

- AmericanPizza and CaprinaPizza are recognised as cheesey
- MargheritaPizza and CaprinaPizza are recognised as veggie
- ... **but Caprina is not recognised as CheesyAndVeggie**

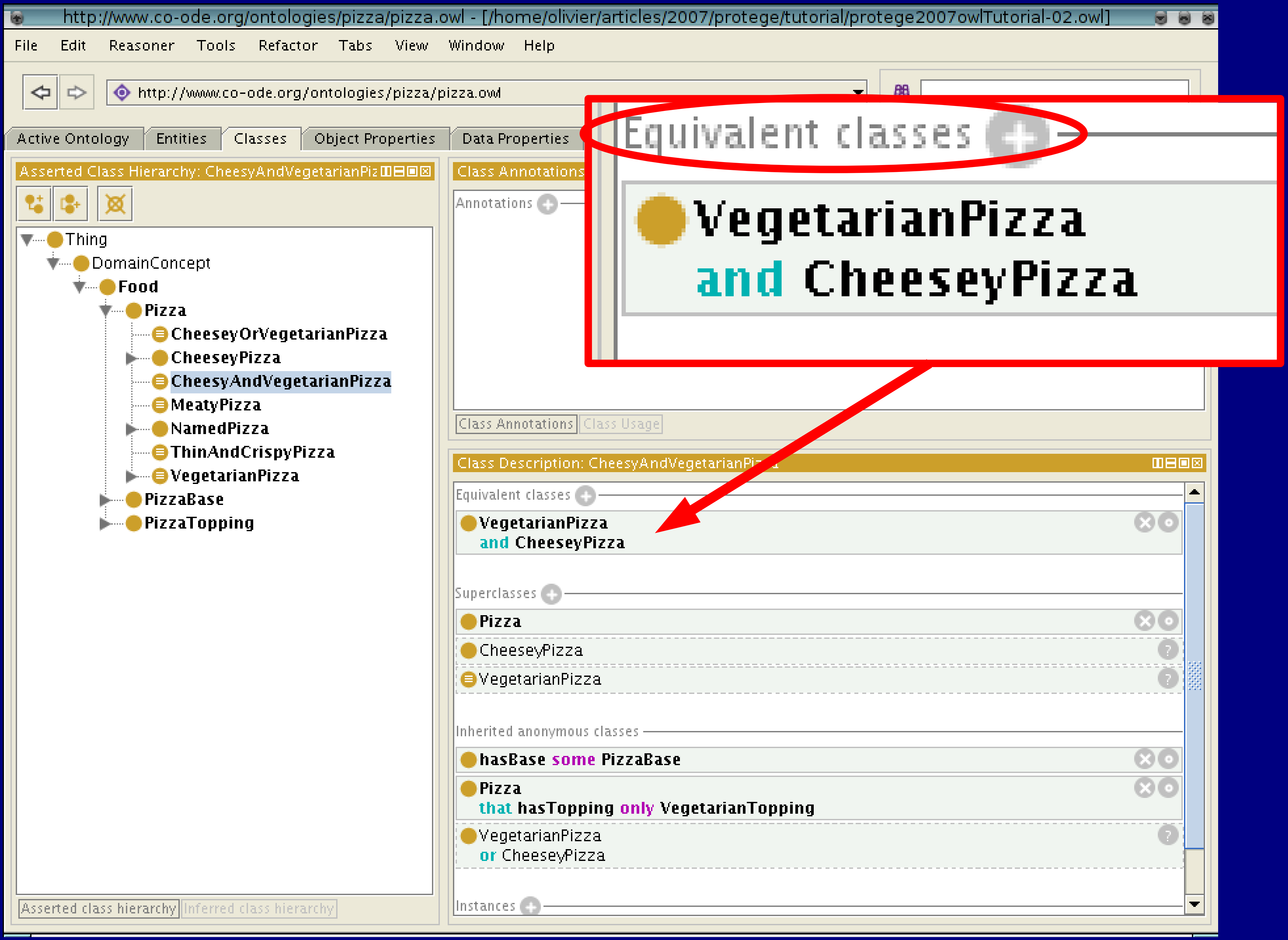
AND (Intersection)



CheesyAndVegetarianPizza

A A ⊓ B B

Ex: VegetarianPizza ⊓ CheesyPizza


http://www.co-ode.org/ontologies/pizza/pizza.owl - [/home/olivier/articles/2007/protege/tutorial/protege2007owlTutorial-02.owl]
File
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Refactor
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Window
Help
http://www.co-ode.org/ontologies/pizza/pizza.owl
Active Ontology
Entities
Classes
Object Properties
Data Properties
Asserted Class Hierarchy: CheesyAndVegetarianPiz
Class Annotations
Annotations
Class Annotations
Class Usage
Class Description: CheesyAndVegetarianPizza
Asserted class hierarchy
Inferred class hierarchy

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping

Equivalent classes

VegetarianPizza
and CheeseyPizza

Superclasses

Pizza

CheeseyPizza

VegetarianPizza

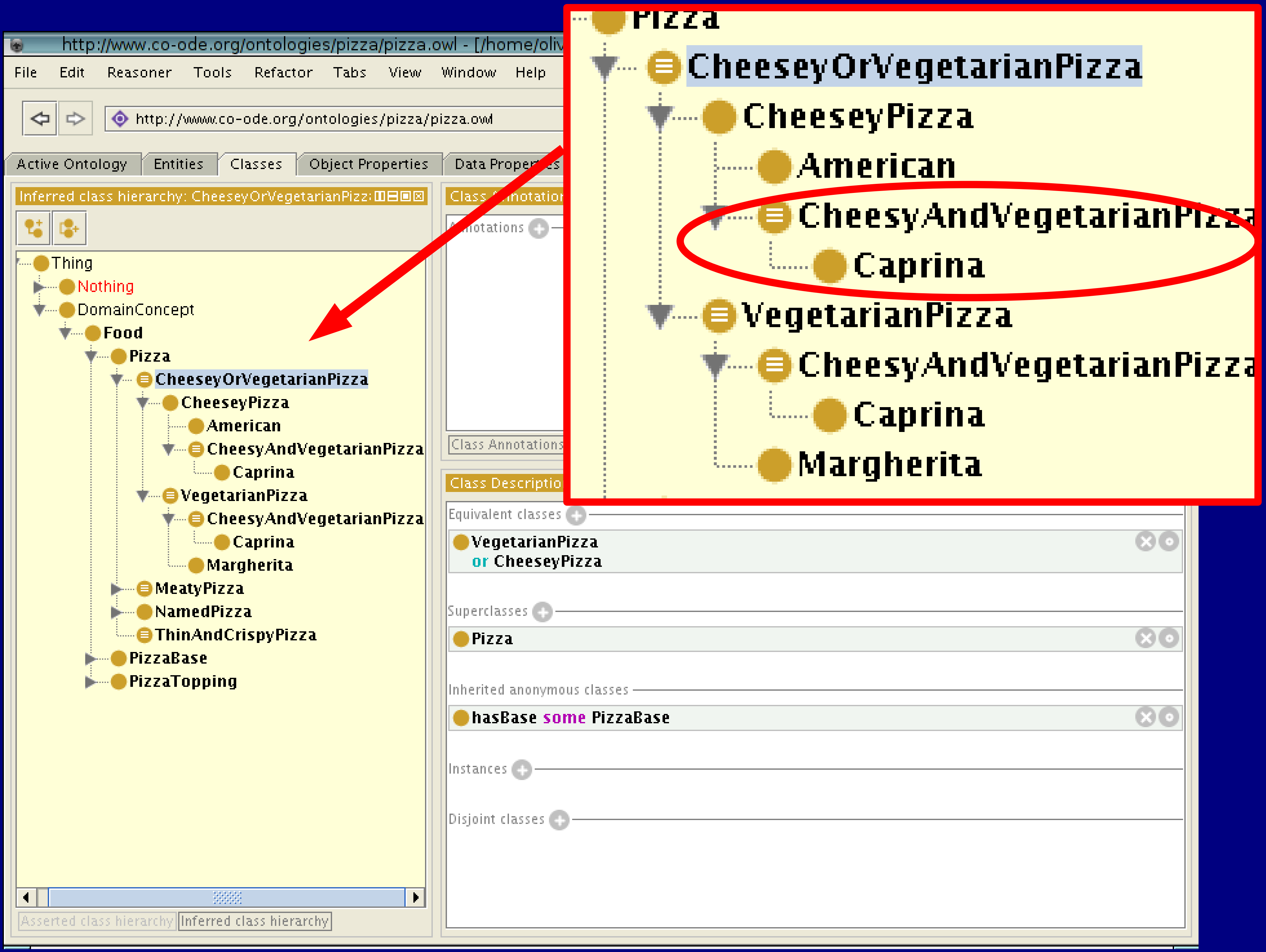
Inherited anonymous classes

hasBase some PizzaBase

Pizza
that hasTopping only VegetarianTopping

VegetarianPizza
or CheeseyPizza

Instances



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http://www.co-ode.org/ontologies/pizza/pizza.owl

Inferred class hierarchy: CheeseyOrVegetarianPizza

```
Thing
  Nothing
  DomainConcept
    Food
      Pizza
        CheeseyOrVegetarianPizza
          CheeseyPizza
            American
            CheesyAndVegetarianPizza
              Caprina
          VegetarianPizza
            CheesyAndVegetarianPizza
              Caprina
            Margherita
        MeatyPizza
        NamedPizza
        ThinAndCrispyPizza
      PizzaBase
      PizzaTopping
```

Class Annotations

Annotations

Class Description

Equivalent classes

VegetarianPizza
or CheeseyPizza

Superclasses

Pizza

Inherited anonymous classes

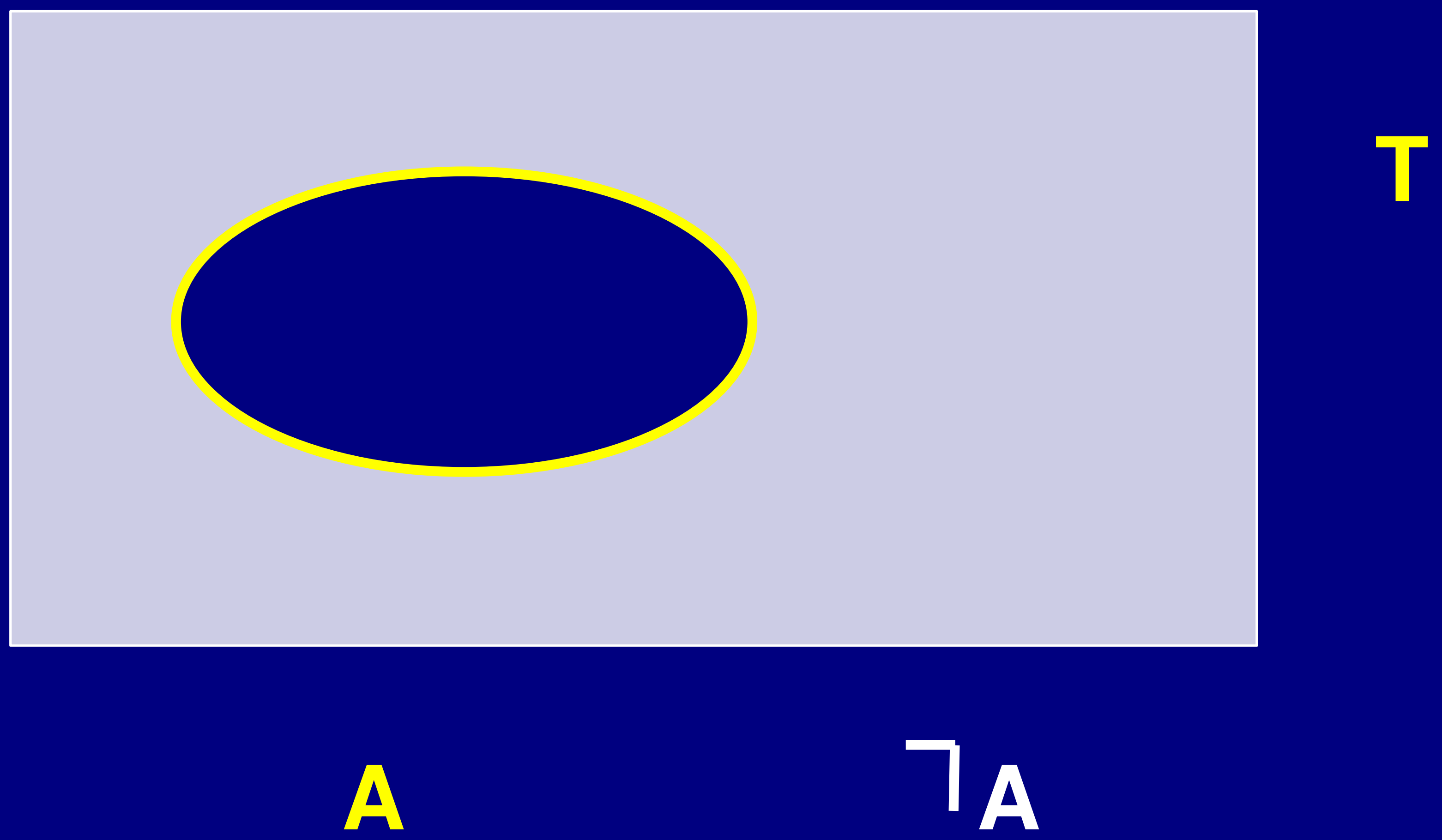
hasBase some PizzaBase

Instances

Disjoint classes

```
Pizza
  CheeseyOrVegetarianPizza
    CheeseyPizza
      American
      CheesyAndVegetarianPizza
        Caprina
    VegetarianPizza
      CheesyAndVegetarianPizza
        Caprina
      Margherita
```

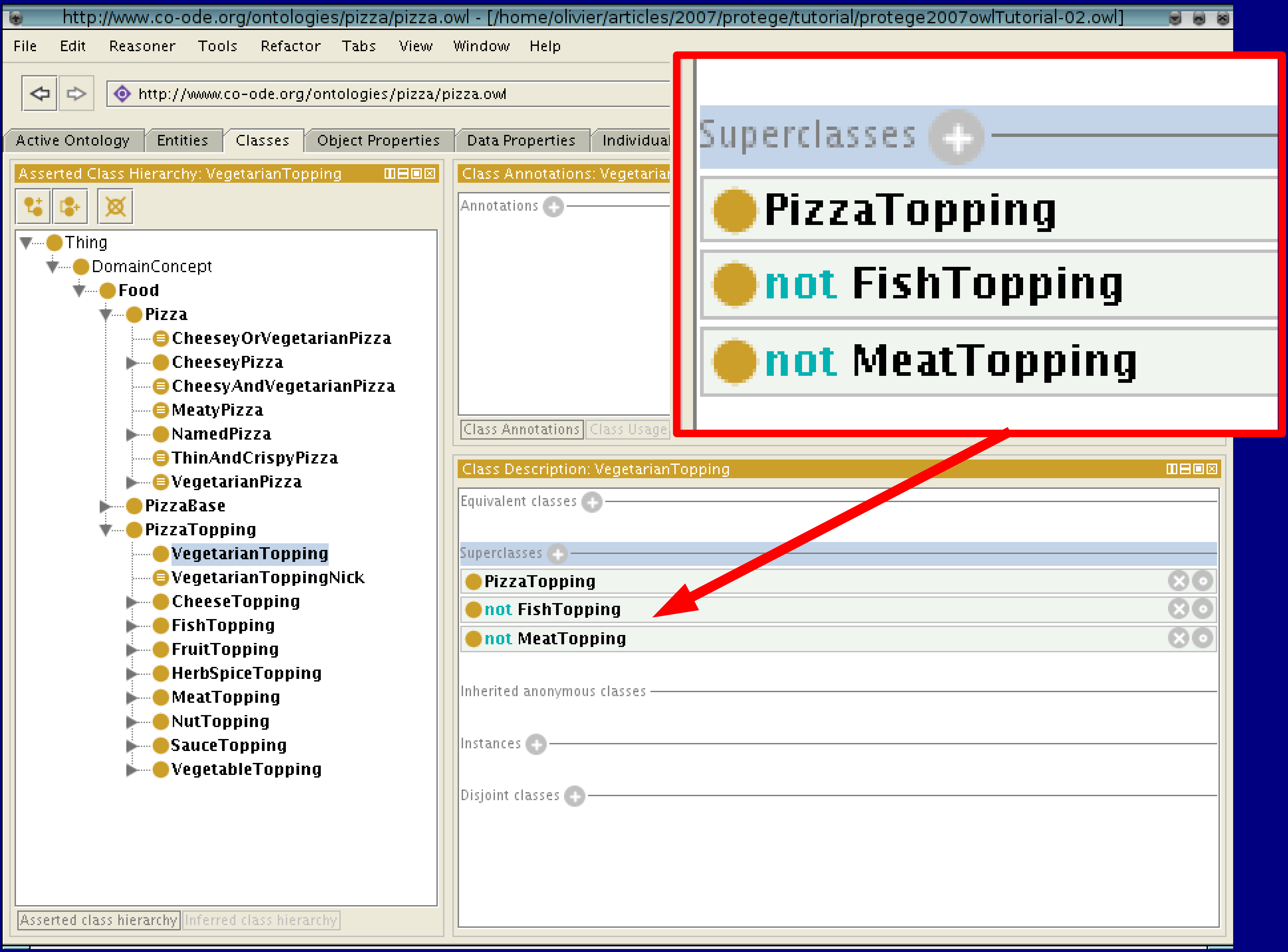
NEGATION (Complement)



Ex: ¬ VegetarianPizza

NEGATION (Complement)

- Create VegetarianTopping as a subclass of PizzaTopping
- A Vegetarian topping is
  - a topping
  - neither a meat topping, nor a fish topping



Asserted Class Hierarchy: VegetarianTopping

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

Class Description: VegetarianTopping

Equivalent classes

Superclasses

PizzaTopping

not FishTopping

not MeatTopping

Inherited anonymous classes

Instances

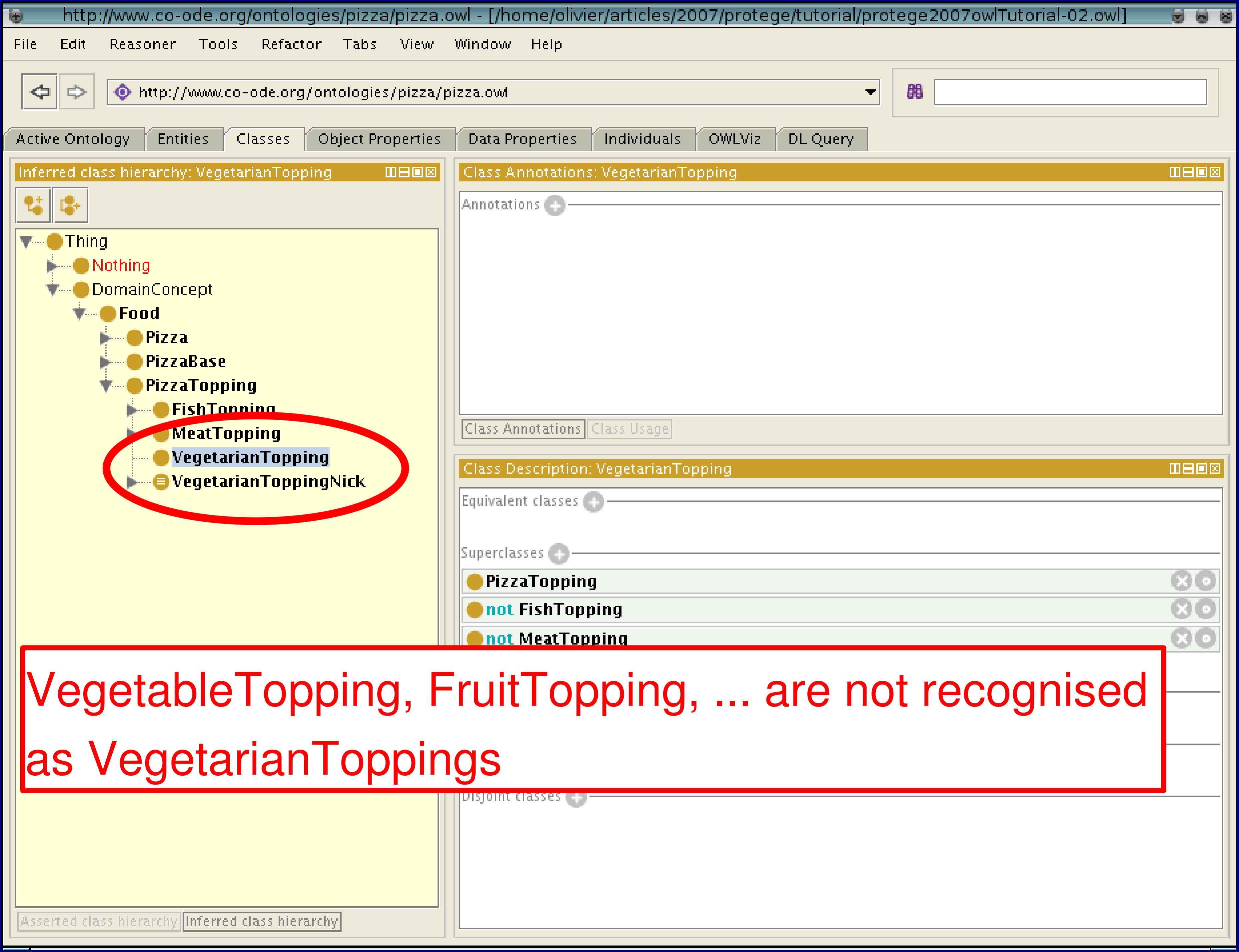
Disjoint classes

Superclasses

PizzaTopping

not FishTopping

not MeatTopping



Inferred class hierarchy: VegetarianTopping

- Thing
  - Nothing
  - DomainConcept
    - Food
      - Pizza
      - PizzaBase
      - PizzaTopping
        - FishTopping
        - MeatTopping
        - VegetarianTopping
        - VegetarianToppingNick

Class Annotations: VegetarianTopping

Annotations

Class Description: VegetarianTopping

Equivalent classes

Superclasses

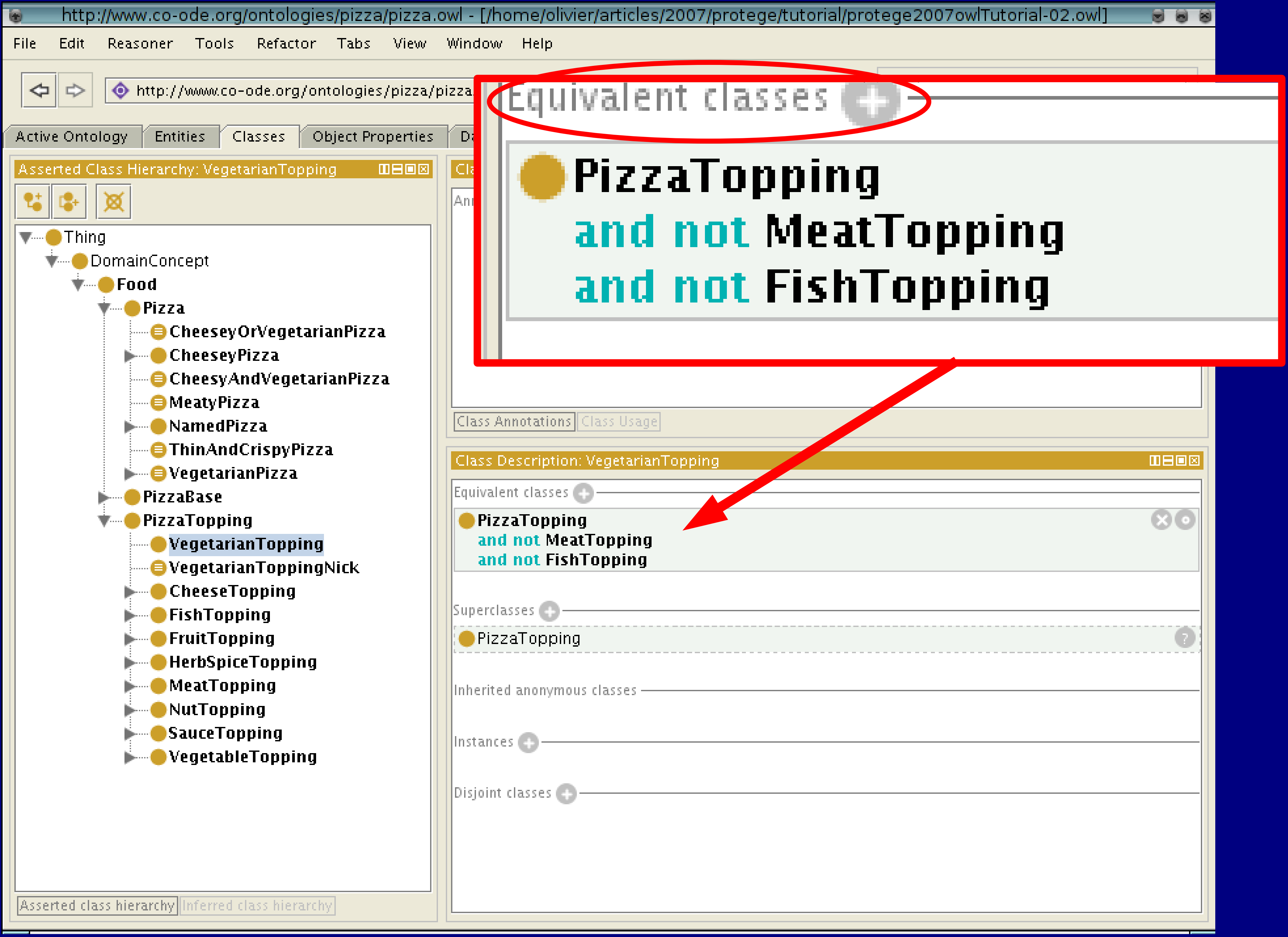
- PizzaTopping
- not FishTopping
- not MeatTopping

Disjoint classes

VegetableTopping, FruitTopping, ... are not recognised as VegetarianToppings

NEGATION (Complement)

- Create VegetarianTopping as a subclass of PizzaTopping
- A Vegetarian topping is neither a meat topping, nor a fish topping
- Classify
- Why do we have to provide a Necessary and Sufficient definition ?


http://www.co-ode.org/ontologies/pizza/pizza.owl - [/home/olivier/articles/2007/protege/tutorial/protege2007owlTutorial-02.owl]
File
Edit
Reasoner
Tools
Refactor
Tabs
View
Window
Help
http://www.co-ode.org/ontologies/pizza/pizza
Active Ontology
Entities
Classes
Object Properties
Asserted Class Hierarchy: VegetarianTopping
Class Annotations
Class Usage
Asserted class hierarchy
Inferred class hierarchy

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

Class Description: VegetarianTopping

Equivalent classes

PizzaTopping
and not MeatTopping
and not FishTopping

Superclasses

PizzaTopping

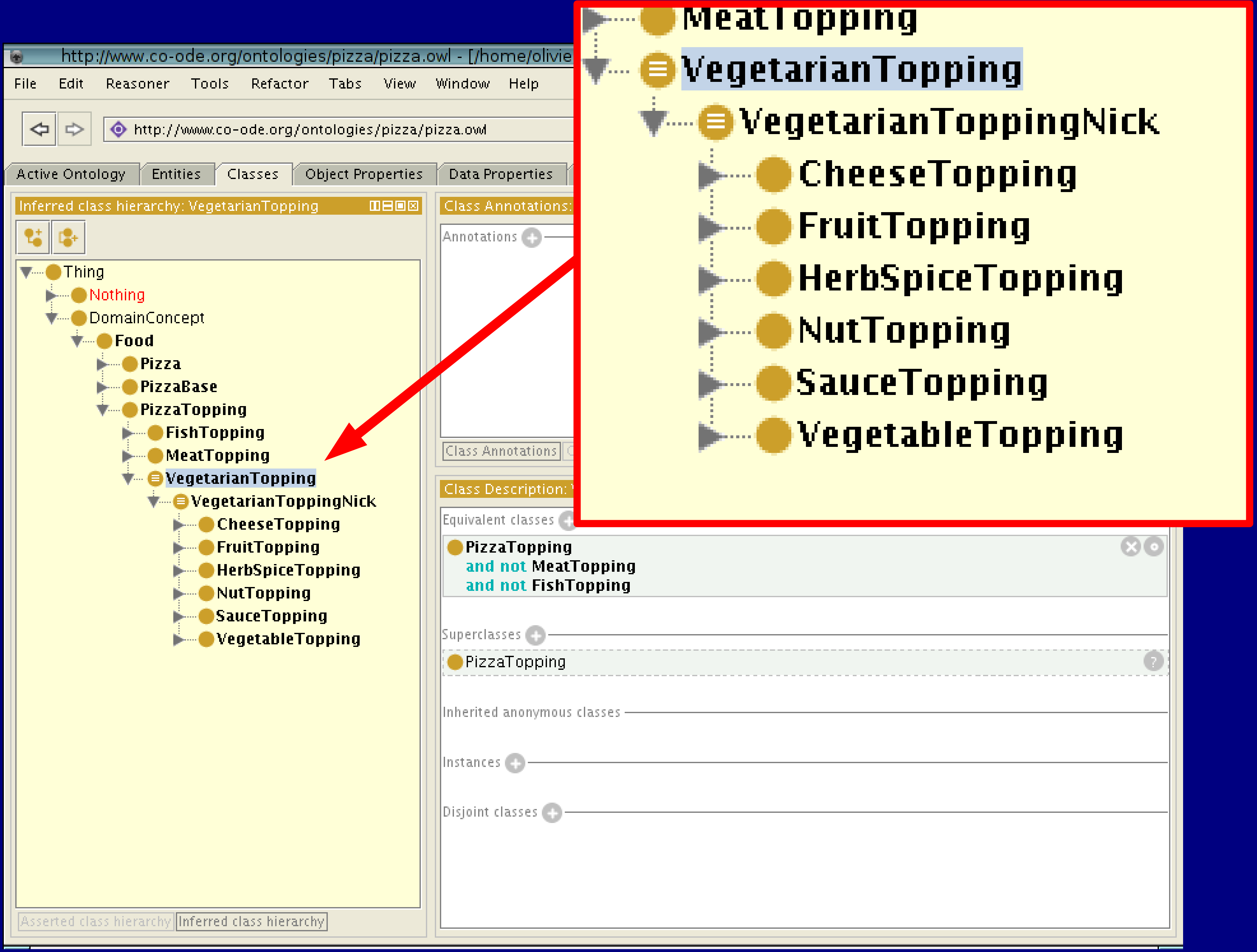
Inherited anonymous classes

Instances

Disjoint classes

Equivalent classes

PizzaTopping
and not MeatTopping
and not FishTopping



Inferred class hierarchy: VegetarianTopping

- Thing
  - Nothing
  - DomainConcept
    - Food
      - Pizza
      - PizzaBase
      - PizzaTopping
        - FishTopping
        - MeatTopping
        - VegetarianTopping
          - VegetarianToppingNick
            - CheeseTopping
            - FruitTopping
            - HerbSpiceTopping
            - NutTopping
            - SauceTopping
            - VegetableTopping

Equivalent classes

PizzaTopping
and not MeatTopping
and not FishTopping

Superclasses

PizzaTopping

Inherited anonymous classes

Instances

Disjoint classes

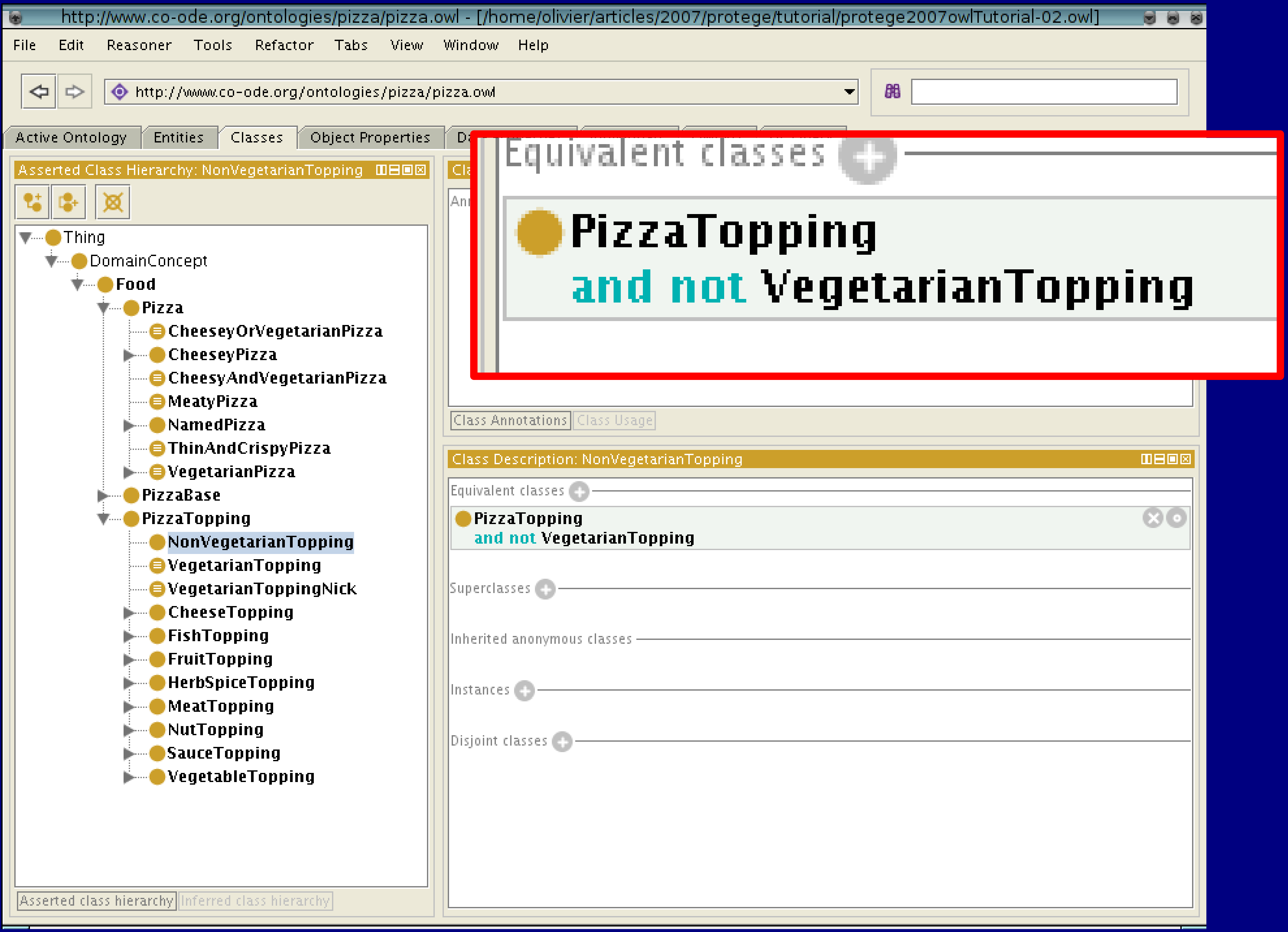
- MeatTopping
- VegetarianTopping
  - VegetarianToppingNick
    - CheeseTopping
    - FruitTopping
    - HerbSpiceTopping
    - NutTopping
    - SauceTopping
    - VegetableTopping

NEGATION (Complement)

- A Vegetarian topping is neither a meat topping, nor a fish topping
- Why do we have to provide a Necessary and Sufficient definition ?
  - it ensures that all the instances of PizzaTopping that are neither instances of MeatTopping nor of FishTopping are inferred to be instances of VegetarianTopping

NEGATION (Complement)

- Create VegetarianTopping as a subclass of PizzaTopping
- A Vegetarian topping is neither a meat topping, nor a fish topping
- Why do we have to provide a N&S definition ?
- Create NonVegetarianTopping
- Classify



Asserted Class Hierarchy: NonVegetarianTopping

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping
        - NonVegetarianTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

Class Description: NonVegetarianTopping

Equivalent classes

PizzaTopping
and not VegetarianTopping

Superclasses

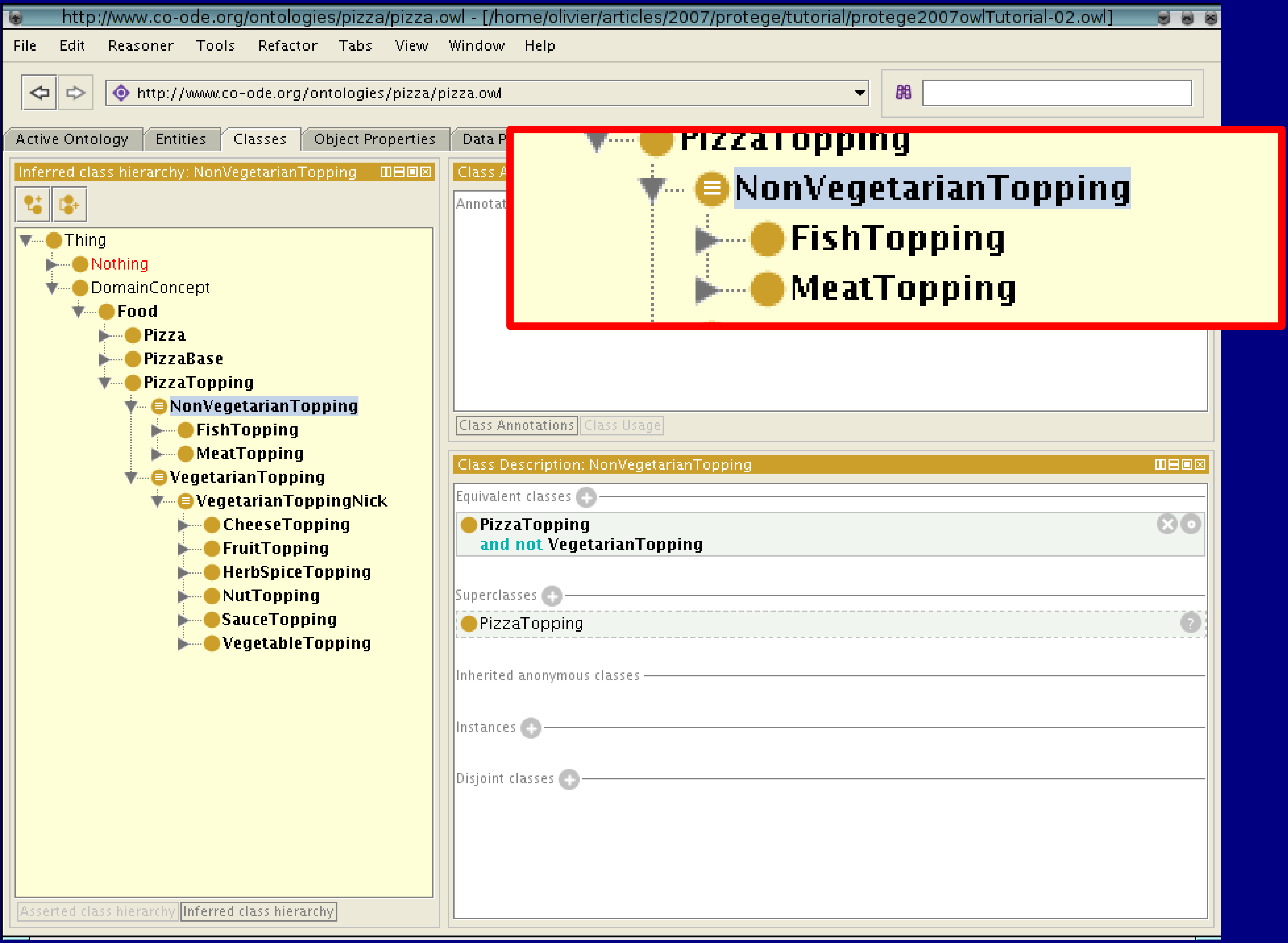
Inherited anonymous classes

Instances

Disjoint classes

Equivalent classes

PizzaTopping
and not VegetarianTopping



Inferred class hierarchy: NonVegetarianTopping

```
Thing
  Nothing
  DomainConcept
    Food
      Pizza
      PizzaBase
      PizzaTopping
        NonVegetarianTopping
          FishTopping
          MeatTopping
        VegetarianTopping
          VegetarianToppingNick
            CheeseTopping
            FruitTopping
            HerbSpiceTopping
            NutTopping
            SauceTopping
            VegetableTopping
```

```
PizzaTopping
  NonVegetarianTopping
    FishTopping
    MeatTopping
```

Class Description: NonVegetarianTopping

Equivalent classes

PizzaTopping
and not VegetarianTopping

Superclasses

PizzaTopping

Inherited anonymous classes

Instances

Disjoint classes

NEGATION (Complement)

- Note that the reasoner found out that CheeseTopping and VegetableTopping are subclasses of VegetarianTopping whereas the definition of VegetarianTopping does not mention CheeseTopping nor VegetableTopping (intentionality)

Expressing constraints

Objective

Application of the intensional approach: leverage the expressivity of the OWL-DL language for a precise representation of the classes' features

- We will describe the pizze ingredients and use the reasoner to find out which one are cheesy and/or vegetarian

Getting in sync!

If you need to catch-up,
the ontology at this point is
protege2007owlTutorial-02.owl

from:

http://www.ea3888.univ-rennes1.fr/dameron/protege2007/

Constraints

1. Quantifier restriction (at least one, all of)
    - How to represent the fact that every pizza must have *at least* a topping ?
    - How to represent the fact that *all* the ingredients of a vegetarian pizza must be vegetarians ?
2. Cardinality restrictions
    - How to represent that a Hand must have *5* fingers as parts ?
3. hasValue restrictions
    - How to define the value of a relation for a class ?

Principles

- A restriction describes an anonymous class composed of all the individuals that satisfy the restriction
  - e.g. all the individuals that have (amongst other things) mozzarella as topping
- This anonymous class is used as a superclass of the (named) class we want to express a constraint on
  - e.g. MargheritaPizza

Existential restriction

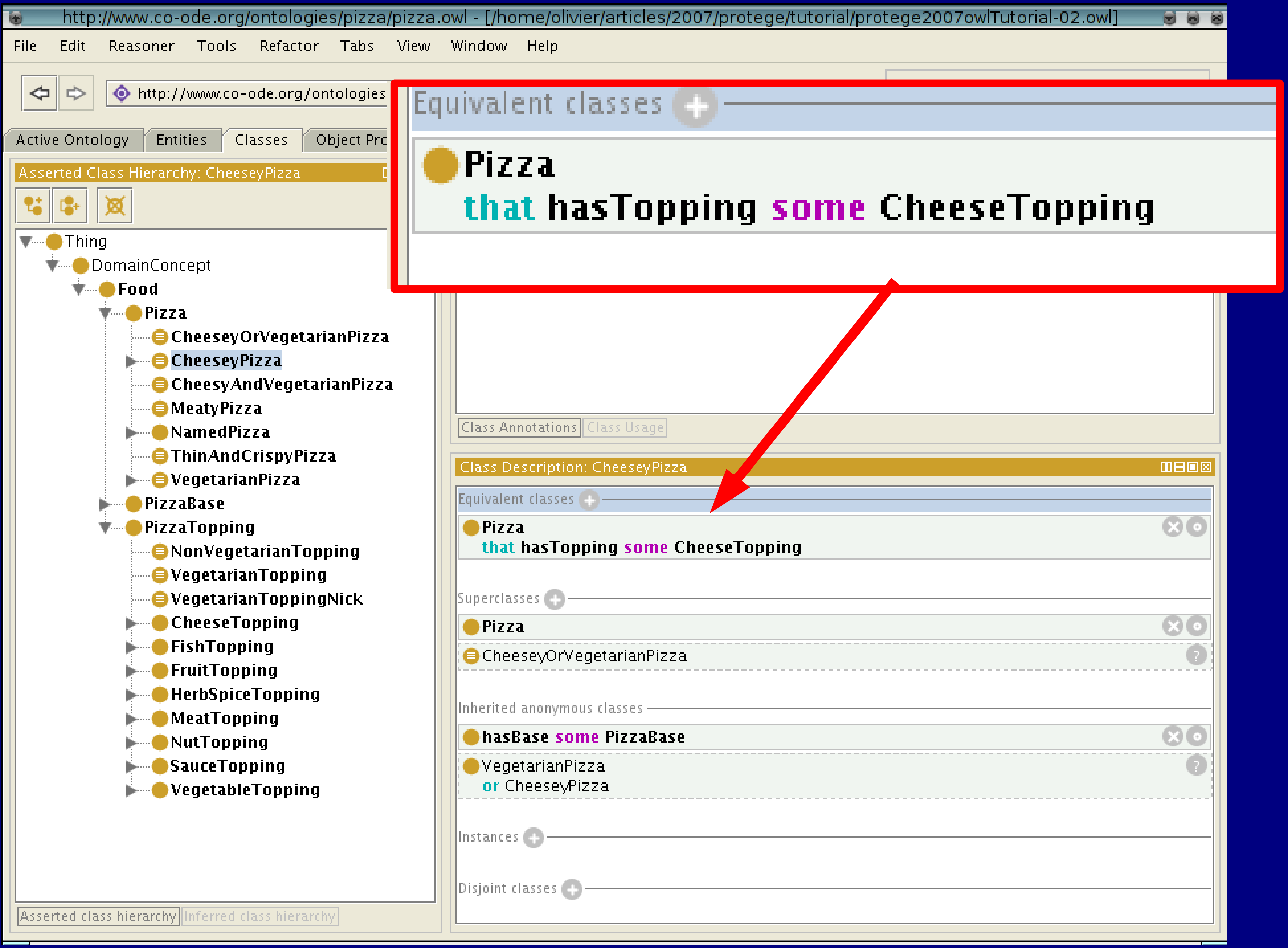
- ($\exists$ *hasTopping* Mozzarella) : set of the individuals being linked to at least one instance of Mozzarella through the *hasTopping* property
  - They can be linked to multiple instances of Mozzarella
  - They can also be linked to instances of other classes (provided domain and range integrity)
- Margherita $\sqsubseteq$ ($\exists$ *hasTopping* Mozzarella)

Existential restriction

- $(\exists$ *hasTopping* Mozzarella$)$: set of the individuals being linked to at least one instance of Mozzarella through the *hasTopping* property
  - They can be linked to multiple instances of Mozzarella
  - They can also be linked to instances of other classes (provided domain and range integrity)
- Margherita $\sqsubseteq$ $(\exists$ *hasTopping* Mozzarella$)$
  - Other pizze can also have Mozzarella!

Complete the ontology

- Define CheesyPizza as a pizza having at least one cheese topping
- Remove the fact that AmericanPizza and CaprinaPizza are subclasses of CheesyPizza !



Equivalent classes

Pizza
that hasTopping some CheeseTopping

Asserted Class Hierarchy: CheeseyPizza

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping
        - NonVegetarianTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

Class Description: CheeseyPizza

Equivalent classes

Pizza
that hasTopping some CheeseTopping

Superclasses

Pizza

CheeseyOrVegetarianPizza

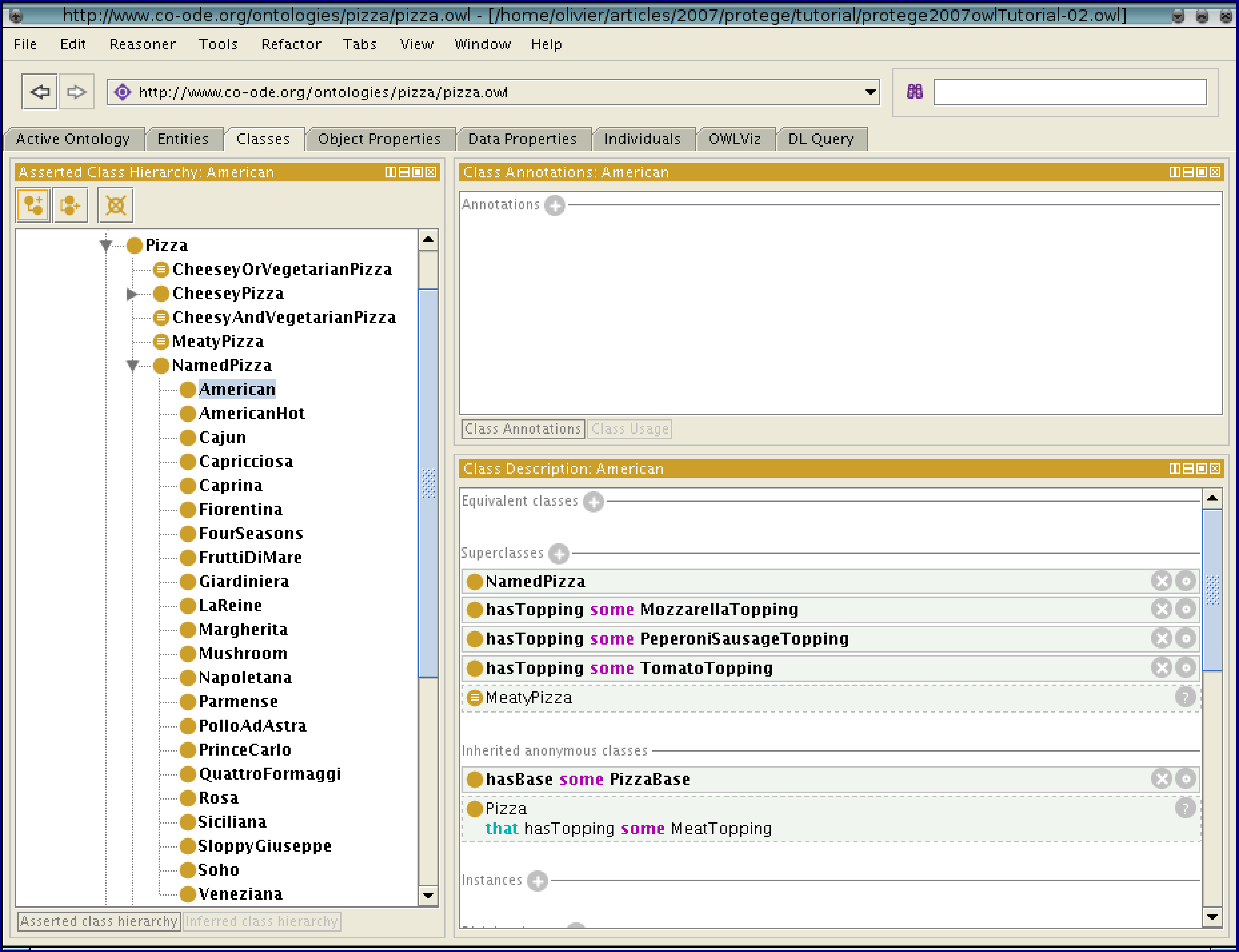
Inherited anonymous classes

hasBase some PizzaBase

VegetarianPizza
or CheeseyPizza

Instances

Disjoint classes



Asserted Class Hierarchy: American

- Pizza
  - CheeseyOrVegetarianPizza
  - CheeseyPizza
  - CheesyAndVegetarianPizza
  - MeatyPizza
  - NamedPizza
    - American
    - AmericanHot
    - Cajun
    - Capricciosa
    - Caprina
    - Fiorentina
    - FourSeasons
    - FruttiDiMare
    - Giardiniera
    - LaReine
    - Margherita
    - Mushroom
    - Napoletana
    - Parmense
    - PolloAdAstra
    - PrinceCarlo
    - QuattroFormaggi
    - Rosa
    - Siciliana
    - SloppyGiuseppe
    - Soho
    - Veneziana

Class Annotations: American

Annotations

Class Description: American

Equivalent classes

Superclasses

NamedPizza

hasTopping some MozzarellaTopping

hasTopping some PeperoniSausageTopping

hasTopping some TomatoTopping

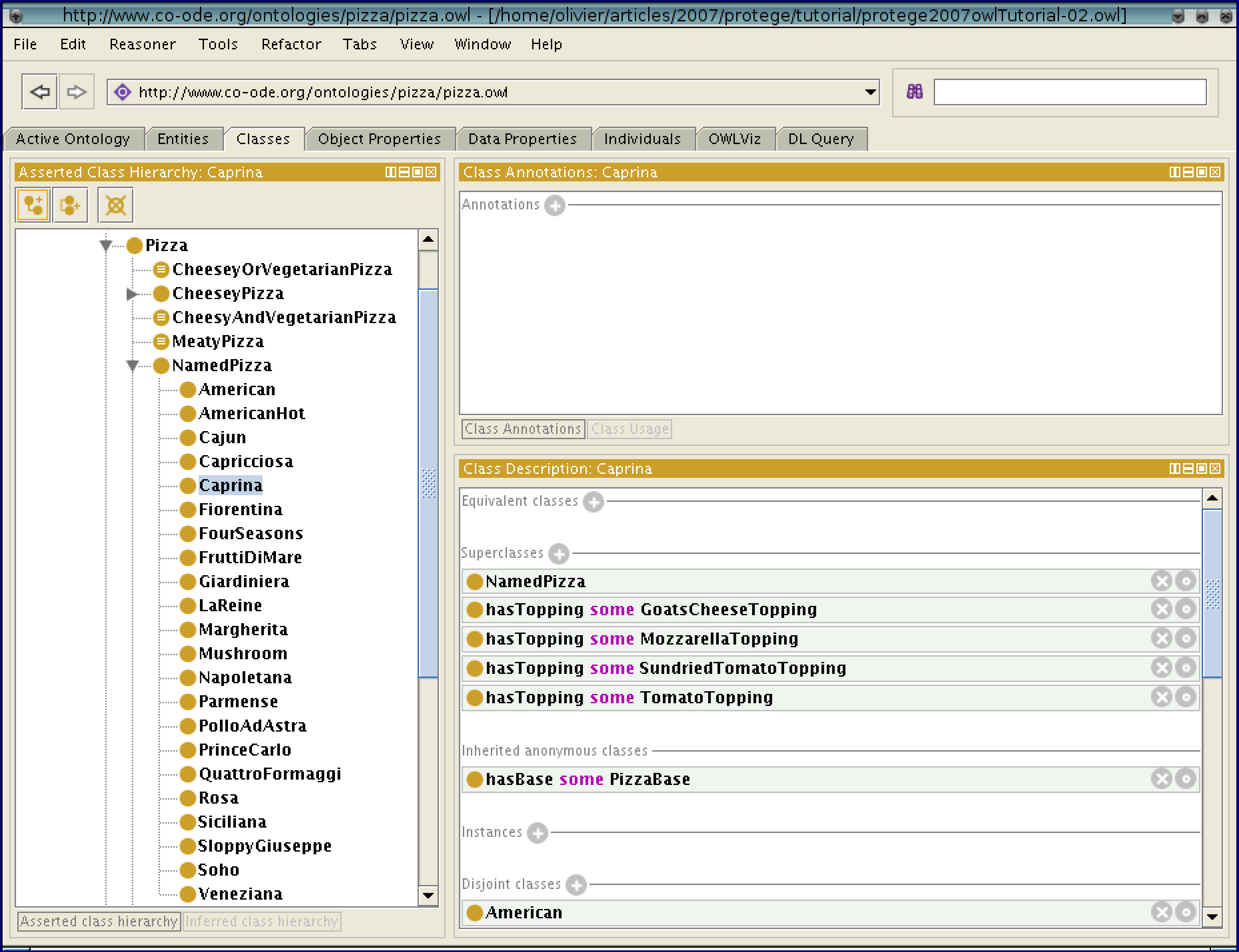
MeatyPizza

Inherited anonymous classes

hasBase some PizzaBase

Pizza
that hasTopping some MeatTopping

Instances



http://www.co-ode.org/ontologies/pizza/pizza.owl - [/home/olivier/articles/2007/protege/tutorial/protege2007owlTutorial-02.owl]

http://www.co-ode.org/ontologies/pizza/pizza.owl

Asserted Class Hierarchy: Caprina

```
Pizza
  CheeseyOrVegetarianPizza
  CheeseyPizza
  CheesyAndVegetarianPizza
  MeatyPizza
  NamedPizza
    American
    AmericanHot
    Cajun
    Capricciosa
    Caprina
    Fiorentina
    FourSeasons
    FruttiDiMare
    Giardiniera
    LaReine
    Margherita
    Mushroom
    Napoletana
    Parmense
    PolloAdAstra
    PrinceCarlo
    QuattroFormaggi
    Rosa
    Siciliana
    SloppyGiuseppe
    Soho
    Veneziana
```

Class Annotations: Caprina

Annotations

Class Description: Caprina

Equivalent classes

Superclasses

- NamedPizza
- hasTopping some GoatsCheeseTopping
- hasTopping some MozzarellaTopping
- hasTopping some SundriedTomatoTopping
- hasTopping some TomatoTopping

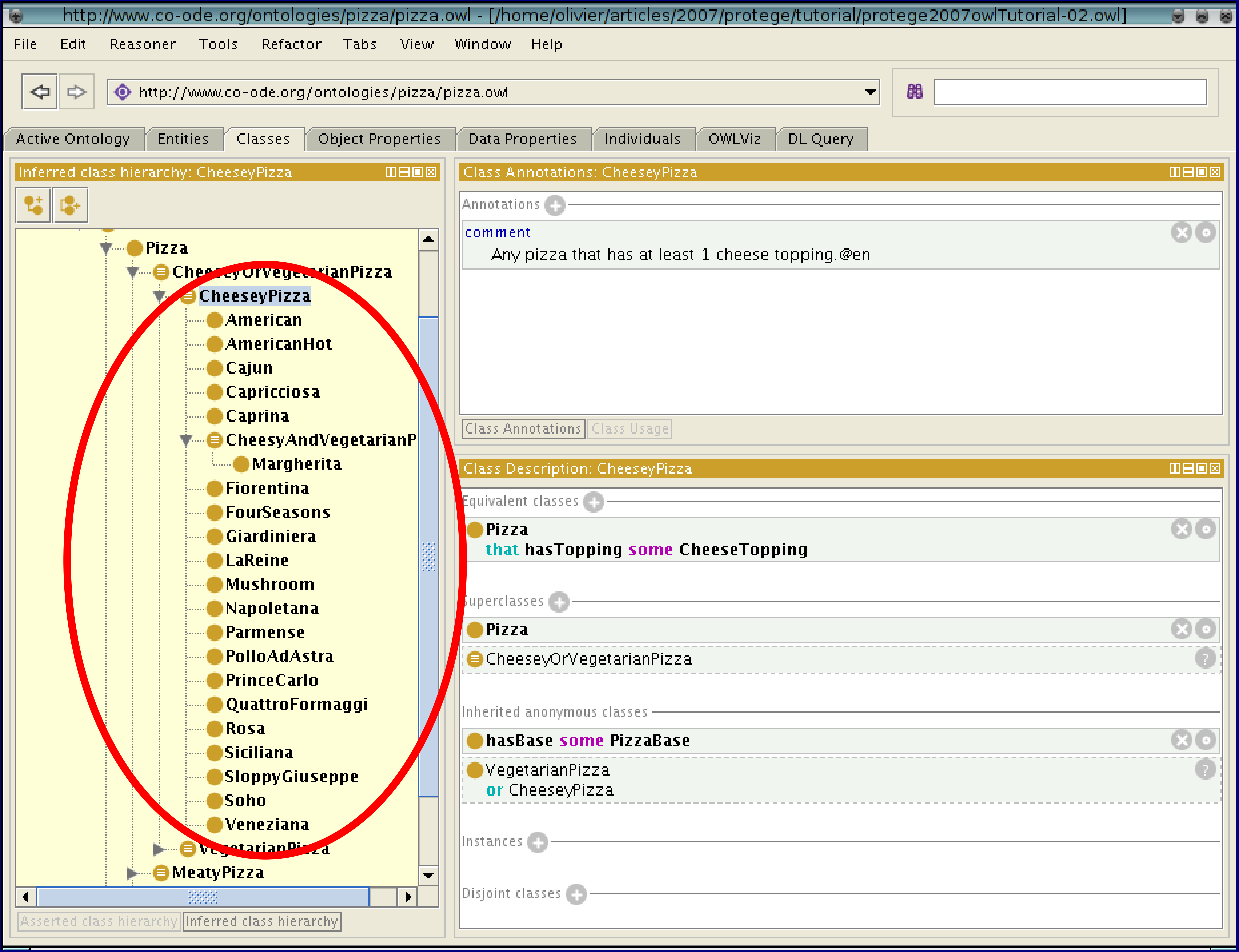
Inherited anonymous classes

- hasBase some PizzaBase

Instances

Disjoint classes

- American


http://www.co-ode.org/ontologies/pizza/pizza.owl - [/home/olivier/articles/2007/protege/tutorial/protege2007owlTutorial-02.owl]
File
Edit
Reasoner
Tools
Refactor
Tabs
View
Window
Help
http://www.co-ode.org/ontologies/pizza/pizza.owl
Active Ontology
Entities
Classes
Object Properties
Data Properties
Individuals
OWLViz
DL Query
Inferred class hierarchy: CheeseyPizza
Class Annotations: CheeseyPizza
Class Annotations
Class Usage
Class Description: CheeseyPizza
Asserted class hierarchy
Inferred class hierarchy

Inferred class hierarchy: CheeseyPizza

- Pizza
  - CheeseyOrVegetarianPizza
    - CheeseyPizza
      - American
      - AmericanHot
      - Cajun
      - Capricciosa
      - Caprina
      - CheesyAndVegetarianP
        - Margherita
      - Fiorentina
      - FourSeasons
      - Giardiniera
      - LaReine
      - Mushroom
      - Napoletana
      - Parmense
      - PolloAdAstra
      - PrinceCarlo
      - QuattroFormaggi
      - Rosa
      - Siciliana
      - SloppyGiuseppe
      - Soho
      - Veneziana
    - VegetarianPizza
  - MeatyPizza

Class Annotations: CheeseyPizza

Annotations

comment
Any pizza that has at least 1 cheese topping.@en

Class Description: CheeseyPizza

Equivalent classes

Pizza
that hasTopping some CheeseTopping

Superclasses

Pizza

CheeseyOrVegetarianPizza

Inherited anonymous classes

hasBase some PizzaBase

VegetarianPizza
or CheeseyPizza

Instances

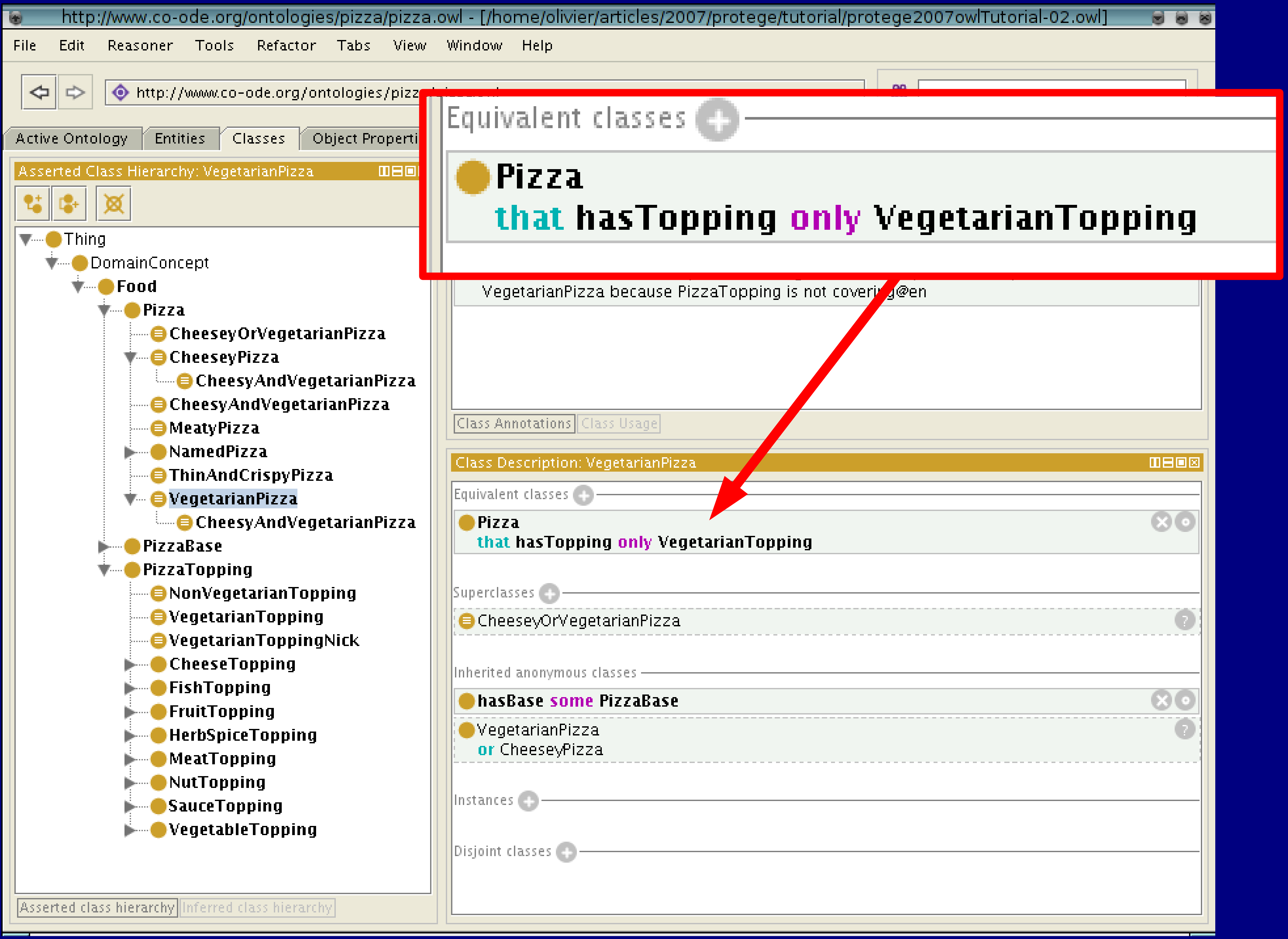
Disjoint classes

Universal restriction

- ($\forall$ *hasTopping* VegetarianTopping) : set of all the individuals only linked to instances of VegetarianTopping through the *hasTopping* property
- Warning: also includes all the individuals linked to nothing through the *hasTopping* property

Universal restriction

- (∀ *hasTopping* VegetarianTopping)
- Remove the fact that MargheritaPizza and CaprinaPizza are subclasses of VegetarianPizza
- Define VegetarianPizza as any pizza for which all the toppings are vegetarian toppings
- Classify :-(



Equivalent classes

Pizza
that hasTopping only VegetarianTopping

Asserted Class Hierarchy: VegetarianPizza

- Thing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
          - CheesyAndVegetarianPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
          - CheesyAndVegetarianPizza
      - PizzaBase
      - PizzaTopping
        - NonVegetarianTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

VegetarianPizza because PizzaTopping is not coveri g@en

Class Description: VegetarianPizza

Equivalent classes

Pizza
that hasTopping only VegetarianTopping

Superclasses

CheeseyOrVegetarianPizza

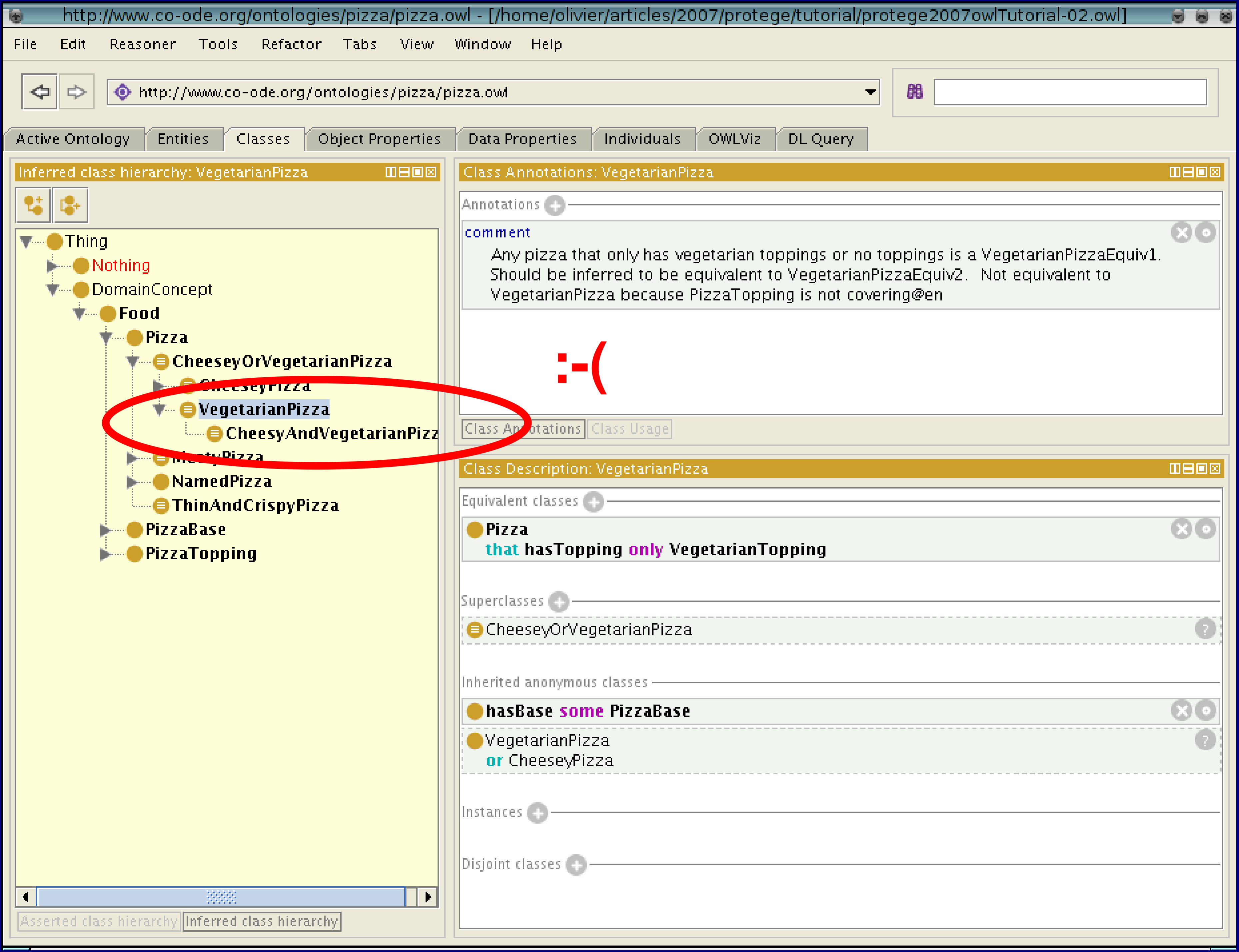
Inherited anonymous classes

hasBase some PizzaBase

VegetarianPizza
or CheeseyPizza

Instances

Disjoint classes



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Data Properties
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OWLViz
DL Query
Inferred class hierarchy: VegetarianPizza
Class Annotations: VegetarianPizza
Class Annotations
Class Usage
Class Description: VegetarianPizza
Asserted class hierarchy
Inferred class hierarchy
:-(

```
Thing
    Nothing
    DomainConcept
        Food
            Pizza
                CheeseyOrVegetarianPizza
                    CheeseyPizza
                    VegetarianPizza
                        CheesyAndVegetarianPizz
                MeatyPizza
                NamedPizza
                ThinAndCrispyPizza
            PizzaBase
            PizzaTopping
```

Annotations

comment
Any pizza that only has vegetarian toppings or no toppings is a VegetarianPizzaEquiv1. Should be inferred to be equivalent to VegetarianPizzaEquiv2. Not equivalent to VegetarianPizza because PizzaTopping is not covering@en

Equivalent classes

Pizza
that hasTopping only VegetarianTopping

Superclasses

CheeseyOrVegetarianPizza

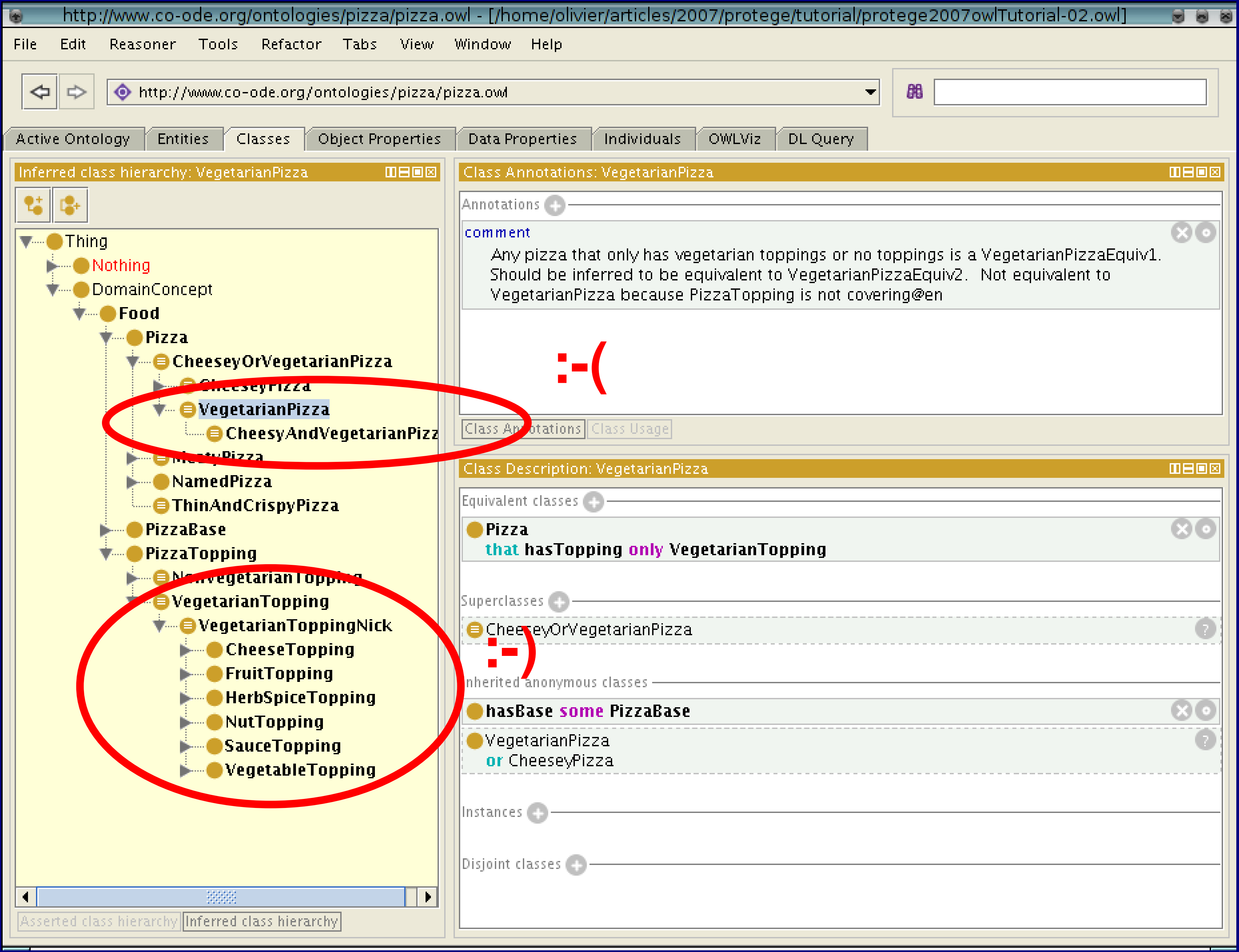
Inherited anonymous classes

hasBase some PizzaBase

VegetarianPizza
or CheeseyPizza

Instances

Disjoint classes



comment

Any pizza that only has vegetarian toppings or no toppings is a VegetarianPizzaEquiv1. Should be inferred to be equivalent to VegetarianPizzaEquiv2. Not equivalent to VegetarianPizza because PizzaTopping is not covering@en

Equivalent classes:

Pizza
that hasTopping only VegetarianTopping

Superclasses:

CheeseyOrVegetarianPizza

Inherited anonymous classes:

hasBase some PizzaBase

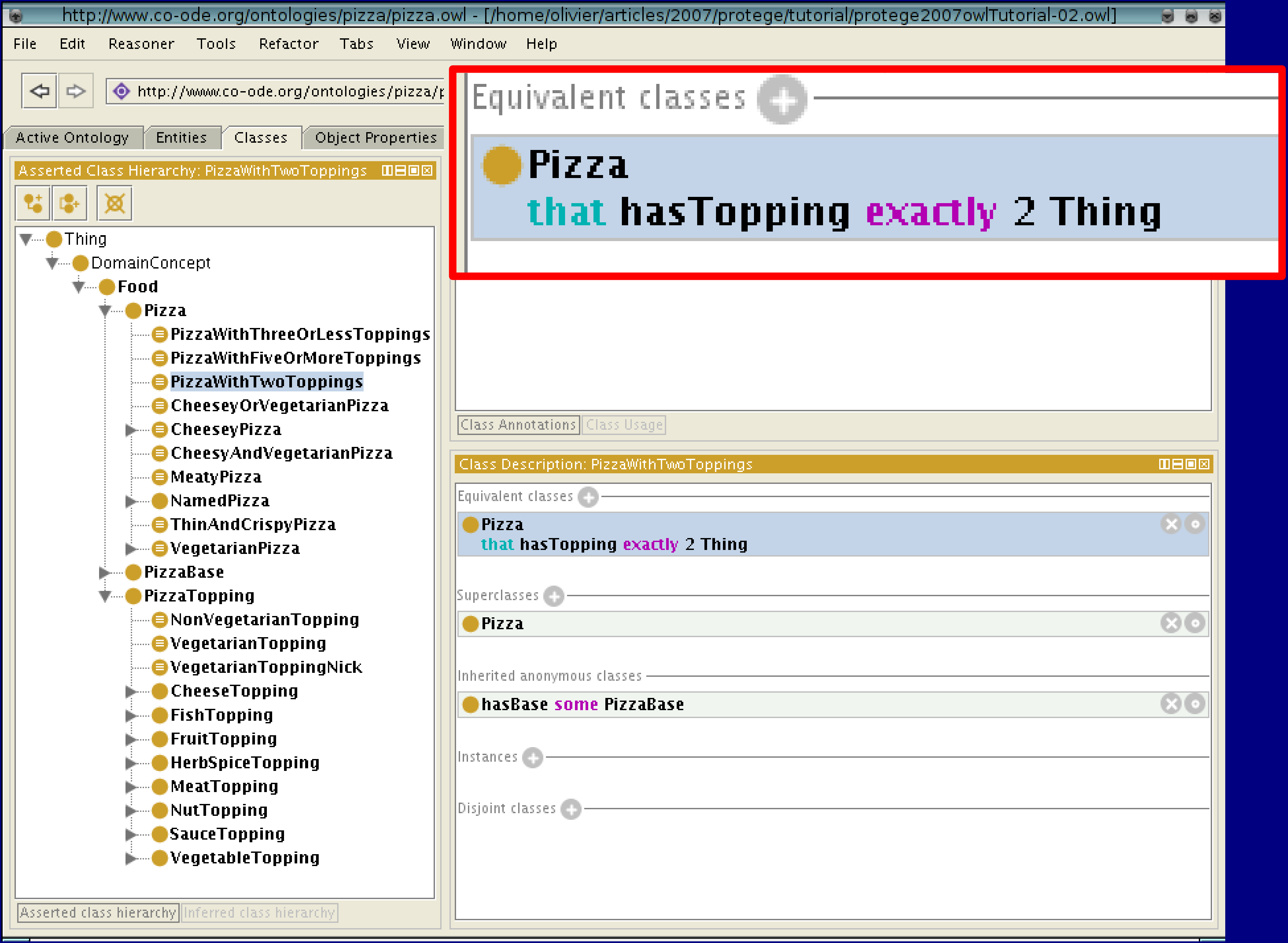
VegetarianPizza
or CheeseyPizza

Universal restriction

- Why Margherita and Caprina pizze were not recognised as vegetarian pizze?
  (even though the vegetarian toppings were correctly recognised)
- ... find out in a few slides

Cardinality restriction

- PizzaWithTwoToppings
  - Pizza $\sqcap$ (hasTopping $=$ 2)
- PizzaWithFiveOrMoreToppings
  - Pizza $\sqcap$ (hasTopping $\geq$ 5)
- PizzaWithThreeOrLessToppings
  - Pizza $\sqcap$ (hasTopping $\leq$ 3)
- Warning: This is NOT qualified cardinality restr.



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http://www.co-ode.org/ontologies/pizza/p

Active Ontology | Entities | Classes | Object Properties

Equivalent classes

Pizza
that hasTopping exactly 2 Thing

Asserted Class Hierarchy: PizzaWithTwoToppings

- Thing
  - DomainConcept
    - Food
      - Pizza
        - PizzaWithThreeOrLessToppings
        - PizzaWithFiveOrMoreToppings
        - PizzaWithTwoToppings
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping
        - NonVegetarianTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

Asserted class hierarchy | Inferred class hierarchy

Class Annotations | Class Usage

Class Description: PizzaWithTwoToppings

Equivalent classes

Pizza
that hasTopping exactly 2 Thing

Superclasses

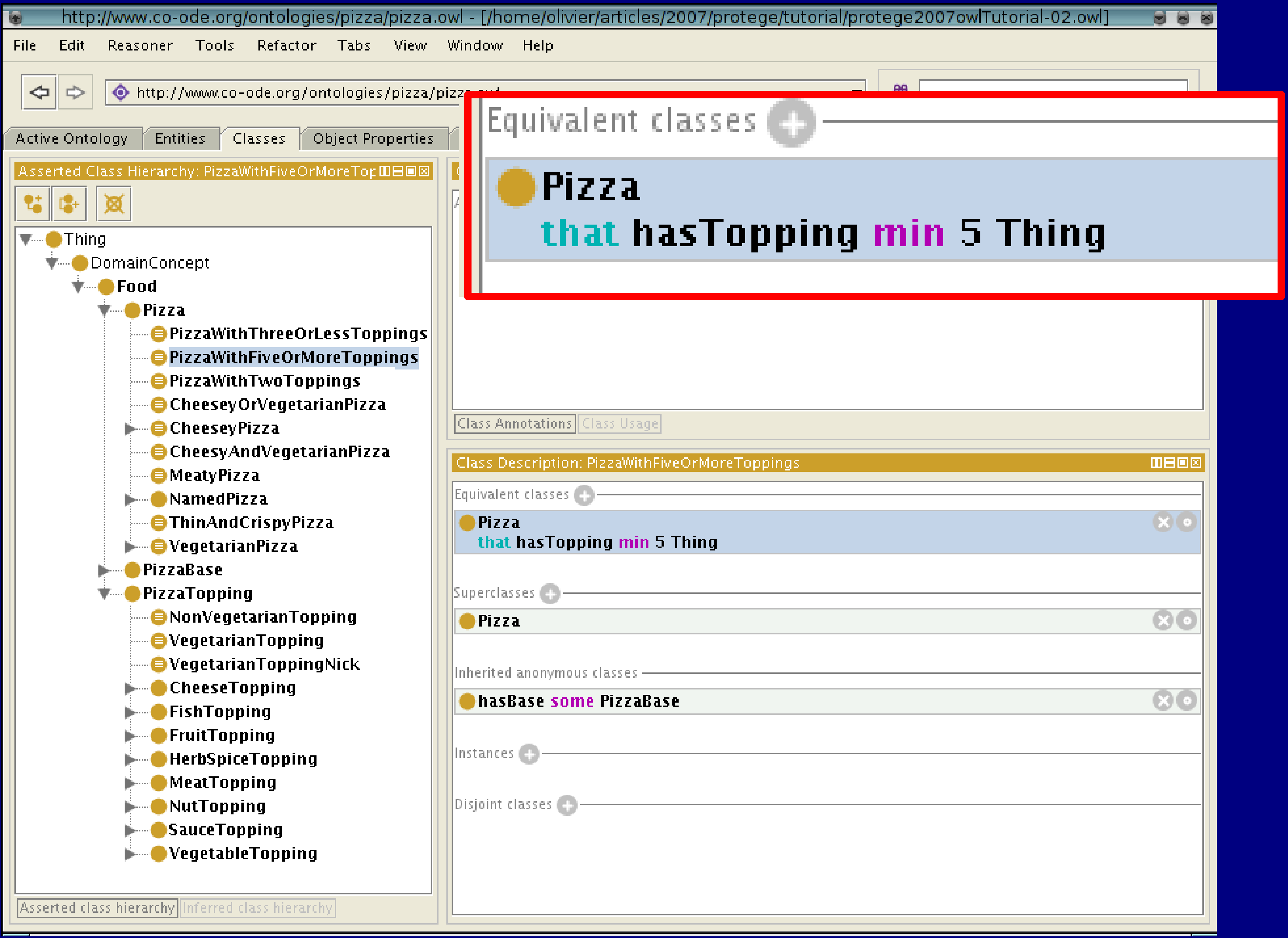
Pizza

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes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Active Ontology
Entities
Classes
Object Properties
Class Annotations
Class Usage
Asserted class hierarchy
Inferred class hierarchy

Equivalent classes

Pizza
that hasTopping min 5 Thing

Asserted Class Hierarchy: PizzaWithFiveOrMoreTop

- Thing
  - DomainConcept
    - Food
      - Pizza
        - PizzaWithThreeOrLessToppings
        - PizzaWithFiveOrMoreToppings
        - PizzaWithTwoToppings
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping
        - NonVegetarianTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

Class Description: PizzaWithFiveOrMoreToppings

Equivalent classes

Pizza
that hasTopping min 5 Thing

Superclasses

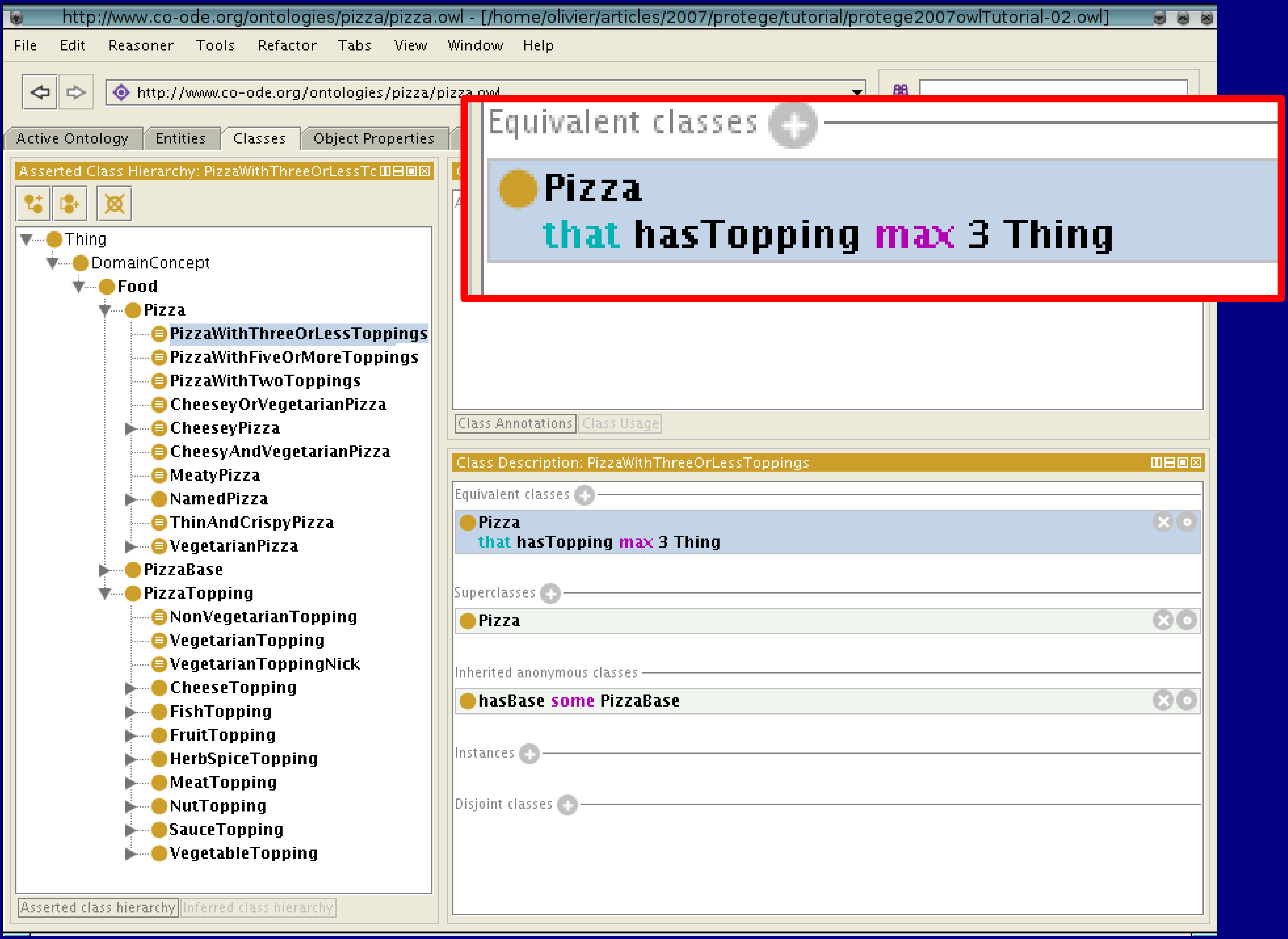
Pizza

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes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http://www.co-ode.org/ontologies/pizza/pizza.owl
Active Ontology
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Classes
Object Properties
Class Annotations
Class Usage
Asserted class hierarchy
Inferred class hierarchy

Equivalent classes

Pizza
that hasTopping max 3 Thing

Asserted Class Hierarchy: PizzaWithThreeOrLessTc

- Thing
  - DomainConcept
    - Food
      - Pizza
        - PizzaWithThreeOrLessToppings
        - PizzaWithFiveOrMoreToppings
        - PizzaWithTwoToppings
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping
        - NonVegetarianTopping
        - VegetarianTopping
        - VegetarianToppingNick
        - CheeseTopping
        - FishTopping
        - FruitTopping
        - HerbSpiceTopping
        - MeatTopping
        - NutTopping
        - SauceTopping
        - VegetableTopping

Class Description: PizzaWithThreeOrLessToppings

Equivalent classes

Pizza
that hasTopping max 3 Thing

Superclasses

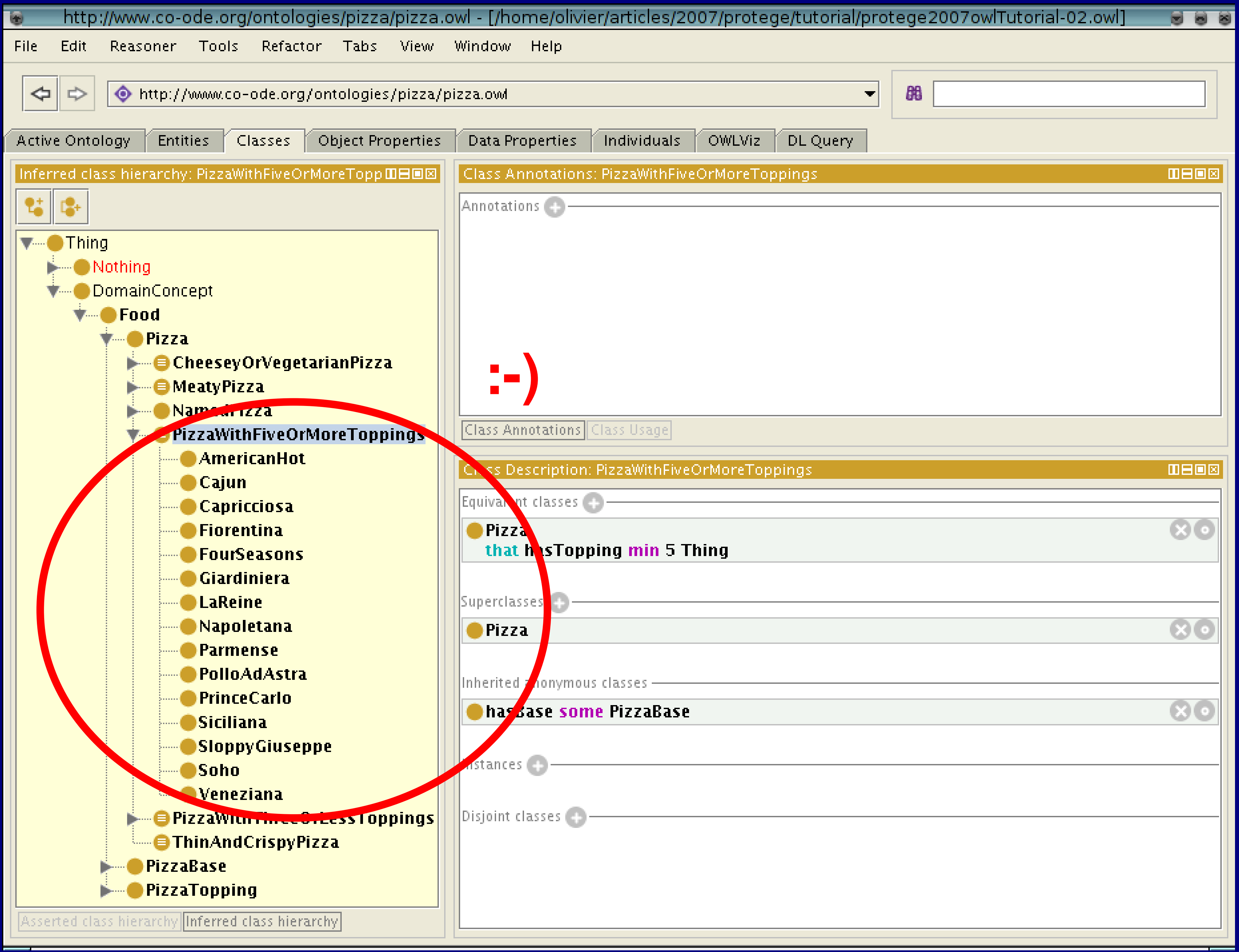
Pizza

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes



Inferred class hierarchy: PizzaWithFiveOrMoreTopp

- Thing
  - Nothing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - PizzaWithFiveOrMoreToppings
          - AmericanHot
          - Cajun
          - Capricciosa
          - Fiorentina
          - FourSeasons
          - Giardiniera
          - LaReine
          - Napoletana
          - Parmense
          - PolloAdAstra
          - PrinceCarlo
          - Siciliana
          - SloppyGiuseppe
          - Soho
          - Veneziana
        - PizzaWithThreeOrLessToppings
        - ThinAndCrispyPizza
      - PizzaBase
      - PizzaTopping

Class Annotations: PizzaWithFiveOrMoreToppings

Annotations

Class Description: PizzaWithFiveOrMoreToppings

Equivalent classes

Pizza
that hasTopping min 5 Thing

Superclasses

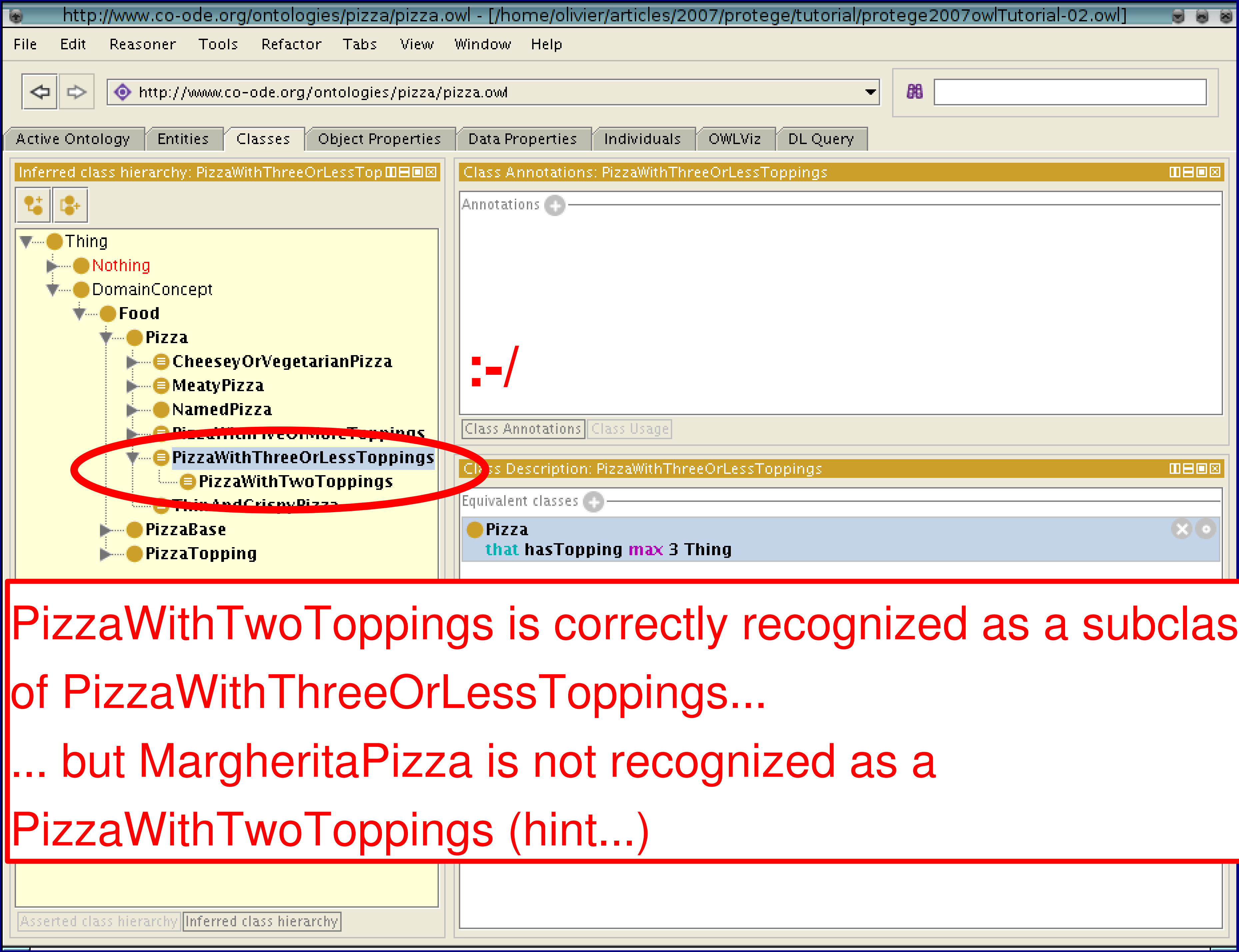
Pizza

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes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DL Query
Inferred class hierarchy: PizzaWithThreeOrLessTop
Class Annotations: PizzaWithThreeOrLessToppings
Annotations
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Class Annotations
Class Usage
Class Description: PizzaWithThreeOrLessToppings
Equivalent classes
Asserted class hierarchy
Inferred class hierarchy

```
Thing
  Nothing
  DomainConcept
    Food
      Pizza
        CheeseyOrVegetarianPizza
        MeatyPizza
        NamedPizza
        PizzaWithFiveOrMoreToppings
        PizzaWithThreeOrLessToppings
          PizzaWithTwoToppings
        ThinAndCrispyPizza
      PizzaBase
      PizzaTopping
```

Pizza
that hasTopping max 3 Thing

PizzaWithTwoToppings is correctly recognized as a subclass of PizzaWithThreeOrLessToppings...

... but MargheritaPizza is not recognized as a PizzaWithTwoToppings (hint...)

Open world assumption

Open VS Closed World Reasoning

- Remember a few slides ago ???
- MargheritaPizza $\sqsubseteq$ ($\exists$ *hasTopping* Mozzarella) $\sqcap$ ($\exists$ *hasTopping* Tomato)
- VegetarianPizza = Pizza $\sqcap$ ($\forall$ *hasTopping* VegetarianTop.)
- Tomato and Mozzarella ARE Vegetarian toppings
- **So, why isn't Margherita classified under VegetarianPizza ?**

Open VS Closed World Reasoning

- Remember a few slides ago ???
- MargheritaPizza $\sqsubseteq$ ($\exists$ *hasTopping* Mozzarella) $\sqcap$
($\exists$ *hasTopping* Tomato)
- VegetarianPizza = Pizza $\sqcap$
($\forall$ *hasTopping* VegetarianTop.)
- Tomato and Mozzarella ARE Vegetarian toppings
- **Because some Margheritas may have other toppings (e.g. HotSpicedBeefTopping) !**

Open VS Closed World Reasoning

- Closed-World reasoning
  - Negation as failure
  - Anything that cannot be found is false
  - Reasoning about this world
- Open-World reasoning
  - Negation as contradiction
  - Anything might be true unless it can be proven false
  - Reasoning about any world consistent with the model

Need for closure

Margherita pizzas **only** have Tomato and Mozzarella for topping

- MargheritaPizza $\sqsubseteq$ ($\exists$ *hasTopping* Mozzarella) $\sqcap$ ($\exists$ *hasTopping* Tomato) $\sqcap$ **?????**

Need for closure

Margherita pizzas **only** have Tomato and Mozzarella for topping

- MargheritaPizza $\sqsubseteq$ ($\exists$ *hasTopping* Mozzarella) $\sqcap$ ($\exists$ *hasTopping* Tomato) $\sqcap$ ($\forall$ *hasTopping* **???**)

Need for closure

Margherita pizzas **only** have Tomato and Mozzarella for topping

- $\text{MargheritaPizza} \sqsubseteq (\exists\ \textit{hasTopping}\ \text{Mozzarella}) \sqcap (\exists\ \textit{hasTopping}\ \text{Tomato}) \sqcap (\forall\ \textit{hasTopping}\ (\text{Mozzarella} \sqcup \text{Tomato}))$

Need for closure

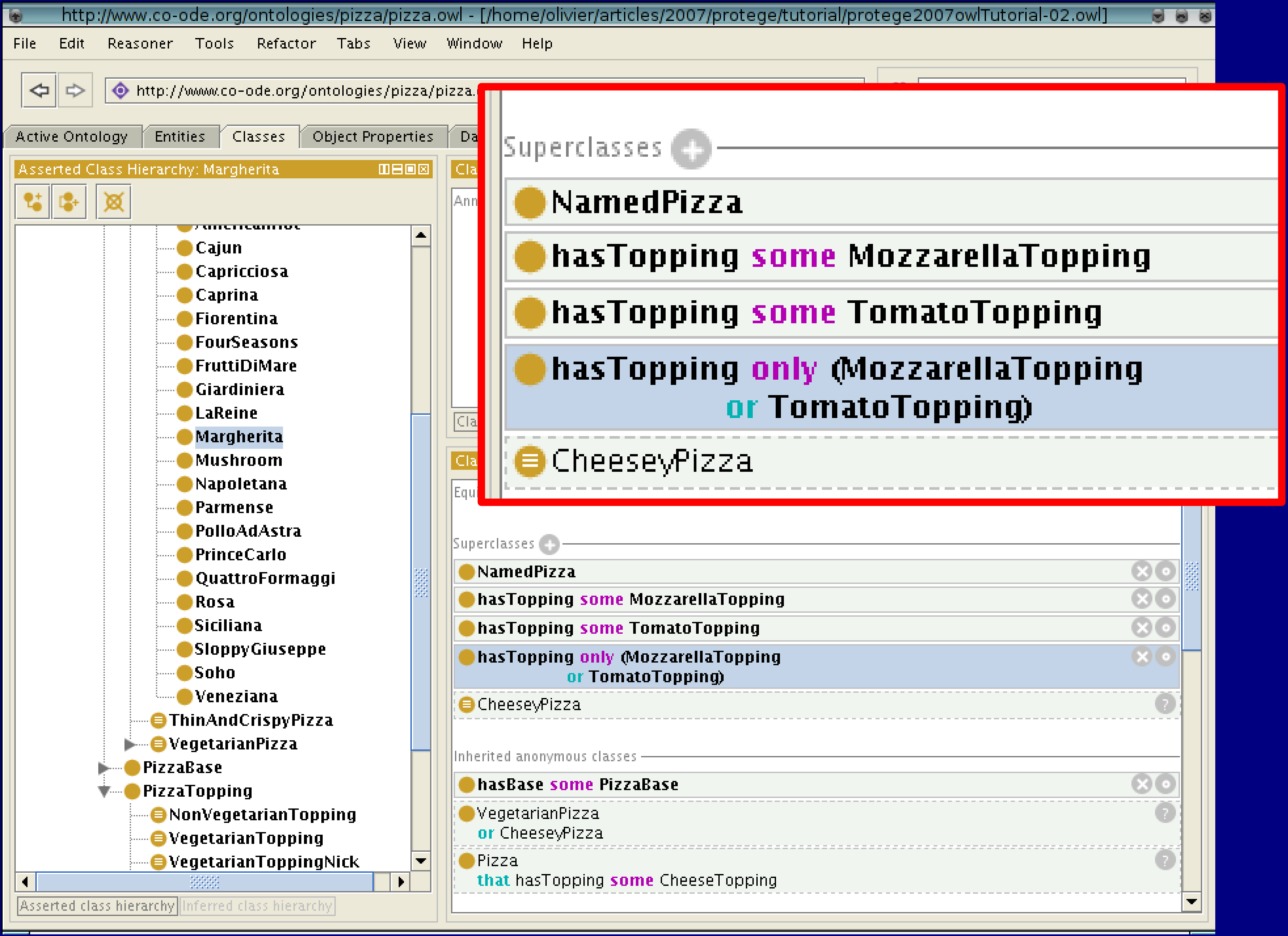
Margherita pizzas **only** have Tomato and Mozzarella for topping

- MargheritaPizza $\sqsubseteq$ ($\exists$ *hasTopping* Mozzarella) $\sqcap$ ($\exists$ *hasTopping* Tomato) $\sqcap$ ($\forall$ *hasTopping* (Mozzarella $\sqcup$ Tomato))
- The universal constraint ($\forall$) alone is not enough ! We need both $\exists$ and $\forall$ constraints

Need for closure

Margherita pizzas **only** have Tomato and Mozzarella for topping

- MargheritaPizza $\sqsubseteq$ ($\exists$ *hasTopping* Mozzarella) $\sqcap$ ($\exists$ *hasTopping* Tomato) $\sqcap$ ($\forall$ *hasTopping* (Mozzarella $\sqcup$ Tomato))
- Same principle for all the other pizze!



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AmericanHot
Cajun
Capricciosa
Caprina
Fiorentina
FourSeasons
FruttiDiMare
Giardiniera
LaReine
Margherita
Mushroom
Napoletana
Parmense
PolloAdAstra
PrinceCarlo
QuattroFormaggi
Rosa
Siciliana
SloppyGiuseppe
Soho
Veneziana
ThinAndCrispyPizza
VegetarianPizza
PizzaBase
PizzaTopping
NonVegetarianTopping
VegetarianTopping
VegetarianToppingNick

Superclasses

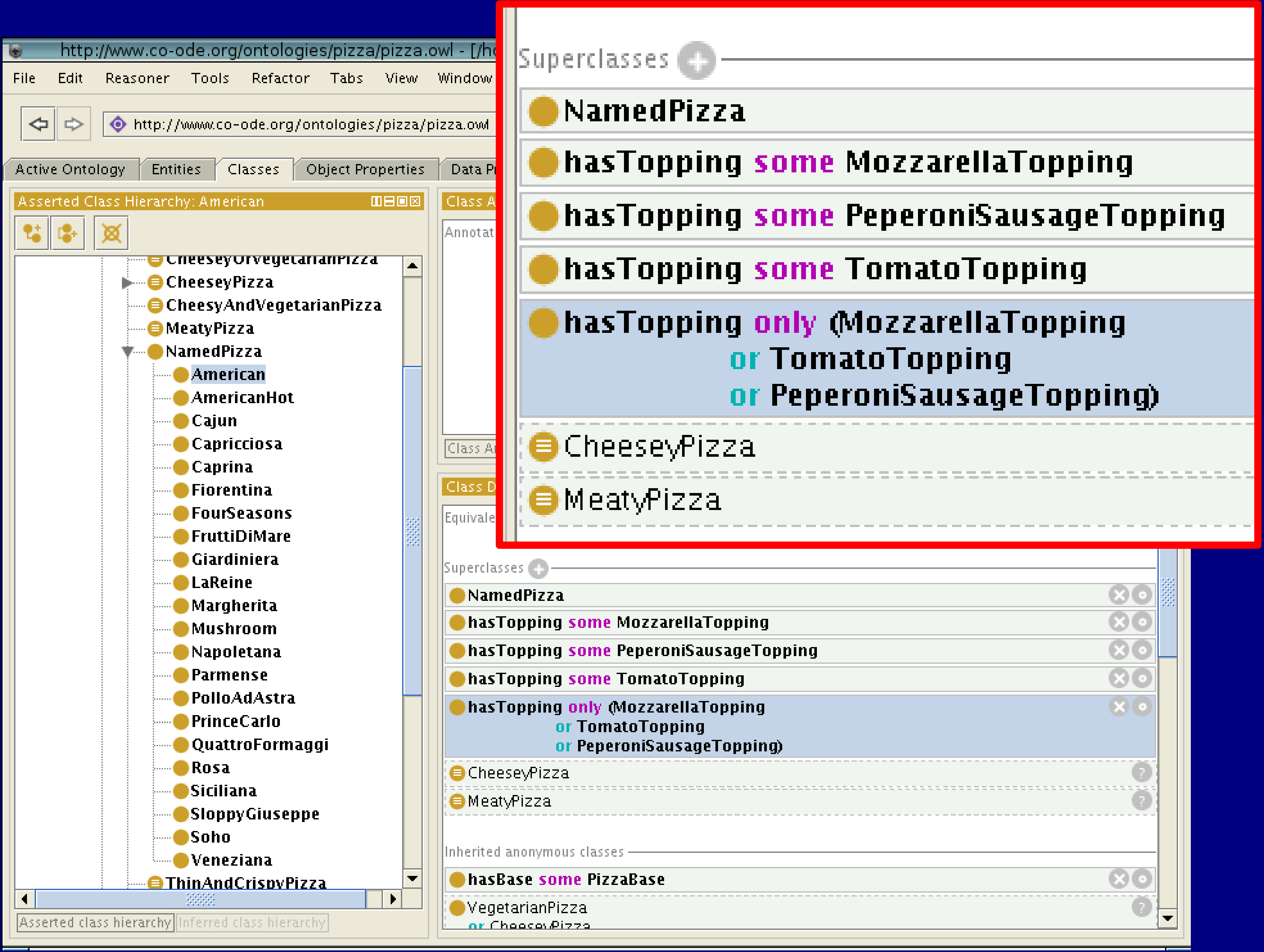
NamedPizza
hasTopping some MozzarellaTopping
hasTopping some TomatoTopping
hasTopping only (MozzarellaTopping
or TomatoTopping)
CheeseyPizza

Superclasses

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

Inherited anonymous classes

hasBase some PizzaBase
VegetarianPizza
or CheeseyPizza
Pizza
that hasTopping some CheeseTopping



- CheeseyVegetarianPizza
- CheeseyPizza
- CheesyAndVegetarianPizza
- MeatyPizza
- NamedPizza
  - American
  - AmericanHot
  - Cajun
  - Capricciosa
  - Caprina
  - Fiorentina
  - FourSeasons
  - FruttiDiMare
  - Giardiniera
  - LaReine
  - Margherita
  - Mushroom
  - Napoletana
  - Parmense
  - PolloAdAstra
  - PrinceCarlo
  - QuattroFormaggi
  - Rosa
  - Siciliana
  - SloppyGiuseppe
  - Soho
  - Veneziana
- ThinAndCrispyPizza

Superclasses

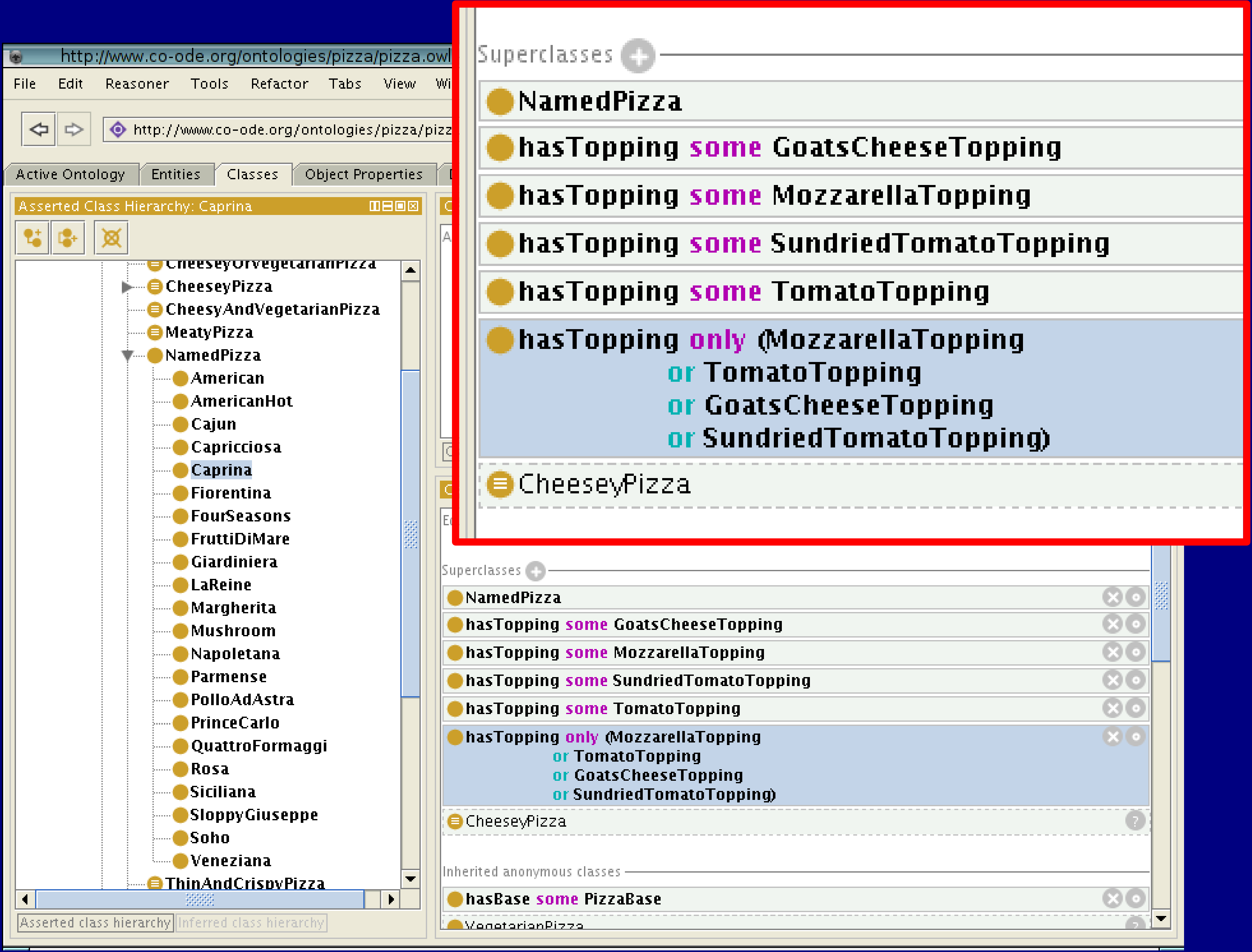
```
NamedPizza
hasTopping some MozzarellaTopping
hasTopping some PeperoniSausageTopping
hasTopping some TomatoTopping
hasTopping only (MozzarellaTopping
                 or TomatoTopping
                 or PeperoniSausageTopping)
CheeseyPizza
MeatyPizza
```

Superclasses

```
NamedPizza
hasTopping some MozzarellaTopping
hasTopping some PeperoniSausageTopping
hasTopping some TomatoTopping
hasTopping only (MozzarellaTopping
                 or TomatoTopping
                 or PeperoniSausageTopping)
CheeseyPizza
MeatyPizza
```

Inherited anonymous classes

```
hasBase some PizzaBase
VegetarianPizza
 or CheeseyPizza
```



Superclasses

NamedPizza

hasTopping some GoatsCheeseTopping

hasTopping some MozzarellaTopping

hasTopping some SundriedTomatoTopping

hasTopping some TomatoTopping

```
hasTopping only (MozzarellaTopping
                 or TomatoTopping
                 or GoatsCheeseTopping
                 or SundriedTomatoTopping)
```

CheeseyPizza

Inherited anonymous classes

hasBase some PizzaBase

VegetarianPizza

Superclasses

NamedPizza

hasTopping some GoatsCheeseTopping

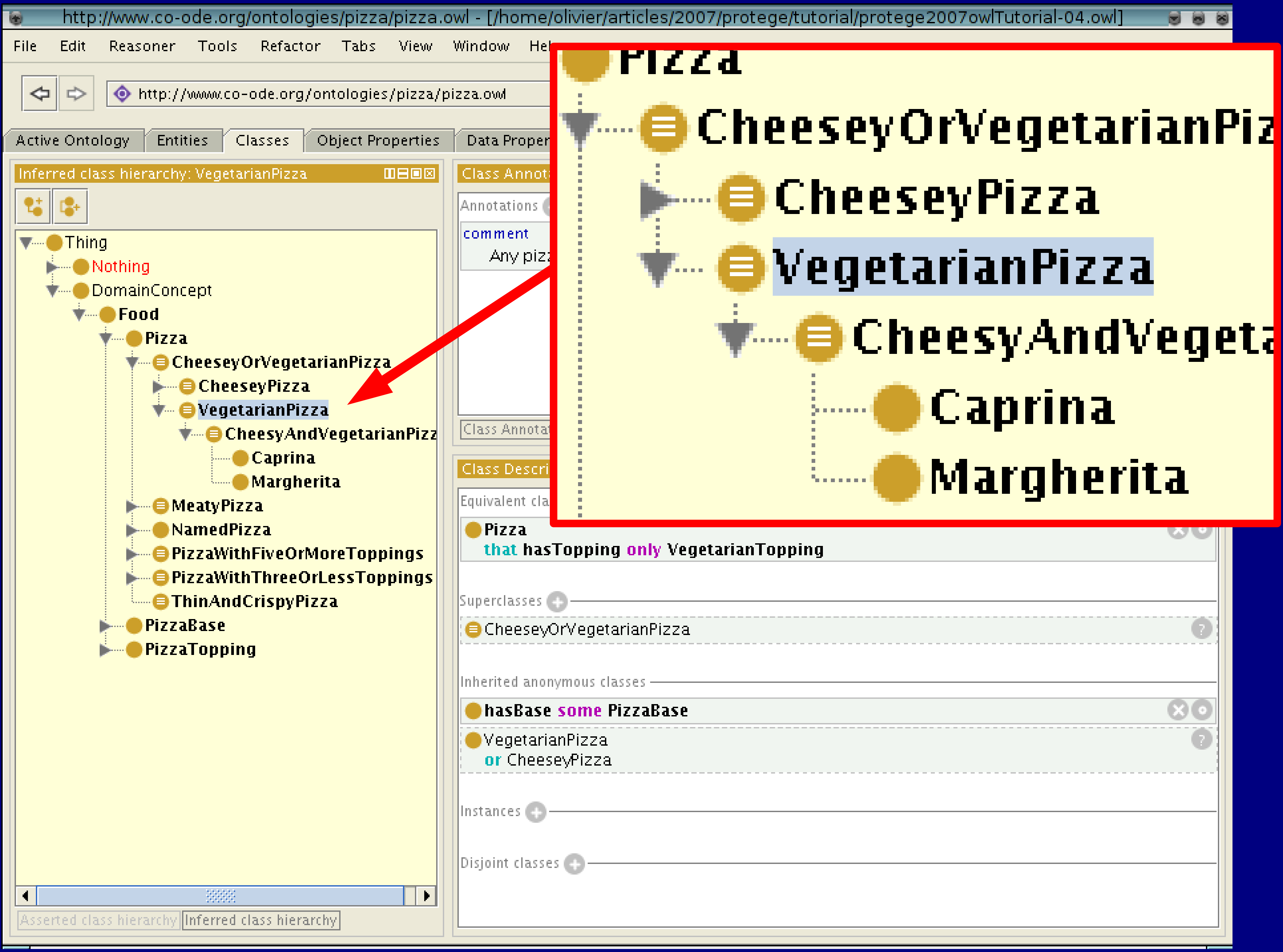
hasTopping some MozzarellaTopping

hasTopping some SundriedTomatoTopping

hasTopping some TomatoTopping

hasTopping only (MozzarellaTopping
or TomatoTopping
or GoatsCheeseTopping
or SundriedTomatoTopping)

CheeseyPizza



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Inferred class hierarchy: VegetarianPizza
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Class Annota
Class Descri
Asserted class hierarchy
Inferred class hierarchy

- Thing
  - Nothing
  - DomainConcept
    - Food
      - Pizza
        - CheeseyOrVegetarianPizza
          - CheeseyPizza
          - VegetarianPizza
            - CheesyAndVegetarianPizz
              - Caprina
              - Margherita
        - MeatyPizza
        - NamedPizza
        - PizzaWithFiveOrMoreToppings
        - PizzaWithThreeOrLessToppings
        - ThinAndCrispyPizza
      - PizzaBase
      - PizzaTopping

comment

Any piz

Equivalent cla

Pizza
that hasTopping only VegetarianTopping

Superclasses

CheeseyOrVegetarianPizza

Inherited anonymous classes

hasBase some PizzaBase

VegetarianPizza
or CheeseyPizza

Instances

Disjoint classes

Getting in sync!

If you need to catch-up,
the ontology at this point is
protege2007owlTutorial-03.owl

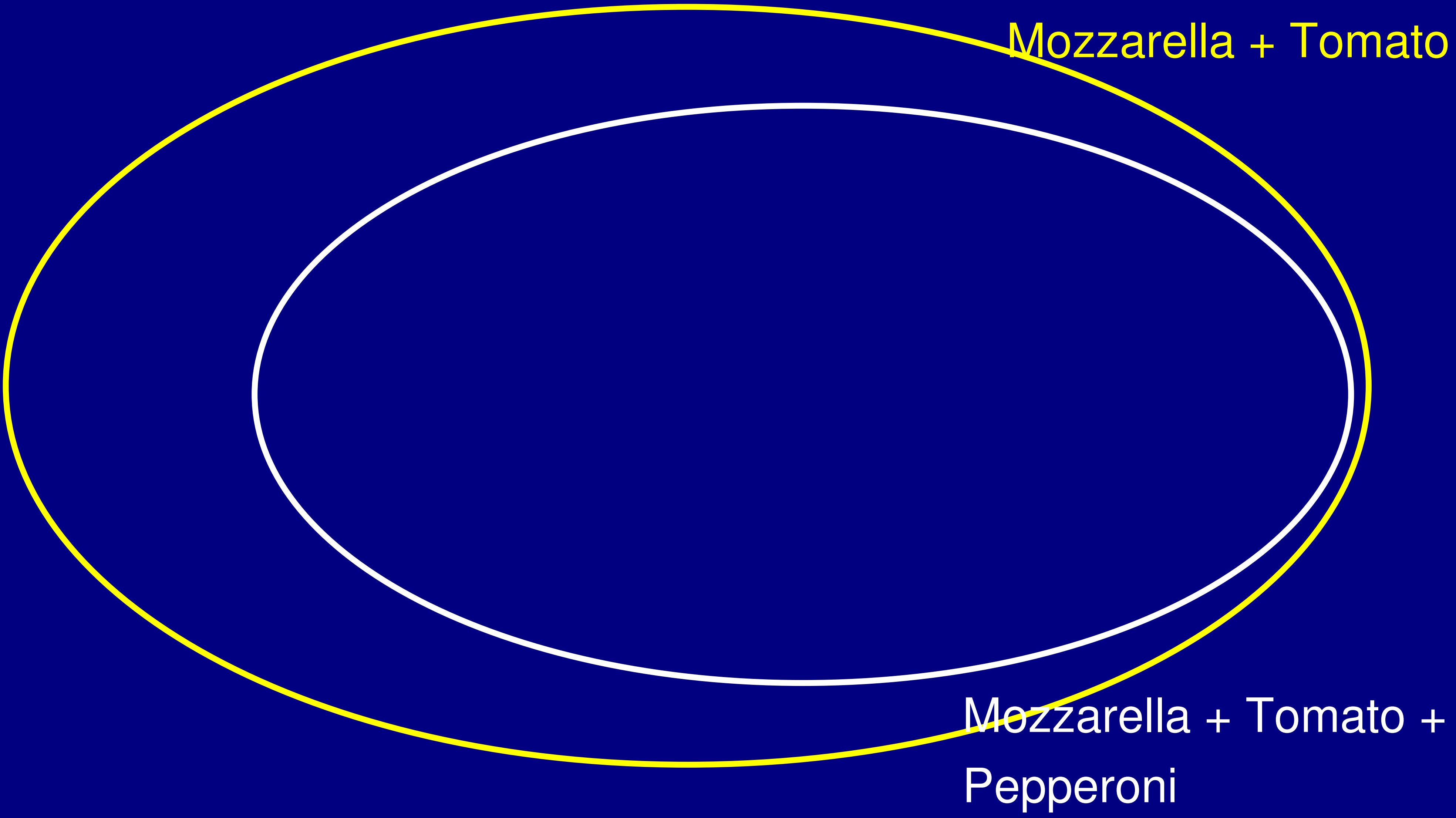
from:

http://www.ea3888.univ-rennes1.fr/dameron/protege2007/

More fun with closure and defined classes

- Before we added the closures, why wasn't AmericanPizza recognised as a subclass of MargheritaPizza ?

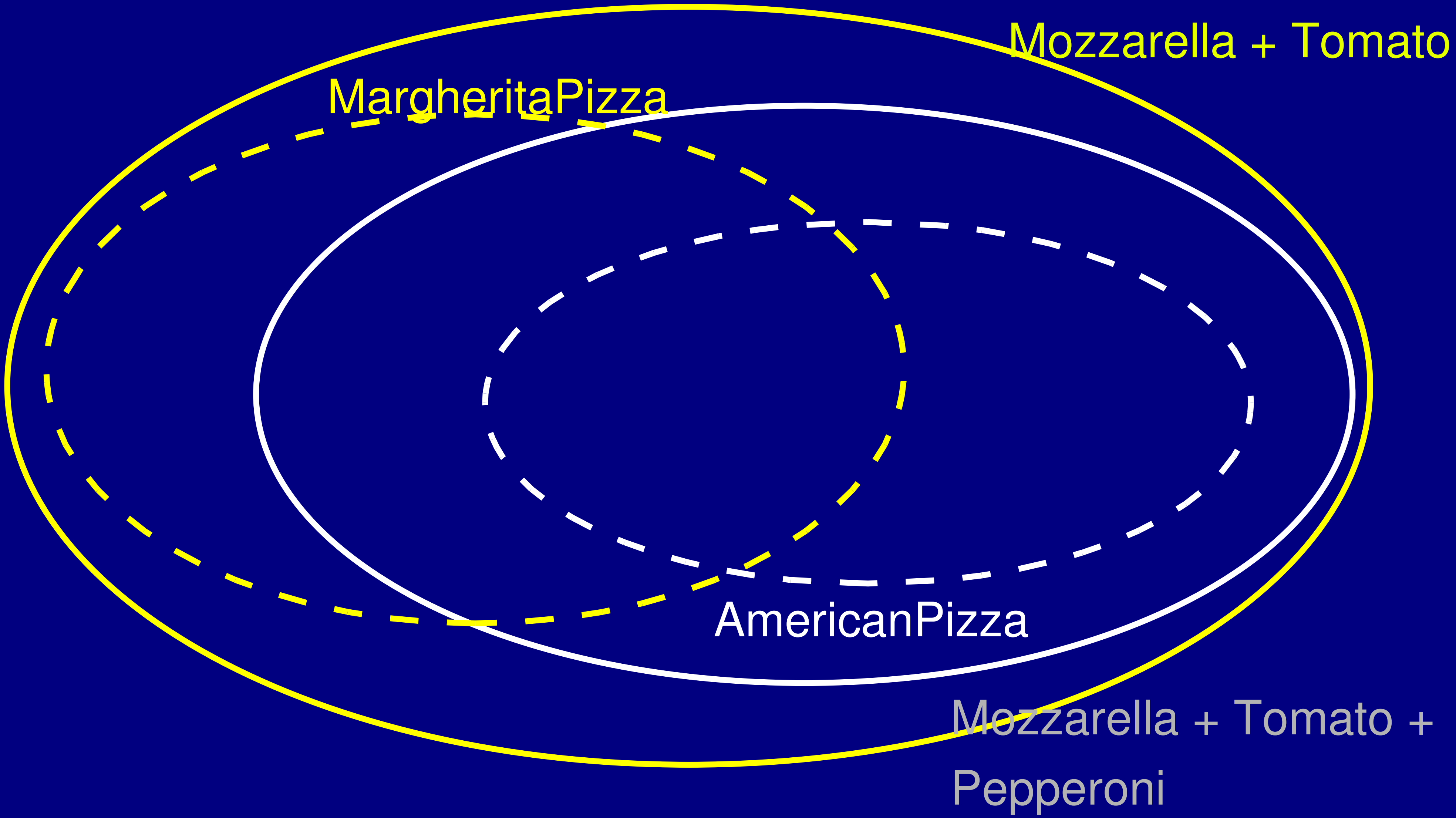
Need for closure



Mozzarella + Tomato

Mozzarella + Tomato + Pepperoni

Need for closure



Need for closure

Margherita pizzas only have Tomato and Mozzarella for topping

- $\text{MargheritaPizza} = (\exists\ \textit{hasTopping}\ \text{Mozzarella}) \sqcap (\exists\ \textit{hasTopping}\ \text{Tomato}) \sqcap (\forall\ \textit{hasTopping}\ (\text{Mozzarella} \sqcup \text{Tomato}))$

Getting in sync!

If you need to catch-up,

the ontology at this point is

protege2007owlTutorial-04.owl

from:

http://www.ea3888.univ-rennes1.fr/dameron/protege2007/

More fun with cardinality

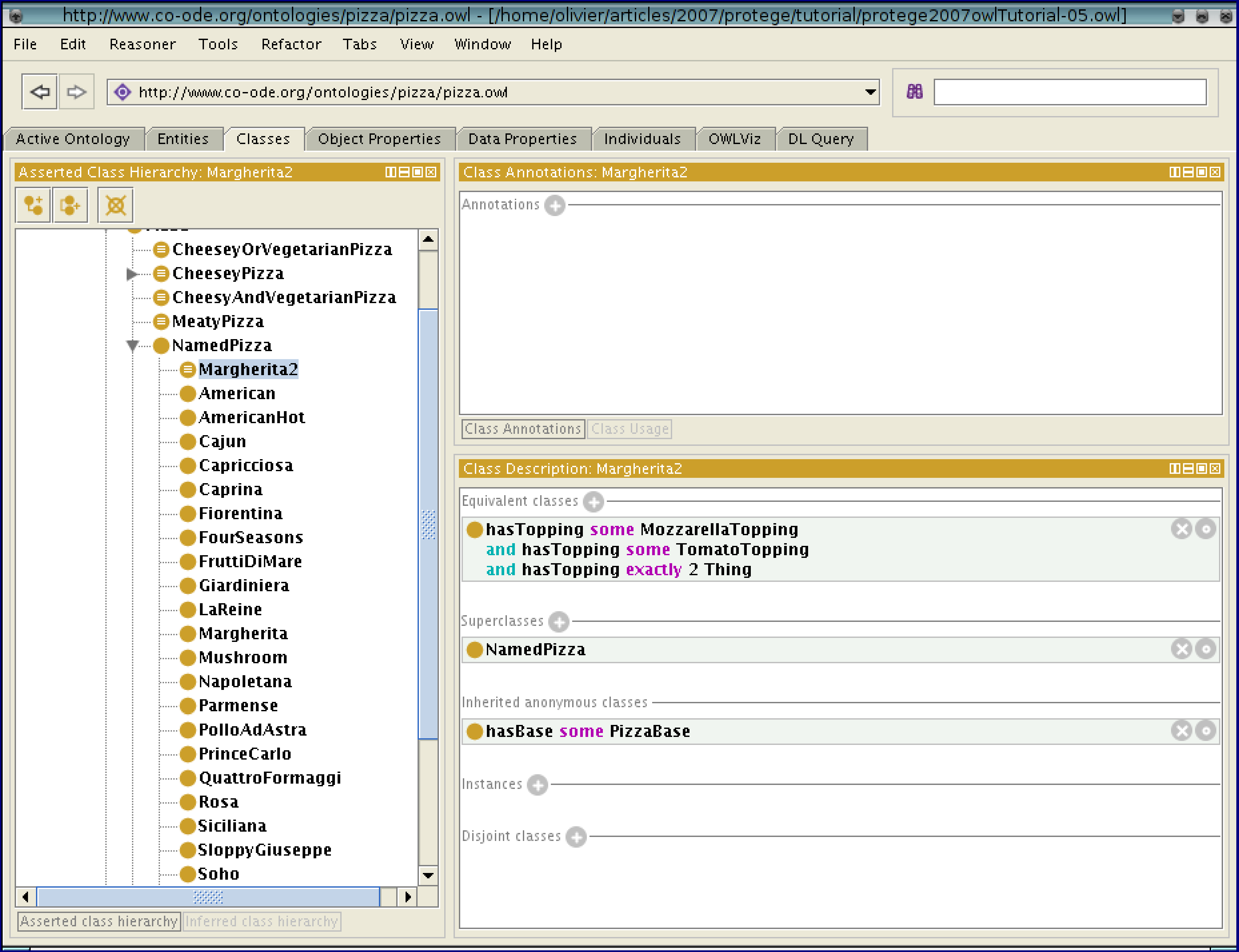
- Why isn't MargheritaPizza classified under PizzaWithTwoToppings ?

More fun with cardinality

- Why isn't MargheritaPizza classified under PizzaWithTwoToppings?
- Hints:
  - Why isn't it classified under PizzaWithThreeOrLessToppings ?
  - Why isn't it even classified under PizzaWithFiveOrMoreToppings ?... do Margherita pizze have exactly 4 toppings ?

More fun with cardinality

- Why isn't MargheritaPizza classified under PizzaWithTwoToppings?
- Still... the open-world assumption: imagine one instance of MargheritaPizza having as topping:
  - one instance of MozzarellaTopping
  - one other instance of MozzarellaTopping
  - one instance of TomatoTopping



Asserted Class Hierarchy: Margherita2

- CheeseyOrVegetarianPizza
- CheeseyPizza
- CheesyAndVegetarianPizza
- MeatyPizza
- NamedPizza
  - Margherita2
  - American
  - AmericanHot
  - Cajun
  - Capricciosa
  - Caprina
  - Fiorentina
  - FourSeasons
  - FruttiDiMare
  - Giardiniera
  - LaReine
  - Margherita
  - Mushroom
  - Napoletana
  - Parmense
  - PolloAdAstra
  - PrinceCarlo
  - QuattroFormaggi
  - Rosa
  - Siciliana
  - SloppyGiuseppe
  - Soho

Class Annotations: Margherita2

Annotations

Class Description: Margherita2

Equivalent classes

```
hasTopping some MozzarellaTopping
  and hasTopping some TomatoTopping
  and hasTopping exactly 2 Thing
```

Superclasses

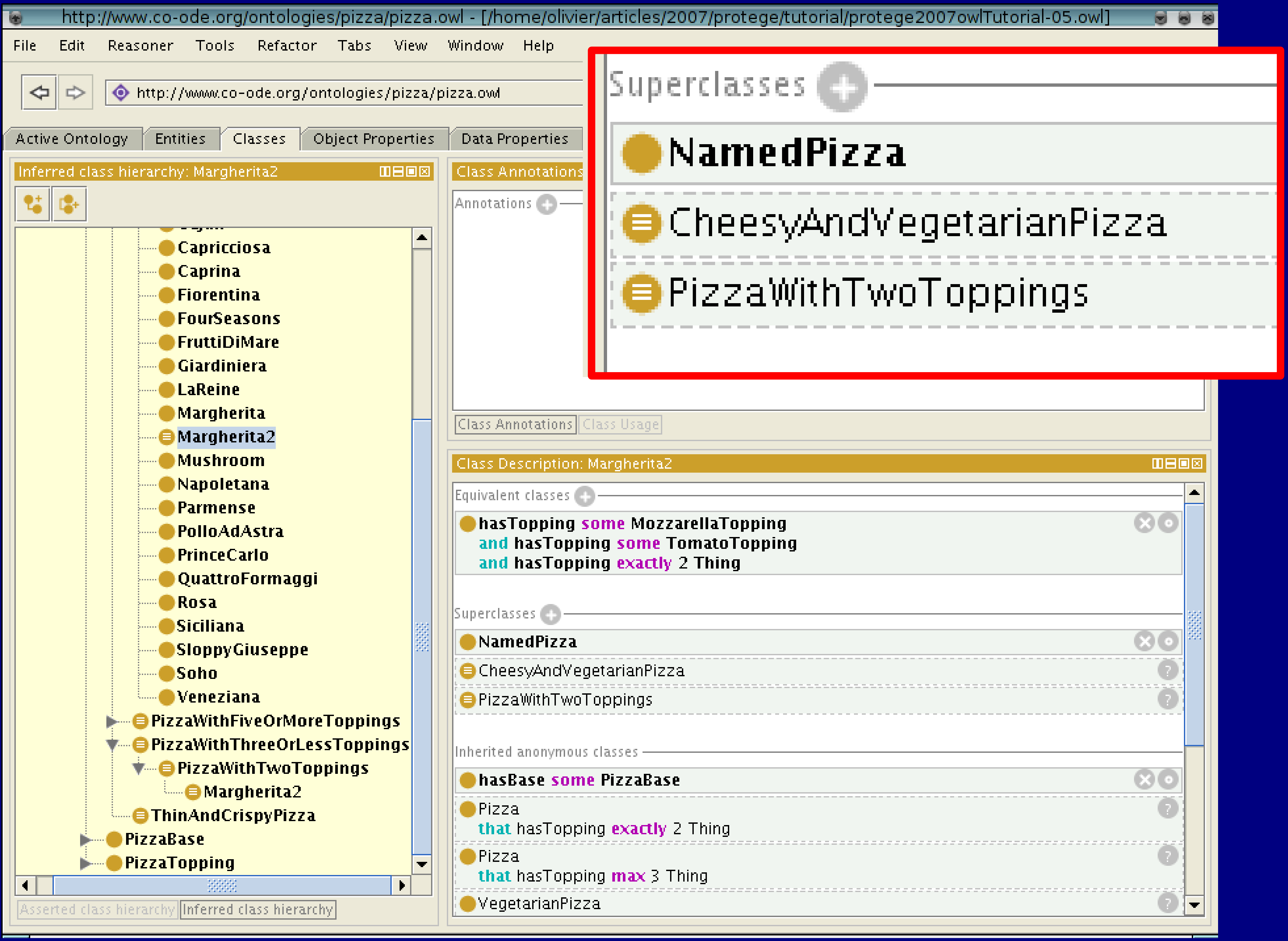
NamedPizza

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes



Equivalent classes

```
hasTopping some MozzarellaTopping
  and hasTopping some TomatoTopping
  and hasTopping exactly 2 Thing
```

Superclasses

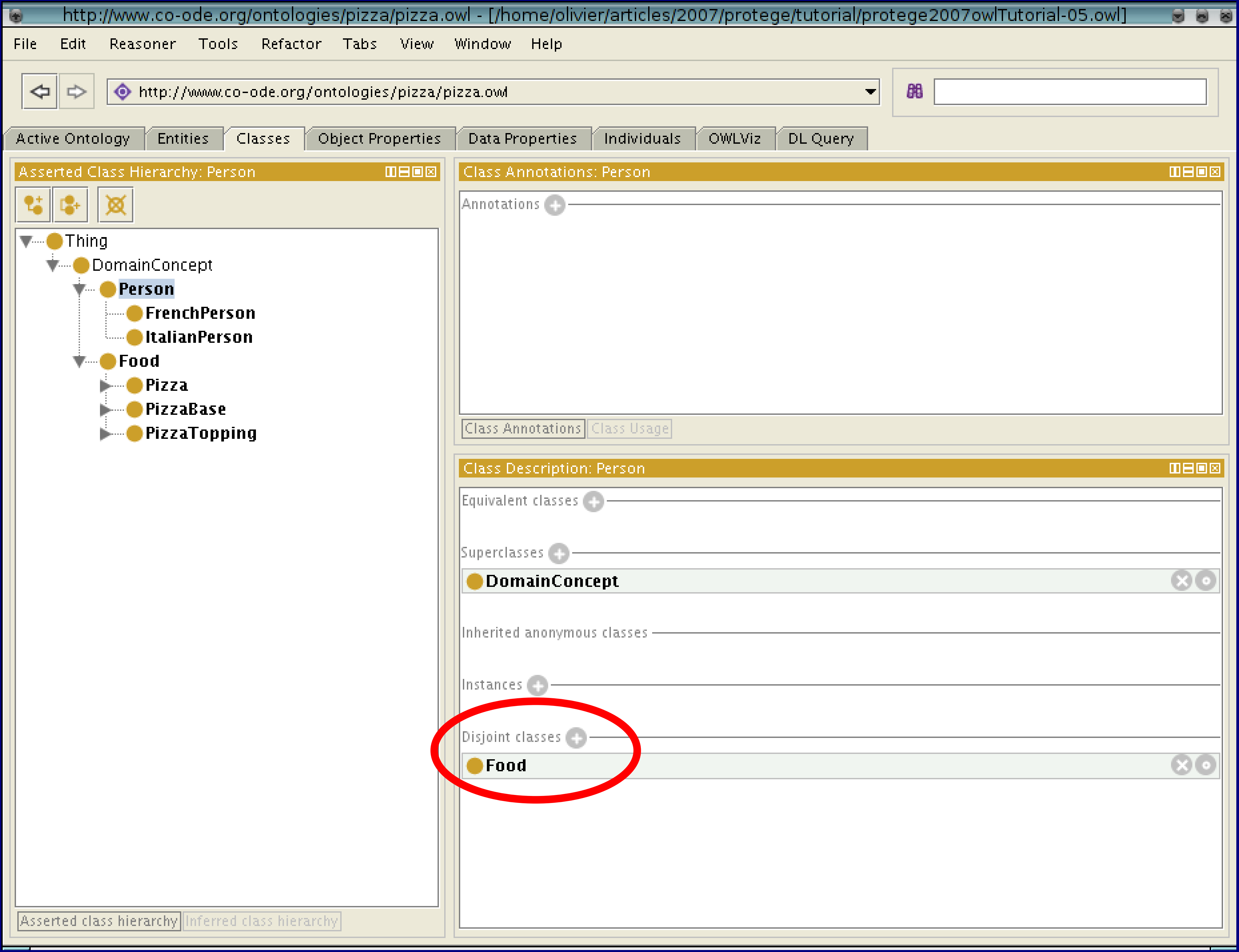
```
NamedPizza
CheesyAndVegetarianPizza
PizzaWithTwoToppings
```

Inherited anonymous classes

```
hasBase some PizzaBase
Pizza
  that hasTopping exactly 2 Thing
Pizza
  that hasTopping max 3 Thing
VegetarianPizza
```

hasValue restriction

- So far, we have been narrowing the range of relationship
  - create the class Person
  - create the relation *hasPizzaMaker*: Pizza -> Person
  - create ItalianPerson as as subclass of Person
  - define GenuinePizza = (∃ *hasPizzaMaker* ItalianPers.)



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http://www.co-ode.org/ontologies/pizza/pizza.owl

Asserted Class Hierarchy: Person

- Thing
  - DomainConcept
    - Person
      - FrenchPerson
      - ItalianPerson
    - Food
      - Pizza
      - PizzaBase
      - PizzaTopping

Class Annotations: Person

Annotations

Class Description: Person

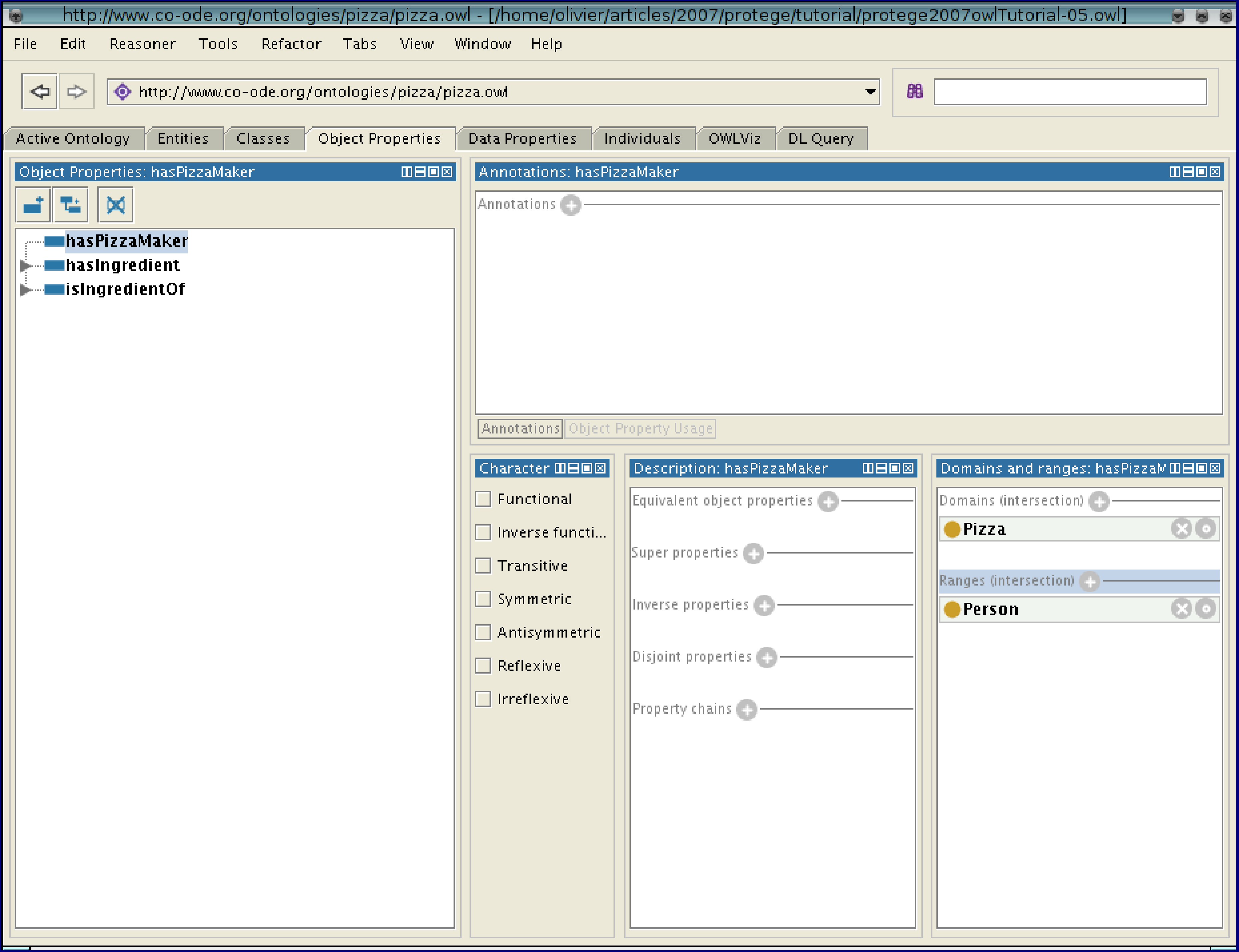
Equivalent classes

Superclasses
- DomainConcept

Inherited anonymous classes

Instances

Disjoint classes
- Food



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hasPizzaMaker
hasIngredient
isIngredientOf
Annotations: hasPizzaMaker
Annotations
Annotations
Object Property Usage
Character
Description: hasPizzaMaker
Equivalent object properties
Super properties
Inverse properties
Disjoint properties
Property chains
Domains and ranges: hasPizzaM

□ Functional

□ Inverse functi...

□ Transitive

□ Symmetric

□ Antisymmetric

□ Reflexive

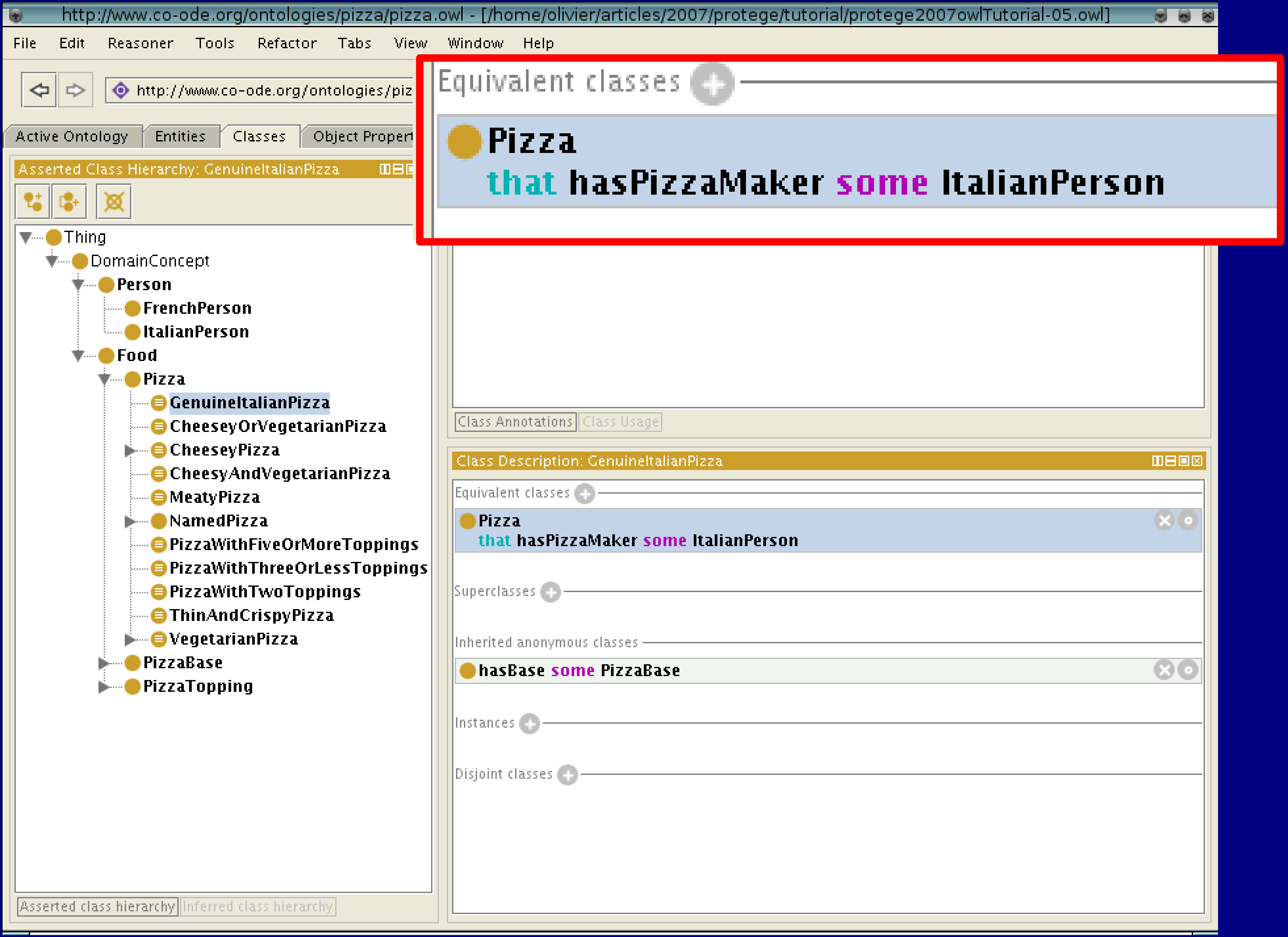
□ Irreflexive

Domains (intersection)

● Pizza

Ranges (intersection)

● Person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Asserted Class Hierarchy: GenuineItalianPizza
Class Annotations
Class Usage
Class Description: GenuineItalianPizza
Asserted class hierarchy
Inferred class hierarchy

Equivalent classes

Pizza
that hasPizzaMaker some ItalianPerson

```
Thing
  DomainConcept
    Person
      FrenchPerson
      ItalianPerson
    Food
      Pizza
        GenuineItalianPizza
        CheeseyOrVegetarianPizza
        CheeseyPizza
        CheesyAndVegetarianPizza
        MeatyPizza
        NamedPizza
        PizzaWithFiveOrMoreToppings
        PizzaWithThreeOrLessToppings
        PizzaWithTwoToppings
        ThinAndCrispyPizza
        VegetarianPizza
      PizzaBase
      PizzaTopping
```

Equivalent classes

Pizza
that hasPizzaMaker some ItalianPerson

Superclasses

Inherited anonymous classes

hasBase some PizzaBase

Instances

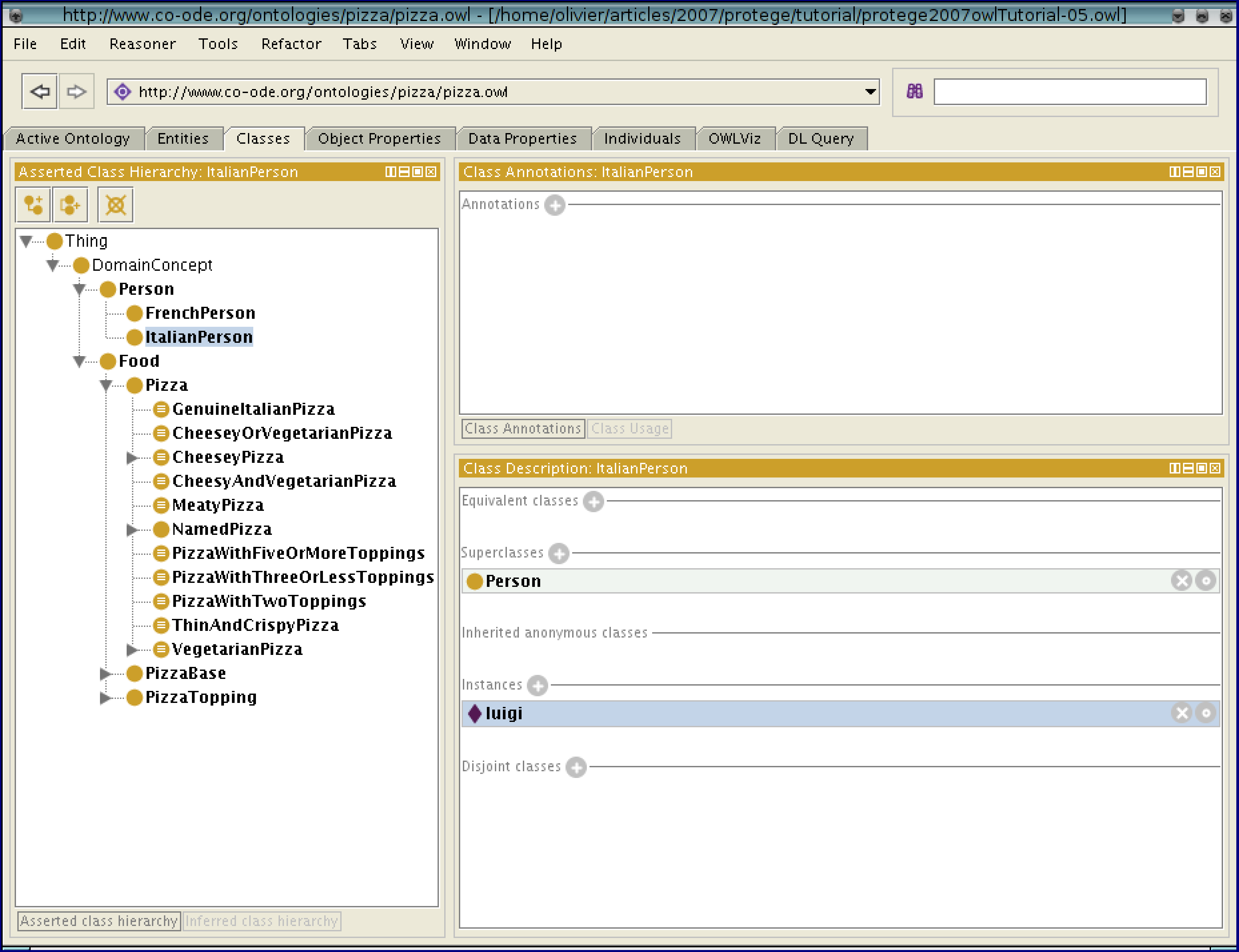
Disjoint classes

hasValue restriction

- So far, we have been narrowing the range of relationship
- We may also want to restrict it to a precise value (and not to a set of values)
  - create olivier as an instance of Person
  - define OliviersPizza = (*hasPizzaMaker* ∍ olivier)

hasValue restriction

- Create luigi as an instance of ItalianPerson
- Create LuigisPizza
- Classify :-)



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http://www.co-ode.org/ontologies/pizza/pizza.owl

Asserted Class Hierarchy: ItalianPerson

- Thing
  - DomainConcept
    - Person
      - FrenchPerson
      - ItalianPerson
    - Food
      - Pizza
        - GenuineItalianPizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - PizzaWithFiveOrMoreToppings
        - PizzaWithThreeOrLessToppings
        - PizzaWithTwoToppings
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping

Class Annotations: ItalianPerson

Annotations

Class Description: ItalianPerson

Equivalent classes

Superclasses

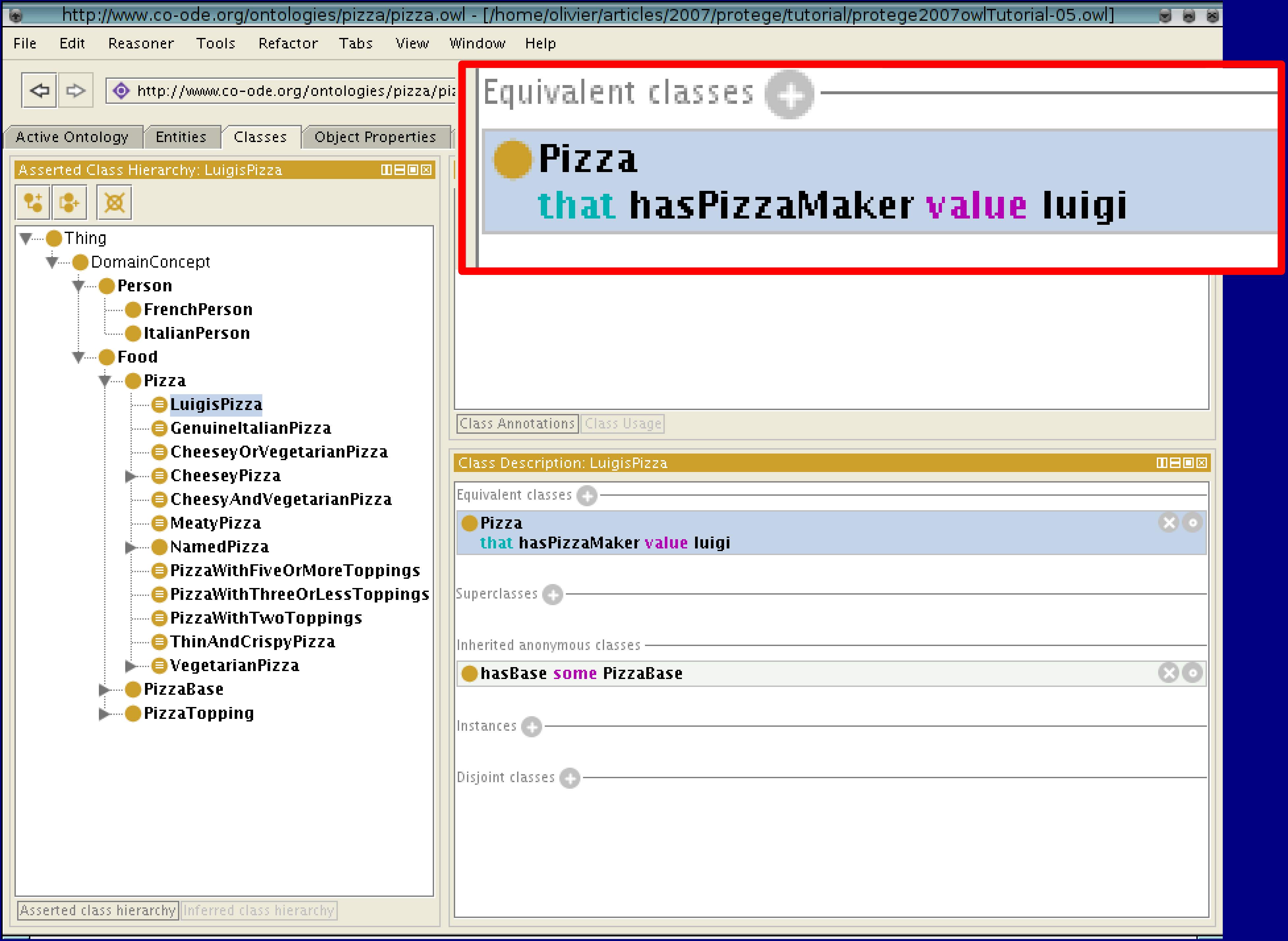
Person

Inherited anonymous classes

Instances

luigi

Disjoint classes



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Equivalent classes

Pizza
that hasPizzaMaker value luigi

Asserted Class Hierarchy: LuigisPizza

- Thing
  - DomainConcept
    - Person
      - FrenchPerson
      - ItalianPerson
    - Food
      - Pizza
        - LuigisPizza
        - GenuineItalianPizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - PizzaWithFiveOrMoreToppings
        - PizzaWithThreeOrLessToppings
        - PizzaWithTwoToppings
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping

Class Description: LuigisPizza

Equivalent classes

Pizza
that hasPizzaMaker value luigi

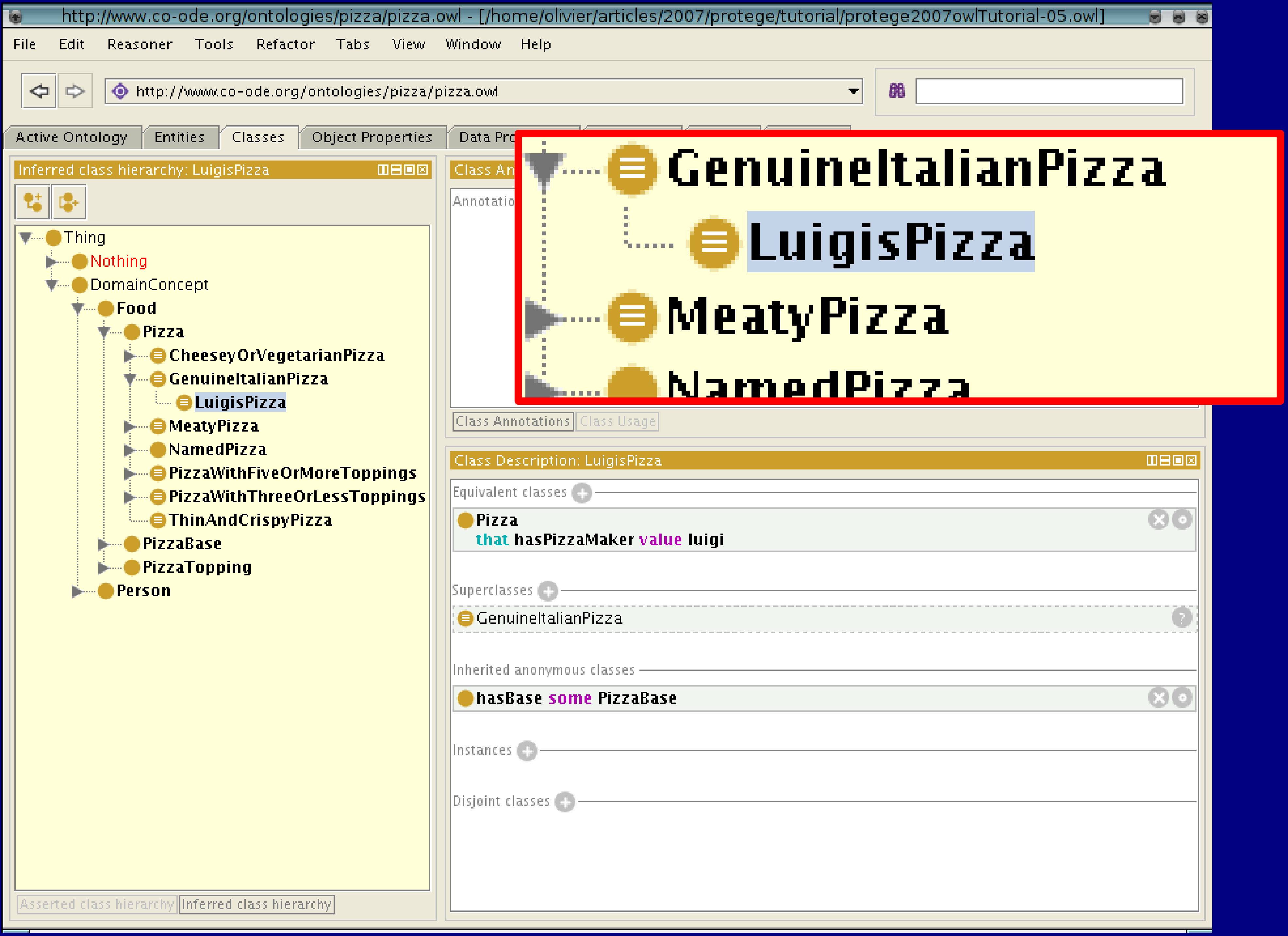
Superclasses

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes



Class Description: LuigisPizza

Equivalent classes

Pizza
that hasPizzaMaker value luigi

Superclasses

GenuineItalianPizza

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes

(slightly off topic) remark

- ItalianPerson and FrenchPerson are not disjoint
- Because there is no Unique Name Assumption, luigi and olivier could be the same person
- Use the owl:differentFrom and owl:allDifferent constructs (in the OWL menu)!

Reasoning makes life easier :-)

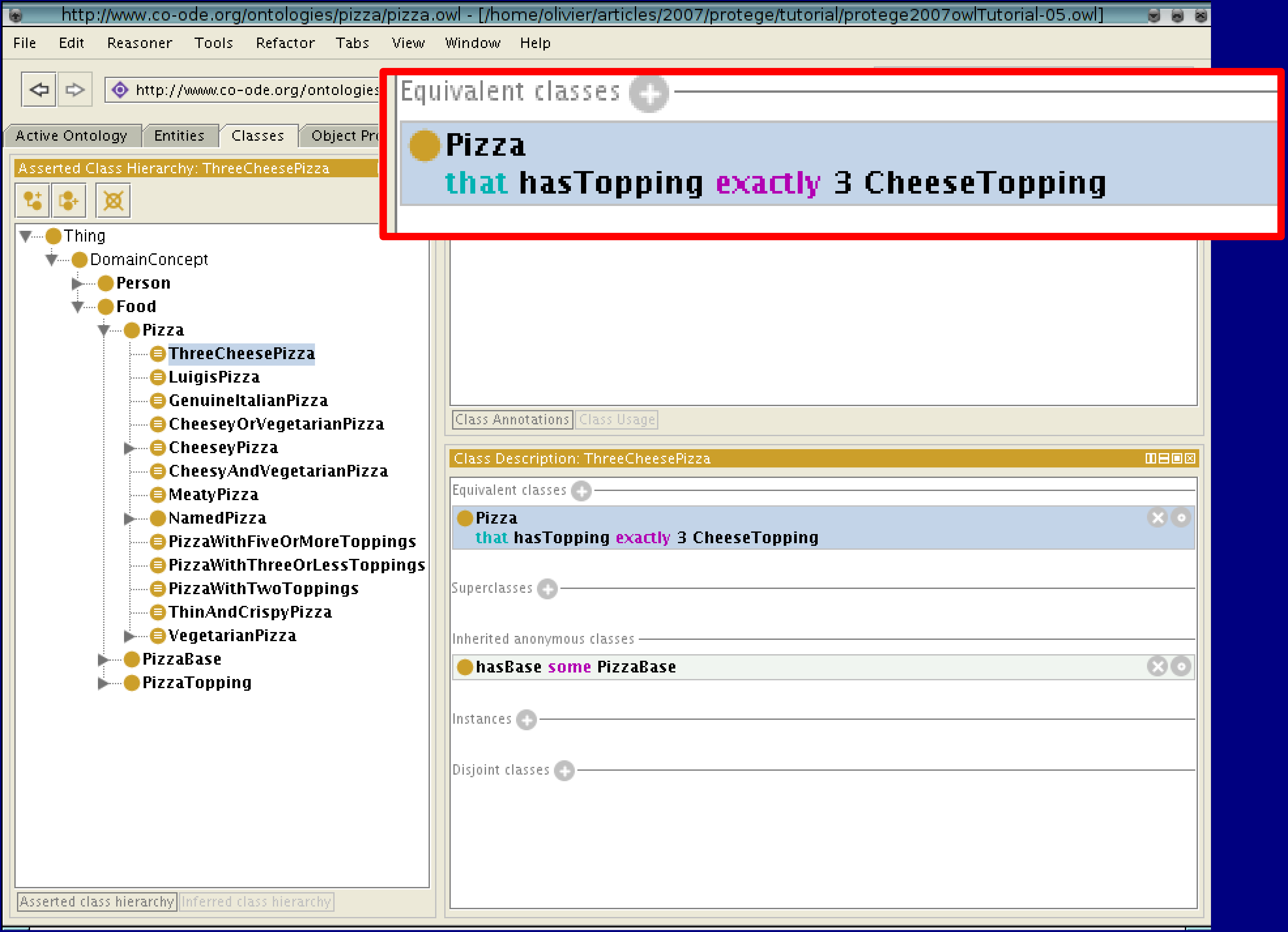
- Supports queries such as:
  - What are the vegetarian pizze ?
  - What are the cheesy pizze ?
  - What are the non-cheesy pizze ?
  - What are the cheesy vegetarian pizze ?
- ... it allows you to take advantage of the knowledge you put into your ontology

OWL and beyond...

OWL 1.1

Qualified Cardinality Restriction

- OWL 1.0 Cardinality restrictions:
  - PizzaWithTwoToppings
  - PizzaWithFiveOrMoreToppings
  - PizzaWithThreeToppingsOrLess
- OWL 1.1 Qualified cardinality restrictions
  - PizzaWithThreeCheese
  - PizzaWithAtLeastTwoCheese
  - PizzaWithAtLeastTwoCheeseAnd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Object Pro
Asserted Class Hierarchy: ThreeCheesePizza
Class Annotations
Class Usage
Class Description: ThreeCheesePizza
Asserted class hierarchy
Inferred class hierarchy

Equivalent classes

Pizza
that hasTopping exactly 3 CheeseTopping

- Thing
  - DomainConcept
    - Person
    - Food
      - Pizza
        - ThreeCheesePizza
        - LuigisPizza
        - GenuineItalianPizza
        - CheeseyOrVegetarianPizza
        - CheeseyPizza
        - CheesyAndVegetarianPizza
        - MeatyPizza
        - NamedPizza
        - PizzaWithFiveOrMoreToppings
        - PizzaWithThreeOrLessToppings
        - PizzaWithTwoToppings
        - ThinAndCrispyPizza
        - VegetarianPizza
      - PizzaBase
      - PizzaTopping

Class Description: ThreeCheesePizza

Equivalent classes

Pizza
that hasTopping exactly 3 CheeseTopping

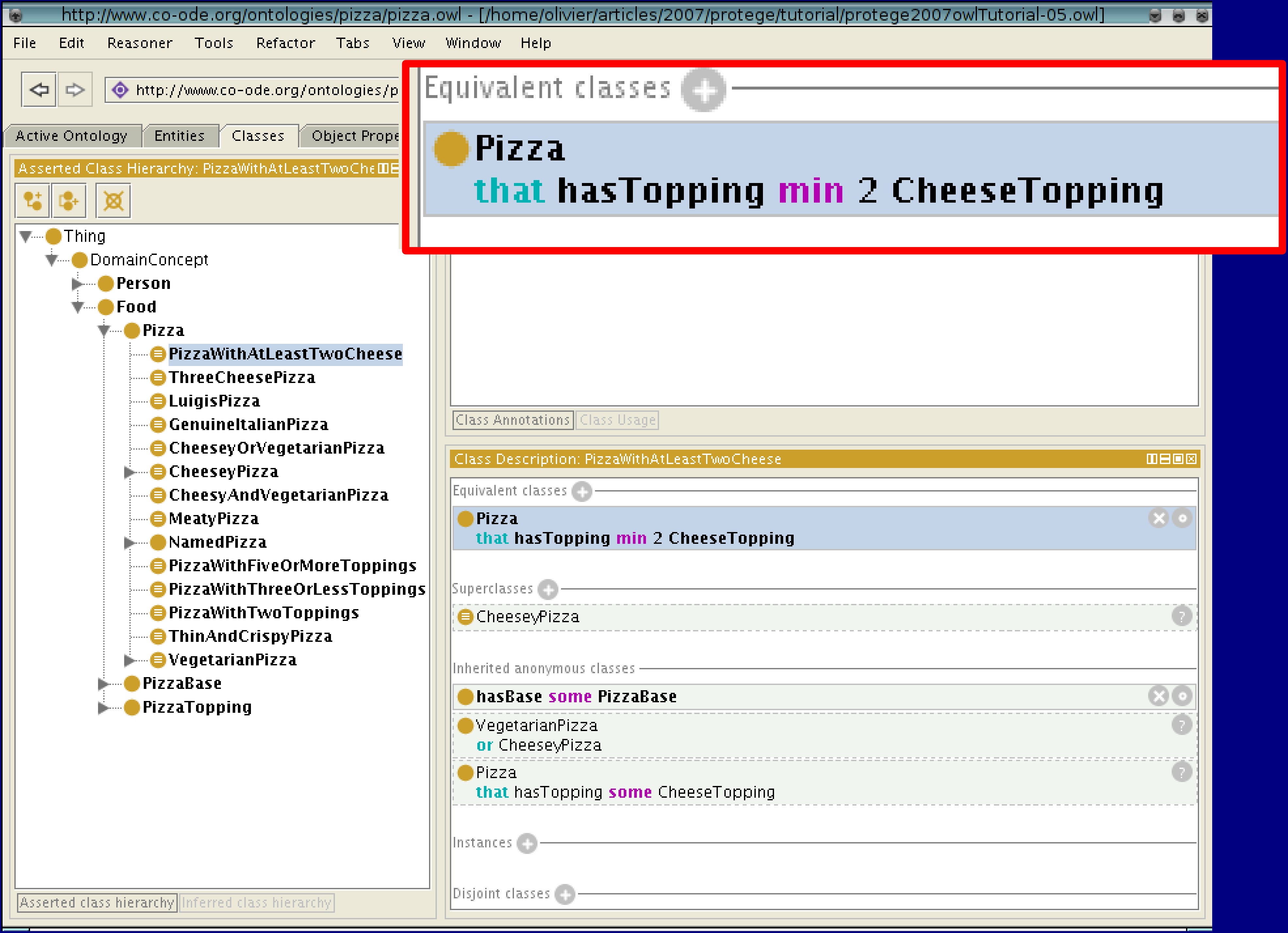
Superclasses

Inherited anonymous classes

hasBase some PizzaBase

Instances

Disjoint classes



Equivalent classes

Pizza
that hasTopping min 2 CheeseTopping

Class Description: PizzaWithAtLeastTwoCheese

Equivalent classes

Pizza
that hasTopping min 2 CheeseTopping

Superclasses

CheeseyPizza

Inherited anonymous classes

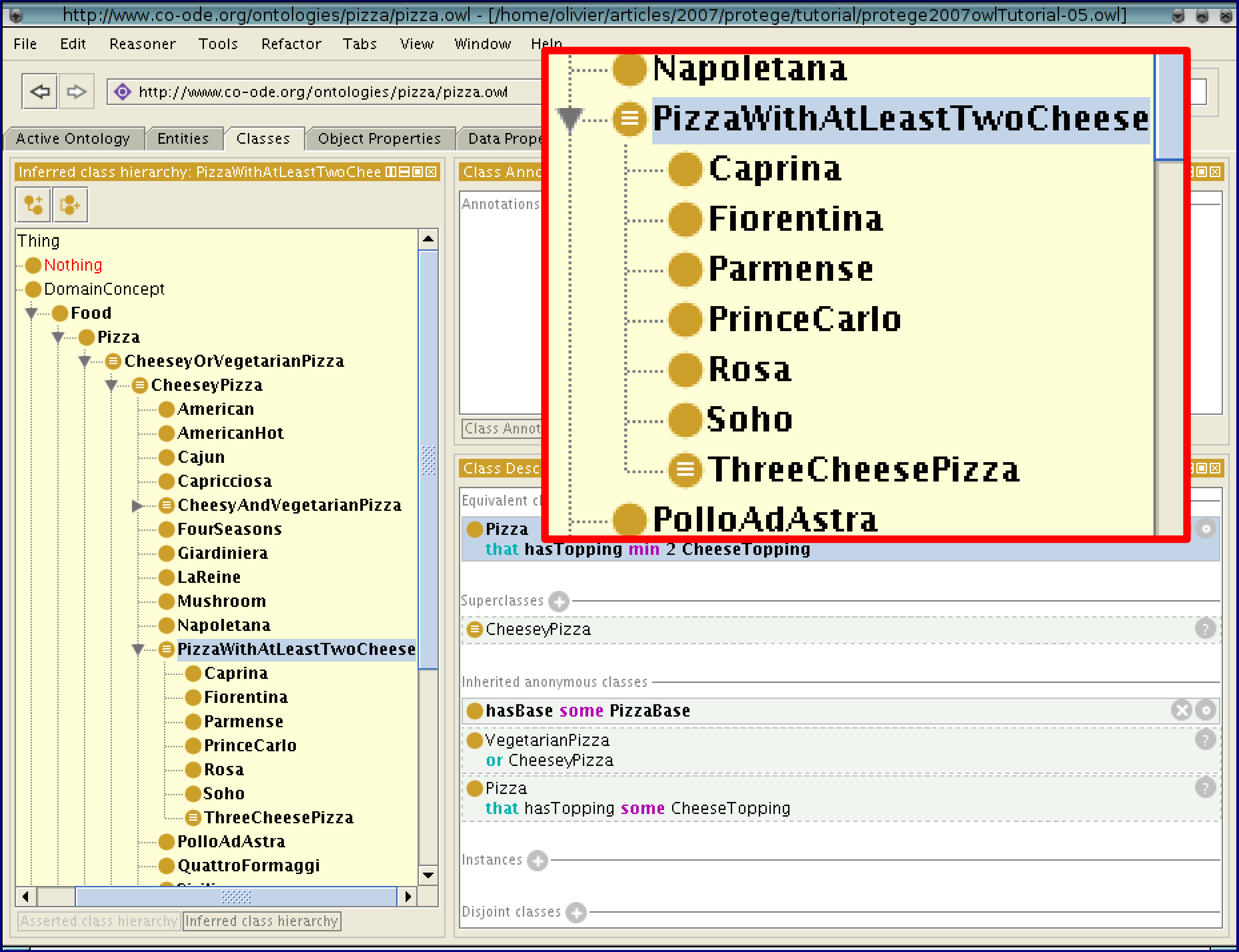
hasBase some PizzaBase

VegetarianPizza
or CheeseyPizza

Pizza
that hasTopping some CheeseTopping

Instances

Disjoint classes



Inferred class hierarchy: PizzaWithAtLeastTwoChee

```
Thing
  Nothing
  DomainConcept
    Food
      Pizza
        CheeseyOrVegetarianPizza
          CheeseyPizza
            American
            AmericanHot
            Cajun
            Capricciosa
            CheesyAndVegetarianPizza
            FourSeasons
            Giardiniera
            LaReine
            Mushroom
            Napoletana
            PizzaWithAtLeastTwoCheese
              Caprina
              Fiorentina
              Parmense
              PrinceCarlo
              Rosa
              Soho
              ThreeCheesePizza
            PolloAdAstra
            QuattroFormaggi
```

```
Napoletana
PizzaWithAtLeastTwoCheese
  Caprina
  Fiorentina
  Parmense
  PrinceCarlo
  Rosa
  Soho
  ThreeCheesePizza
PolloAdAstra
```

Equivalent cl

Pizza
that hasTopping min 2 CheeseTopping

Superclasses

CheeseyPizza

Inherited anonymous classes

hasBase some PizzaBase

VegetarianPizza
or CheeseyPizza

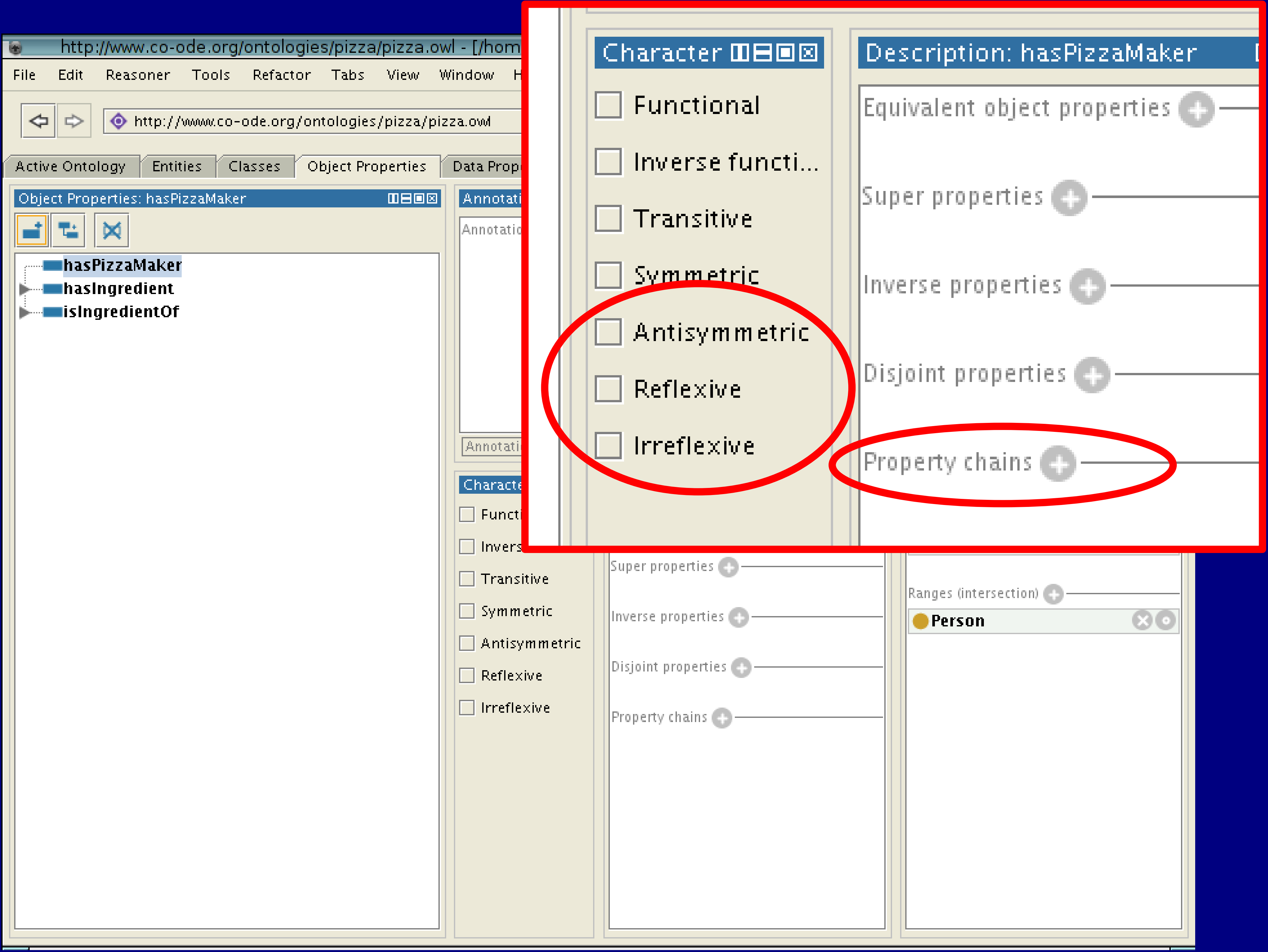
Pizza
that hasTopping some CheeseTopping

Instances

Disjoint classes

Additional features for properties

- Reflexivity $\forall a \in X,\ aRa$
  - e.g. *knows*, *isGreaterOrEqualTo*
- Irreflexivity $\forall a \in X,\ \neg(aRa)$
  - e.g. *isMotherOf*, *isGreaterThan*
- Antisymmetry $\forall a, b \in X,\ aRb \wedge bRa\ \Rightarrow\ a = b$
  - e.g. *isAncestorOf, isGreaterOrEqualTo*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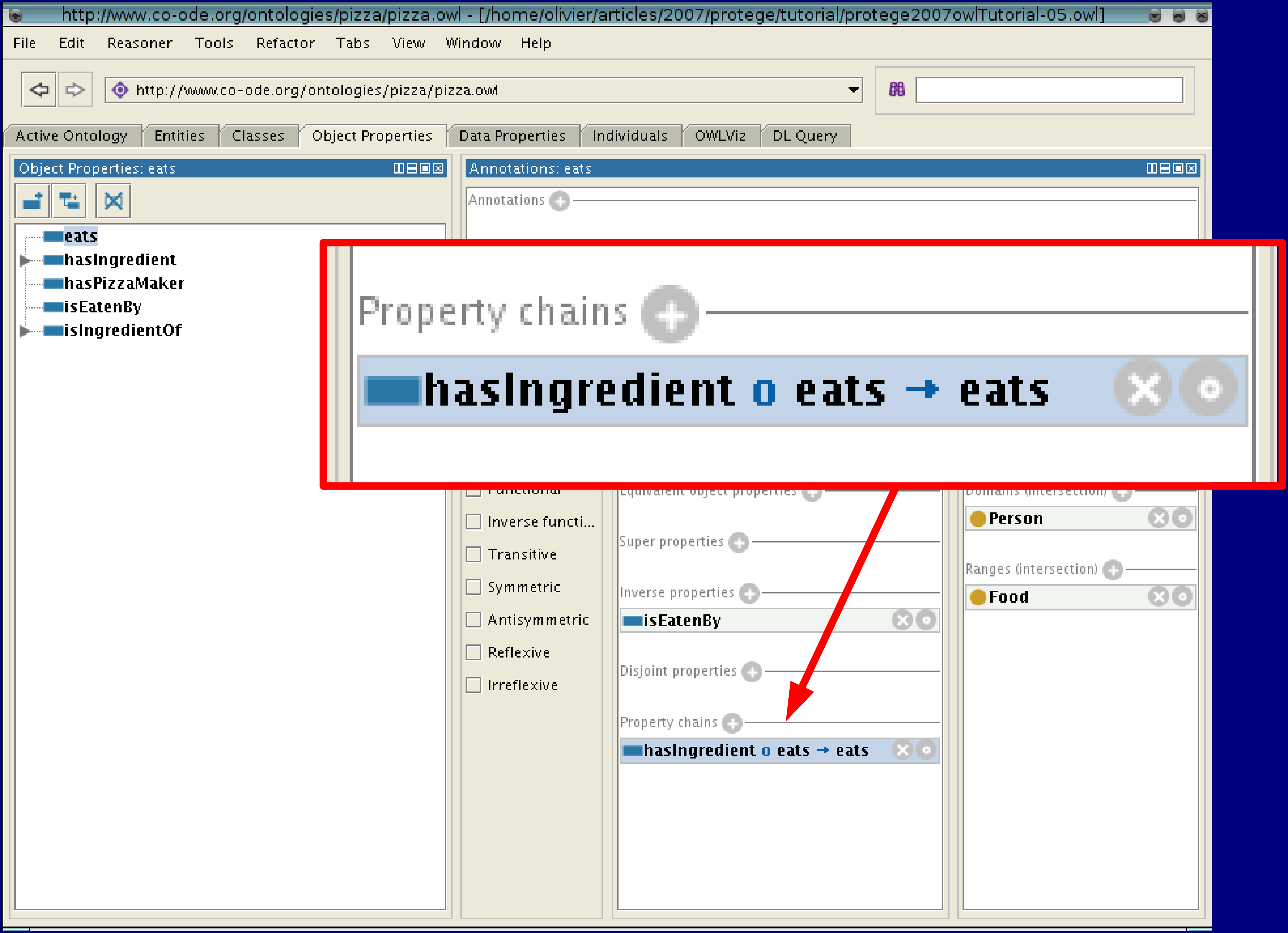
Entities
Classes
Object Properties
Data Prop
Object Properties: hasPizzaMaker
hasPizzaMaker
hasIngredient
isIngredientOf
Annotati
Annotatio
Annotati
Characte
□ Functi
□ Invers
□ Transitive
□ Symmetric
□ Antisymmetric
□ Reflexive
□ Irreflexive
Super properties
Inverse properties
Disjoint properties
Property chains
Ranges (intersection)
Person
Character
□ Functional
□ Inverse functi...
□ Transitive
□ Symmetric
□ Antisymmetric
□ Reflexive
□ Irreflexive
Description: hasPizzaMaker
Equivalent object properties
Super properties
Inverse properties
Disjoint properties
Property chains

Property chains

- Allow to describe (simple) composition of relations
- e.g.:
  if X *eats* Y and Y *hasIngredient* Z
  then X *eats* Z
- Notation: fog(x) = f(g(x))



- eats
- hasIngredient
- hasPizzaMaker
- isEatenBy
- isIngredientOf

Property chains

hasIngredient o eats → eats

□ Functional
□ Inverse functi...
□ Transitive
□ Symmetric
□ Antisymmetric
□ Reflexive
□ Irreflexive

Equivalent object properties

Super properties

Inverse properties

isEatenBy

Disjoint properties

Property chains

hasIngredient o eats → eats

Domains (intersection)

Person

Ranges (intersection)

Food

Summary

Summary

1. Compositional approach
2. Intensional description
3. Reasoning
   - classification
   - open-world assumption
   - inconsistency