The Rough Guide to the OWL API: a tutorial

Version 3.2.3 for OWL 2

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5 June 2011 / OWLED

Outline

MANCHESTER 1824

Where was the API born? Where is it now?

- WonderWeb
  - http://wonderweb.semanticweb.org/
  - first incarnation of the API in this EU STREP project, dated 2003
- CO-ODE
  - http://www.co-ode.org/
  - further support and development in this UK JISC project, until 2009
- currently hosted on SourceForge at http://owlapi.sourceforge.net
  - available under LGPL and/or Apache license
  - a few developers (19 at last count) scattered around, highest concentration at University of Manchester

What's OWL 2?

OWL 2

The OWL 2 Web Ontology Language, informally OWL 2, is an ontology language for the Semantic Web with formally defined meaning.

from: http://www.w3.org/TR/owl2-overview

Description Logics are the formal languages underlying OWL 2

OWL 2 Profiles

Not all DLs are created equal:
OWL 2 EL, OWL 2 QL, OWL 2 RL,
OWL 1 DL (slightly enriched in OWL 2 DL)
from: http://www.w3.org/TR/owl2-profiles/#Computational_Properties

What's an ontology?

I'm not answering THAT...

What's an ontology? Take two

For the purposes of the OWL API:

- An OWL ontology is a specification of a conceptualization (as defined by Gruber)
- An OWL ontology is structured as described in the OWL 2 specs

I'm a Java developer (get me out of here)

In the OWL API, an `OWLOntology` is an interface, modelling a set of logical and nonlogical `OWLAxioms`, with a name (an `IRI`), an (optional) physical location and convenience methods to retrieve such axioms.

OWL Axioms, Classes, Properties, Individuals and Entities...

- `OWLEntity`: anything that can be identified with an `IRI`, i.e., class names, data and object properties (and annotation properties) and named individuals
- `OWLAnonymousIndividual`, `OWLClassExpression`, `OWLPropertyExpression`: unnamed individuals, class expressions such as restrictions, property expressions such as the inverse of a property
- `OWLAnnotation`: an annotation for any entity, ontology, expression or axiom; characterized by an `OWLAnnotationProperty` and an `OWLAnnotationValue`

OWL Axioms, Classes, Properties, Individuals and Entities...

- `OWLAxiom`: the basic unity
  - TBox axioms describe relations between classes and class expressions (equivalence, subsumption, disjointness)
  - ABox axioms (assertions) describe relations between individuals and between individuals and classes/class expressions
  - RBox axioms describe relations between properties

How do I build an object of type. . . ?

- `OWLOntologies` are created by `OWLOntologyManagers`
- All other interfaces are built using `OWLDataFactory`
  - `OWLDataFactory` is an interface itself
  - A few implementations available: with and without cache, and experiments with threadsafe/memory friendly versions
- Binding to an implementation
  - Only binding needed: `OWLOntologyManager`
  - `OWLManager` in the `apibinding` package
  - `OWLDataFactory` is bound in `OWLManager` for convenience

A Visitor to visit them all

- All important interfaces accept two kinds of visitor
  - *ClassName*Visitor: visitor stores a value or performs an action
  - *ClassName*VisitorEx: visitor returns a value
- Most Visitor interfaces have a base implementation
  - VisitorAdapter
  - all methods implemented as empty ones
  - Developers only need to override methods they need

Loading or creating an ontology

OntologyCreation

```
OWLOntologyManager m = create();
OWLOntology o = m.createOntology(example_iri);
assertNotNull(o);
```

OntologyLoading

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
assertNotNull(o);
```

A few helpers

- Code snippets from **`TutorialSnippets.java`**
- Real code (it runs, I promise)
- Box title corresponds to JUnit test name

TutorialSnippets looks like this...

```
public class TutorialSnippets extends TestCase {
  public static final IRI pizza_iri = IRI
    .create("http://www.co-ode.org/ontologies/pizza/pizza.owl");
  public static final IRI example_iri = IRI
    .create("http://www.semanticweb.org/ontologies/ont.owl");
  OWLDataFactory df = OWLManager.getOWLDataFactory();
  public OWLOntologyManager create() {
    OWLOntologyManager m =
      OWLManager.createOWLOntologyManager();
    m.addIRIMapper(new AutoIRIMapper(
      new File("materializedOntologies"), true));
    return m;
  }
  ...
```

Alternative loading methods...

OntologyLoadingFromStringSource

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
assertNotNull(o);
StringDocumentTarget target = new StringDocumentTarget();
m.saveOntology(o, target);
m.removeOntology(o);
OWLOntology o2 = m
   .loadOntologyFromOntologyDocument(
     new StringDocumentSource(target.toString()));
assertNotNull(o2);
```

- **`OWLOntologyDocumentSource`** is an interface for document sources, e.g., readers
- **`OWLOntologyDocumentTarget`** is an interface for document destinations, e.g., writers

Alternative loading methods...

IRIMapper

```
OWLOntologyManager m = OWLManager.createOWLOntologyManager();
// map the ontology IRI to a physical IRI (files for example)
File output = File.createTempFile("saved_pizza", "owl");
IRI documentIRI = IRI.create(output);
// Set up a mapping, which maps the ontology to the document IRI
SimpleIRIMapper mapper =
   new SimpleIRIMapper(example_save_iri, documentIRI);
m.addIRIMapper(mapper);
// set up a mapper to read local copies of ontologies
File localFolder = new File("materializedOntologies");
// the manager will look up an ontology IRI by checking
// localFolder first for a local copy
m.addIRIMapper(new AutoIRIMapper(localFolder, true));
// Now create the ontology using the ontology IRI (not the
physical URI)
OWLOntology o = m.createOntology(example_save_iri);
// save the ontology to its physical location - documentIRI
m.saveOntology(o);
```

Adding axioms to an ontology

AddAxioms

```
OWLOntologyManager m = create();
OWLOntology o = m.createOntology(pizza_iri);
// class A and class B
OWLClass clsA = df.getOWLClass(IRI.create(pizza_iri + "#A"));
OWLClass clsB = df.getOWLClass(IRI.create(pizza_iri + "#B"));
// Now create the axiom
OWLAxiom axiom = df.getOWLSubClassOfAxiom(clsA, clsB);
// add the axiom to the ontology.
AddAxiom addAxiom = new AddAxiom(o, axiom);
// We now use the manager to apply the change
m.applyChange(addAxiom);
// remove the axiom from the ontology
RemoveAxiom removeAxiom = new RemoveAxiom(o,axiom);
m.applyChange(removeAxiom);
```

Various kinds of changes. . . SWRL rules

SWRL

```
OWLOntologyManager m = create();
OWLOntology o = m.createOntology(example_iri);
// Get hold of references to class A and class B.
OWLClass clsA = df.getOWLClass(
   IRI.create(example_iri + "#A"));
OWLClass clsB = df.getOWLClass(
   IRI.create(example_iri + "#B"));
SWRLVariable var = df.getSWRLVariable(
   IRI.create(example_iri + "#x"));
SWRLClassAtom body = df.getSWRLClassAtom(clsA, var);
SWRLClassAtom head = df.getSWRLClassAtom(clsB, var);
SWRLRule rule = df.getSWRLRule(Collections.singleton(body),
   Collections.singleton(head));
m.applyChange(new AddAxiom(o, rule));
```

Various kinds of changes. . . Assertions

IndividualAssertions

```
OWLOntologyManager m = create();
OWLOntology o = m.createOntology(example_iri);
// We want to state that matthew has a father who is peter.
OWLIndividual matthew = df.getOWLNamedIndividual(
   IRI.create(example_iri + "#matthew"));
OWLIndividual peter = df.getOWLNamedIndividual(
   IRI.create(example_iri + "#peter"));
// We need the hasFather property
OWLObjectProperty hasFather = df.getOWLObjectProperty(
   IRI.create(example_iri + "#hasFather"));
// matthew -> hasFather -> peter
OWLAxiom assertion = df.getOWLObjectPropertyAssertionAxiom(
   hasFather, matthew, peter);
// Finally, add the axiom to our ontology
AddAxiom addAxiomChange = new AddAxiom(o, assertion);
m.applyChange(addAxiomChange);
```

Various kinds of changes. . . Delete individuals

Delete

```
// Delete individuals representing countries
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// Ontologies don't directly contain entities but axioms
// OWLEntityRemover will remove an entity
// from a set of ontologies by removing all referencing axioms
OWLEntityRemover remover = new OWLEntityRemover(m,
Collections.singleton(o));
int previous = o.getIndividualsInSignature().size();
// Visit all individuals with the remover
// Changes needed for removal will be prepared
for (OWLNamedIndividual ind :  o.getIndividualsInSignature())
   ind.accept(remover);
m.applyChanges(remover.getChanges());
assertTrue(previous > o.getIndividualsInSignature().size());
```

Various kinds of changes. . . Existential restrictions

AddSomeRestriction

```
OWLOntologyManager m = create();
OWLOntology o = m.createOntology(example_iri);
// all Heads have parts that are noses (at least one)
// We do this by creating an existential (some) restriction
OWLObjectProperty hasPart = df.getOWLObjectProperty(
   IRI.create(example_iri + "#hasPart"));
OWLClass nose = df.getOWLClass(
   IRI.create(example_iri + "#Nose"));
// Now let's describe the class of individuals that have at
// least one part that is a kind of nose
OWLClassExpression hasPartSomeNose =
   df.getOWLObjectSomeValuesFrom(hasPart, nose);
OWLClass head =
   df.getOWLClass(IRI.create(example_iri + "#Head"));
// Head subclass of our restriction
OWLSubClassOfAxiom ax =
   df.getOWLSubClassOfAxiom(head, hasPartSomeNose);
m.applyChange(new AddAxiom(o, ax));
```

Various kinds of changes. . . Datatype restrictions

DatatypeRestriction

```
OWLOntologyManager m = create();
OWLOntology o = m.createOntology(example_iri);
// Adults have an age greater than 18.
OWLDataProperty hasAge = df.getOWLDataProperty(
   IRI.create(example_iri + "#hasAge"));
// Create the restricted data range
OWLDataRange greaterThan18 = df.getOWLDatatypeRestriction(
   df.getIntegerOWLDatatype(), OWLFacet.MIN_INCLUSIVE,
   df.getOWLLiteral(18));
// Now we can use this in our datatype restriction on hasAge
OWLClassExpression adultDefinition =
   df.getOWLDataSomeValuesFrom(hasAge, greaterThan18);
OWLClass adult = df.getOWLClass(IRI.create(
   example_iri + "#Adult"));
OWLSubClassOfAxiom ax =
   df.getOWLSubClassOfAxiom(adult, adultDefinition);
m.applyChange(new AddAxiom(o, ax));
```

Various kinds of changes. . . Add a comment (or any annotation)

Comment

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// We want to add a comment to the pizza class.
OWLClass pizzaCls = df.getOWLClass(
   IRI.create(pizza_iri + "#Pizza"));
// the content of our comment:  a string and a language tag
OWLAnnotation commentAnno = df.getOWLAnnotation(
   df.getRDFSComment(),
   df.getOWLLiteral("A class which represents pizzas", "en"));
// Specify that the pizza class has an annotation
OWLAxiom ax = df.getOWLAnnotationAssertionAxiom(
   pizzaCls.getIRI(), commentAnno);
// Add the axiom to the ontology
m.applyChange(new AddAxiom(o, ax));
```

Various kinds of changes. . . Add version info

VersionInfo

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// We want to add a comment to the pizza class.
OWLLiteral lit =
   df.getOWLLiteral("Added a comment to the pizza class");
// create an annotation to pair a URI with the constant
OWLAnnotationProperty owlAnnotationProperty =
   df.getOWLAnnotationProperty(
   OWLRDFVocabulary.OWL_VERSION_INFO.getIRI());
OWLAnnotation anno =
   df.getOWLAnnotation(owlAnnotationProperty, lit);
// Now we can add this as an ontology annotation
m.applyChange(new AddOntologyAnnotation(o, anno));
```

Save changes to an ontology

SaveOntology

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
assertNotNull(o);
File output = File.createTempFile("saved_pizza", "owl");
IRI documentIRI2 = IRI.create(output);
// save in OWL/XML format
m.saveOntology(o, new OWLXMLOntologyFormat(), documentIRI2);
// save in RDF/XML
m.saveOntology(o, documentIRI2);
// print out the ontology on System.out
m.saveOntology(o, new SystemOutDocumentTarget());
// Remove the ontology from the manager
m.removeOntology(o);
```

Check OWL profile violations

CheckProfile

```
OWLOntologyManager m = create();
OWLOntology o = m.createOntology(pizza_iri);
// Available profiles:  DL, EL, QL, RL, OWL2 (Full)
OWL2DLProfile profile = new OWL2DLProfile();
OWLProfileReport report = profile.checkOntology(o);
for(OWLProfileViolation v:report.getViolations()) {
   System.out.println(v);
}
```

Explore classes

ShowClasses

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
assertNotNull(o);
// Named classes referenced by axioms in the ontology.
for (OWLClass cls :  o.getClassesInSignature())
  System.out.println(cls);
```

AssertedSuperclasses

```
OWLClass clsA = df.getOWLClass(IRI.create(example_iri + "#A"));
Set<OWLClassExpression> superClasses = clsA.getSuperClasses(o);
// for each superclass there will be a corresponding axiom
// the ontology indexes axioms in a variety of ways
Set<OWLSubClassOfAxiom> sameSuperClasses = o
  .getSubClassAxiomsForSubClass(clsA);
assertEquals(superClasses.size(), sameSuperClasses.size());
```

Walking an ontology

OntologyWalker

```
// How to walk the asserted structure of an ontology
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// Create the walker
OWLOntologyWalker walker =
   new OWLOntologyWalker(Collections.singleton(o));
// Now ask our walker to walk over the ontology
OWLOntologyWalkerVisitor<Object> visitor =
   new OWLOntologyWalkerVisitor<Object>(walker) {
   @Override
   public Object visit(OWLObjectSomeValuesFrom desc) {
      System.out.println(desc);
      System.out.println("    " + getCurrentAxiom());
      return null;
      }
   };
// Have the walker walk...
walker.walkStructure(visitor);
```

Merge ontologies

MergedOntology

```
OWLOntologyManager m = create();
OWLOntology o1 = m.loadOntology(pizza_iri);
OWLOntology o2 = m.loadOntology(example_iri);
// Create our ontology merger
OWLOntologyMerger merger = new OWLOntologyMerger(m);
// Merge all of the loaded ontologies, specifying an IRI for the
new ontology
IRI mergedOntologyIRI =
   IRI.create("http://www.semanticweb.com/mymergedont");
OWLOntology merged = merger.createMergedOntology(m,
mergedOntologyIRI);
assertTrue(merged.getAxiomCount() > o1.getAxiomCount());
assertTrue(merged.getAxiomCount() > o2.getAxiomCount());
```

Search for restrictions...

LookupRestrictions

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// We want to examine the restrictions on all classes
for (OWLClass c :  o.getClassesInSignature()) {
// collect properties used in existential restrictions
   RestrictionVisitor visitor =
    new RestrictionVisitor(Collections.singleton(o));
   for (OWLAxiom ax:  o.getSubClassAxiomsForSubClass(c)) {
   ax.getSuperClass().accept(visitor);
   }
// Our RestrictionVisitor has now collected all
// properties that have been restricted in existential
// restrictions - print them out.
   System.out.println("Properties for " + labelFor(c, o));
   for (OWLObjectPropertyExpression prop:
     visitor.getRestrictedProperties()) {
   System.out.println("   " + prop);
   }
}
```

Search for restrictions...

`RestrictionVisitor` extends an adapter class:

```
private class RestrictionVisitor extends
   OWLClassExpressionVisitorAdapter {
// A few internals omitted...
public Set<OWLObjectPropertyExpression>
getRestrictedProperties() { return properties; }
public void visit(OWLClass desc) {
   if (!classes.contains(desc)) {
      classes.add(desc);
      for (OWLOntology ont :  onts)
         for (OWLSubClassOfAxiom ax:
            ont.getSubClassAxiomsForSubClass(desc))
            ax.getSuperClass().accept(this);
   }
}
public void visit(OWLObjectSomeValuesFrom desc) {
   properties.add(desc.getProperty());
}

}
```

Search annotations

ReadAnnotations

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
for (OWLClass cls :  o.getClassesInSignature()) {
// Get the annotations on the class that use the label property
   for (OWLAnnotation annotation :  cls
      .getAnnotations(o, df.getRDFSLabel())) {
      if (annotation.getValue() instanceof OWLLiteral) {
         OWLLiteral val = (OWLLiteral) annotation.getValue();
// look for portuguese labels
         if (val.hasLang("pt"))
            System.out.println(cls +
            " labelled " + val.getLiteral());
      }
   }
}
```

Change default rendering formats...

Rendering

```
// Read an ontology and then render it
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// Register the ontology storer with the manager
m.addOntologyStorer(new OWLTutorialSyntaxOntologyStorer());
// Save using a different format
m.saveOntology(o, new OWLTutorialSyntaxOntologyFormat(),
   new SystemOutDocumentTarget());
```

Change default rendering formats...

Classes needed:

- **`OWLTutorialSyntaxOntologyStorer`**: the **`OWLOntologyStorer`** implementation
  - refers **`OWLTutorialSyntaxObjectRenderer`** and **`OWLTutorialSyntaxRenderer`**
  - renders an ontology as an HTML page[1]
- **`OWLTutorialSyntaxOntologyFormat`**: a **`PrefixOWLOntologyFormat`** extension

[1] Too long to turn into slides, but source available - ask to switch to Eclipse

Visiting labels

```
class LabelExtractor extends OWLObjectVisitorExAdapter<String>
   implements OWLAnnotationObjectVisitorEx<String> {
   @Override
   public String visit(OWLAnnotation annotation) {
      if (annotation.getProperty().isLabel()) {
         OWLLiteral c = (OWLLiteral) annotation.getValue();
         return c.getLiteral();
      }
      return null;
   }
}
```

Looking for entity annotations

```
private LabelExtractor le = new LabelExtractor();

private String labelFor(OWLEntity clazz, OWLOntology o) {
   Set<OWLAnnotation> annotations = clazz.getAnnotations(o);
   for (OWLAnnotation anno :  annotations) {
      String result = anno.accept(le);
      if (result != null) {
         return result;
      }
   }
   return clazz.getIRI().toString();
}
```

DL reasoners and the OWL API

- **`OWLReasoner`** and **`OWLReasonerFactory`**
- A few OWL DL reasoners available
  - HermiT
  - FaCT++
  - Pellet
  - Reasoners available through OWLLink (e.g., RacerPro)
  - New kid on the block: JFact (a port of FaCT++ to Java)

Hierarchy printing...

Hierarchy

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// Get Thing
OWLClass clazz = df.getOWLThing();
System.out.println("Class   :  " + clazz);
// Print the hierarchy below thing
printHierarchy(o, clazz, new HashSet<OWLClass>());
```

Hierarchy printing...

Helper method:

```
public void printHierarchy(OWLReasoner r, OWLClass clazz,
   int level, Set<OWLClass> visited) throws OWLException {
//Only print satisfiable classes to skip Nothing
if (!visited.contains(clazz) && reasoner.isSatisfiable(clazz)) {
   visited.add(clazz);
   for (int i = 0; i < level * 4; i++) {
      System.out.print(" ");
   }
   System.out.println(labelFor(clazz, r.getRootOntology()));
// Find the children and recurse
   NodeSet<OWLClass> classes = r.getSubClasses(clazz, true);
   for (OWLClass child :  classes.getFlattened()) {
      printHierarchy(r, child, level + 1);
   }
}

}
```

List unsatisfiable classes

UnsatisfiableClasses

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// Create a reasoner; it will include the imports closure
OWLReasoner reasoner = reasonerFactory.createReasoner(o);
// Ask the reasoner to precompute some inferences
reasoner.precomputeInferences(InferenceType.CLASS_HIERARCHY);
// We can determine if the ontology is actually consistent
assertTrue(reasoner.isConsistent());
// get a list of unsatisfiable classes
Node<OWLClass> bottomNode = reasoner.getUnsatisfiableClasses();
System.out.println("Unsatisfiable classes:");
// leave owl:Nothing out
for (OWLClass cls :  bottomNode.getEntitiesMinusBottom())
  System.out.println(labelFor(cls, o));
```

Direct subclasses

Descendants

```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
OWLReasoner r = reasonerFactory.createReasoner(o);
r.precomputeInferences(InferenceType.CLASS_HIERARCHY);
// Look up and print all direct subclasses for all classes
// a NodeSet represents a set of Nodes.
// a Node represents a set of equivalent classes
for (OWLClass c :  o.getClassesInSignature()) {
// the boolean argument specifies direct subclasses
  NodeSet<OWLClass> subClasses = r.getSubClasses(c, true);
  for (OWLClass subClass :  subClasses.getFlattened())
    System.out.println(labelFor(subClass, o)
      + " subclass of " + labelFor(c, o));
}
```

Looking up instances and property values

PetInstances

```
// reasoner from previous example...
// for each class, look up the instances
for (OWLClass c :  o.getClassesInSignature()) {
// the boolean argument specifies direct subclasses
   for (OWLNamedIndividual i :
     r.getInstances(c, true).getFlattened()) {
   System.out.println(labelFor(i, o) +":"+ labelFor(c, o));
// look up all property assertions
     for (OWLObjectProperty op:
       o.getObjectPropertiesInSignature()) {
       NodeSet<OWLNamedIndividual> petValuesNodeSet =
         r.getObjectPropertyValues(i, op);
       for (OWLNamedIndividual value :
         petValuesNodeSet.getFlattened())
         System.out.println(labelFor(i, o) + " " +
           labelFor(op, o) + " " + labelFor(value, o));
     }
   }
}
```

Compute inferences

InferredOntology

```
// reasoner from previous example...
// Use an inferred axiom generators
List<InferredAxiomGenerator<? extends OWLAxiom» gens =
   Collections.singletonList(
   new InferredSubClassAxiomGenerator());
OWLOntology infOnt = m.createOntology();
// create the inferred ontology generator
InferredOntologyGenerator iog =
   new InferredOntologyGenerator(r, gens);
iog.fillOntology(m, infOnt);
```

Necessary property assertions...

Margherita

```
// reasoner from previous example...
// For this ontology, we know that classes, properties, ...have
// IRIs of the form:  ontology IRI + # + local name
String iri = pizza_iri + "#Margherita";
// Now we can query the reasoner
// to determine the properties that
// instances of Margherita MUST have
OWLClass margherita = df.getOWLClass(IRI.create(iri));
printProperties(m, o, r, margherita);
```

Necessary property assertions. . . helper

```
// Prints out the properties that instances must have
private void printProperties(
     OWLOntologyManager man, OWLOntology o,
     OWLReasoner reasoner, OWLClass cls) {
System.out.println("Properties of " + cls);
for (OWLObjectPropertyExpression prop :
     o.getObjectPropertiesInSignature()) {
// To test if an instance of A MUST have a p-filler,
// check for the satisfiability of A and not (some p Thing)
// if this is unsatisfiable, then a p-filler is necessary
   OWLClassExpression restriction =
        df.getOWLObjectSomeValuesFrom(prop, df.getOWLThing());
     OWLClassExpression intersection =
        df.getOWLObjectIntersectionOf(cls,
          df.getOWLObjectComplementOf(restriction));
     if (!reasoner.isSatisfiable(intersection))
        System.out.println("Instances of "
          + cls + " must have " + prop);
   }
}
```

Concurrent access: Default implementations

- **`OWLOntology`** contains maps
  - **`OWLAxioms`** indexed by **`OWLEntity`** in the signature
  - **`OWLAxioms`** indexed by **`AxiomType`**
  - . . . and more
- **`OWLOntologyManager`** contains maps and sets
  - **`OWLOntologies`** indexed by **`IRI`**
  - **`OWLOntologies`** indexed by **`OWLOntologyFormat`**
  - . . . and more
- **`OWLDataFactory`** uses caches to internalize **`OWLEntities`**

1. All these are weak spots
2. The list is not exhaustive
3. Transactions: a series of changes instead of a single change? Rollback if the last one fails?

Wait, who changed my ontology?

When multithread is the issue...

- Diagnosis can be hard
  - **`ConcurrentModificationException`** is common but not reliable
  - **`NullPointerException`** happens sometimes
  - Threading issues masquerading as parsing errors
- Fixes can slow things down
- Immutability a great help

Which solutions are available?

- Synchronize everything? S l o w w w
- Locks? Explicit or implicit? ReadWriteLocks?
- Caches are a vulnerability. Drop them?
- Transaction support. . . hard to figure out

The implConcurrent module

- Alternate implementation for **`OWLOntologyManager`**, **`OWLOntology`**, **`OWLDataFactory`**
- Alternate implementation binding: **`ThreadSafeOWLManager`**
  - Alternate implementations can be configured via **`OWLImplementationBinding`**
  - **`OWLDataFactory`** implementations: cacheless, with explicit locks, **`ConcurrentHashMaps`** and LRU partial caches

How do I pick and mix?

ThreadSafeBinding

```
public final class ThreadSafeBinding implements
OWLImplementationBinding {
   public OWLOntologyManager getOWLOntologyManager(
      OWLDataFactory d) {
      return new LockingOWLOntologyManagerImpl(d);
   }
   public OWLOntology getOWLOntology(
      OWLOntologyManager oom, OWLOntologyID id) {
      return new LockingOWLOntologyImpl(oom, id);
   }
   public OWLDataFactory getOWLDataFactory() {
      return DataFactoryCSR.getInstance();
   }
}
```

Does it work? Is it fast? Where's the catch?

- Concurrent implementation passes same tests as default
- Extra tests run same operations multiple times on multiple threads
- Speed varies, depending on choices - usually not much worse

Any catch?

- No transaction support
  - A sequence of changes won't roll back if the last one fails
  - A thread cannot lock an ontology or a manager and call a sequence of methods
  - Threads can step on each other's toes
- Protégé offers some support for this

Modularization

- Ontology modularization is a broad topic
- Locality based modularization
  - Many people at Manchester working on it
  - Start from a signature S (set of IRIs) from O
  - Compute a set of axioms M
  - Any expression built with elements from S has the same interpretation in O and in M
  - M is smaller than O $\rightarrow$ reasoning is faster(ish)
- The only challenge left to the user is how to choose the signature...

Modularization example

Modularization

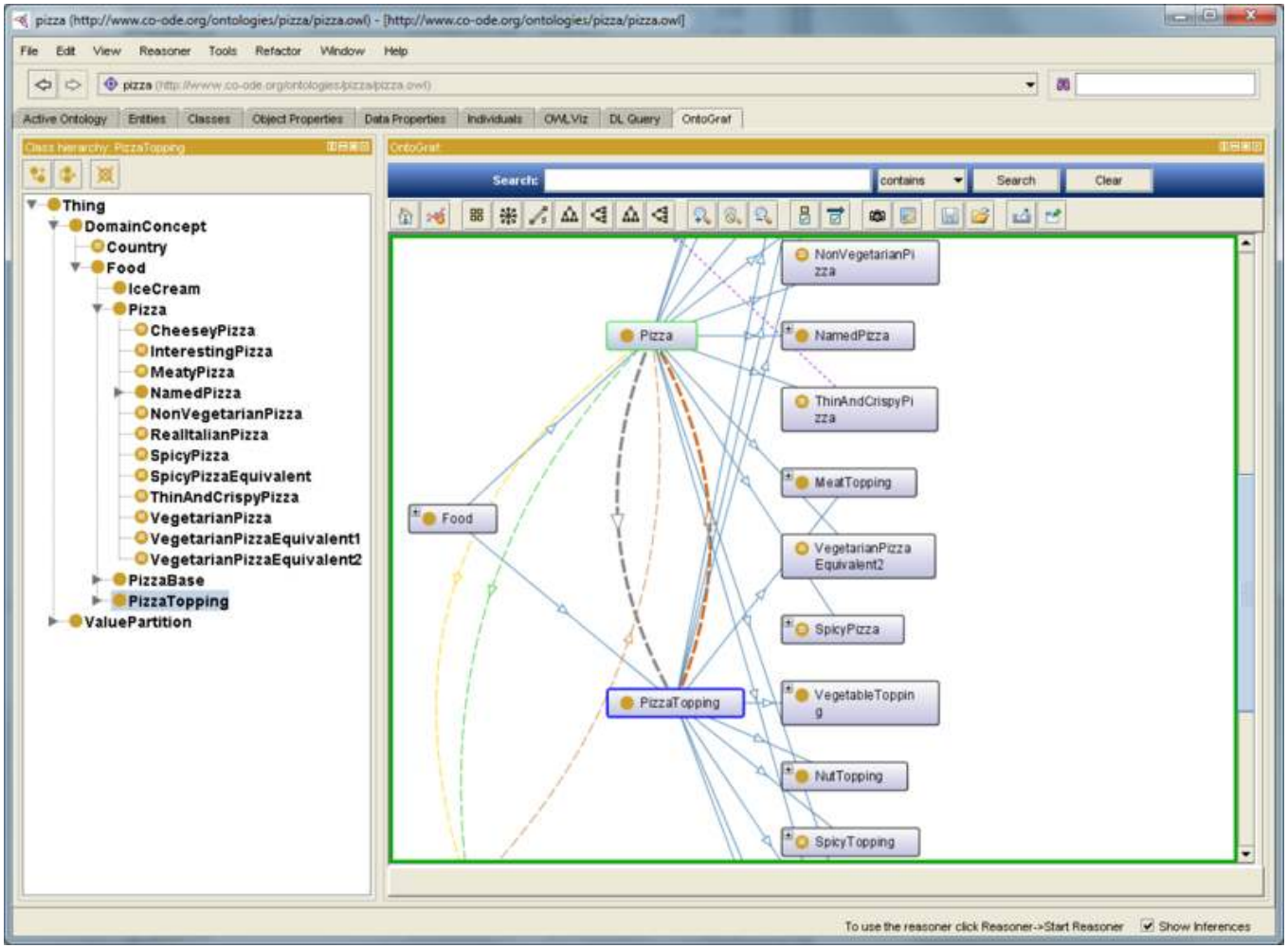
```
OWLOntologyManager m = create();
OWLOntology o = m.loadOntologyFromOntologyDocument(pizza_iri);
// extract a module for all toppings
// start by creating a signature "PizzaTopping"
OWLClass topping =
   df.getOWLClass(IRI.create(pizza_iri + "#PizzaTopping"));
// We now add all subclasses of the chosen classes.
Set<OWLEntity> seedSig = new HashSet<OWLEntity>();
OWLReasoner reasoner = reasonerFactory.createReasoner(o);
seedSig.add(topping);
seedSig.addAll(reasoner
   .getSubClasses(ent.asOWLClass(), false).getFlattened());
// Extract a locality-based module
SyntacticLocalityModuleExtractor sme =
   new SyntacticLocalityModuleExtractor(m, o, ModuleType.STAR);
Set<OWLAxiom> mod = sme.extract(seedSig);
System.out.println("Module size "+ mod.size());
```

Protégé: You may have heard of it. . .

Protégé is a well known ontology editor

- http://protege.stanford.edu
- it tracks the latest OWL API developments very closely
- it provides a lot of useful bug reports
- Thanks, Timothy :-)

Looks like this. . .



OPPL: OWL PreProcessing Language (2)

- http://oppl2.sourceforge.net
- Add/remove axioms from ontologies
- Can be used with or without a reasoner
- Plugs into Protégé

A few OPPL scripts...

Declare matched classes disjoint

```
?x:CLASS, ?y:CLASS
SELECT ?x subClassOf gender,
  ?y subClassOf gender
  WHERE ?x != ?y
BEGIN
  ADD ?x disjointWith ?y
END;
```

A few OPPL scripts...

Add restrictions

```
?x:CLASS
SELECT ?x subClassOf person
BEGIN
  ADD ?x subClassOf has_age some int
END;
```

A few OPPL scripts...

Assertions can be changed too

```
?country:INDIVIDUAL[instanceOf Country],
?adiacentCountry:INDIVIDUAL[instanceOf
Country]
SELECT ?country adjacentTo ?adiacentCountry
BEGIN
  REMOVE ?country adjacentTo ?adiacentCountry,
  ADD ?country instanceOf
    hasLandBoundary some (LandBoundaryFragment
    and boundaryOf value ?adiacentCountry)
END;
```

Patterns

- OPPL scripts without a SELECT section
- Variable binding done manually
- Useful for more localized tasks
- Available in Protégé too

Question time

Questions?

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For feature requests & bugs: http://owlapi.sourceforge.net trackers