Extending OWL with Finite Automata Constraints

Jignesh Borisa

December 15,2010

Advisor

Dr. Chris Pollett

Committee Members

Dr. Jon Pearce

Dr. Robert Chun

Agenda

- What the project is about?
- Introduction
- Motivation
- Design and Specification
- Tools Used
- Implementation
- Test Case Outputs
- Demo
- Conclusion

What the project is about?

Developed an extension to OWL that allows one to support collections and constraints where membership in the collections can be computed by finite automata

What is an ontology?

- Formal representation of the knowledge by a set of concepts within a domain and relationships between those concepts.
- Used to reason about the properties of that domain and describe the domain.
- Ontology consists of
  - Classes: sets, collections, concepts
  - Relations between classes(consists of, must be preceded by, etc)
  - Functions (relation with 1 result)
  - Individuals (instances or objects)
  - Axiomata (knowledge on concepts/relations that can be checked on its logics)
  - Attributes : properties, parameters or characteristics that objects can have

XML and RDF

- Extensible Markup Language(XML)
  - Defines rules to mark-up a document in a way that allows the author to express semantic meaning in the mark-up
  - Data format used primarily for sharing data
- Resource Description Framework(RDF)
  - Framework for describing resources on the web
  - Designed to be read and understood by computer applications
  - RDF descriptions are not designed to be displayed on the web
  - Datamodel for objects ("resources") and relations between them
  - RDF is a collection of triples , each consisting of a subject, a predicate and an object.
  - An open-world framework that allows anyone to make statements about any resources

Web Ontology Language(OWL)

- Markup language for sharing and publishing data using ontologies on the Internet
- It belongs to a family of knowledge representation languages for writing ontologies
- Provides more vocabulary for describing properties and classes than XML and RDF like cardinality (i.e. exactly one), relations between classes (i.e. disjointness), etc.
- Used for representing the meaning of the terms in vocabularies and their interrelationships

Answer Set Programming

- Logic programming paradigms are also used for knowledge representation.
- We considered answer set programming, a particular form of logic programming.
- It is a declarative programming approach to knowledge representation.
- It is oriented towards difficult search problems.
- It is based on the stable model semantics of logic programming.

What is Logic Program?

- It is the use of mathematic logic for computer program.
- The logic programming is the use of logic as both a declarative and procedural representation language.
- It is based upon the fact that a backwards theorem-prover applied to declarative sentences in the form of implications:

  If B_1 and … and B_n then H
- It also treats the implications as goal-reduction procedures:

  to show/solve H, show/solve B_1 and … and B_n.

Example of Logic Program

- As the implication:

  If you press the alarm signal button, then you alert the driver of the train of a possible emergency

- As the procedure:

  To alert the driver of the train of a possible emergency, press the alarm signal button.

Stable Model Semantics

- This model was proposed by Gelfond and Lifschitz in 1988.
- It defines a declarative semantics for logic program with negation as failure.
- Let P be a logic program and Q be a subset of variables of P.
- Let P^Q be the program.
- If the program contains clause C of P, which contains the negated variable Not A in its body such that $A \in Q$, then C is not counted.
- If a body of clause contains a negated Not A such that $A \notin Q$, then Not A is not counted from the clause body.
- If Q is a least Herbrand model of P^Q, then Q is a stable model of P.

Computing Stable Model

Consider the following logic program:

x2:- ¬x1

x1:- ¬x2

Truth Table for Computed Stable Model

X1	X2	Stable Model exist?
False	False	No
False	True	Yes
True	False	Yes
True	True	No

Computing Stable Model(Cont…)

- Consider the following logic program:

  x1:- x4,¬x2

  x2:- x4,¬x3

  x3:- ¬x2
- Reduced model is derived from this logic program. It is as follow:

  x1:- x4

  x2:- x4

  x3:-
- Let us look at truth table of this program for computing Stable model

Truth Table

x1	x2	x3	x4	Stable Model exist?
False	False	False	False	No
False	False	False	True	No
False	False	True	False	Yes
False	False	True	True	No
False	True	False	False	No
False	True	False	True	Yes
False	True	True	False	No
False	True	True	True	No
True	False	False	False	No
True	False	False	True	No
True	False	True	False	No
True	False	True	True	Yes
True	True	False	False	No
True	True	False	True	No
True	True	True	False	No
True	True	True	True	No

OWL Capabilities

- Three sublanguages : OWL Lite, OWL DL and OWL Full.
- While OWL Lite supports cardinality constraints, it only permits cardinality values of 0 or 1.
- OWL DL includes all OWL language constructs, but they can be used only under certain restrictions.
- For example, while a class may be a subclass of many classes, a class cannot be an instance of another class.
- In OWL Full, a class can be treated simultaneously as a collection of individuals and as an individual.
- OWL Full allows an ontology to augment the meaning of the pre-defined (RDF or OWL) vocabulary.

Denotation in Description Logic

- Consider following denotation in Description Logic:

(union Male Female)

∧ (subClass ≤2hasChild)

⇒ (class Person)

An Example OWL Document

The denotation in DL is equivalent to following OWL code :

```
  <owl:Class rdf:about="#Person">
        <owl:disjointUnionOf rdf:parseType="Collection">
                <owl:Class rdf:ID="Male"/>
                 <owl:Class rdf:ID="Female"/>
        </owl:disjointUnionOf>
        <rdfs:subClassOf>
             <owl:Restriction>
                  <owl:onProperty rdf:resource="#hasChild"/>
                  <owl:mincardinality
   rdf:datatype="&xsd;string">1</owl:mincardinality>
             </owl:Restriction>
        </rdfs:subClassOf>
</owl:Class>
```

One way to Extend OWL

Consider the following denotation in Description Logic :

(subClass (∃hasDNASequence.{ A*TA*G}))

⇒(Class Person)

- Here A*TA*G is some regular expression such that only humans have DNA sequences of this type.
- This is something you could do in OWL. What we can't do is come up with a parameterized family of subclasses of this…
- i.e., we might want to define:

(subClass (hasDNASequence.{ A*TA*G}))

⇒(Class Person{A*TA*G})

And have (Class Person{AATAAG}) be class which is an instance of this family. For example, this might represent Person's with Dwarfism.

One way to extend OWL Document

```
<owl:Class rdf:about="#Person">
    <rdfs:subClassOf>
             <owl:Restriction>
             <owl:onProperty rdf:resource="#hasDNASequence"/>
                <owl:hasValue rdf:datatype="xsd:string">
                      A*TA*G
                 </owl:hasValue>
            </owl:Restriction>
      </rdfs:subClassOf>
  </owl:Class>
```

Let Person be an OWL class and hasDNASequence be its data property. The value of hasTelphone is A*TA*G which is regular expression.

Person Example in Our Extended Syntax

```
<owl:CollectionClass rdf:about="#Person">
    <rdfs:subClassOf>
            <owl:Restriction>
            <owl:onProperty rdf:resource="#hasDNASequence"/>
               <owl:hasValue rdf:datatype="xsd:string">
                    A*TA*G
               </owl:hasValue>
            </owl:Restriction>
      </rdfs:subClassOf>
  </owl:Class>
```

Motivation: Incapability of OWL

- The previous experiment with OWL does not work because
  - Regular expression provides concise and flexible means of matching strings of text.
  - OWL can only support inflexible or fixed value for data property.
  - OWL cannot allow set of values for property.
- We decided to extend OWL to support collections.
  - Collections are a natural part of the world that we need to model such as protein sequences, SSN, email ID, etc.

Motivation: Extension to Answer Set Programming

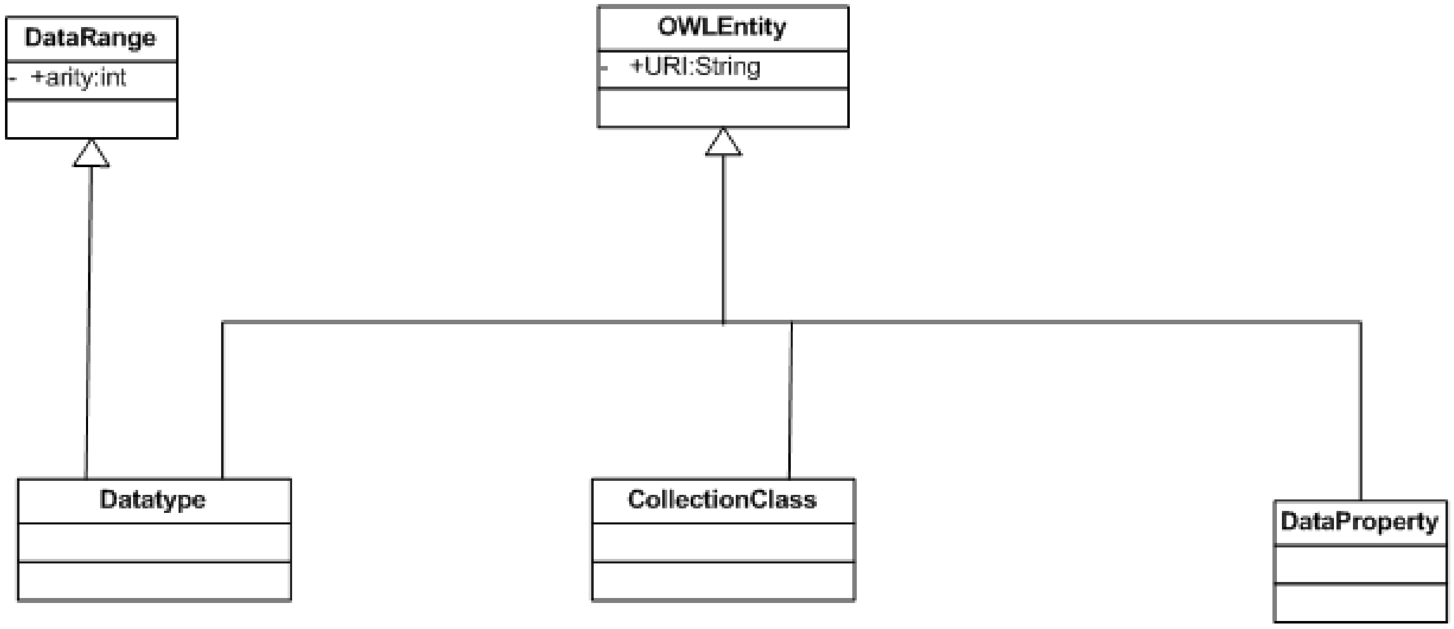
- A recent extension to answer set programming is to support constraints where membership in the sets can be computed by finite automata.
- In this extension, new types of constraints are introduced that allow for a more compact representation of problem in answer set programming.
- We attempted to extend OWL with feature from this new approach to answer set programming.

Design

- Created the following language constructs to support collections and finite automata constraints

1. CollectionClass
2. memberClassOf
3. collectionClassOf
4. instanceOf

CollectionClass



CollectionClass Specification

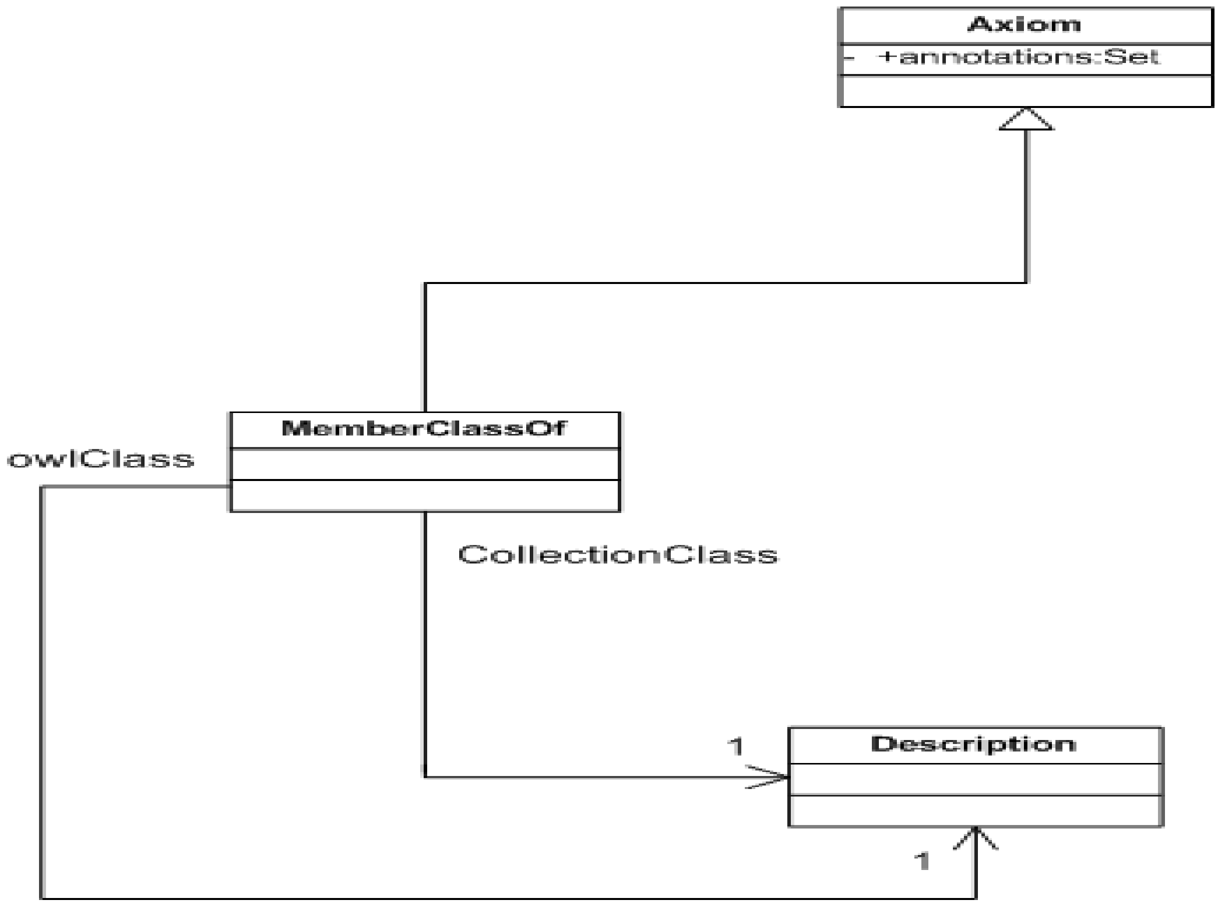
- Defined by URI

```
datatypeURI : = URI
dataPropertyURI := URI
CollectionClassURI : = URI
```

- Syntax for CollectionClass

```
entity : = datatype | CollectionClass | dataProperty
datatype := 'Datatype' '(' datatypeURI ')'
CollectionClass : = ‘ CollectionClass’ ‘(‘ CollectionClassURI ‘)’
dataProperty : = ‘DataProperty’ ‘(‘ dataPropertyURI ‘)’
```

memberClassOf axiom

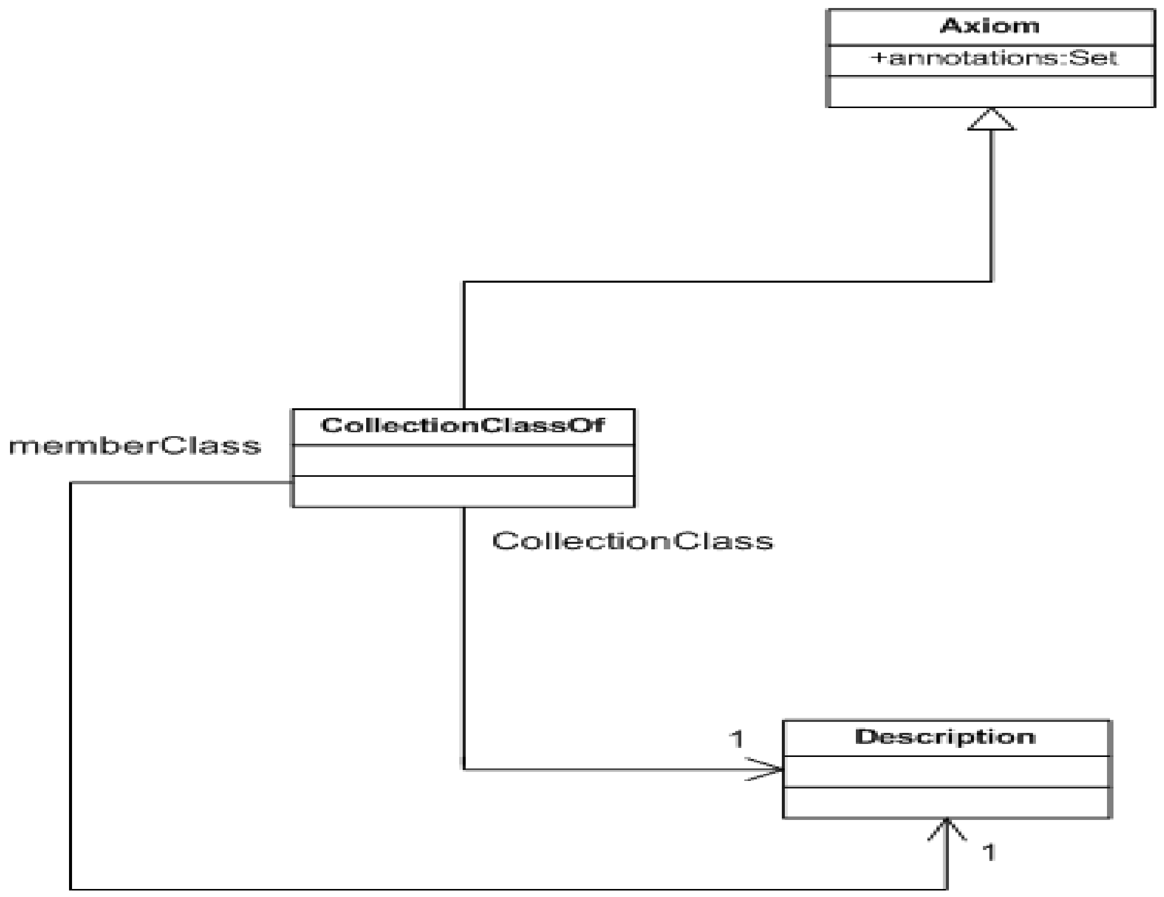


memberClassOf Specification

- Syntax for memberClassOf axiom

```
 owlClass : = description
CollectionClass : = description
memberClassOf : = ‘MemberClassOf’ ‘(‘{ annotation }
                                  owlClass  CollectionClass ‘)’
```

collectionClassOf axiom

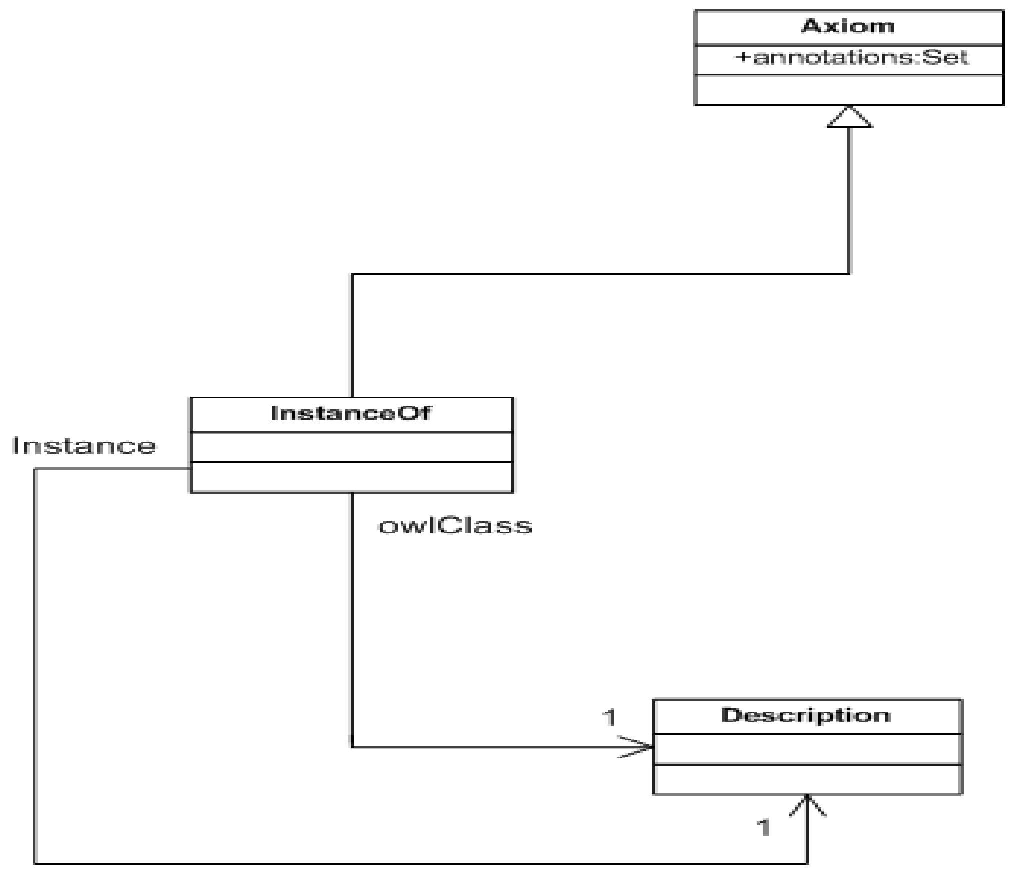


collectionClassOf Specification

- Syntax for collectionClassOf axiom

```
memberClass : = description
CollectionClass : = description
collectionClassOf : = ‘CollectionClassof’ ‘(‘ { annotation }
                         memberClass CollectionClass ‘)’
```

instanceOf axiom



instanceOf Specification

- Syntax for instanceOf axiom

```
 instance : = individual
owlClass : = description
instanceOf : = ‘InstanceOf’ ‘(‘  { annotation} instance
                                              owlClass ‘)’
```

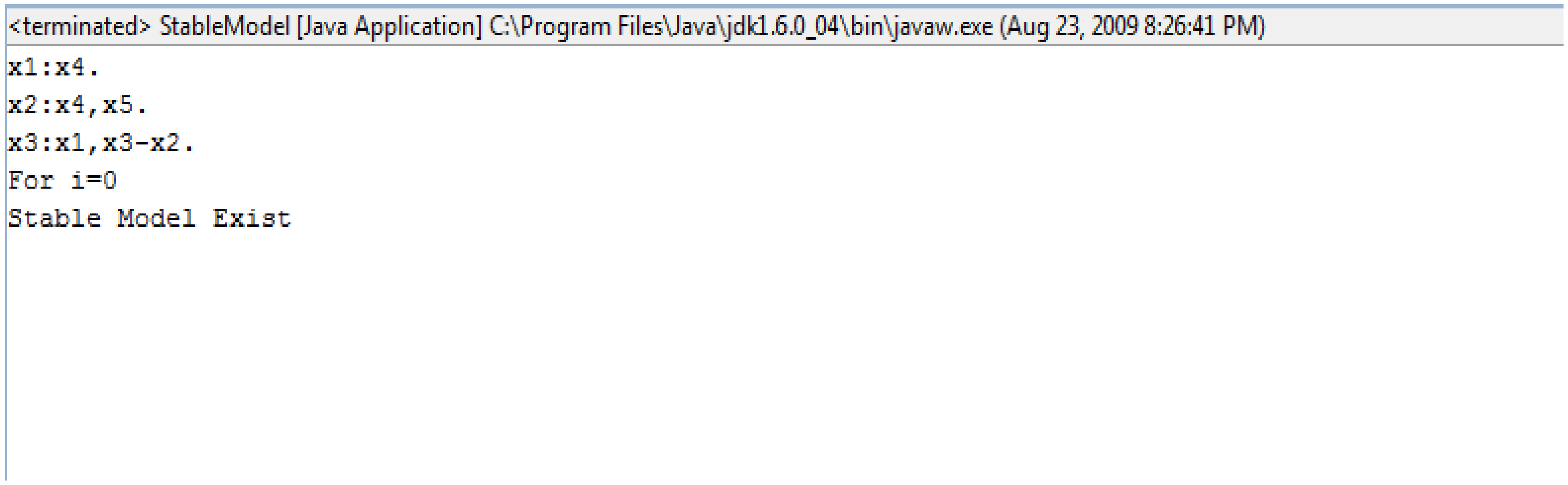
Tools Used

- OWL 2.0
- Pellet
  - Java-based open source OWL reasoner
  - Provides various features like data type reasoning, ontology analysis, ontology debugging etc.
  - Used Pellet to reason about OWL document
- DOM API
  - Component API of the Java API for XML processing
  - Allows programs to dynamically access and update the content of documents
  - Used DOM API to parse an extended OWL document

Initial Research

1. Compute Stable Model Semantics

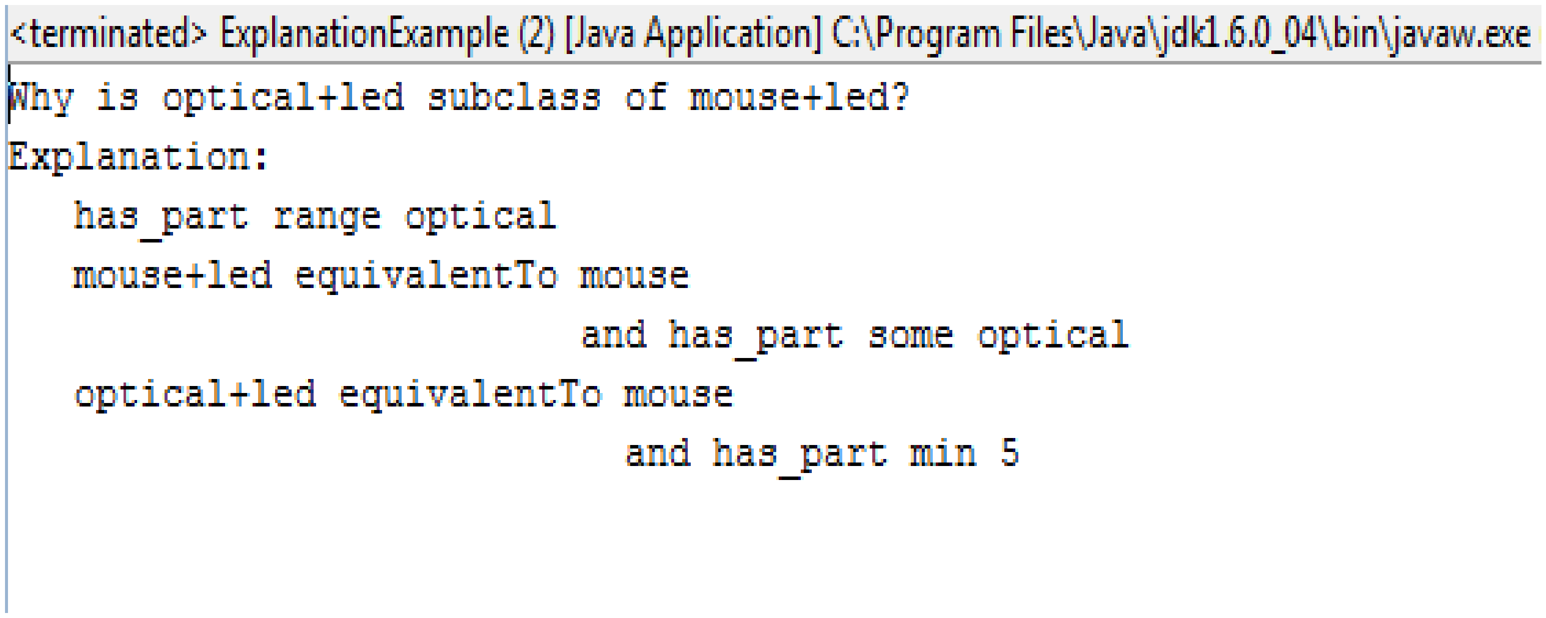
Rule :
x1:- x4.
x2:- x4,x5.
x3:- x1,x3,-x2.



```
<terminated> StableModel [Java Application] C:\Program Files\Java\jdk1.6.0_04\bin\javaw.exe (Aug 23, 2009 8:26:41 PM)
x1:x4.
x2:x4,x5.
x3:x1,x3-x2.
For i=0
Stable Model Exist
```

Initial Research (Cont...)

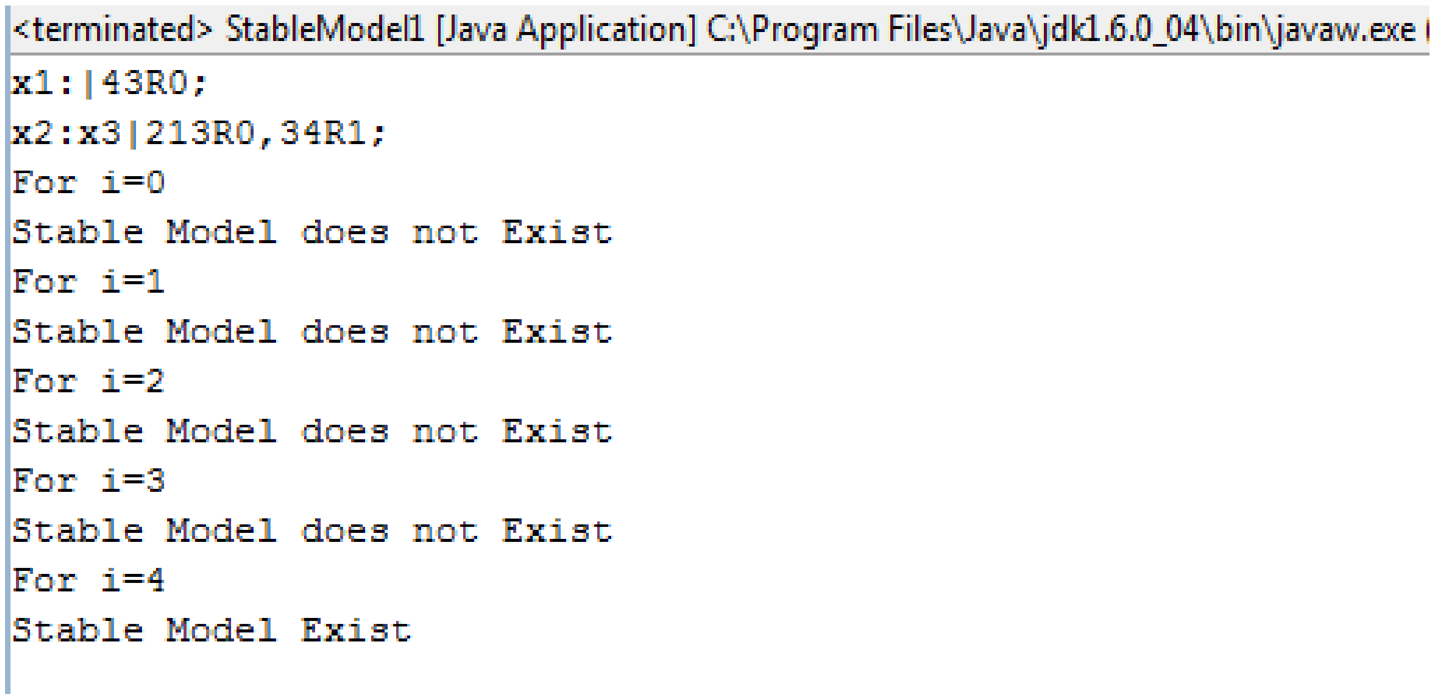
2.Created and reasoned about OWL document



```
<terminated> ExplanationExample (2) [Java Application] C:\Program Files\Java\jdk1.6.0_04\bin\javaw.exe
Why is optical+led subclass of mouse+led?
Explanation:
   has_part range optical
   mouse+led equivalentTo mouse
                          and has_part some optical
   optical+led equivalentTo mouse
                            and has_part min 5
```

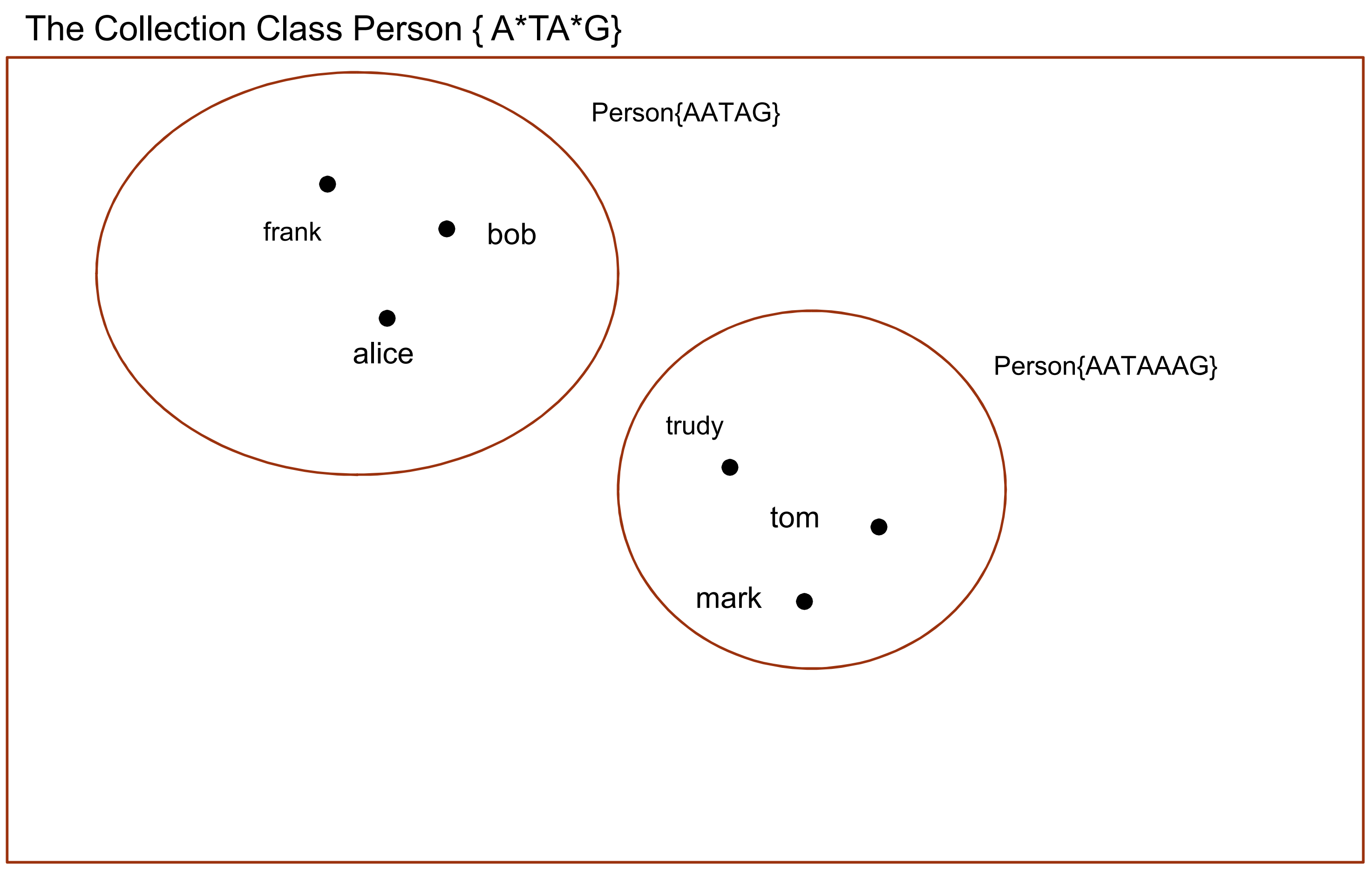
Initial Research (Cont...)

3.Implemented Finite Automata Closure Algorithm



```
<terminated> StableModel1 [Java Application] C:\Program Files\Java\jdk1.6.0_04\bin\javaw.exe
x1:|43R0;
x2:x3|213R0,34R1;
For i=0
Stable Model does not Exist
For i=1
Stable Model does not Exist
For i=2
Stable Model does not Exist
For i=3
Stable Model does not Exist
For i=4
Stable Model Exist
```

Venn Diagram for Extended OWL



Implementation

- To support collections
  - We added CollectionClass entity to OWL to represent collections.

$$(\text{subClass} \ (\exists \text{hasTelephone}.\{ [0\text{-}9]\{3\}\text{-}[0\text{-}9]\{3\}\text{-}[0\text{-}9]\{4\}\}))$$

$$\Rightarrow (\text{CollectionClass TelephonePattern})$$

```
<owl:CollectionClass rdf:about="#TelephonePattern">
        < rdfs:subClassOf>
             <owl:Restriction>
                     <owl:onProperty rdf:resource="#hasTelephone"/>
                   <owl:hasValue rdf:datatype="xsd:string">
                       [0-9]{3}-[0-9]{3}-[0-9]{4}
                  </owl:hasValue>
             </owl:Restriction>
        </rdfs:subClassOf>
</owl:CollectionClass>
```

Implementation(Cont..)

- Now that we extended OWL, we need to add support for reasoning about these kind of extended documents. This is where incorporated idea from Remmel and Marek paper for answer set programming
- We extended subclass definition. We added positive variables and constraints.

Implementation (Cont…)

- The semantics for extension to subclass is as follows:

  $e \in$ subclass : $-e_1 \in c_1, e_2 \in c_2, \ldots, e_n \in c_n, c_1 \in \lambda_1, c_2 \in \lambda_2 \ldots, c_n \in \lambda_n$

Here, $e_1, e_2, \ldots, e_n$ are instances of any OWL class in ontology

$c_1, c_2, \ldots, c_n$ are OWL classes in ontology

$\lambda_1, \lambda_2, \ldots \lambda_n$ are CollectionClasses in ontology

$e_1 \in c_1, e_2 \in c_2, \ldots,$ are positive variables

$c_1 \in \lambda_1, c_2 \in \lambda_2 \ldots, c_n \in \lambda_n$ are constraints

Implementation of Semantics

- We guessed true or false value for every constraints from 0 to 2^{max} times where max is number of constraints.
- We checked membership of OWL class in CollectionClasss . If the property values of all the instances of OWL class match the regular expression of property of CollectionClass then we can derive true as a value for that constraint.
- If the derived values of all the constraints are same as guessed values for those constraints then we can say that stable model exist.

Implementation (Cont…)

- Consider following denotation of extended class in Description Logic (DL) :

(member maddox Male)

∧ (member braddpitt Adult)

∧ (member angelinajolie PersonWithAtLeastTwoChildren)

∧ (memberClass Daughter FatherDNASequence)

∧ (memberClass Son MotherDNASequence)

⇒ (class Son)

Implementation (Cont…)

The denotation in DL is equivalent to following description of class in OWL

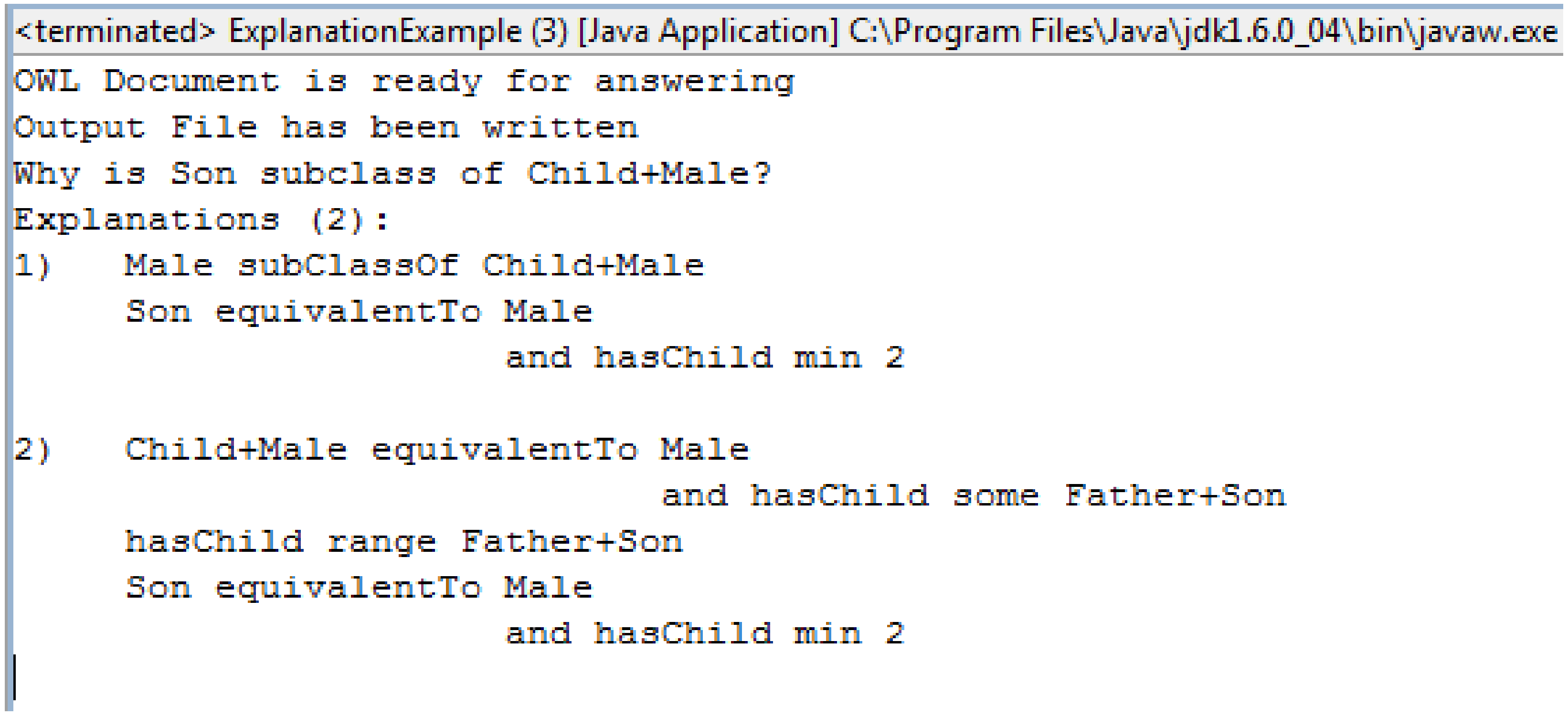
```
<owl:Class rdf:about="#Person">
        <owl:instanceOf rdf:ID="maddox">
              <owl:Class rdf:ID="Male"/>
        </owl:instanceOf>
        <owl:instanceOf rdf:ID="bradpitt">
               <owl:Class rdf:ID="Adult"/>
        </owl:instanceOf>
        <owl:instanceOf rdf:ID="angelinajolie">
          <owl:Class rdf:ID="PersonWithAtLeastTwoChildren"/>
        </owl:instanceOf>

       <owl:memberClassOf rdf:ID="Daughter">
              <owl:CollectionClassOf rdf:about="#FatherDNASequence"/>
        </owl:memberClassOf>
       <owl:memberClassOf rdf:ID="Son">
                     <owl:CollectionClassOf rdf:about="#MotherDNASequence"/>
        </owl:memberClassOf>
</owl:Class>
```

Implementation(Cont…)

- Reason about extended OWL document
  - Extended Pellet to parse an extended OWL document.
  - Added DOMParser class to Pellet which can parse extended OWL document.
  - DOMParser can compute stable model by guessing and deriving values for constraints.
  - Guessed values for constraints from 0 to 2^{max} times
  - Checked membership of OWL class in CollectionClasss for given constraints and computed stable model
  - If stable model exists then it can remove all the extended tags from the OWL document and write a new reduced OWL document
  - Pellet can reason about this reduced OWL document.

Test Case Output

- Explanation Inference

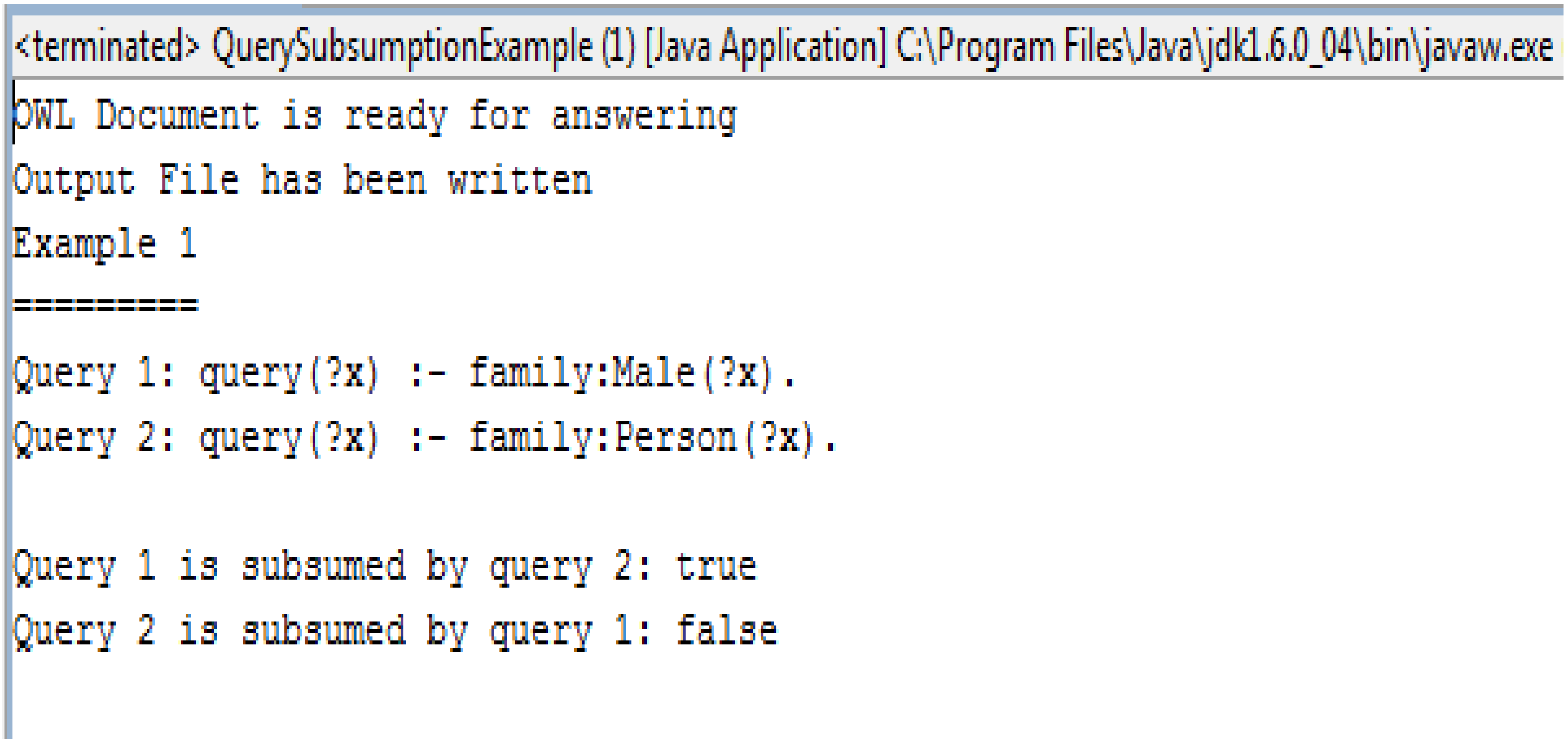


<terminated> ExplanationExample (3) [Java Application] C:\Program Files\Java\jdk1.6.0_04\bin\javaw.exe

```
OWL Document is ready for answering
Output File has been written
Why is Son subclass of Child+Male?
Explanations (2):
1)    Male subClassOf Child+Male
      Son equivalentTo Male
                       and hasChild min 2

2)    Child+Male equivalentTo Male
                              and hasChild some Father+Son
      hasChild range Father+Son
      Son equivalentTo Male
                       and hasChild min 2
```

Test Case Output (Cont…)

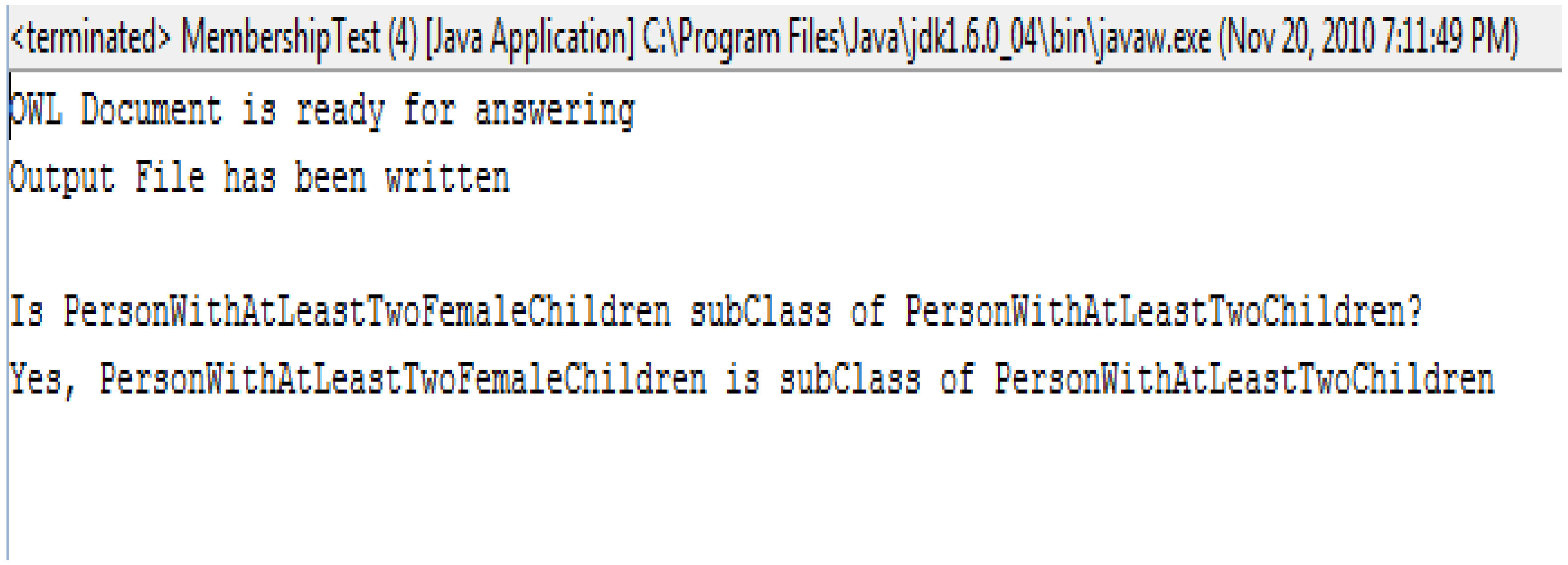
- Query Subsumption Inference



```
<terminated> QuerySubsumptionExample (1) [Java Application] C:\Program Files\Java\jdk1.6.0_04\bin\javaw.exe
OWL Document is ready for answering
Output File has been written
Example 1
=========
Query 1: query(?x) :- family:Male(?x).
Query 2: query(?x) :- family:Person(?x).

Query 1 is subsumed by query 2: true
Query 2 is subsumed by query 1: false
```

Test Case Output (Cont…)

- Logical Inference



```
<terminated> MembershipTest (4) [Java Application] C:\Program Files\Java\jdk1.6.0_04\bin\javaw.exe (Nov 20, 2010 7:11:49 PM)
OWL Document is ready for answering
Output File has been written

Is PersonWithAtLeastTwoFemaleChildren subClass of PersonWithAtLeastTwoChildren?
Yes, PersonWithAtLeastTwoFemaleChildren is subClass of PersonWithAtLeastTwoChildren
```

DEMO…

Conclusion

- Experimented and observed that OWL did not support infinite sets of collections.
- Created new entity called CollectionClass to support collections.
- Created new axioms called memberClassOf, instanceOf and collectionClassOf for adding constraints and positive variables to OWL.
- Extended subclass definition that can support constraints where membership in CollectionClass could be computed by finite automata.
- Developed three inferences to reason about extended OWL document.

References

1. Victor Marek and Jeffery B. Remmel, Automata and Answer Set Programming,2009.
2. L.Niemela, P.Simons and T. Syrjanen, Smodels: A System for Answer Set Programming,2000.
3. D.Cenzer, J.Remmel and V.Marek, Logic programming with infinite sets,2005.
4. A.Rector, R.Stevent and G.Moulton, Putting OWL in order: Pattern for sequences in OWL,2003.
5. Y.Ding, D.Embley and S.Liddle, OWL-AA: Enriching OWL with instance recognition semantics for automated semantic annotation,2005.
6. M. Gelfond and V. Lifschitz, The Stable Model Semantics for logic programming. In *Proceedings of the Fifth Logic Programming Symposium*, pages 1070-1080. The MIT Press, 1988.
7. W.Chen and D. Warren, Computation of Stable Models and its integration with logical Query Procession.
8. B. Motik, P. Patel-Schneider and I. Harrocks (2007). OWL 1.1 Web Ontology Language Structural Specification and Functional-Style Syntax [Online]. Available: http://www.webont.org/owl/1.1/owl_specification.html

Thank you

Question