Supporting Open and Closed World Reasoning in the Semantic Web

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Overview

- Motivation
- Open and Closed World Reasoning
- Building blocks
- Knowledge in the Semantic Web
- Composing modules together
- Transformational Semantics
- Conclusions

Motivation

- Merging knowledge in the Semantic Web is one fundamental unsolved problem
- The need of combining closed and open world reasoning is desirable
- The adopted mechanisms should be modular
- The solution should be independent of the semantics adopted
- Use of nonmonotonic reasoning in the Semantic Web should be carefully controlled

Approach

- Open and closed world assumptions can be already combined in extended logic programming!
- It is required two forms of negation:
  - strong or explicit
  - weak, default or *as failure*
- The two forms of negation are available in
  - Well-founded semantics with explicit negation (WFSX)
  - Answer Set Semantics (AS)
- The proposed solution uses the same program transformation for both semantics
- The user should have an easy syntactic mechanisms to specify the use of nonmonotonic reasoning constructs

Open and Closed World reasoning

- Open World Reasoning
  - Founded on First Order Logic
  - Adopted in Description Logics, OWL and SWRL
  - Appropriate for the Semantic Web
  - Sometimes too conservative

- Closed World Reasoning
  - Founded on Nonmonotonic Logics
  - Adopted in Logic Programming and WRL
  - Appropriate for (Deducitive) Databases
  - Sometimes too brave

Example

- Consider the following list of facts

% All current EU countries

CountryEU(Austria) … CountryEU(UK)

% Some non EU countries (not all…)

$\neg$ CountryEU(China)

$\neg$ CountryEU(Djibuti)

A little geography…

- Is Austria a EU country ?
  - YES, because it appears the fact CountryEU(Austria) in the knowledge base
- Is China a EU country ?
  - NO, because it is expressed that ¬ CountryEU(China)
- Is Montenegro a EU country ?
  - NO, because it is not listed there and the list is complete (CLOSED WORLD REASONING)
  - DON'T KNOW, since it is not listed then it might be or not (OPEN WORLD REASONING)

The help of extended LP

- Closed world reasoning:

  $\neg$ CountryEU(?C) ← ~ CountryEU(?C)

- Open world reasoning:

  $\neg$ CountryEU(?C) ← ~ CountryEU(?C)
  CountryEU(?C) ← ~ $\neg$ CountryEU(?C)

A syntactic detour

- Rule bases are sets of rules of the form
  - $L_0 \leftarrow L_1 , \ldots, L_m , \sim L_{m+1} , \ldots,\sim L_n$

- Each L_i ($0 \leq i \leq n$) is an objective literal, i.e.
  - An atom A(t), or
  - The strong negation of an atom $\neg$ A(t)

- The symbol ~ represents nonmonotonic weak negation, and cannot occur in the head
- The symbol $\neg$ represents monotonic strong negation, and can occur in the head and in the body of rules
- The discussion is restricted to the DATALOG case, i.e. no function symbols in the language

Putting weak negation on the leash

- The following predicate types are proposed
  - Definite or objective predicates
  - Open predicates
  - Closed predicates
  - Normal or unrestricted predicates
- Definite, open and closed predicates are limited to be defined by rules without weak negation
- Normal predicates can use the full language

Definite Predicates

- Similar to Definite Logic Programming, but allowing for explicit negation in the head and body of rules
- There can exist information gaps: predicates are partial
- Reasoning is purely monotonic
- Reasoning is polynomial on the size of the ground rule base and can be readily implemented in Prolog

Open Predicates

- Rules are like in the previous case, but additionally it is added the following pair of rules for each open predicate A with arity n
  - $\neg\ A(?x_1,\ldots,?x_n) \leftarrow \sim A(?x_1,\ldots,?x_n)$
  - $A(?x_1,\ldots,?x_n) \leftarrow \sim \neg\ A(?x_1,\ldots,?x_n)$
- Reasoning is monotonic
- Reasoning is polynomial for WFSX and co-NP complete for AS
- Can be implemented with XSB or any answer set programming system like DLV, Smodels, etc.

Closed Predicates

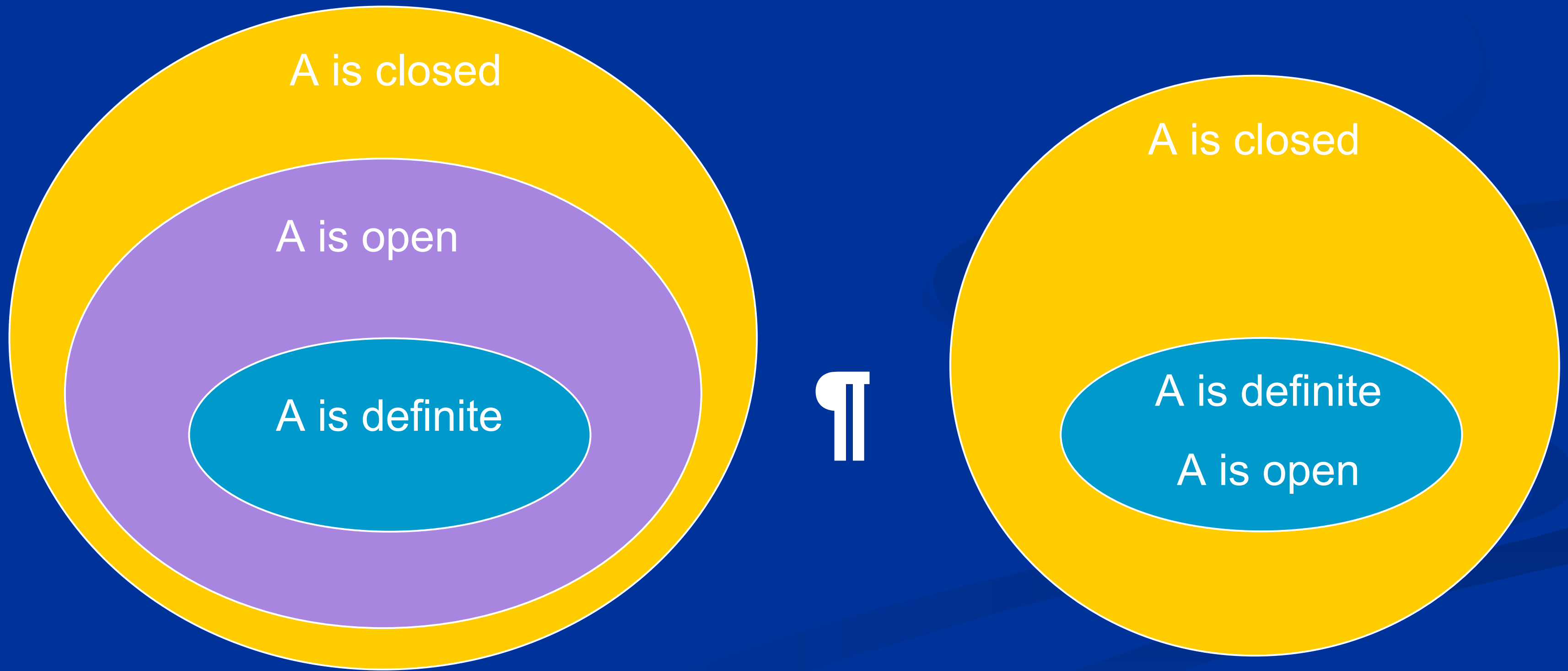
- Rules are like in the previous case, but it is added only one of the following pair of rules for closed predicate A with arity n
  - $\neg A(?x_1,\ldots,?x_n) \leftarrow \sim A(?x_1,\ldots,?x_n)$
  - $A(?x_1,\ldots,?x_n) \leftarrow \sim \neg A(?x_1,\ldots,?x_n)$
- Reasoning is nonmonotonic
- Conclusions obtained by objective predicates are also obtained by closed ones (common safe knowledge)

Normal Predicates

- Full syntax of extended logic programming
- Nonmonotonic
- No guarantees…
- Sometimes it is required

Entailment of Objective Literals

- Predicates are all definite or open, except varying A

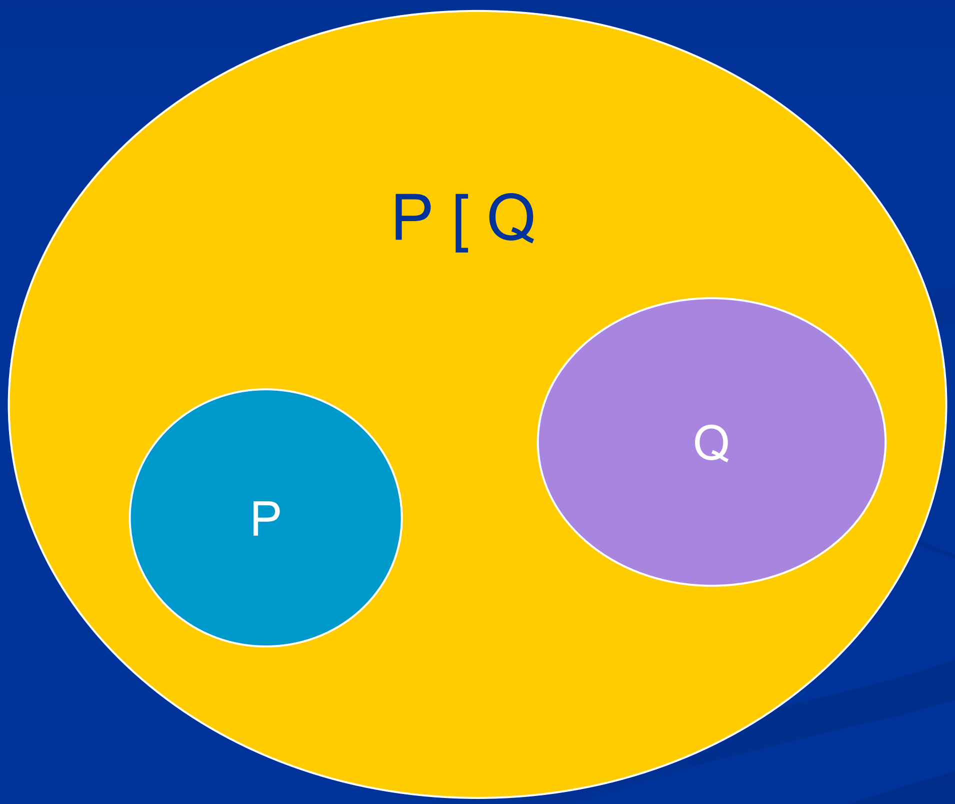


Answer Set Semantics

Well-founded Semantics with Explicit Negation

Monotonicity of Reasoning

- All predicates in rule bases P and Q are either definite or open



Particularities of the Semantic Web

- Rule bases cannot be seen isolated
- Modularity, encapsulation, information hiding and access control mechanisms are required
- Have to deal with four levels of context
  - Semantic Web context
  - Application context
  - Rule base context
  - Predicate context
- IRIs should be used in names of rule bases and predicates

Requirements

- Applications loading/asserting knowledge need mechanisms to express that
  - Nonmonotonic reasoning is allowed or inhibited
  - Force to use only safe knowledge
- Producers of knowledge need mechanisms to
  - Declare that a predicate cannot be redefined
  - Declare hidden predicates not visible in the Semantic Web
  - Use all available knowledge in the application context, or get it explicitly from particular rule bases
- Monotonic reasoning is the default, not the exception

DEFINES and USES declaration

- The DEFINES declaration states
  - The predicates defined in a rule base and their type
  - The predicates exported and their scope
- The USES declaration states
  - The predicates imported, and from where
  - Reasoning mode to be used

DEFINES

[*RuleBaseIRI*]	(Absolute IRI, default is the rule base where it occurs)
defines	
[*ScopeDecl*]	global | local | internal
PredDeclList	(objective | open | closed [┐] | normal) *AbsIRI* [/*N*], …
[visible to	
RuleBaseList]	(list of Absolute IRIs, if omitted, visible everywhere)

USES declaration

[*RuleBaseIRI*]	(Absolute IRI, default is the rule base where it occurs)
uses	
PredDeclList	(objective | open | closed [¬] | normal) *AbsIRI* [/*N*], …
[from	
RuleBaseList]	(list of Abs. IRIs, by default uses from any available rulebase)

NOTE: The scope of an imported predicate is given by a corresponding defines declaration. If absent, the predicate is global and open; the defaults adopted!

Combining reasoning forms

normal	objective	open	closed	normal
closed	objective	open	closed	error
open	objective	open	open	error
objective	objective	objective	objective	error
	objective	open	closed	normal

uses (importer)

defines (exporter)

Defining and using the same predicate

uses

global	allowed	error	allowed
local	error	error	allowed
internal	error	error	error
	global	local	internal

defines

Example

- <http://w

d_<http://www.eu.int><http://www.eu.int#CountryEU>(Austria).
o_<http://www.eu.int><http://www.eu.int#CountryEU>(Austria).
c_<http://www.eu.int><http://www.eu.int#CountryEU>(Austria).
n_<http://www.eu.int><http://www.eu.int#CountryEU>(Austria).

defines local closed eu#CountryEU/1.

eu:CountryEU(Austria).

o_<http://www.eu.int><http://www.eu.int#CountryEU>(X) :-
~ - o_<http://www.eu.int><http://www.eu.int#CountryEU>(X).
-o_<http://www.eu.int><http://www.eu.int#CountryEU>(X) :-
~ o_<http://www.eu.int><http://www.eu.int#CountryEU>(X).

-c_<http://www.eu.int><http://www.eu.int#CountryEU>(X) :-
~ c_<http://www.eu.int><http://www.eu.int#CountryEU>(X).

-n_<http://www.eu.int>n_CountryEU(X) :-
~ n_<http://www.eu.int><http://www.eu.int#CountryEU>(X).

d_<http://w … (X).
-d_<http://w … >(X).
o_<http://w … (X).
-o_<http://w … >(X).
c_<http://w … (X).
-c_<http://w … >(X).
n_<http://w … (X).
-n_<http://www.eu.int#CountryEU>(X) :- -n_<http://www.eu.int><http://www.eu.int#CountryEU>(X).

Example

- <http://security.int>

defines global open sec#citizenOf/2.

sec:citizenOf(Anne,Austria).
sec:citizenOf(Boris,Bulgaria).
sec:cit
sec:cit

```
o_<http://security.int><http://security.int#citizenOf>(X,Y) :-
        ~ - o_<http://security.int><http://security.int#citizenOf>(X,Y).
-o_<http://security.int><http://security.int#citizenOf>(X,Y) :-
        ~  o_<http://security.int><http://security.int#citizenOf>(X,Y).

c_<http://security.int><http://security.int#citizenOf>(X,Y) :-
        ~ - c_<http://security.int><http://security.int#citizenOf>(X,Y).
-c_<http://security.int><http://security.int#citizenOf>(X,Y) :-
        ~ c_<http://security.int><http://security.int#citizenOf>(X,Y).

n_<http://security.int>n_citizenOf(X,Y) :-
        ~ - n_<http://security.int><http://security.int#citizenOf>(X,Y).
-n_<http://security.int>n_citizenOf(X,Y) :-
        ~ n_<http://security.int><http://security.int#citizenOf>(X,Y).
```

Example

- <http://gov.coun

defines local closed
defines internal obje
defines internal clos
defines internal ope
uses objective eu:C
defines internal obje
uses sec:citizenOf/2

d_ <http://gov.country><http://security.int#citizenOf>(X,Y) :-
d_<http://security.int#citizenOf>(X,Y).
-d_<http://gov.country><http://security.int#citizenOf>(X,Y) :-
- d_<http://security.int#citizenOf>(X,Y).

o_<http://gov.country><http://security.int#citizenOf>(X,Y) :-
o_<http://security.int#citizenOf>(X,Y).
-o_<http://gov.country><http://security.int#citizenOf>(X,Y) :-
- o_<http://security.int#citizenOf>(X,Y).

c_<http://gov.country><http://security.int#citizenOf>(X,Y) :-
o_<http://security.int#citizenOf>(X,Y).
-c_<http://gov.country><http://security.int#citizenOf>(X,Y) :-
- o_<http://security.int#citizenOf>(X,Y).

n_<http://gov.country><http://security.int#citizenOf>(X,Y) :-
o_<http://security.int#citizenOf>(X,Y).
-n_<http://gov.country><http://security.int#citizenOf>(X,Y) :-
- o_<http://security.int#citizenOf>(X,Y).

Example

gov:Enter(?p) ← eu:CountryEU(?c), sec:citizenOf(?p,?c).
gov:Enter(?p) ← ¬ eu:CountryEU(?c), sec:citizenOf(?p,?c).

gov:Enter(?p)

¬ gov:Require
¬ gov:Require
gov:RequiresV

gov:HasVisa(
gov:HasVisa(

¬ eu:CountryE
¬ eu:Country

d_<http://gov.country><http://gov.countryt#Enter>(P) :-
d_<http://gov.country><http://www.eu.int#CountryEU>(C),
d_<http://gov.country><http://security.int#citizenOf>(P,C).

o_<http://gov.country><http://gov.countryt#Enter>(P) :-
o_<http://gov.country><http://www.eu.int#CountryEU>(C),
o_<http://gov.country><http://security.int#citizenOf>(P,C).

c_<http://gov.country><http://gov.countryt#Enter>(P) :-
c_<http://gov.country><http://www.eu.int#CountryEU>(C),
c_<http://gov.country><http://security.int#citizenOf>(P,C).

n_<http://gov.country><http://gov.countryt#Enter>(P) :-
n_<http://gov.country><http://www.eu.int#CountryEU>(C),
n_<http://gov.country><http://security.int#citizenOf>(P,C).

Summary of the program transformation

- Each rule is translated into four different rules, one for each reasoning mode
  - Definite (prefix d)
  - Open (prefix o)
  - Closed (prefix c)
  - Normal (prefix n)
- The predicate name is obtained by composition of the IRI of the Rule base plus prefix and the IRI of the predicate name
- The rules for open and closed predicates are as well introduced.
- Global and local predicates introduce a rule with prefix plus the IRI of the predicate, in order to make it visible everywhere
- USES declarations are introduced by respecting combination of reasoning forms in the table.

Problems to be addressed

- Implicit Domain Closure Assumption
- Unique Names Assumption
- Expressing the domain of predicates in order avoid floundering, using for instance rdf:domain and rdf:range
- Optimisation of the program transformation: too many repeated rules
- Handling disjunction and paraconsistency

Conclusions

- Modular approach to mixing open and closed world reasoning
- Users have mechanisms to control the use of nonmonotonic reasoning in the Semantic Web
- Defines the notion of scope of predicates
- Captures the intuitions of knowledge merging in the Semantic Web
- Solution based on widely accepted semantics
- Polynomial program transformation for WFSX and AS