Expressive Querying of Semantic Databases with Incremental Query Rewriting

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Semantic Databases (RDF Triplestores)

Keep large volumes of RDF data.

subject	***predicate***	***object***
http://www.freewebs.com/riazanov	rdf:type	foaf:Person
http://www.freewebs.com/riazanov	foaf:name	“Alexandre Riazanov”
http://www.freewebs.com/riazanov	foaf:mbox	“mailto:alexr@unb.ca”
	...	

Why Semantic Databases?

- Semantic Databases *don't have fixed schemas* ⇒ greater flexibility and no DB design.
- *Data* in Semantic DBs *carries its meaning directly*, i.e., can be interpreted directly, even by end users ⇒ more straightforward drill-down and browsing, easier integration.
- **Likely replacement for Relational Databases**.
- Most likely basis for **Web-scale querying of semantic documents**: relevant RDF or OWL documents can be loaded in a transient Semantic DB before a query is computed on it.

Querying Semantic DB

- Typically, SPARQL or similar languages are used:

```
SELECT ?x ?y
WHERE { ?x rdf:type foaf:Person . ?x foaf:name ?y }
```

- Predicates and individuals can be defined externally in ontologies and other KBs **axiomatically**: *foaf:Person rdfs:subClassOf foaf:Agent*.
- **Querying should be done modulo the KBs** (deductive queries), but current implementations can only cope with very inexpressive KBs – little more than just hierarchies.
- Techniques for Semantic Querying of Relational Databases can be transfered to Semantic DB:
  - *Direct application* is possible when Semantic DBs are implemented on top of RDBs.
  - *New!* Some techniques can be *adapted* to work on SPARQL endpoints rather than directly on triplestore actual representation.

Talk Outline

- Semantic Querying of Relational Databases in general.
- Expressive querying with Incremental Query Rewriting.
- Querying RDB-based Sesame triplestores.
- SPARQL-to-SPARQL query rewriting.

Semantic Querying of RDB in General

Main scenario:

- One or more relational databases (RDB). Tables are conceptually treated as sets of ground logical assertions:

UNIV_DB_TAKES_COURSE	STUDENT	COURSE	
	s1	c1	UNIV_DB_TAKES_COURSE(s1,c1)
	s2	c2	UNIV_DB_TAKES_COURSE(s2,c2)
	...	...	...

- KBs for the domains: e.g., ontologies (OWL) and rule sets (RuleML):

$$graduateStudent(X) :- takesCourse(X, C),\ graduateCourse(C)$$

- Semantic mapping for RDB schemas:

$$takesCourse(X, C)\ :-\ univ\_db\_takes\_course(X, C)$$

- User/client software formulates logical queries that have to be answered modulo the KB:

$$?-\ \ graduateStudent(S),\ memberOf(S, D),\ suborganization(D, 'UNB').$$

$$S = 'JohnSmith',\ D = 'CSAS'\ ;$$

$$S = 'MaryTaylor',\ D = 'Math'\ ;$$

$$\ldots$$

Applications

Non-programmer interface to RDB:

- financial analysts, biomedical researchers, criminal investigators, patent examiners, etc., etc., don't (want to) know RDB programming!
  But they are usually able to formulate *complex queries in terms of their domains* or, at least, browse the virtual assertion space.

Applications by domain:

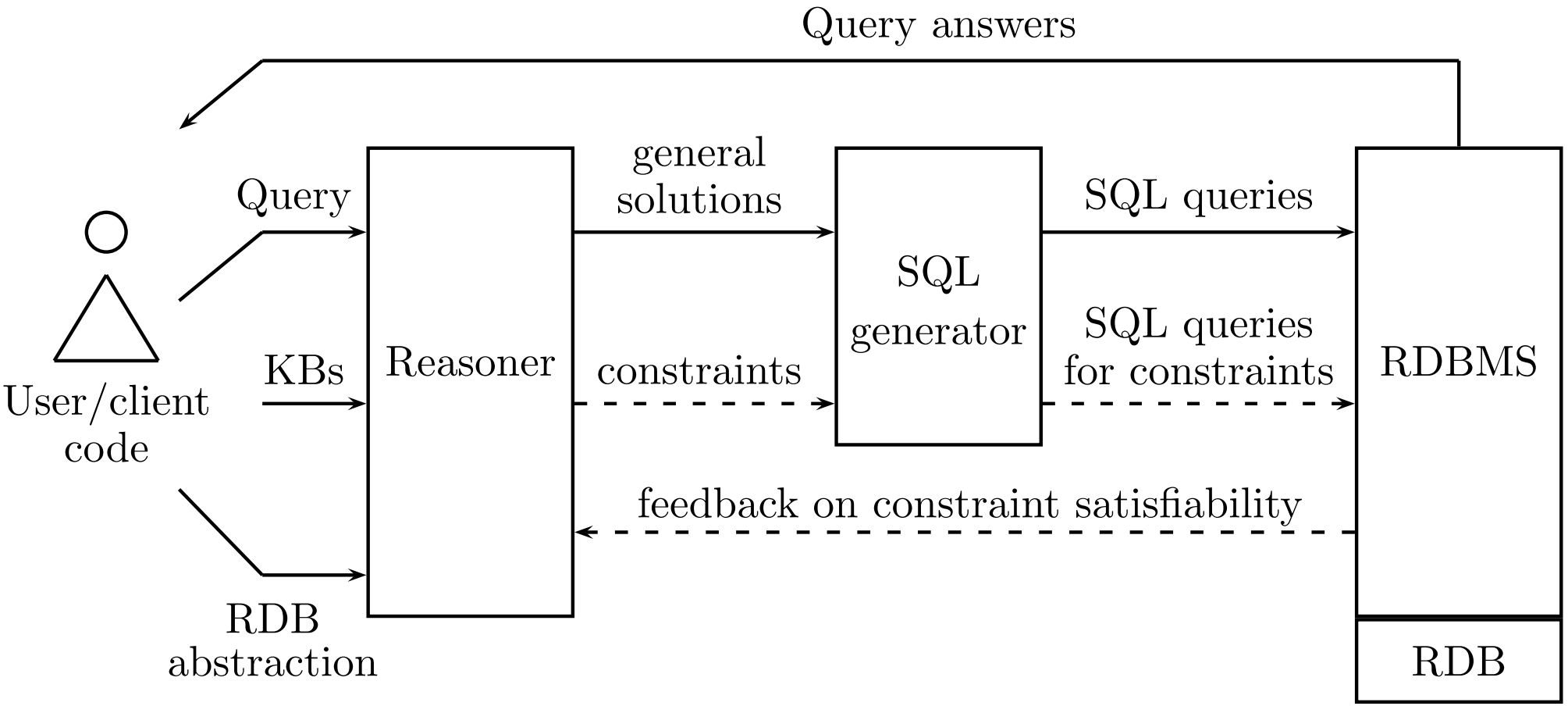
- Business Intelligence: *How many of our customers live within 2 km from a Future Shop?*
- especially Data Federation: before/instead of doing an 8 month/$1M ETL product, describe you RDBs semantically and play with queries.
- especially personalisation for e-marketing: advertise the right goods/services to the right customers by using rules. *A customer with a new laptop is unlikely to be interested in another laptop.*
- Health Care IT and Bioinformatics: agile querying of data for health care research, surveilance or clinical trials, semantic access to biological data.

Our Approach: Incremental Query Rewriting with Resolution

- **Query rewriting**, but with very expressive KBs (full First-Order Logic).
- A reasoner rewrites a semantic query into a possibly infinite sequence of **schematic answers**, using a *resolution*-based procedure. The schematic answers can be straightforwardly represented as **SQL queries**.
- **Completeness**: eventually the union of produced SQL queries covers all answers to the semantic query.
- Albeit **no general termination guarantee**: the reasoner may keep working indefinitely, producing or not producing new SQL queries.

Very expressive querying at reasonable cost.

Architecture



Example

Query: $?- \ stud(S), \ memberOf(S,''UNB'').$

Schematic answers:

$answer(S) :-$
$takes\_course(S, C),$
$gr\_course(C),$
$member\_of(S, D),$
$suborganization(D,''UNB'')$

$answer(S) :-$
$registered\_students(S, Deg),$
$Deg \simeq \text{“}MSc''$,
$member\_of(S, D),$
$suborganization(D,''UNB'')$

SQL query for the 1st schematic answer:

```
SELECT takes_course.subject AS S
FROM takes_course, gr_course, member_of, suborganization
WHERE takes_course.object = gr_course.instance
    AND takes_course.subject = member_of.subject
    AND member_of.object = suborganization.subject
    AND suborganization.object = “UNB”
```

Prototype Implementation

- Vampire was modified to do query rewriting. Accepts full FOL in the TPTP format, generates a stream of schematic answers in XML.
- A Java program translates the schematic answers to SQL. Optionally, can query a MySQL or Derby DB directly and print the results.
- User writes a semantic mapping as TPTP axioms –

  $$\textit{table predicates} \leftrightarrow \text{ontological primitives},$$

  and binds the *table predicates* to *SQL queries*, possibly complex.
- Components are glued with a shell script.
- Converters from OWL 2, SWRL and RIF, to TPTP.
- Experiment with a toy University DB queried modulo LUBM ontology. **Optional demo.**

Sesame Triplestores with RDBMS

- Sesame is an API. It allows different implementations of triplestores.
- RDB-based triplestores are conventions about how RDF triples are stored in RDB tables.
- Specify RDB layout, e.g., one table for all predicates or a separate binary table for each predicate.
- Specify how SPARQL queries are mapped to SQL.
- Address performance issues, e.g., sharing for URIs and/or literals.
- Can be viewed as semantically mapped RDB schemas: **RDF predicates are defined as SQL views** over the schemas ⇒ Incremental Query Rewriting and other semantic querying techniques for RDB are directly applicable.

MySQL RDF Store

- A separate table for each predicate:
  lubm:emailAddress $\rightarrow$ *emailAddress_25*(subj,obj), *rdf:type* $\rightarrow$ *type_3*(subj,obj)
- Surrogate keys for URIs: URI_VALUES(pk id: INTEGER, value: VARCHAR(255)). Improves join speed and saves memory.
- Surrogate keys for literals: $LABEL\_VALUES$(pk id: INTEGER, value: VARCHAR(255)).

MySQL Triplestore Layout as a Semantic Mapping

- lubm:emailAddress(subject,object) :-

```
SELECT subj_uri.value AS subject, obj_val.value AS object
  FROM emailAddress_25 rel, URI_VALUES subj_uri,
       LABEL_VALUES obj_val
 WHERE rel.subj = subj_uri.id
   AND rel.obj = obj_val.id
```

- lubm:GraduateCourse(instance) :-

```
SELECT instance_uri.value as instance
  FROM type_3 rel, URI_VALUES instance_uri, URI_VALUES class_uri
 WHERE instance_uri.id = rel.subj
   AND class_uri.id = rel.obj
   AND class_uri.value =
'http://www.lehigh.edu/~zhp2/2004/0401/univ-bench.owl#GraduateCourse'
```

Experiment

- Lehigh University Benchmark – toy Semantic DB for universities.
- OWL ontology: departments, research groups, students, professors, etc. Quite expressive: DL features outside RDFS, e.g., inverse and transitive properties.
- 14 standard queries modulo the ontology.
- Data for 5 universities: 100K instance assertions, 500K property assertions.
- **Demo.**

SPARQL-to-SPARQL rewriting

- Previous scheme works *only for RDB-based triplestores*. Can we use the method in a triplestore-independent manner?
- Most triplestores are accessible with *endpoints* conforming to one standard protocol.
- Idea: rewrite SPARQL queries using axioms from KBs into SPARQL queries that can be directly executed via the endpoints. The endpoint plays the role of a Relational DB in the original method.
- Minor technical adjustment – RDF predicates have two versions: *intensional* and *extensional*.
- The semantic mapping trivially maps extensional versions to intensional ones: $p(X, Y) \ :- \ p'(X, Y)$. The original query and the KBs use intensional versions, the rewritten queries use the extensional versions.
- **Demo.**

Very expressive querying of any SPARQL endpoints.

Conclusions and Future Work

- Incremental Query Rewriting – possible new foundation for much more expressive querying in Semantic DB.
- Next steps: (i) an experiment with D2R (having in mind the emerging RDB2RDF W3C standard), (ii) experiments within our SADI use cases, to enable simpler and nicer queries to the SHARE engine.