dlvhex-sparql:
A SPARQL-compliant Query Engine based on dlvhex

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Outline

Preliminaries
  dlvhex
  From SQL to Datalog
  RDF

From SPARQL to dlvhex
  Basic Graph Patterns
  GRAPH Patterns
  FILTERs
  UNION Patterns
  OPTIONAL

SPARQL Specification compliance
  ORDER BY, LIMIT, OFFSET
  Multi-set semantics
  FILTERs in OPTIONALs
  CONSTRUCTs and blank nodes

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Summary
dlvhex

- a flexible plugin-framework for the DLV engine
- extends Answer Set Programming by external atoms
- implemented plugins
  - for importing Semantic Web data (RDF)
  - for calling DL reasoners (OWL)
  - etc.
dlvhex Syntax

- **external atoms**

\[ \& g[Y_1, \ldots, Y_n](X_1, \ldots, X_m) \]

where \( Y_1, \ldots, Y_n \) are "input" parameters and \((X_1, \ldots, X_m)\) is the output tuple.

- Rules:

\[
h := b_1, \ldots, b_m, \text{not } b_{m+1}, \ldots \text{not } b_n.
\]

where \( h \) and \( b_i \ (1 \leq i \leq n) \) are atoms, \( b_k \ (1 \leq k \leq m) \) either atoms or external atoms.
• external atoms

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where \(h\) and \(b_i\) (\(1 \leq i \leq n\)) are atoms, \(b_k\) (\(1 \leq k \leq m\)) either atoms or external atoms
semantics of dlvhex generalizes the answer-set semantics

external predicates similar to function calls, but can have multiple “return” tuples

We use particularly 2 external predicates in this work:

- \( \&rdf[i](s, p, o) \) is true if \((s, p, o)\) is an RDF triple entailed by the RDF graph which is accessibly at IRI \(i\).
- \( \&sk[id, v_1, \ldots, v_n](sk_{n+1}) \) computes a unique, new “Skolem”-like term \(id(v_1, \ldots, v_n)\), from its input parameters.
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Starting point: SQL can (to a large extent) be encoded in Datalog with *negation as failure* (=Datalog\(^\text{not}\))

Example: Two tables containing addressbooks

\begin{verbatim}
myAddr(Name, Street, City, Telephone)
yourAddr(Name, Address)

SELECT name FROM myAddr WHERE City = "Innsbruck"
    UNION
SELECT name FROM yourAddresses

answer1(Name) :- myAddr(Name, Street, "Innsbruck", Tel).
answer1(Name) :- yourAddr(Name, Address).
?- answer1(Name).
\end{verbatim}

That was easy... Now what about SPARQL?
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**RDF**

- SPARQL (W3C Candidate Recommendation), a query language for RDF
- RDF is sets of \((S, P, O)\) triples, often written in the following notation:

\[
<\text{axel}> <\text{foaf:knows}> _:x . \\
_:x \text{ foaf:name } "\text{Roman}" . \\
<\text{axel}> <\text{rdf:type}> <\text{foaf:Person}> . \\
<\text{axel}> <:\text{age}> "33"^\text{<xsd:integer>}. \\
\]

- special thing: “blank” nodes (\(\_:_x\)) are kind of existential variables in the data, to represent incomplete data, may be read:

\[
\exists X.\text{triple}(\text{axel, foaf:knows, } X) \land \text{triple}(X, \text{foaf:name, } "\text{Roman"}) \land \ldots
\]

- this is somewhat different from SQL.
- How to get RDF data into dlvhex? We use the &\text{rdf} external atom:

\[
\{\text{triple}(S,P,O) \leftarrow平衡["http://ex.org/bob.rdf"](S,P,O)\).
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\]
\[
\text{_:x foaf:name "Roman" .}
\]
\[
\text{<axel> <rdf:type> <foaf:Person> .}
\]
\[
\text{<axel> :<age> "33"^^<xsd:integer> .}
\]

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\[
\exists X.\text{triple(axel, foaf:knows, X)} \land \text{triple(X, foaf:name, "Roman")} \land \ldots
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Summary
We import all triples in a predicate `triple(Subj,Pred,Object,Graph)` which carries an additional argument for the dataset.

Basic Graph patterns = simple conjunctive queries:

"select persons and their names"

```
SELECT ?X ?Y
FROM <http://alice.org>
FROM <http://ex.org/bob>
WHERE { ?X a foaf:Person . ?X foaf:name ?Y . }
```

```
answer1(X,Y,def) :- triple(X,"rdf:type","foaf:Person",def),
                    triple(X,"foaf:name",Y,def).

?- answer1(X,Y,def).
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```
“select creators of graphs and the persons they know”

SELECT ?X ?Y
FROM <alice.org>
FROM NAMED <alice.org>
FROM NAMED <ex.org/bob>
WHERE {
  GRAPH ?G { ?X foaf:knows ?Y. } }

triple(S,P,O,def) :- &rdf["alice.org"](S,P,O).
triple(S,P,O,"alice.org") :- &rdf["alice.org"](S,P,O).
triple(S,P,O,"ex.org/bob") :- &rdf["ex.org/bob"](S,P,O).
answer1(X,Y,def) :- triple(G,"foaf:maker",X,def),

For legibility we left out the http:// prefix
"select creators of graphs and the persons they know"

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For legibility we left out the http:// prefix
FILTERs are used to filter the result set of a query. FILTER expressions can be encoded by built-in predicates:

```sql
SELECT ?X
FROM ...
    FILTER( ?Age > 30 )
}
```

```
answer1(X,def) :-
    triple(X,foaf:mbox,M,def), triple(X,:age,Age,def),
    Age > 30.
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Unbound variables in FILTERs need to be replaced by constant, to avoid unsafe rules.
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SELECT ?X
FROM ...
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}
```

```prolog
answer1(X,def) :-
    triple(X,foaf:mbox,M,def),
    null > 30.
```

unbound variables in FILTERs need to be replaced by constant, to avoid unsafe rules.
UNIONs are split off into several rules:

"select Persons and their names or nicknames"

```
SELECT ?X ?Y
FROM ...
WHERE {
  { ?X foaf:name ?Y . }
  UNION { ?X foaf:nick ?Y . }
}
```

```
triple(S,P,O,def) :- ...
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```
What if variables of the constituent patterns don’t coincide? Slightly different than in SQL! We emulate this by special null values!

```
SELECT ?X ?Y ?Z
FROM ...
WHERE {
    { ?X foaf:name ?Y . } 
    UNION { ?X foaf:nick ?Z . } 
}
```

Data:
<alice.org#me> foaf:name "Alice".
<ex.org/bob#me> foaf:name "Bob" .
<ex.org/bob#me> foaf:nick "Bobby".

Result:

<table>
<thead>
<tr>
<th>?X</th>
<th>?Y</th>
<th>?Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;alice.org#me&gt;</td>
<td>&quot;Alice&quot;</td>
<td></td>
</tr>
<tr>
<td>&lt;ex.org/bob#me&gt;</td>
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```prolog
triple(S,P,O,def) :- ... 
answer1(X,Y,null,def) :- triple(X,"foaf:name",Y,def).
```
“select all persons and optionally their names”

```sql
SELECT *
WHERE
{
    ?X a foaf:Person .
    OPTIONAL {?X foaf:name ?N }
}
```

OPTIONAL is similar to an OUTER JOIN in SQL, actually it is a combination of a join and set difference:

```
{ P₁ OPTIONAL { P₂} }: M₁ \Join M₂ = (M₁ \Join M₂) ∪ (M₁ \setminus M₂)
```

where $M_1$ and $M_2$ are variable binding for $P_1$ and $P_2$, resp.
“select all persons and optionally their names”

```
SELECT *
WHERE
{
    ?X a foaf:Person .
    OPTIONAL {?X foaf:name ?N }
}
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Observation: SPARQL allows to express set difference / negation as failure by combining OPTIONAL and !bound

“select all persons without an email address”

```
SELECT ?X
WHERE
{
  ?X a ?Person
  OPTIONAL {?X :email ?Email }
  FILTER ( !bound( ?Email ) )
}
```

Same effect as “NOT EXISTS” in SQL, set difference!.
We’ve seen before that OPTIONAL, has set difference inherent, with the “!bound” we get it back again “purely”.

A. Polleres – dlvhex-sparql
SPARQL’s OPTIONAL has “negation as failure”, hidden:

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A. Polleres – dlvhex-sparql 17 / 26
From SPARQL to dlvhex: OPTIONAL Patterns

SELECT *
WHERE
{
    ?X a foaf:Person .
    OPTIONAL {?X foaf:name ?N }
}

Recall: \((P_1 \text{ OPT} P_2)\): \(M_1 \smallfrown M_2 = (M_1 \smallfrown M_2) \cup (M_1 \smallfrown M_2)\)

triple(S,P,O,def) :- ... 
answer1(X,N,def) :- triple(X,"rdf:type","foaf:Person",def),
                      triple(X,"foaf:name",N,def).
answer1(X,null,def) :- triple(X,"rdf:type","foaf:Person",def),
                     not answer2(X).
answer2(X) :- triple(X,"foaf:name",N,def).

We use \texttt{null} and negation as failure \texttt{not} to "emulate" set difference.

Note: Additional machinery needed for special OPTIONAL queries... out of scope of this short paper, see \cite{Polleres, WWW2007}.  

A. Polleres – dlvhex-sparql
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Recall: (P_1 OPT P_2): M_1 \bowtie M_2 = (M_1 \bowtie M_2) \cup (M_1 \setminus M_2)
```

```prolog
triple(S,P,O,def) :- ...
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SELECT *  
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\begin{align*}
\text{triple}(S,P,O,\text{def}) & \leftarrow \ldots \\
\text{answer1}(X,N,\text{def}) & \leftarrow \text{triple}(X,\text{"rdf:type"},\text{"foaf:Person"},\text{def}), \text{triple}(X,\text{"foaf:name"},N,\text{def}). \\
\text{answer1}(X,\text{null},\text{def}) & \leftarrow \text{triple}(X,\text{"rdf:type"},\text{"foaf:Person"},\text{def}), \text{not} \text{answer2}(X). \\
\text{answer2}(X) & \leftarrow \text{triple}(X,\text{"foaf:name"},N,\text{def}).
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We use \text{null} and negation as failure \text{not} to “emulate” set difference.

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triple(S,P,0,def) :- ...
answer1(X,N,def) :- triple(X,"rdf:type","foaf:Person",def),
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Outline

Preliminaries

dlvhex
From SQL to Datalog
RDF

From SPARQL to dlvhex
Basic Graph Patterns
GRAPH Patterns
FILTERs
UNION Patterns
OPTIONAL

SPARQL Specification compliance
ORDER BY, LIMIT, OFFSET
Multi-set semantics
FILTERs in OPTIONALs
CONSTRUCTs and blank nodes

Summary
That’s all? So, can we use a bottom-up engine like dlvhex as a SPARQL engine? Not quite . . .

Some peculiarities are hidden in the SPARL specification document:

1. How to deal with solution modifiers (ORDER BY, LIMIT, OFFSET).
2. SPARQL defines a multi-set semantics.
3. SPARQL allows FILTER expressions in OPTIONAL patterns to refer to variables bound outside the enclosing OPTIONAL pattern.
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Not treated at the moment in our implementation, in principle doable by postprocessing of the results:

Data:
<ex.org/bob#me> foaf:name "Bob" .
<alice.org#me> foaf:name "Alice".
<ex.org/bob#me> foaf:nick "Bobby".

SELECT ?Y
WHERE { ?X foaf:name ?Y }
ORDER BY ?Y LIMIT 1

Result: { answer1("Bob",def), answer1("Alice",def) }
Sort answer set by parameter (ORDER BY),
only output first result (LIMIT 1) ⇒ "Alice"
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1. be careful with projections (SELECT)
2. add some machinery for UNIONs

Data:
:alice foaf:knows _:a . 
_:a foaf:name "Bob". _:a foaf:nick "Bob" .

SELECT ?Y WHERE {?X foaf:name ?Y }

answer1(Y,def) :- triple(X,foaf:name,Y,def).

Answer set: { answer("Bob") },
but expected 2 (identical) solutions!
SPARQL Specification: multi-set semantics

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SELECT ?Y WHERE {?X foaf:name ?Y }

answer1(X,Y,def) :- triple(X,foaf:name,Y,def).

Answer set: \{ answer1(...,"Bob"), answer1(...,"Bob") \},
2 solutions, leave projection to postprocessing!
SPARQL Specification: multi-set semantics

1. be careful with projections (SELECT)
2. add some machinery for UNIONs

Data:
:alice foaf:knows _:a .
_:a foaf:name "Bob". _:a foaf:nick "Bob" .

SELECT ?N

```
answer1(?N,?X,def) :- triple(X,foaf:name,Y,def).
answer1(?N,?X,def) :- triple(X,foaf:nick,Y,def).
```

Answer set: { answer1(..., "Bob"), answer1(..., "Bobby"), answer1(..., "Bob") },
but expected 4 solutions!
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Data:
:alice foaf:knows _:a .
_:a foaf:name "Bob" . _:a foaf:nick "Bob" .

SELECT ?N

answer1(?N,?X,def) :- triple(X,foaf:name,Y,def).
answer1(?N,?X,def) :- triple(X,foaf:nick,Y,def).

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SPARQL Specification: multi-set semantics

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Data:
:alice foaf:knows _:a .
_:a foaf:name "Bob". _:a foaf:nick "Bob" .

SELECT ?N

answer1(?N,?X,1,def) :- triple(X,foaf:name,Y,def).
answer1(?N,?X,2,def) :- triple(X,foaf:nick,Y,def).

Answer set: { answer1(...,"Bob"), answer1(...,"Bobby"),
answer1(...,"Bob"), answer1(...,"Bob") },
Add a new constant for any "branch" of a UNION.
“select names and email addresses only of those older than 30”

SELECT ?N ?M WHERE {
  OPTIONAL {
    FILTER(?Age > 30)
  }
}

Needs 3 case distinctions:

- There is an email address and the FILTER is fulfilled (join)
- There is an email address and the FILTER is not fulfilled (leave ?M unbound)
- There is no email address (leave ?M unbound)
“select names and email addresses only of those older than 30”

   OPTIONAL { ?X foaf:mbox ?M . FILTER(?Age > 30) }}

Needs 3 case distinctions:

- There is an email address and the FILTER is fulfilled (join)
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“select names and email addresses only of those older than 30”

  OPTIONAL { ?X foaf:mbox ?M . FILTER(?Age > 30) }}

answer1ₚ(Age,N,M,X,def) :-
  tripleₚ(X,foaf:name,N,def),
  tripleₚ(X,:age,Age,def),
  answer2ₚ(M,X,def), Age > 30.

answer1ₚ(Age,N,null,X,def) :-
  tripleₚ(X,foaf:name,N,def),
  tripleₚ(X,:age,Age,def),
  answer2ₚ(M,X,def), not Age > 30.

answer1ₚ(Age,N,null,X,def) :-
  tripleₚ(X,foaf:name,N,def),
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answer2ₚ(M,X,def) :-
  tripleₚ(X,foaf:mbox,M,def).

answer2’ₚ(X,def) :- answer2ₚ(M,X,def).

answerₚ(N,M) :- answer1ₚ(Age,N,M,X,def).
SPARQL Specification: CONSTRUCT queries and blank nodes

How to deal with this one?

CONSTRUCT  _:b a foaf:Agent.  _:b foaf:name ?N.  ?Doc foaf:maker _:b.  FROM ...
  WHERE  ?Doc dc:creator ?N.

CONSTRUCT queries create new triples (similar to views in Rel. DBs).

For blank nodes in CONSTRUCTs, we need Skolem terms as blank node identifiers!

answer1(Doc,N,def) :- tripleQ(Doc,dc:creator,N,def).
tripleRes(BLANK_b,rdf:type,foaf:Agent,res) :- answer1(Doc,N,def),
&sk[b,Doc,N](BLANK_b).
tripleRes(BLANK_b,foaf:name,N,res) :- answer1(Doc,N,def),
&sk[b,Doc,N](BLANK_b).
tripleRes(Doc,foaf:maker,BLANK_b,res) :- answer1(Doc,N,def),
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For blank nodes in CONSTRUCTs, we need *Skolem terms* as blank node identifiers!

```
answer1(Doc,N,def) :- tripleQ(Doc,dc:creator,N,def).
tripleRes(BLANK_b,rdf:type,foaf:Agent,res) :- answer1(Doc,N,def),
        &sk[b,Doc,N](BLANK_b).
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        &sk[b,Doc,N](BLANK_b).
tripleRes(Doc,foaf:maker,BLANK_b,res) :- answer1(Doc,N,def),
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\[
\text{answer1}(\text{Doc}, N, \text{def}) \leftarrow \text{triple}_Q(\text{Doc}, \text{dc:creator}, N, \text{def}).
\]
\[
\text{triple}_R (\text{BLANK}_b, \text{rdf:type}, \text{foaf:Agent}, \text{res}) \leftarrow \text{answer1}(\text{Doc}, N, \text{def}), & \text{sk}[b, \text{Doc}, N](\text{BLANK}_b).
\]
\[
\text{triple}_R (\text{BLANK}_b, \text{foaf:name}, N, \text{res}) \leftarrow \text{answer1}(\text{Doc}, N, \text{def}), & \text{sk}[b, \text{Doc}, N](\text{BLANK}_b).
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```
Summary:

▶ SPARQL to Datalog seems easy
▶ Actual implementation raises some issues ... not SOOO easy.
▶ We have implemented a recursive translation from arbitrarily nested SPARQL queries to dlvhex
▶ We further are working towards a full implementation of SPARQL on dlvhex
▶ Why do we do that?
  ▶ dlvhex is a good platform for extensions (aggregates), additional built-in functions
  ▶ CONSTRUCTs may be viewed as rules them selves, useful for defining implicit, interlinked metadata in RDF. ⇒ We can implement such an extension to RDF right away.
  ▶ combination with RDFS inference rules
  ▶ Recent results on dlv-db for RDF give us confidence that this is not only a “toy” implementation of SPARQL, but could in fact lead to a competitive RDF-Store
▶ We are currently implementing these extensions to SPARQL!
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