Next Steps on SPARQL

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Outline

From SPARQL to LP
- Basic Graph Patterns
- GRAPH Patterns
- FILTERs
- UNION Patterns
- OPTIONAL and Negation as failure

Full SPARQL-Spec compliance
- ORDER BY, LIMIT, OFFSET
- Multi-set semantics
- FILTERs in OPTIONALs

SPARQL++ for Ontology alignment
- Mapping by SPARQL
- Examples
- Implementation
- Example Translation
- RDFS

Wrap-up

SPARQL and LP 1/2

- Starting point: SQL can (to a large extent) be encoded in LP with *negation as failure* (=Datalog$^{\mathrm{not}}$)

  Example: Two tables containing adressbooks

  ```
  myAddr(Name, Street, City, Telephone)
  yourAddr(Name, Address)
  ```

  ```
  SELECT name FROM myAddr WHERE City = "Cosenza"
    UNION
  SELECT name FROM yourAddresses
  ```

  ```
  answer1(Name) :- myAddr(Name, Street, "Cosenza", Tel).
  answer1(Name) :- yourAddr(Name, Address).
  ?- answer1(Name).
  ```

- That was easy... Now what about SPARQL?
- OPTIONAL and UNION cause some trouble, also FILTERs and CONSTRUCTs

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We take as an example the language of dlvhex (`http://www.kr.tuwien.ac.at/research/dlvhex`):

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- dlvhex is implemented on top of the DLV engine (`http://www.dlvsystem.com/`)
- supports so-called answer set semantics (extension of the stable model semantics) for a language extending Datalog [Eiter et al., 2006].
- plugin-mechanism for easy integration of external function calls (built-in predicates, also called HEX-atoms).
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SPARQL and LP: Basic Graph Patterns

- We import all triples in a predicate `triple(Subj,Pred,Object,Graph)` which carries an additional argument for the dataset.
- For the import, we use the `rdf[URL](S,P,O)` built-in.

"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 . }
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triple(S,P,O,def) :- rdf["http://ex.org/bob"](S,P,O).
triple(S,P,O,def) :- rdf["http://alice.org"](S,P,O).
answer1(X,Y,def)  :- triple(X,"rdf:type","foaf:Person",def),
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SPARQL and LP: GRAPH Patterns and NAMED graphs

"select creators of graphs and the persons they know"

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SELECT ?X ?Y
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FROM NAMED <alice.org>
FROM NAMED <ex.org/bob>
WHERE { ?G foaf:maker ?X .
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For legibility we left out the `http://` prefix

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SPARQL and LP: FILTERs

FILTERs are used to filter the result set of a query.
FILTER expressions can be encoded by built-in predicates:

```
SELECT ?X
FROM ...
WHERE { ?X foaf:mbox ?M . ?X :age ?Age .
        FILTER( ?Age > 30 )
      }
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answer1(X,def) :-
   triple(X,foaf:mbox,M,def), triple(X,:age,Age,def),
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SPARQL and LP: UNION Patterns 1/2

UNIONs are split off into several rules:

*"select Persons and their names **or** nicknames"*

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SELECT ?X ?Y
FROM ...
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triple(S,P,O,def) :- ...
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SPARQL and LP: UNION Patterns 2/2

What if variables of the of constituent patterns don't coincide? Slightly different than in SQL!

We emulate this by special `null` values!

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Data:

```
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```

Result:

?X	?Y	?Z
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SPARQL and LP: *OPTIONAL* Patterns 1/2

"select all persons and optionally their names"

```
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** (see [Pérez et al., 2006]):

$\{P_1\ \texttt{OPTIONAL}\ \{P_2\}\}$: $\mathcal{M}_1 ⟕ \mathcal{M}_2 = (\mathcal{M}_1 \bowtie \mathcal{M}_2) \cup (\mathcal{M}_1 \smallsetminus \mathcal{M}_2)$

where $\mathcal{M}_1$ and $\mathcal{M}_2$ are variable bindings for P_1 and P_2, resp.

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SPARQL's OPTIONAL has "negation as failure", hidden:

- Observation: SPARQL allows to express set difference / negation as failure by combining OPT and FILTER !bound

"select all persons *without* an email address"

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SELECT ?X
WHERE
{
  ?X a ?Person
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  FILTER ( !bound( ?Email ) )
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- 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".

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SPARQL and LP: OPT Patterns – First Try

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

Recall: $(P_1 \text{ OPT } P_2)$: $\mathcal{M}_1 ⟕ \mathcal{M}_2 = (\mathcal{M}_1 \bowtie \mathcal{M}_2) \cup (\mathcal{M}_1 \setminus \mathcal{M}_2)$

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triple(S,P,O,def) :- ...
answer1(X,N,def) :- triple(X,"rdf:type","foaf:Person",def),
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We use `null` and negation as failure `not` to "emulate" set difference.

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We use `null` and negation as failure `not` to "emulate" set difference.

SPARQL and LP: OPT Patterns – Example

`# Graph: ex.org/bob`
`@prefix foaf: <http://xmlns.com/foaf/0.1/> .`
`@prefix bob: <ex.org/bob#> .`
 	
`<ex.org/bob> foaf:maker _:a.`
`_:a a foaf:Person ; foaf:name "Bob";`
`foaf:knows _:b.`
 	
`_:b a foaf:Person ; foaf:nick "Alice".`
`<alice.org/> foaf:maker _:b`
	`# Graph: alice.org`
	
	`@prefix foaf: <http://xmlns.com/foaf/0.1/> .`
	`@prefix alice: <alice.org#> .`
	
	`alice:me a foaf:Person ; foaf:name "Alice" ;`
	`foaf:knows _:c.`
	
	`_:c a foaf:Person ; foaf:name "Bob" ;`
	`foaf:nick "Bobby".`

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

Result:

?X	?N
_:a	"Bob"
_:b	
_:c	"Bob"
alice.org#me	"Alice"

```
{ answer1("_:a","Bob",def), answer1("_:b",null, def),
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```

```
# Graph: alice.org

@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix alice: <alice.org#> .

  alice:me a foaf:Person ; foaf:name "Alice" ;
           foaf:knows _:c.

  _:c  a foaf:Person ; foaf:name "Bob" ;
           foaf:nick "Bobby".
```

```
SELECT *
FROM <http://alice.org>
FROM <http://ex.org/bob>
WHERE { ?X a foaf:Person . OPTIONAL { ?X foaf:name ?N } }
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SPARQL and LP: OPT Patterns – Nasty Example

Ask for pairs of persons $?X1$, $?X2$ who share the same name and nickname where both, name and nickname are optional:

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SELECT *
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WHERE { { ?X1 a foaf:Person . OPTIONAL { ?X1 foaf:name ?N } }
        { ?X2 a foaf:Person . OPTIONAL { ?X2 foaf:nick ?N } } }
```

?X1	?N
_:a	"Bob"
_:b	
_:c	"Bob"
alice.org#me	"Alice"

$\bowtie$

?X2	?N
_:a	
_:b	"Alice"
_:c	"Bobby"
alice.org#me	

Now this is strange, as we join over unbound variables.

Remark: this pattern is not well-designed, following [Pérez et al., 2006]

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SPARQL and LP: OPT Patterns – With our translation?:

?X1	?N
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_:c	"Bob"
alice.org#me	"Alice"

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?X2	?N
_:a	null
_:b	"Alice"
_:c	"Bobby"
alice.org#me	null

=

?X1	?N	X2
_:b	null	_:a
_:b	null	alice.org#me
alice.org#me	"Alice"	_:b

What's wrong here? Join over null, as if it was a normal constant.

Compared with SPARQL's notion of compatibility of mappings, this is too cautious!

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SPARQL and LP: OPT Patterns – Correct Result:

?X1	?N
_:a	"Bob"
_:b	
_:c	"Bob"
alice.org#me	"Alice"

$\bowtie$

?X2	?N
_:a	
_:b	"Alice"
_:c	"Bobby"
alice.org#me	

$=$

?X1	?N	X2
_:a	"Bob"	_:a
_:a	"Bob"	alice.org#me
_:b		_:a
_:b	"Alice"	_:b
_:b	"Bobby"	_:c
_:b		alice.org#me
_:c	"Bob"	_:a
_:c	"Bob"	alice.org#me
alice.org#me	"Alice"	_:a
alice.org#me	"Alice"	_:b
alice.org#me	"Alice"	alice.org#me

SPARQL defines a very brave way of joins: unbound, i.e. null should join with anything!

SPARQL and LP: OPT Patterns – Correct Result:

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?X1	?N	X2
_:a	"Bob"	_:a
_:a	"Bob"	alice.org#me
_:b		_:a
_:b	"Alice"	_:b
_:b	"Bobby"	_:c
_:b		alice.org#me
_:c	"Bob"	_:a
_:c	"Bob"	alice.org#me
alice.org#me	"Alice"	_:a
alice.org#me	"Alice"	_:b
alice.org#me	"Alice"	alice.org#me

SPARQL defines a very brave way of joins: unbound, i.e. `null` should join with anything!

Semantic variations of SPARQL

We could call these alternatives of treatment of possibly `null`-joining values alternative semantics for SPARQL:

- c-joining: cautiously joining semantics
- b-joining: bravely joining semantics (normative)

Which is the most intuitive? DAWG basically decided for b-join.

Now let's see to how to fix our translation to logic programs...

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```

```
triple(S,P,O,def) :- rdf["ex.org/bob"](S,P,O).
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answer1(N,X1,X2,def) :- answer2(N,X1,def), answer4(N,X2,def).

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SPARQL and LP: OPT Patterns – Improved!

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We need to take care for variables which are joined and possibly unbound, due to the special notion of compatibility in SPARQL

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answer4(N,   X2,def) :- triple(X2,"a","Person",def),
                        triple(X2,"nick",N,def).
answer4(null,X2,def) :- triple(X2,"a","Person",def),
                        not answer5(X2,def).
answer5(X2,def)     :- triple(X2,"nick",N,def).
```

SPARQL and LP: OPT Patterns

Attention:

- The “fix” we used to emulate b-joining semantics is potentially exponential in the number of possibly-null-joining variables.
- This is not surprising, since the complexity of OPTIONAL/UNION corner cases is PSPACE, see [Pérez et al., 2006].
- But: A slight modification of the translation (in the tech. report version of [Polleres, 2007]) shows that this translation is optimal: Non-recursive Datalog with negation as failure is also PSPACE complete!

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- GRAPH Patterns
- FILTERs
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- OPTIONAL and Negation as failure

Full SPARQL-Spec compliance
- ORDER BY, LIMIT, OFFSET
- Multi-set semantics
- FILTERs in OPTIONALs

SPARQL++ for Ontology alignment
- Mapping by SPARQL
- Examples
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Wrap-up

SPARQL Specification compliance

That's all? So, can we use a bottom-up datalog engine like delvhex as a SPARQL engine? Not quite ...

- What we presented so far was reflecting [Pérez et al., 2006] semantics.
- The SPARQL spec defines an algebra which adds some peculiarities, namely:
  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.
  4. SPARQL allows blank nodes in the result form of CONSTRUCT queries (more on that in the 3rd part of the talk)

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SPARQL Specification: ORDER BY, LIMIT, OFFSET

- 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 corresponding to `?Y` (ORDER BY), only output first result (LIMIT 1) $\Rightarrow$ `"Alice"`

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SPARQL Specification: multi-set semantics

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

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: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!

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```

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

Answer set: `{ answer1(...,"Bob"), answer1(...,"Bob") },`
2 solutions, leave projection to postprocessing !

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```

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

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

SPARQL Specification: FILTER expressions in OPTIONAL patterns

"select names and email addresses only of those older than 30"

```
SELECT ?N ?M WHERE { ?X foaf:name ?N . ?X :age ?Age .
                     OPTIONAL { ?X foaf:mbox ?M . 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)

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```
answer1_P(Age,N,M,X,def) :- triple_Q(X,foaf:name,N,def), triple_Q(X,:age,Age,def),
                            answer2_P(M,X,def), Age > 30.
answer1_P(Age,N,null,X,def) :- triple_Q(X,foaf:name,N,def),
                               triple_Q(X,:age,Age,def),
                               answer2_P(M,X,def), not Age > 30.
answer1_P(Age,N,null,X,def) :- triple_Q(X,foaf:name,N,def),
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answer2'_P(X,def) :- answer2_P(M,X,def).
answer_Q(N,M) :- answer1_P(Age,N,M,X,def).
```

Outline

From SPARQL to LP

- Basic Graph Patterns
- GRAPH Patterns
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Full SPARQL-Spec compliance

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SPARQL++ for Ontology alignment

- Mapping by SPARQL
- Examples
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Wrap-up

Use Case – Ontology Alignment/Mapping

- Typically: Description of correspondences and overlaps between ontological entities (properties, classes, individuals, etc.)
- W3C standards for writing ontologies in place (RDFS, OWL), but limited expressivity for describing mappings.
- Which language to use?
- How to **publish** mappings/alignments? This is important to make *Open Linked Data*[1] happen!

We define some useful extensions of SPARQL – SPARQL++ – and our translation towards a language to define such mappings

[1] Combining RDF data that is "out there", e.g. Sindice, DBPedia, SWPipes etc.

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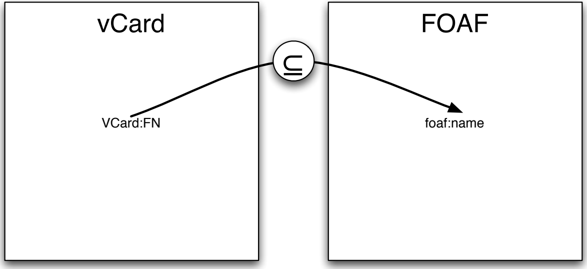
Mapping Scenarios

Map from vCard to FOAF:



Expressible by `rdfs:subPropertyOf`:

```
VCard:FN rdfs:subPropertyoF foaf:name .
```

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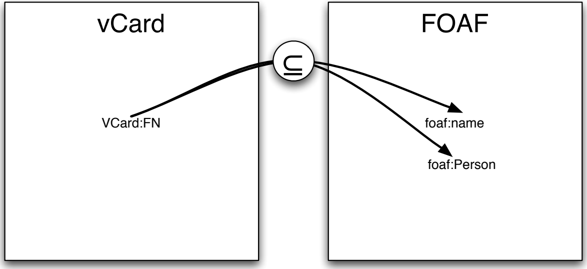

Also expressible in RDFS or in OWL DL:

```
VCard:FN rdfs:subPropertyOf foaf:name.
VCard:FN rdfs:domain foaf:Person.
```

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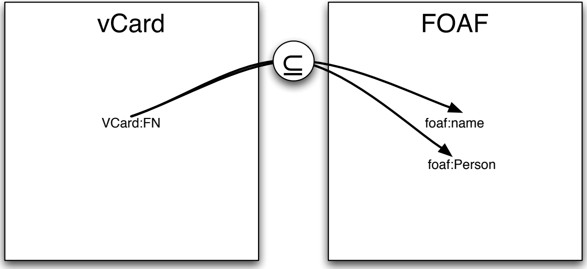

Also expressible in RDFS or in OWL DL:

$\mathtt{VCard{:}FN} \sqsubseteq \mathtt{foaf{:}name}$

$\exists\mathtt{VCard{:}FN}.\top \sqsubseteq \mathtt{foaf{:}Person}$

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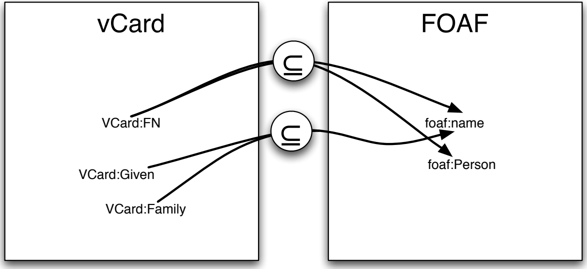

Needs string concatenation, not expressible in OWL or RDFS...

maybe SWRL can help, but

(1) implementations missing

(2) no W3C stamp

Mapping Scenarios

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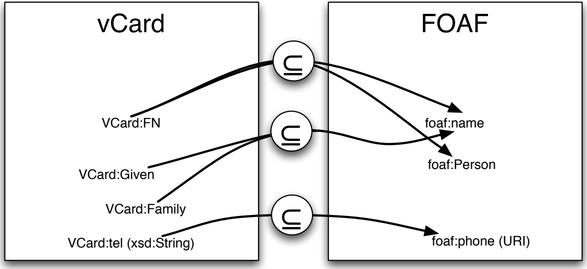

What shall we do here?

Needs conversion from String to rdf:Resource (URI)...how?

Let's see what SPARQL can do for us...

Mapping by SPARQL

Observation:
SPARQL (Proposed W3C Rec since two weeks, BTW) offers CONSTRUCT queries to generate new graphs from existing ones

```
CONSTRUCT { Basic triple patterns }
FROM dataset (source graph)
WHERE {Pattern}
```

- This may be read as a *view* definition ...
- ... and views can be understood as *(mapping) rules*

Attention: if you allow such views to mutually refer to each other, you get a recursive rules language!

- By OPTIONAL patterns you get even non-monotonicity (negation as failure)
- By bnodes in the CONSTRUCT part, you might run into non-termination issues!

BTW: How can this interact with ontological inferences of OWL and RDFS?
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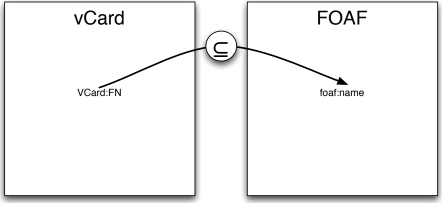
Example 1

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CONSTRUCT { ?X foaf:name ?Y }
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Easy!

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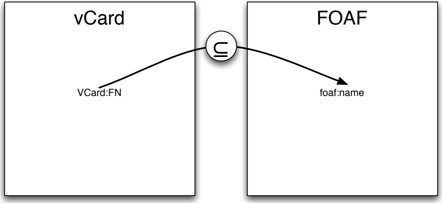


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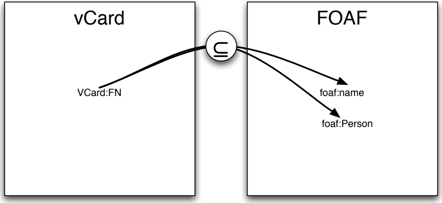


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CONSTRUCT { ?X foaf:name ?Y . ?X rdf:type foaf:person . }
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No problem either.

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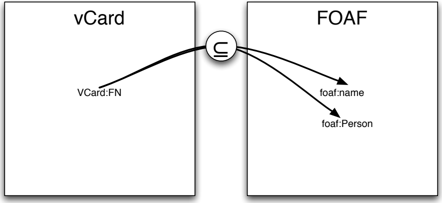


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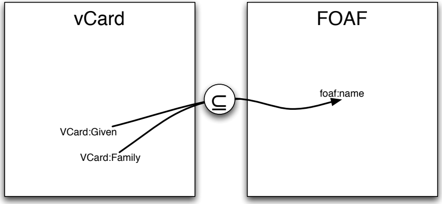


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          }
```

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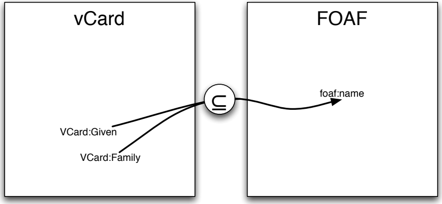


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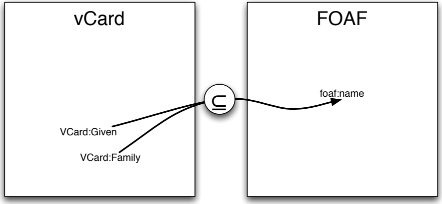
How to tackle? FILTERs?

Example 3




```
CONSTRUCT { ?X foaf:name ?FN }
WHERE     { ?X VCard:Given ?N. ?X VCard:Family ?F
            FILTER( ?FN = fn:concat(?N," ",?F))}
```

Doesn't work :-| FILTERs only bind variables, can't create new bindings

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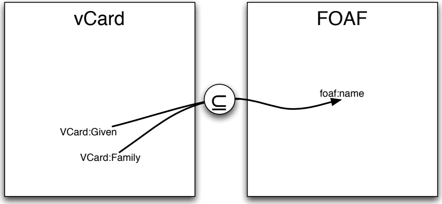


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You rather want built-in functions in the CONSTRUCT part.
This is what SPARQL++ provides.

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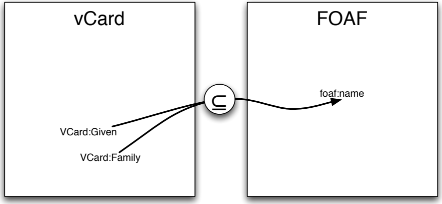


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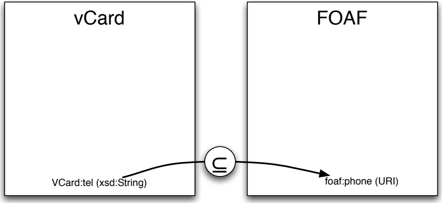
Attention: Value generation in the CONSTRUCT part might again raise non-termination issues!

Example 4



With value generation in CONSTRUCTs and respective built-in support, this becomes easy again in SPARQL++:

```
CONSTRUCT { ?X foaf:phone
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WHERE { ?X VCard:tel ?T . }
```
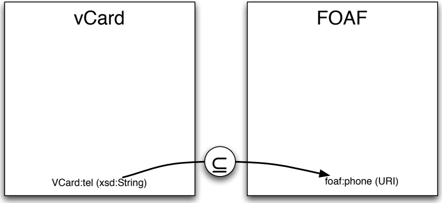

Example 4



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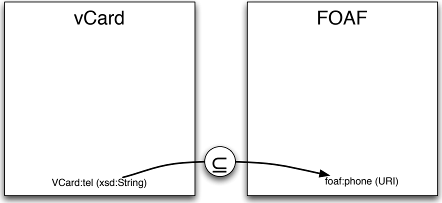

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Example 5

We want more: Aggregates!

Example: Map from DOAP to RDF Open Source Software Vocabulary:

```
CONSTRUCT { ?P os:latestRelease
   MAX(?V : ?P doap:release ?R. ?R doap:revision ?V) }
WHERE { ?P rdf:type doap:Project .  }
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Example 6

Note: “Views” – as we use them here for mappings – are also good for defining implicit knowledge within an RDF graph:

Example: “Import” my co-authors in my FOAF file, mapping from `myPubl.rdf` which uses the Dublin Core (DC) Vocabulary: “I know all my co-authors”

`foafWithImplicitdData.rdf`

```
:me a foaf:Person.
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CONSTRUCT{ :me foaf:knows _:P . _:P foaf:name ?N }
FROM <http://www.polleres.net/myPubl.rdf>
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:me foaf:knows [foaf:name "Stefan Decker"].
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SPARQL++ allows such extended RDF Graphs!

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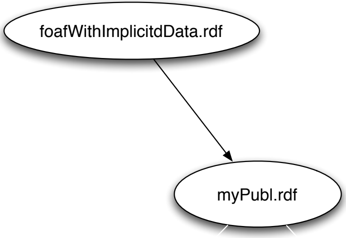

Goal: you can publish extended RDF Graphs, linked via mappings!

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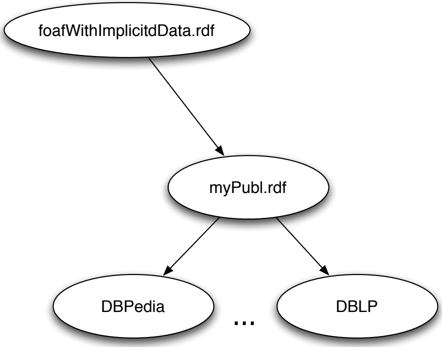

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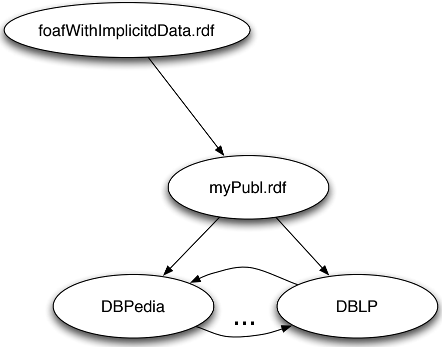

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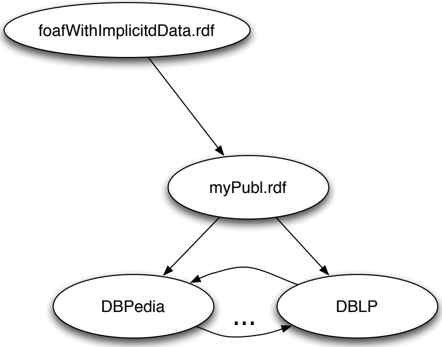

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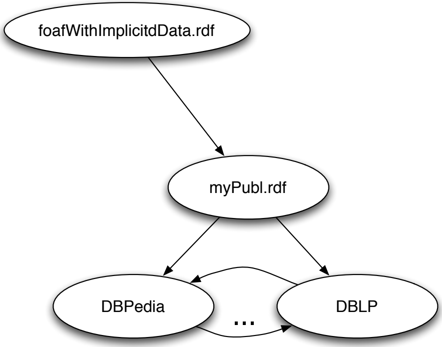

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Web = HTML + Links

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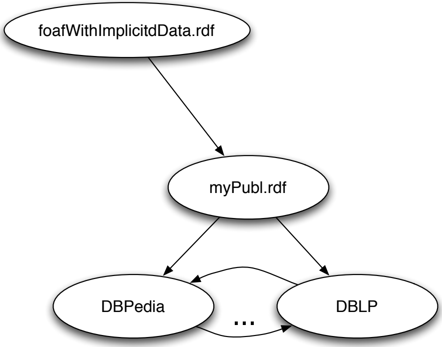

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Semantic Web = RDF + Mappings

Our Implementation: HEX-Programs

- We again translate (possibly nested and cross-referencing) SPARQL queries to Logic Programs with external atoms (HEX-atoms)
- HEX-programs are Datalog programs with negation as failure and a very generic Built-in mechanism.
- A HEX-program is a set of rules:[2]

$$h \leftarrow b_1, \ldots, b_m, \ \mathtt{not} \ \ b_{m+1}, \ldots \ \mathtt{not} \ \ b_n \tag{1}$$

- where so-called *external atoms* of the form

$$EXT[Input](Output) \tag{2}$$

  are allowed.
- Note: External Atoms can take *predicates* as inputs $\longrightarrow$ More generic than "normal" built-in predicates in logic programming!

[2]Note: Generally, HEX-programms also allow disjunctive rules, but not necessary here.

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SPARQL-specific external Atoms:

For the additional features, we need more than just the `rdf` atom from before:

- `rdf[URL](S,P,O)` ...imports all RDF Triples from a given URL
- `CONCAT[`$\mathtt{Str}_1$`,...,`$\mathtt{Str}_n$`](Str)` concatenates Strings.
- `COUNT[Predicate, BindingPattern](Cnt)` ...returns the count of a certain predicate extension, given a certain binding pattern.
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Demo Translation

Data in `myPubl.rdf`:

```
:p1 a :Publ.
:p1 dc:author "Axel Polleres".
:p1 dc:author "Francois Scharffe".
:p1 dc:author "Roman Schindlauer".
...
```

Query:

```
CONSTRUCT{ :me foaf:knows _:P . _:P foaf:name ?N }
FROM <http://www.polleres.net/myPubl.rdf>
WHERE { ?P a :Publ. ?P dc:author ?N.
        FILTER(?N != "Axel Polleres") }
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Translated HEX Program:

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triple(S,P,O) :- &rdf["http://www.polleres.net/myPubl.rdf"](S,P,O).
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answer(N,P) :- triple(P,"rdf:type",":Publ"),
               triple(P,"dc:author",N),
               N != "Axel Polleres".
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triple_result(":me","foaf:knows",Blank_P) :-
   answer(N,P), &SK[ "#genid_P",N,P](Blank_P).
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Result:

```
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triple_result("#genid_P('Francois Scharffe',:p1)","foaf:name","Francois Scharffe")
triple_result(":me","foaf:knows","#genid_P('Roman Schindlauer',:p1)")
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```

Can in turn be translated back to RDF Triples:

```
:me foaf:knows _:b1.
_:b1 foaf:name "Francois Scharffe".
:me foaf:knows _:b2.
_:b2 foaf:name "Roman Schindlauer".
```

Aggregates Translation:

```
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Find more details on the translation in the paper.

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- RDFS Semantics can be expressed in Rules
- So, it is expressible as CONSTRUCT queries

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- Simply add these to you extended graph, if RDFS needed. Will be evaluated (recursively) by our translation.

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From SPARQL to LP
Basic Graph Patterns
GRAPH Patterns
FILTERs
UNION Patterns
OPTIONAL and Negation as failure
Full SPARQL-Spec compliance
ORDER BY, LIMIT, OFFSET
Multi-set semantics
FILTERs in OPTIONALs
SPARQL++ for Ontology alignment
Mapping by SPARQL
Examples
Implementation
Example Translation
RDFS
Wrap-up

Summary

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Find more details in [Polleres et al., 2007]:

- Formal Semantics of Extended Graphs, based on Stable Model Semantics for HEX-Programs.
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[3] diff: stable vs. well-founded semantics, safe value-generation allowed, aggregates, built-ins

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