Next Steps on SPARQL

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Outline

SPARQL and LP 1/2

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

  Example: Two tables containing adressbooks

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

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

  ```
  answer1(Name) :- myAddr(Name, Street, "Bolzano", 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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SPARQL and LP 2/2

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

- Prolog-like syntax
- We assume availability of built-in predicate `rdf[URL](S,P,O)` to import RDF data.
- 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"

```
SELECT ?X ?Y
FROM <alice.org>
FROM NAMED <alice.org>
FROM NAMED <ex.org/bob>
WHERE { ?G foaf:maker ?X .
         GRAPH ?G { ?X foaf:knows ?Y. } }
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triple(S,P,O,def) :- rdf["alice.org"](S,P,O).
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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) :-
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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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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:

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

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]):

$\{P_1$ `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"

```
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".

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"

```
SELECT ?X
WHERE
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  ?X a ?Person
  OPTIONAL {?X :email ?Email }
  FILTER ( !bound( ?Email ) )
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SPARQL and LP: OPT Patterns – First Try

```
SELECT *
WHERE
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  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.

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),
  answer1("_:c","Bob",def), answer1("alice.org#me","Alice", def) }
```

SPARQL and LP: OPT Patterns – Example

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           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 } }
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```

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```

```
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FROM <http://ex.org/bob>
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```

Result:

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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:

```
SELECT *
FROM ...
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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```

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

⋈

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

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

⋈

?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!

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

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SPARQL and LP: OPT Patterns – Correct Result:

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

⋈

?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!

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?X1	?N
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alice.org#me	

=

?X1	?N	X2
_:a	"Bob"	_:a
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_: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!

How do I emulate b-joining Semantics? Solution:

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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```

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

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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) ⇒ `"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 .
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```

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

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```
SELECT ?N
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```

answer1(?N,?X,def) :- triple(X,foaf:name,Y,def).
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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(M,X,def) :- triple_Q(X,foaf:mbox,M,def).
answer2'_P(X,def) :- answer2_P(M,X,def).
answer_Q(N,M) :- answer1_P(Age,N,M,X,def).
```

Outline

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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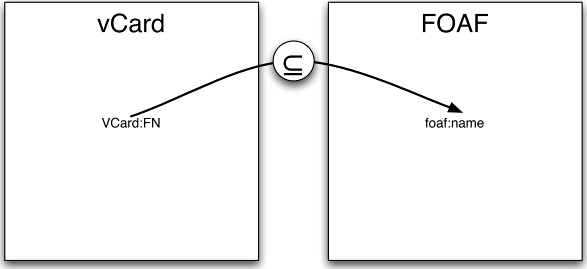
Mapping Scenarios

Map from vCard to FOAF:



Expressible by `rdfs:subPropertyOf`:

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

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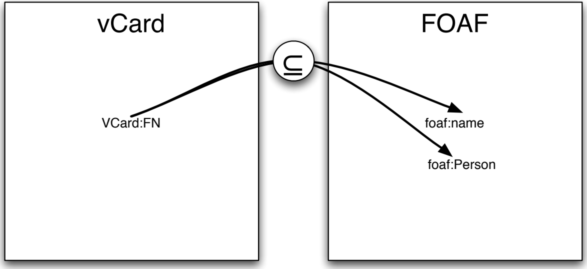

Also expressible in RDFS or in OWL DL:

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

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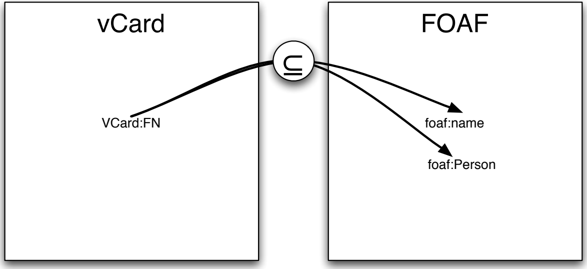

Also expressible in RDFS or in OWL DL:

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

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

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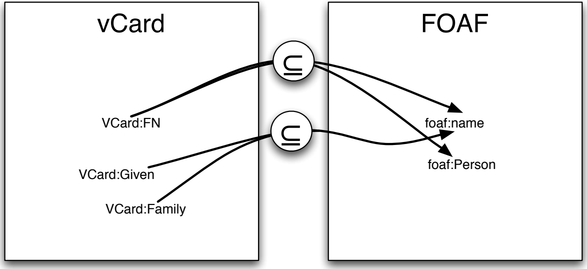

Needs string concatenation, not expressible in OWL or RDFS...

maybe SWRL can help, but

(1) implementations missing

(2) no W3C stamp

Mapping Scenarios

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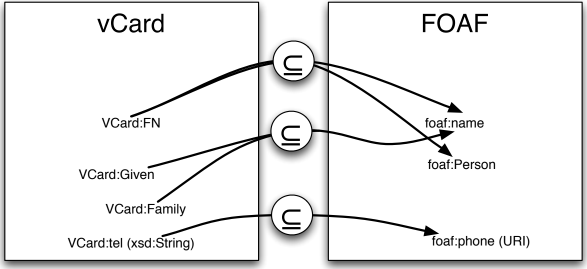

What shall we do here?
Needs conversion from String to rdf:Resource (URI)...how?
Let's see what SPARQL can do for us...

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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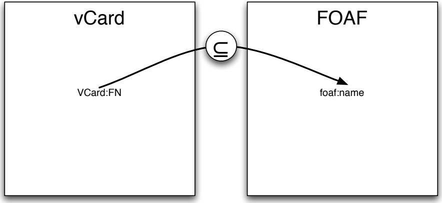


```
CONSTRUCT { ?X foaf:name ?Y }
WHERE     { ?X VCard:FN  ?Y }
```

Easy!

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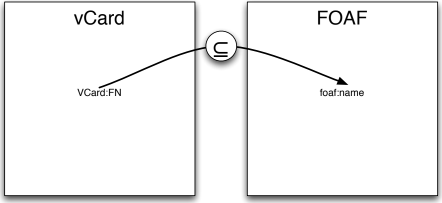


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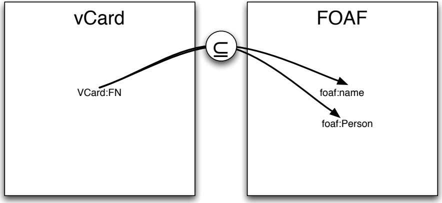
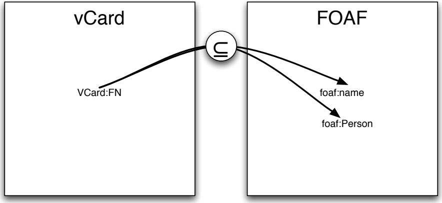



```
CONSTRUCT { ?X foaf:name ?Y . ?X rdf:type foaf:person . }
WHERE     { ?X VCard:FN  ?Y }
```

No problem either.

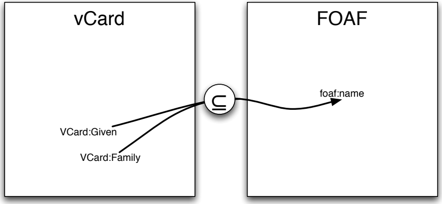
Example 2




```
CONSTRUCT { ?X foaf:name ?Y . ?X rdf:type foaf:person . }
WHERE     { ?X VCard:FN  ?Y }
```

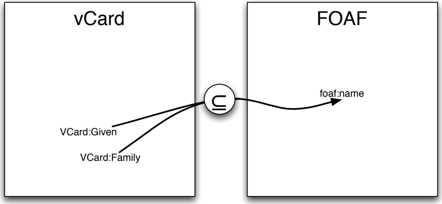
No problem either.

Example 3




```
CONSTRUCT { ?X foaf:name ???  }
WHERE     { ?X VCard:Given ?N. ?X VCard:Family ?F
          }
```

Example 3

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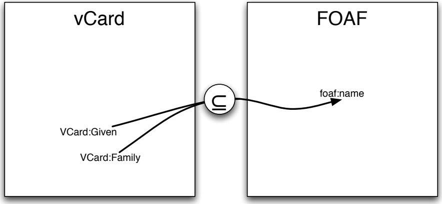
How to tackle? FILTERs?

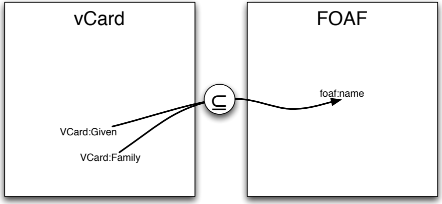
Example 3




```
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

Example 3

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

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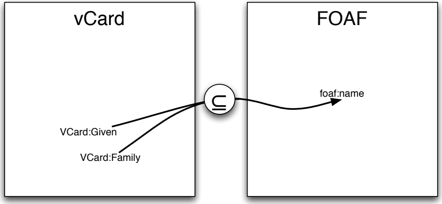


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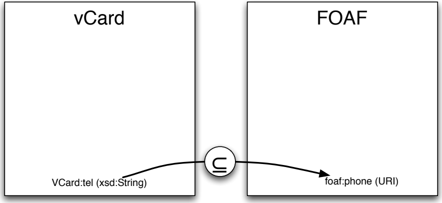
You rather want built-in functions in the CONSTRUCT part.
This is what SPARQL++ provides.
Attention: Value generation in the CONSTRUCT part might again raise non-termination issues!

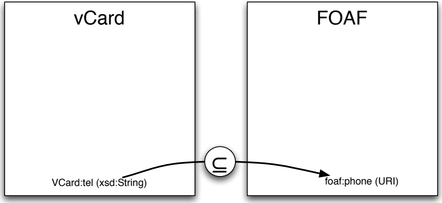
Example 4



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

```
CONSTRUCT { ?X foaf:phone
   rdf:Resource(fn:concat("tel:",fn:encode-for-uri(?T)) . }
WHERE { ?X VCard:tel ?T . }
```

Example 4



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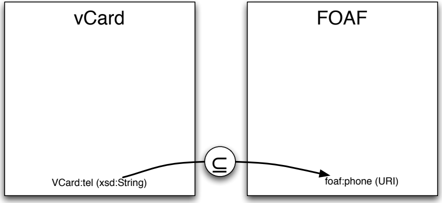

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Example 5

We want more: Aggregates!

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

```
CONSTRUCT { ?P os:latestRelease
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Example 5

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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.
:me foaf:name "Axel Polleres".
CONSTRUCT{ :me foaf:knows _:P . _:P foaf:name ?N }
FROM <http://www.polleres.net/myPubl.rdf>
WHERE { ?P rdf:type :Publ.
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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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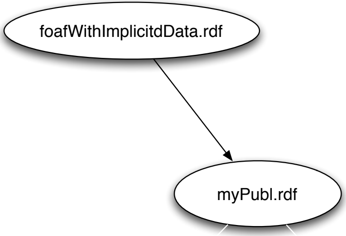
Open Linked data with extended RDF Graphs:



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

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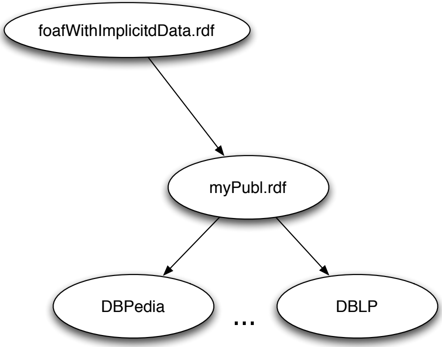

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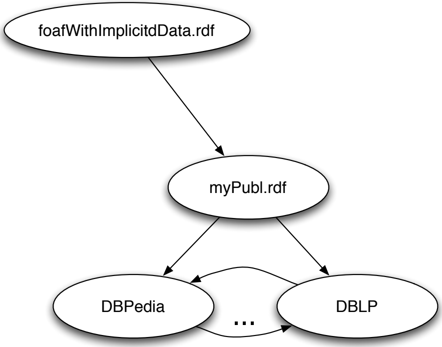

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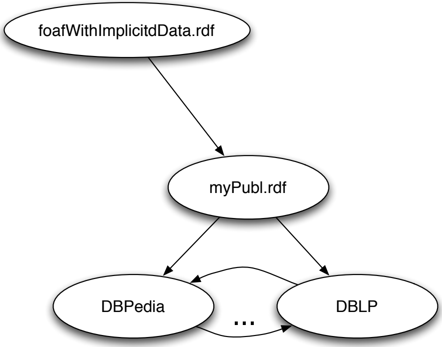

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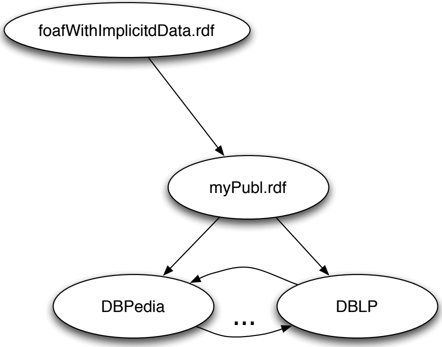

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Web = HTML + Links

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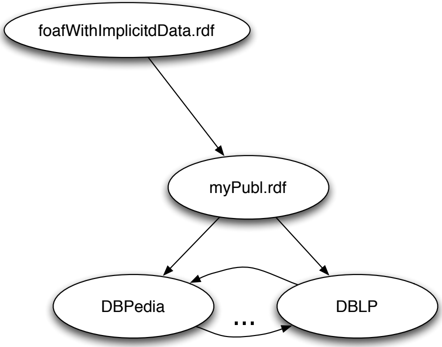

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Semantic Web = RDF + Mappings

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]

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

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

$$EXT[Input](Output) \qquad (2)$$

are allowed.

- Note: External Atoms can take *predicates* as inputs → 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:

```
triple(S,P,O) :- &rdf["http://www.polleres.net/myPubl.rdf"](S,P,O).
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Translated HEX Program:

```
triple(S,P,O) :- &rdf["http://www.polleres.net/myPubl.rdf"](S,P,O).
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).
triple_result(Blank_P,"foaf:name",N) :-
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:p1 a :Publ.
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Result:

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

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

will become:

```
triple_result(P,os:latestRelease,V_a) :- MAX[aux_a,P,mask](V_a),
                                         triple(P,rdf:type,doap:Project,def).
aux_a(P,V) :- answer_a(P,R,V).
answer_a(P,R,V) :- triple(P,doap:release R,def),
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Find more details on the translation in the paper.

RDFS Inference:

- 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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Outline

Summary

Take-home message:

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- Application ontology mappings: Current standards don't provide the right "ingredients" to describe the necessary mappings
- extended version of SPARQL, SPARQL++, fills this gap and adds more...
- SPARQL++ allows the definition of "Extended Graphs", i.e. Mappings+RDF Data in one file, similar to "Networked Graphs" [Schenk and Staab, 2007][3]

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

- Formal Semantics of Extended Graphs, based on Stable Model Semantics for HEX-Programs.
- A "safety condition" for recursive mappings with bnodes and value-generating CONSTRUCTs.

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- ... i.e. allow to publish mappings and implicit RDF data on the Web.
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