SPARQL and the Rules Layer

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Outline

The SW Rules layer in a nutshell
   Rules for the Semantic Web

Translating SPARQL to LP style rules languages
   Basic Graph Patterns
   GRAPH Patterns
   UNION Patterns
   OPTIONAL and Negation as failure

Other Rules languages and formats
   SWI Prolog, TRIPLE, N3
   SPARQL and RIF
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Back to the layer cake...

Hope you enjoyed the coffee break...
Back to the layer cake...

Bijan will talk about this one in the last part . . .
Back to the layer cake...

...Now what about that one?
Several proposals for systems and rules languages on the Web usable on top of RDF/RDFS:

- TRIPLE [Decker et al., 2005]
- N3 [Berners-Lee et al., 2005]
- dlvhex [Eiter et al., 2005]
- SWI-Prolog’s semweb library [Wielemaker, ]
- SWRL [Horrocks et al., 2004]
- SWSL Rules [Battle et al., 2005]
- WRL, WSML [Angele et al., 2005, de Bruijn et al., 2005]

RIF working group chartered in Dec 2005 to provide common interchange format (sic! Not a rule language) for the Web:

- Is currently producing first concrete results and first draft format, in the future likely a common format for the approaches above
- apart from deductive rules also concerned with other “rules”: business rules, ECA rules, (integrity) constraints
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Starting point: SQL can (to a large extent) be encoded in LP with negation as failure ($=\text{Datalog}^{\not\text{not}}$)

Example: Two tables containing address books
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).

That was easy... Now what about SPARQL?

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myAddr(Name, Street, City, Telephone)
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SELECT name FROM myAddr WHERE City = "Innsbruck"
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We take as an example the language of dlvhex (http://con.fusion.at/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).

`rdf[URL](S,P,O)` is one such built-in to import RDF data.

The example translations in this Unit work similarly using e.g. SWI-Prolog’s rdf_db module (see, http://www.swi-prolog.org/packages/semweb.html).
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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 . }
```

```
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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We import all triples in a predicate `triple(Subject, Predicate, Object, Graph)` which carries an additional argument for the dataset.

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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>  
    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),  

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UNIONs are split of into several rules:

“select Persons and their names or nicknames”

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SELECT ?X ?Y
FROM ...
WHERE { { ?X foaf:name ?Y . }
    UNION { ?X foaf:nick ?Y . } }
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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"; foaf:nick "Bobby".

Result:

<table>
<thead>
<tr>
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```
“select all persons and optionally their names”

```sparql
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`:

\[
\{ P_1 \text{ OPTIONAL } \{ P_2 \} \} : \quad M_1 \bowtie M_2 = (M_1 \bowtie M_2) \cup (M_1 \setminus M_2)
\]

where \( M_1 \) and \( M_2 \) are variable binding for \( P_1 \) and \( P_2 \), resp.
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Observation: SPARQL allows to express set difference / negation as failure by combining OPT 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”.

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SPARQL’s OPTIONAL has “negation as failure”, hidden:

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SELECT *  
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}

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

\[\text{triple}(S,P,O,\text{def}) :- \ldots \]
\[\text{answer1}(X,N,\text{def}) :- \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}), \]
\[\quad \text{triple}(X,"\text{foaf:name}",N,\text{def}). \]
\[\text{answer1}(X,\text{null},\text{def}) :- \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}), \]
\[\quad \text{not } \text{answer2}(X). \]
\[\text{answer2}(X) :- \text{triple}(X,"\text{foaf:name}",N,\text{def}). \]

We use \textbf{null} and negation as failure \textbf{not} to “emulate” set difference.
SELECT *
WHERE
{
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  OPTIONAL {?X foaf:name ?N }
}

Recall: \( (P_1 \text{ OPT } P_2): \quad M_1 \bowtie M_2 = (M_1 \bowtie M_2) \cup (M_1 \setminus M_2) \)

\[
\begin{align*}
\text{triple}(S,P,O,\text{def}) :& \quad \ldots \\
\text{answer1}(X,N,\text{def}) :& \quad \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}), \\
& \quad \text{triple}(X,"\text{foaf:name}",N,\text{def}). \\
\text{answer1}(X,\text{null},\text{def}) :& \quad \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}), \\
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\end{align*}
\]

We use \text{null} and negation as failure \text{not} to “emulate” set difference.
SPARQL and LP: OPT Patterns – First Try

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

Recall: \((P_1 \ OPT \ P_2)\):  \(M_1 \bowtie M_2 = (M_1 \bowtie M_2) \cup (M_1 \setminus M_2)\)

\begin{align*}
\text{triple}(S,P,O,\text{def}) & : \quad \cdots \\
\text{answer1}(X,N,\text{def}) & : \quad \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}), \\
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\end{align*}

We use \textit{null} and negation as failure not to “emulate” set difference.
SELECT *
WHERE
{
  ?X a foaf:Person .
  OPTIONAL {?X foaf:name ?N }
}

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

\[
\text{triple}(S,P,0,\text{def}) :- \ldots
\]
\[
\text{answer1}(X,N,\text{def}) :- \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}),
\text{triple}(X,"\text{foaf:name}",N,\text{def}).
\]
\[
\text{answer1}(X,\text{null},\text{def}) :- \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}),
\text{not}\ \text{answer2}(X).
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SPARQL and LP: OPT Patterns – First Try

SELECT *
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\[\text{triple}(S,P,0,\text{def}) \leftarrow \ldots\]
\[\text{answer1}(X,N,\text{def}) \leftarrow \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}),\]
\[\quad \text{triple}(X,"\text{foaf:name}",N,\text{def}).\]
\[\text{answer1}(X,\text{null},\text{def}) \leftarrow \text{triple}(X,"\text{rdf:type}","\text{foaf:Person}",\text{def}),\]
\[\quad \text{not answer2}(X).\]
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We use \textbf{null} and negation as failure \textbf{not} to “emulate” set difference.
SELECT *
WHERE
{
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    OPTIONAL { ?X foaf:name ?N }
}

Recall: \((P_1 \lor P_2)\)
\[
M_1 \lor M_2 = (M_1 \times M_2) \cup (M_1 \setminus M_2)
\]

\begin{verbatim}
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).
\end{verbatim}

We use **null** and negation as failure **not** to “emulate” set difference.
SELECT *
FROM <http://alice.org>
FROM <http://ex.org/bob>
WHERE { ?X a foaf:Person . OPTIONAL { ?X foaf:name ?N } }

Result:

<table>
<thead>
<tr>
<th>?X</th>
<th>?N</th>
</tr>
</thead>
</table>
| _:a   | "Bob"
| _:b   | "Bob"
| _: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

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

Result:

<table>
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<th>?N</th>
</tr>
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<tbody>
<tr>
<td>_:a</td>
<td>&quot;Bob&quot;</td>
</tr>
<tr>
<td>_:b</td>
<td>&quot;Bob&quot;</td>
</tr>
<tr>
<td>_:c</td>
<td>&quot;Bob&quot;</td>
</tr>
<tr>
<td>alice.org#me</td>
<td>&quot;Alice&quot;</td>
</tr>
</tbody>
</table>

{ answer1("_:a","Bob",def), answer1("_:b",null, def), answer1("_:c","Bob",def), answer1("alice.org#me","Alice", def) }
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:

<table>
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<th>?N</th>
</tr>
</thead>
<tbody>
<tr>
<td>_:a</td>
<td>&quot;Bob&quot;</td>
</tr>
<tr>
<td>_:b</td>
<td>null</td>
</tr>
<tr>
<td>_:c</td>
<td>&quot;Bob&quot;</td>
</tr>
<tr>
<td>alice.org#me</td>
<td>&quot;Alice&quot;</td>
</tr>
</tbody>
</table>

{ answer1("_:a","Bob",def), answer1("_:b",null, def),
  answer1("_:c","Bob",def), answer1("alice.org#me","Alice", def) }
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 } } }

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

**Remark:** this pattern is not well-designed, following Unit 4!
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 } } }
```

<table>
<thead>
<tr>
<th>(?X1)</th>
<th>(?N)</th>
<th>(?X2)</th>
<th>(?N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>_:a</td>
<td>&quot;Bob&quot;</td>
<td>_:a</td>
<td>&quot;Alice&quot;</td>
</tr>
<tr>
<td>_:b</td>
<td></td>
<td>_:b</td>
<td></td>
</tr>
<tr>
<td>_:c</td>
<td></td>
<td>_:c</td>
<td></td>
</tr>
<tr>
<td>alice.org#me</td>
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```
SELECT *
FROM ...
```

<table>
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<th>?N</th>
</tr>
</thead>
<tbody>
<tr>
<td>_:a</td>
<td>&quot;Bob&quot;</td>
</tr>
<tr>
<td>_:b</td>
<td>&quot;Bob&quot;</td>
</tr>
</tbody>
</table>
| _:c     | "Alice"
| alice.org#me |

<table>
<thead>
<tr>
<th>?X2</th>
<th>?N</th>
</tr>
</thead>
</table>
| _:a     | "Alice"
| _:b     | "Bobby"
| _:c     | "Alice"
| alice.org#me |

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

**Remark:** this pattern is not well-designed, following Unit 4!
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!
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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</tr>
</thead>
<tbody>
<tr>
<td>_:a</td>
<td>&quot;Bob&quot;</td>
<td>_:a</td>
<td><code>null</code></td>
</tr>
<tr>
<td>_:b</td>
<td>&quot;null&quot;</td>
<td>_:b</td>
<td>&quot;Alice&quot;</td>
</tr>
<tr>
<td>_:c</td>
<td>&quot;Bob&quot;</td>
<td>_:c</td>
<td>&quot;Bobby&quot;</td>
</tr>
<tr>
<td>alice.org#me</td>
<td>&quot;Alice&quot;</td>
<td>alice.org#me</td>
<td><code>null</code></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>?X1</th>
<th>?N</th>
<th>X2</th>
</tr>
</thead>
<tbody>
<tr>
<td>_:b</td>
<td><code>null</code></td>
<td>_:a</td>
</tr>
<tr>
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<td><code>null</code></td>
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</tr>
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SPARQL and LP: OPT Patterns – Correct Result:

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

```
spatial join ?X1 ?X2

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</tr>
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</tbody>
</table>
```

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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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SELECT *
FROM ...
WHERE {
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  { ?X2 a foaf:Person . OPTIONAL { ?X2 foaf:nick ?N } }
}

triple(S,P,O,def) :- rdf["ex.org/bob"](S,P,O).
triple(S,P,O,def) :- rdf["alice.org"](S,P,O).

answer1(N,X1,X2,def) :- answer2(N,X1,def), answer4(N,X2,def).

answer2(N, X1,def) :- triple(X1,"a","Person",def),
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answer2(null,X1,def) :- triple(X1,"a","Person",def),
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answer3(X1,def)      :- triple(X1,"name",N,def).

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answer5(X2,def)      :- triple(X2,"nick",N,def).

Here is the problem! Join over a possibly null-joining variable
SELECT *
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Here is the problem! Join over a possibly null-joining variable
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.

```prolog
triple(S,P,0,def) :- rdf["ex.org/bob"](S,P,0).
triple(S,P,0,def) :- rdf["alice.org"](S,P,0).

answer1(N,X1,X2,def) :- answer2(N,X1,def), answer4(N,X2,def).
answer1(N,X1,X2,def) :- answer2(N,X1,def), answer4(null,X2,def).
answer1(N,X1,X2,def) :- answer2(null,X1,def), answer4(N,X2,def).

answer2(N, X1,def) :- triple(X1,"a","Person",def),
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```
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```

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answer2(N, X1, def) :- triple(X1, "a", "Person", def),
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answer5(X2, def) :- triple(X2, "nick", N, def).
```
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!
Attention:

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- This is not surprising, since the complexity of OPTIONAL/UNION corner cases is PSPACE, see [Pérez et al., 2006].

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With these ingredients any SPARQL query $Q$ can be translated recursively to a Datalog program $P_q$ with a dedicated predicate $\text{answer1}_Q$ which contains exactly the answer substitutions for $Q$.

The target language is non-recursive Datalog with neg. as failure.

Non-well-designed combinations of OPTIONAL and UNION are nasty and need special care: Special treatment for the case where possibly null values are joined.

Full details of the translation in [Polleres, 2007].

FILTERS not treated in detail, basically an implementation issue, needs a rules engine with support for external built-ins.

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Prototype engine implemented and available at:
http://con.fusion.at/dlvhex/sparql-query-evaluation.php
Outline

The SW Rules layer in a nutshell
Rules for the Semantic Web

Translating SPARQL to LP style rules languages
Basic Graph Patterns
GRAPH Patterns
UNION Patterns
OPTIONAL and Negation as failure

Other Rules languages and formats
SWI Prolog, TRIPLE, N3
SPARQL and RIF
Other LP style languages

Similar considerations apply to other rule systems that allow to process RDF data, each of which has some syntactic peculiarities. We exemplify here:

- dlvhex
  - Done! SPARQL-plugin available.
- SWI-Prolog
  - similar... rdf_db module supports rdf/3, rdf/4 predicates, analogous to dlvhex rdf built-in.
- TRIPLE
- N3
TRIPLE

- RDF rules processor on top of XSB Prolog, developed by Michael Sintek, Stefan Decker.
- F-Logic style syntax, i.e. triple S P O. viewed as F-Logic molecule S[P→O]
- Special features: module mechanism.

Basic pattern SPARQL query “emulated” in TRIPLE:

```sparql
@PREFIX foaf: <http://xmlns.com/foaf/0.1/> .
SELECT ?X ?Y
FROM <http://alice.org>
FROM <http://ex.org/bob>
WHERE { ?X foaf:name ?Y .
  ?X a foaf:Person . }
```

- UNION can be done as before.
- TRIPLE doesn’t support negation as failure, thus OPTIONAL not possible.
  (Negation as failure can be the well-founded semantics.)
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Basic pattern SPARQL query “emulated” in TRIPLE:

```plaintext
foaf:= 'http://xmlns.com/foaf/0.1/'.
rdf:= 'http://www.w3.org/1999/02/22-rdf-syntax-ns#'.
    S[P->O]@’http://ex.org/bob’.

FORALL X,Y answer(X,Y) <- (X[rdf:name->Y] AND 
    X[foaf:type->foaf:person]).
```

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GRAPH pattern SPARQL query “emulated” in TRIPLE:

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

UNION can be done as before.

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GRAPH pattern SPARQL query “emulated” in TRIPLE:

\[
\text{FORALL } S, P, O \ S[P\rightarrow O] \leftarrow S[P\rightarrow O]@'http://alice.org'.
\]

\[
\text{FORALL } X, Y \ \text{answer}(X,Y) \leftarrow (G[foaf:maker\rightarrow X] \ \text{AND} \ X[foaf:knows\rightarrow Y]@G).
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N3 logic syntax, an extension of Turtle syntax.

Special features: has negation as failure (log:notIncludes).

Semantics... ? Probably perfect model semantics (i.e. only deals with stratified negation as failure)

Basic pattern SPARQL query “emulated” in N3:

```
@PREFIX foaf: <http://xmlns.com/foaf/0.1/> .
SELECT ?X ?Y
FROM <http://alice.org>
FROM <http://ex.org/bob>
WHERE { ?X foaf:name ?Y .
    ?X a foaf:Person . }
```
N3

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- N3 logic syntax, an extension of Turtle syntax.
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Basic pattern SPARQL query “emulated” in N3:

```sparql
{ <http://alice.org> log:semantics ?A.
  (?A ?B) log:conjunction ?C.
} log:implies { myQuery hasAnswer (?X ?Y) . }
```

Remark: We “encode” answer substitutions in triples here.
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GRAPH pattern SPARQL query “emulated” in N3:

\[
\{ <http://alice.org> \text{log:semantics} \ ?A. \\
\ ?A \text{log:supports} \{ \ ?G \text{foaf:maker} \ ?X \ . \} \\
\ ?G \text{log:semantics} \ ?B. \\
\ ?B \text{log:supports} \{ \ ?X \text{foaf:knows} \ ?Y. \} \\
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How to “emulate” OPTIONAL patterns in N3:

log:notIncludes in N3 is negation as failure!
RIF charter requires rules to deal with RDF data

It is also written in the RIF charter that RIF should compatible to deal with SPARQL queries to access (external) datasets

Both not yet addressed in WD1, first step:

Simple “webbish” Horn-style rules language (RIF Core)

Trouble: Has to address incompatibilities at lower levels... e.g.

- URIs: Qnames in XML vs. RDF treatment of namespaces
- compatibility with RDFS, OWL (not fully tackled in SPARQL even)

Last but not least: SPARQL itself may be viewed as a rules language e.g. take the RDFS entailment rule (rdfs3) from [Hayes, 2004]

→ More on that in the next Unit!
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*If an RDF graph contains triples (P rdfs:range C) and (S P O) then the triple O rdf:type C is entailed.*

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