CS 7810 - Knowledge Representation and Reasoning (for the Semantic Web)

05 - SPARQL

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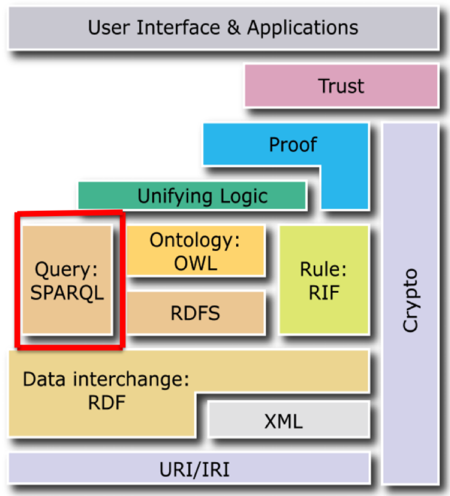
Outline


User Interface & Applications
Trust
Proof
Unifying Logic
Query: SPARQL
Ontology: OWL
RDFS
Rule: RIF
Crypto
Data interchange: RDF
XML
URI/IRI

Acknowledgements

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Materials in this presentation are adapted from:

- Sebastian Rudolph, "SPARQL Syntax and Intuition", slides for Foundations of Semantic Web Technologies course, TU Dresden, May 2, 2014.
- Sebastian Rudolph, "Semantics of SPARQL", slides for Foundations of Semantic Web Technologies course, TU Dresden, May 2, 2014.
- Sebastian Rudolph, "SPARQL Algebra", slides for Foundations of Semantic Web Technologies course, TU Dresden, May 9, 2014.
- Axel Polleres, "Unit 4: SPARQL 1.0 in Detail & SPARQL's formal semantics", slides for Semantic Web Technologies course, TU Vienna, May 14, 2012.
- Axel Polleres, "Unit 5: SPARQL 1.1", slides for Semantic Web Technologies course, TU Vienna, May 14, 2012.

Outline

- RDF(S): "Can one RDF graph be inferred from another one?"
  - Simple entailment
  - RDF entailment
  - RDFS entailment
- OWL Ontologies: "Is a class a subclass of another class?", "What are instances of an (OWL) class?"
  - OWL (logical) entailment
- How about:
  - "Which properties relate two given individuals?"
  - "Who co-authors a paper together with Adila Krisnadhi?"
  - "What is the title of the national anthem of the USA?"

  These are difficult to express (or even not all) via RDF/OWL entailments.

- Stands for: "**S**PARQL **P**rotocol and **R**DF **Q**uery **L**anguage" (recursive acronym ☺)
- Query language for RDF graphs
- SPARQL 1.0: W3C Specification in 2008
- SPARQL 1.1: W3C Specification in 2013

SPARQL Specs Summary

- SPARQL 1.0
  - Syntax and semantics of query language
  - Query results in XML format: how to present results in XML
  - Protocol for transmitting queries to a query processing service and returning the results
- SPARQL 1.1
  - Query: extending SPARQL 1.0 query language
  - RDF graph update through SPARQL
  - Graph Store HTTP Protocol: HTTP operations for managing a graph collection
  - Entailment regimes: query results with (additional) inferences
  - Service description: methods for discovering and describing (using standard vocabulary) SPARQL services
  - Query federation: querying over distributed sources (multiple endpoints)
  - Additional query result format in JSON, CSV, TSV.
- Note: SPARQL queries can, in practice, be run on SPARQL endpoints, behind which RDF data is stored. They cannot be run on plain RDF files.

Outline

DBLP RDF Data from Unofficial Endpoint

http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
@prefix swrc: <http://swrc.ontoware.org/ontology#> .
@prefix dblpa: <http://dblp.l3s.de/d2r/resource/authors/> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dc:identifier "DBLP conf/rweb/KrisnadhiMH11"^^xsd:string ;
    foaf:maker dblpa:Pascal_Hitzler  ;
    dcterms:partOf <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/2011> ;
    foaf:maker  dblpa:Adila_Krisnadhi ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker dblpa:Frederick_Maier ;
    rdfs:label "OWL and Rules."^^xsd:string .
...
<http://dblp.l3s.de/d2r/resource/publications/journals/semweb/BlomqvistHJKNS16>
    foaf:maker dblpa:Adila_Krisnadhi ;
    ...
    rdf:type swrc:Article .
...
dblpa:Adila_Krisnadhi rdf:type foaf:Agent ;
    foaf:name "Adila Krisnadhi" .
...
```

Simple Query Example

Try at http://dblp.l3s.de/d2r/snorql/

"List the title of the publications authored by Adila Krisnadhi?"

```
PREFIX dblpa: <http://dblp.l3s.de/d2r/resource/authors/>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT ?publication ?title
WHERE {
  ?publication foaf:maker dblpa:Adila_Krisnadhi .
  ?publication rdfs:label ?title .
}
```

Basic Graph Patterns

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- The main part of a SPARQL query is located within the WHERE clause, consisting of graph patterns.
  - The SELECT clause is one of the output forms – other output forms include: CONSTRUCT, ASK, DESCRIBE.
- A basic graph pattern (BGP) is a set of triple patterns.
- A triple pattern is an RDF triple, optionally containing variables (prefixed with '?') in subject/predicate/object positions.
- BGP uses Turtle syntax.
- Abbreviated IRIs possible (via PREFIX) – an alternative from the @prefix syntax from Turtle.

Intuition behind SPARQL

Match the given patterns against a given RDF graph and returns a multiset of solution mappings. Each solution mapping itself is a set of particular bindings for the variables in the pattern.

BGP Example

```
{  ?Pub foaf:maker dblpa:Adila_Krisnadhi ;
        foaf:maker  ?CoAuthor .
    ?CoAuthor foaf:name  ?Name . }
```

```
<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker  dblpa:Pascal_Hitzler  ;
    foaf:maker  dblpa:Adila_Krisnadhi ;
    foaf:maker  dblpa:Frederick_Maier .
dblpa:Adila_Krisnadhi foaf:name "Adila Krisnadhi" .
dblpa:Pascal_Hitzler foaf:name "Pascal Hitzler" .
dblpa:Frederick_Maier foaf:name "Frederick Maier" .
```

BGP Example

```
{  ?Pub foaf:maker dblpa:Adila_Krisnadhi ;
        foaf:maker  ?CoAuthor .
    ?CoAuthor foaf:name  ?Name . }
```

```
<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker  dblpa:Pascal_Hitzler  ;
    foaf:maker  dblpa:Adila_Krisnadhi ;
    foaf:maker  dblpa:Frederick_Maier .
dblpa:Adila_Krisnadhi foaf:name "Adila Krisnadhi" .
dblpa:Pascal_Hitzler foaf:name "Pascal Hitzler" .
dblpa:Frederick_Maier foaf:name "Frederick Maier" .
```

```
{  ?Pub foaf:maker dblpa:Adila_Krisnadhi ;
        foaf:maker  ?CoAuthor .
    ?CoAuthor foaf:name  ?Name . }
```

Solution mappings (could be presented as a table):

BGP Example

```
{  ?Pub foaf:maker dblpa:Adila_Krisnadhi ;
        foaf:maker  ?CoAuthor .
   ?CoAuthor foaf:name  ?Name . }
```

Solution mappings (could be presented as a table):

1. ?Pub ↦ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>, ?CoAuthor ↦ dblpa:Adila_Krisnadhi, ?Name ↦ "Adila Krisnadhi"

BGP Example

```
{  ?Pub foaf:maker dblpa:Adila_Krisnadhi ;
        foaf:maker  ?CoAuthor .
   ?CoAuthor foaf:name  ?Name . }
```

Solution mappings (could be presented as a table):

1. ?Pub ↦ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>, ?CoAuthor ↦ dblpa:Adila_Krisnadhi, ?Name ↦ "Adila Krisnadhi"
2. ?Pub ↦ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>, ?CoAuthor ↦ dblpa:Pascal_Hitzler, ?Name ↦ "Adila Krisnadhi"

BGP Example

```
{  ?Pub foaf:maker dblpa:Adila_Krisnadhi ;
        foaf:maker  ?CoAuthor .
   ?CoAuthor foaf:name  ?Name . }
```

Solution mappings (could be presented as a table):

1. ?Pub ↦ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>, ?CoAuthor ↦ dblpa:Adila_Krisnadhi, ?Name ↦ "Adila Krisnadhi"
2. ?Pub ↦ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>, ?CoAuthor ↦ dblpa:Pascal_Hitzler, ?Name ↦ "Adila Krisnadhi"
3. ?Pub ↦ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>, ?CoAuthor ↦ dblpa:Frederick_Maier, ?Name ↦ "Frederick Maier"

BGP Solution

- Evaluating a BGP results in a multiset of solution mappings.
  - Each solution mapping is a mapping from variables in the BGP into graph nodes or undefined value.
  - The evaluation of BGP in the previous slide consists of 3 solution mappings.
- The result of a BGP evaluation is empty if no solution mapping is possible.
- It is a multiset, i.e., it's unordered and the same binding may occur multiple times in a solution .
- If BGP has no variable but the pattern matches any part of the graph, then the result of the evaluation contains an empty solution mapping.
  - Watch out: an evaluation result consisting of an empty solution mapping is NOT the same as the empty result.

Empty Solution Mapping vs. Empty Solution

```
<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker dblpa:Pascal_Hitzler  ;
    foaf:maker dblpa:Adila_Krisnadhi ;
    foaf:maker dblpa:Frederick_Maier .
```

Empty Solution Mapping vs. Empty Solution

```
<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker dblpa:Pascal_Hitzler  ;
    foaf:maker dblpa:Adila_Krisnadhi ;
    foaf:maker dblpa:Frederick_Maier .
```

```
{ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
        foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> . }
```

Empty Solution Mapping vs. Empty Solution

```
<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker dblpa:Pascal_Hitzler  ;
    foaf:maker dblpa:Adila_Krisnadhi ;
    foaf:maker dblpa:Frederick_Maier .
```

```
{ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
        foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> . }
```

Solution $= \{\emptyset\}$.

Empty Solution Mapping vs. Empty Solution

```
<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker dblpa:Pascal_Hitzler  ;
    foaf:maker dblpa:Adila_Krisnadhi ;
    foaf:maker dblpa:Frederick_Maier .
```

```
{ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
        foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> . }
```

Solution $= \{\emptyset\}$.

```
{ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
        foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Carsten_Lutz> . }
```

Empty Solution Mapping vs. Empty Solution

```
<http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
    rdf:type swrc:InProceedings ;
    dcterms:issued "2011"^^xsd:gYear ;
    foaf:maker dblpa:Pascal_Hitzler  ;
    foaf:maker dblpa:Adila_Krisnadhi ;
    foaf:maker dblpa:Frederick_Maier .
```

```
{ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
        foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> . }
```

Solution $= \{\emptyset\}$.

```
{ <http://dblp.l3s.de/d2r/resource/publications/conf/rweb/KrisnadhiMH11>
        foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Carsten_Lutz> . }
```

Solution $= \emptyset$.

- SELECT *variableList* – returns a sequence of solution mappings restricted to the given variables.
  - If a variable in the SELECT clause does not occur in the BGP, it will be returned unbound.
  - If all variables in SELECT clause are unbound, the corresponding solution mapping is empty.
  - SELECT DISTINCT *variableList* – removes duplicate solution mappings.
  - SELECT (DISTINCT) * – returns the whole multiset (set) of solution mappings over all variables in the BGP.
- ASK, CONSTRUCT, DESCRIBE – see later discussion.

SELECT Example

Result may contain duplicates.

```
SELECT ?CoAuthor
WHERE {
   ?Pub foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> ;
        foaf:maker  ?CoAuthor .
   ?CoAuthor foaf:name  ?Name .
}
```

SELECT Example

Result may contain duplicates.

```
SELECT ?CoAuthor
WHERE {
   ?Pub foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> ;
        foaf:maker  ?CoAuthor .
   ?CoAuthor foaf:name  ?Name .
}
```

?CoAuthor
<http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi>
<http://dblp.l3s.de/d2r/resource/authors/Eva_Blomqvist>
<http://dblp.l3s.de/d2r/resource/authors/Krzysztof_Janowicz>
<http://dblp.l3s.de/d2r/resource/authors/Monika_Solanki>
<http://dblp.l3s.de/d2r/resource/authors/Pascal_Hitzler>
<http://dblp.l3s.de/d2r/resource/authors/Tom_Narock>
<http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi>
<http://dblp.l3s.de/d2r/resource/authors/Pascal_Hitzler>
<http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi>
<http://dblp.l3s.de/d2r/resource/authors/Carsten_Lutz>
...

SELECT DISTINCT Example

Result contains no duplicate.

```
SELECT DISTINCT ?CoAuthor
WHERE {
   ?Pub foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> ;
        foaf:maker  ?CoAuthor .
   ?CoAuthor foaf:name  ?Name .
}
```

SELECT DISTINCT Example

Result contains no duplicate.

```
SELECT DISTINCT ?CoAuthor
WHERE {
   ?Pub foaf:maker <http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi> ;
        foaf:maker  ?CoAuthor .
   ?CoAuthor foaf:name  ?Name .
}
```

?CoAuthor
<http://dblp.l3s.de/d2r/resource/authors/Adila_Krisnadhi>
<http://dblp.l3s.de/d2r/resource/authors/Eva_Blomqvist>
<http://dblp.l3s.de/d2r/resource/authors/Krzysztof_Janowicz>
<http://dblp.l3s.de/d2r/resource/authors/Monika_Solanki>
<http://dblp.l3s.de/d2r/resource/authors/Pascal_Hitzler>
<http://dblp.l3s.de/d2r/resource/authors/Tom_Narock>
<http://dblp.l3s.de/d2r/resource/authors/Carsten_Lutz>
...

Blank Nodes in SPARQL

Blank node in query pattern:

- Permitted as subject or object (as in RDF)
- Given an arbitrary ID; not permitted to be reused in different BGPs within one query
- Act like variables, but cannot be selected.

Blank node in result/solution:

- Represent an unknown element
- Given arbitrary ID (possibly different from its ID in the input RDF graph); repeated occurrences in result denote the same element

Queries involving Datatypes

Given RDF data:

```
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix ex: <http://example.org/> .
ex:ex1 ex:p "test" .
ex:ex2 ex:p "test"^^xsd:string .
ex:ex3 ex:p "test"@en .
ex:ex4 ex:p "42"^^xsd:integer .
```

What are the solution mappings for the following BGP?

```
{ ?subject <http://example.org/p> "test" . }
```

Queries involving Datatypes

Given RDF data:

```
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
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ex:ex4 ex:p "42"^^xsd:integer .
```

What are the solution mappings for the following BGP?

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{ ?subject <http://example.org/p> "test" . }
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`?subject` matches only `ex:ex1`. Exact match for datatypes/language tags are required.

Queries involving Datatypes

Given RDF data:

```
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix ex: <http://example.org/> .
ex:ex1 ex:p "test" .
ex:ex2 ex:p "test"^^xsd:string .
ex:ex3 ex:p "test"@en .
ex:ex4 ex:p "42"^^xsd:integer .
```

What are the solution mappings for the following BGP?

```
{ ?subject <http://example.org/p> "test" . }
```

`?subject` matches only `ex:ex1`. Exact match for datatypes/language tags are required. Special for numeric values, some syntactic sugar is allowed:

```
{ ?subject <http://example.org/p> 42 . }
```

has `ex:ex4` as a match for `?subject`.

- Datatype is determined solely from the syntactic form.

Alternative Patterns (UNION)

"List all publication titles authored by Adila Krisnadhi or Adila Alfa Krisnadhi or Adam Shepherd."

```
PREFIX dblpa: <http://dblp.l3s.de/d2r/resource/authors/>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?Title
WHERE {
  {  [ foaf:maker dblpa:Adila_Krisnadhi ;  rdfs:label ?Title ] . }
  UNION
  { [ foaf:maker dblpa:Adila_Alfa_Krisnadhi ;   rdfs:label ?Title ] . }
  UNION
  { [ foaf:maker dblpa:Adam_Shepherd ;  rdfs:label ?Title ] . }
}
```

- Use keyword `UNION`. BGPs are grouped by { ... }
- Result is the multi-set union of the results for each of the alternative BGPs.
- Identical variables within different UNION patterns do not influence each other.
- Some variables may be unbound, e.g., when a BGP in the UNION pattern has a variable that does not occur in the other BGPs.

Unbound Variables in UNION Result

"List the collections edited by Adila Krisnadhi and publications authored by him."

```
PREFIX swrc: <http://swrc.ontoware.org/ontology#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX dblpa: <http://dblp.l3s.de/d2r/resource/authors/>
SELECT ?EditedPub ?AuthoredPub
WHERE {
  {  ?EditedPub swrc:editor dblpa:Adila_Krisnadhi . }
  UNION
  { ?AuthoredPub foaf:maker dblpa:Adila_Krisnadhi . } }
```

Unbound Variables in UNION Result

"List the collections edited by Adila Krisnadhi and publications authored by him."

```
PREFIX swrc: <http://swrc.ontoware.org/ontology#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX dblpa: <http://dblp.l3s.de/d2r/resource/authors/>
SELECT ?EditedPub ?AuthoredPub
WHERE {
  {  ?EditedPub swrc:editor dblpa:Adila_Krisnadhi . }
  UNION
  { ?AuthoredPub foaf:maker dblpa:Adila_Krisnadhi . } }
```

EditedPub	AuthoredPub
http://dblp.l3s.de/.../conf/semweb/2015wop	
http://dblp.l3s.de/.../conf/ijcai/2015jowo	
	http://dblp.l3s.de/.../journals/semweb/BlomqvistHJKNS16
	http://dblp.l3s.de/.../reference/snam/KrisnadhiH14
	http://dblp.l3s.de/.../conf/lpar/KrisnadhiL07
	...

?AuthoredPub is unbound in the first and second solution mappings, while ?EditedPub is unbound in the remaining solution mappings.

From DBPedia repository (http://dbpedia.org/sparql/):
"Give all European countries, and optionally, their capital if the country is a member of European Union, "

```
PREFIX dbo: <http://dbpedia.org/ontology/capital>
PREFIX ygc: <http://dbpedia.org/class/yago/>
SELECT ?country ?capitalname
WHERE  { ?country a ygc:EuropeanCountries .
    OPTIONAL { ?country a ygc:MemberStatesOfTheEuropeanUnion ;
                         dbo:capital ?capital .
                ?capital rdfs:label ?capitalname . } }
```

Note: the predicate 'a' is an abbreviation for rdf:type according to the Turtle syntax spec.

?country	?capitalname
<http://dbpedia.org/resource/Netherlands>	"Amsterdam"@en
...	
<http://dbpedia.org/resource/Germany>	"Berlin"@en
<http://dbpedia.org/resource/Portugal>	"Lisbon"@en
<http://dbpedia.org/resource/Albania>	
<http://dbpedia.org/resource/Denmark>	
...	

Combination of UNION and OPTIONAL

- OPTIONAL always applies to one pattern group, specified to the right of the OPTIONAL keyword.
- OPTIONAL and UNION has equal precedence. Grouping is left-associative.

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- OPTIONAL always applies to one pattern group, specified to the right of the OPTIONAL keyword.
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This BGP

```
{ ?book ex:publishedBy <http://springer.com> .
   { ?book ex:author ?author . } UNION
   { ?book ex:editor ?author . } OPTIONAL
   { ?author ex:surname ?name . } }
```

is equivalent to

Combination of UNION and OPTIONAL

- OPTIONAL always applies to one pattern group, specified to the right of the OPTIONAL keyword.
- OPTIONAL and UNION has equal precedence. Grouping is left-associative.

This BGP

```
{ ?book ex:publishedBy <http://springer.com> .
   { ?book ex:author ?author . } UNION
   { ?book ex:editor ?author . } OPTIONAL
   { ?author ex:surname ?name . } }
```

is equivalent to

```
{ ?book ex:publishedBy <http://springer.com> .
   { { ?book ex:author ?author . } UNION
      { ?book ex:editor ?author . }
   } OPTIONAL { ?author ex:surname ?name . } }
```

Another Example

Given the data below:

```
@prefix dc10: <http://purl.org/dc/elements/1.0/> .
@prefix dc11: <http://purl.org/dc/elements/1.1/> .
@prefix ex: <http://ex.org/> .
_:a dc10:title "SPARQL Query Tutorial" .
_:a dc10:creator "Alice" .
_:b dc11:title "SPARQL Protocol Tutorial" .
_:b dc11:creator "Bob" .
_:b ex:level "beginners" .
```

Write a query that returns all titles (`dc10:title` or `dc11:title`) and, if given, the level (`ex:level`).

Querying Named Graphs I

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- Recall: an RDF Dataset is a set of RDF graphs containing one default graph and zero or more named graphs. Every named graph has a IRI as its name, while default graph has no name and may be empty.
- RDF dataset can be given by the triple store (by default) or specified by the user. The latter by specifying one or more FROM or FROM NAMED clauses. The user-specified RDF dataset is as follows:
  - a default graph consisting of the RDF merge of the graphs referred to in the FROM clauses, and
  - a set of (IRI, graph) pairs, one from each FROM NAMED clause.
- BGPs are matched to an active graph in the RDF dataset. Use GRAPH keyword to specify which named graph is active when matching a BGP. Without enclosing GRAPH keyword, BGP is matched to the default graph.

Querying Named Graphs II

"List people that occurs in the default graph and two different named graphs in a RDF dataset":

```
SELECT ?person WHERE {
 ?person a foaf:Person .
 GRAPH ?g1 { ?person a foaf:Person }
 GRAPH ?g2 { ?person a foaf:Person }
FILTER(?g1 != ?g2) . }
```

- The first BGP is matched against the default graph.
- The variables ?g1, ?g2 can appear in any BGP and can also instead be IRIs.

Querying Named Graphs III

(On `http://data.semanticweb.org/snorql`): "List people appearing in either ESWC 2007 or 2008 graphs, who have the same affiliation to the people appearing in ISWC 2012 or ISWC 2013 graphs."

```
SELECT ?person ?p
FROM <http://data.semanticweb.org/conference/eswc/2007/complete>
FROM <http://data.semanticweb.org/conference/eswc/2008/complete>
FROM NAMED <http://data.semanticweb.org/conference/iswc/2012/complete>
FROM NAMED <http://data.semanticweb.org/conference/iswc/2013/complete>
WHERE {
  ?person a foaf:Person .
  ?org foaf:member ?person .
  GRAPH ?g { ?p a foaf:Person .
             ?org foaf:member ?p .}
  FILTER (?person != ?p) }
```

The user-specified RDF dataset consists of

- A default graph obtained by merging the ESWC 2007 and ESWC 2008 graphs.
- Two named graphs as specified in FROM NAMED clauses.
- BGPs inside GRAPH clause are matched only to the specified named graphs.
- For FILTER keyword, see next.

Outline

Why Filters?

DaSe Lab

Even with complex query patterns, some queries are not expressible:

- "Which persons are between 18 and 23 years old?"
- "Which person has a name that contains a hyphen character?"
- "List the English name of the capital city of European countries".

We use filter as a general mechanism for such expressions.

Filter

DaSe Lab

- Syntax: FILTER(filterExpression)
- By substituting variables in it, a filter expression returns an effective boolean value **true** or **false**, or produces an error. See `https://www.w3.org/TR/sparql11-query/#ebv` for details about EBV of a numeric value, a string, etc.
- A solution mapping is eliminated from the result if substituting it to the filter results in the EBV **false** or produces an error.
- Many SPARQL filters come from outside RDF, e.g., XQuery/XPath
- Filter can be used to express some form of negation.
- See `https://www.w3.org/TR/sparql11-query/#expressions`.

Filter

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- Filter can be used to express some form of negation.
- See `https://www.w3.org/TR/sparql11-query/#expressions`.

```
PREFIX ex: <http://ex.org/>
SELECT ?book
WHERE {
  ?book ex:publishedBy <http://springer.com> .
  ?book ex:price ?price
  FILTER (?price < 35)
}
```

Above, any solution mapping where the value of ?price is less than 35 is eliminated from the result.

Unary Boolean operators: ! $\rightsquigarrow$!A is **true** if A is **false**, vice versa.
Logical connectives: ||, &&
Comparison operators: <, =, >, <=, >=, !=

- Comparison for literals according to the natural ordering
- Support for numerical datatypes (`xsd:integer`, `xsd:decimal`, etc.), `xsd:dateTime`, `xsd:string` (alphabetical order), `xsd:Boolean` $(1 > 0)$
- For non-literals, only = and != are available.
- Comparison cannot be done between incompatible types, e.g., between an `xsd:string` literal and an `xsd:integer` literal.

Filter: Arithmetic Functions

Unary functions: $+$, $-$
Binary functions: $+$, $-$, $*$, $/$

- Support for numerical datatypes.
- Not Boolean; used to obtain a value from other values in filter expression. For example:

```
FILTER( ?weight / (?size * ?size) >= 25 )
```

var is a variable, expr1, expr2, expr3 are expressions interpreted as an EBV, term, term1, term2 are RDF terms (IRIs, literals, blank nodes), pattern is a graph pattern, lit is a literal, res is an IRI

`BOUND( var )`	**true** if var is a bound variable
`IF( expr1, expr2, expr3 )`	returns EBV of expr2 if expr1 is **true**, otherwise returns EBV of expr3
`EXISTS \{ pattern \}`	**true** if pattern matches; **false** otherwise
`NOT EXISTS \{ pattern \}`	**false** if pattern matches; **true** otherwise
`sameTerm( term1, term2 )`	**true** if term1 and term2 are the same; **false** otherwise.
	more general than = operator
`term IN ( expr1, ... )`	**true** if term can be found in the list on the right hand side
`term NOT IN ( expr1, ...)`	**true** if term cannot be found in the list
`isIRI( term ), isURI( term )`	**true** if term is an IRI
`isBlank( term )`	**true** if term is a blank node
`isLiteral( term )`	**true** if term is a literal
`isNumeric( term )`	**true** if term is a numeric value
	17 and "17"\^\^xsd:integer" are numeric, while "17" is not

Other Notable Functions and Function Forms

STR(lit)	returns the lexical form of the literal lit.
STR(res)	returns the codepoint/string representation of the IRI res
LANG(lit)	returns the language tag of the literal lit, if any; returns "" otherwise
DATATYPE(lit)	returns the datatype of lit
IRI(lit), IRI(res)	returns an IRI from the literal lit or an IRI res
	lit must be a simple literal (without explicit datatype).
BNODE(), BNode(lit)	creates a blank node; if given a simple literal argument, the same literal within
	an expression for the same solution mapping yields the same blank node
STRDT(lit, res)	creates a typed literal with lexical form list and datatype res
STRLANG(lit, ltag)	creates a language-tagged literal with lexical form list and language tag ltag
UUID()	returns a fresh IRI using URN scheme (Note: not a HTTP IRI!)
STRUUID()	returns a string that is a scheme specific part of a UUID

Other Notable Functions and Function Forms

- String functions: `langMatches`, `REGEX`, `REPLACE`, `CONCAT`, `STRLEN`, `SUBSTR`, `UCASE`, `LCASE`, `STRSTARTS`, `STRENDS`, `CONTAINS`, `STRBEFORE`, `STRAFTER`, `ENCODE_FOR_URI`
- Numeric functions: `ABS`, `ROUND`, `CEIL`, `floor`, `RAND`
- Data/Time functions: `NOW`, `YEAR`, `MONTH`, `DAY`, `HOURS`, `MINUTES`, `SECONDS`, `TIMEZONE`, `TZ`
- Hash functions: `MD5`, `SHA1`, `SHA256`, `SHA384`, `SHA512`
- Casting operations: `STR`, `BOOL`, `DBL`, `FLT`, `DEC`, `INT`, `dT`, `ltrl`

Try in DBPedia

- Find countries that were founded after December 31, 1799, but were then dissolved before the year of 1900.
- Find the English name of all landlocked countries whose population exceeds 15 million.

Negation Using FILTER

Prefix definition omitted

DaSe Lab

Given data:

```
[] foaf:name  "Alice".
[  foaf:name  "Bob" ;
   foaf:age   "35"^^xsd:integer ] .
```

the following query:

```
SELECT ?name
WHERE { ?x foaf:name  ?name .
        OPTIONAL { ?x foaf:age ?age } .
        FILTER (!bound(?age)) }
```

returns `"Alice"` as the only value for `?name`

Outline

Sorting Results

DaSe Lab

Use keyword ORDER BY

```
SELECT ?book, ?price
WHERE { ?book <http://example.org/Price> ?price . }
ORDER BY ?price
```

- Sorting as with comparison operators in filters.
- IRIs are sorted alphabetically.
- Ordering of elements of different types:
  unbound variables < blank nodes < IRIs < RDF literals
- Spec does not define all possible orderings.
- Descending order: use `ORDER BY DESC (?price)`
- Ascending order (default): `ORDER BY ASC (?price)`
- Hierarchical ordering criteria: `ORDER BY ASC(?price), title`

LIMIT, OFFSET, and DISTINCT

- SELECT DISTINCT: removal of duplicates
- LIMIT: maximal number of results
- OFFSET: position of the first returned result (within the whole result).
- LIMIT and OFFSET only meaningful with ORDER BY.

```
SELECT DISTINCT ?book, ?price
WHERE { ?book <http://ex.org/price> ?price . }
ORDER BY ?price LIMIT 5 OFFSET 25
```

Outline

Output Form SELECT

- SELECT returns sequence of solution mappings.
- Syntax: `SELECT` *variableList* or `SELECT *`
- Advantage: simple sequential processing of results.
- Disadvantage: structure and relationships between the objects are lost.

Output Form CONSTRUCT

- CONSTRUCT returns an RDF graph (i.e., a set of triples) created using results from the graph patterns.
- Can be used to transform a graph to another.
- Advantage: structured results data between the objects
- Disadvantage: harder to process sequentially
- Disadvantage: if a solution mapping contains unbound variable, triples corresponding to that solution mapping will be omitted.

```
PREFIX ex: <http://example.org/>
CONSTRUCT {
   ?person ex:mailbox ?email .
   ?person ex:telephone ?tel . }
WHERE {
   ?person ex:email ?email .
   ?person ex:tel ?tel . }
```

Given data:

```
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
_:a foaf:firstname "Alice" ;
foaf:surname "Hacker" .
_:b foaf:firstname "Bob" ;
foaf:surname "Hacker" .
```

and query:

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX vcard: <http://www.w3.org/2001/vcard-rdf/3.0#>
CONSTRUCT {
  ?x vcard:N _:v .
  _:v vcard:givenName ?gname ;
  vcard:familyName ?fname
} WHERE {
  ?x foaf:firstname ?gname .
  ?x foaf:surname ?fname }
```

we would obtain an RDF graph:

```
@prefix vcard: <http://www.w3.org/2001/vcard-rdf/3.0#> .
_:v1 vcard:N _:x .
_:x vcard:givenName "Alice" ;
vcard:familyName "Hacker" .
_:v2 vcard:N _:z .
_:z vcard:givenName "Bob" ;
vcard:familyName "Hacker" .
```

Notice that the blank nodes in the output may have completely different IDs than what was provided by the solution mappings and the template.

ASK and DESCRIBE Output Forms

- ASK: checks if the query has at least one answer, i.e., non-empty solution – returns true/false.
- DESCRIBE: returns an RDF description for each resulting IRI – the actual description returned is application-dependent.

```
DESCRIBE ?x WHERE { ?x <http://ex.org/emplID> "123" }
```

may return something like:

```
_:a exOrg:emplID "123" ;
     foaf:mbox_sha1sum "ABCD1234" ;
     vcard:N
          [ vcard:Family "Smith" ;
            vcard:Given "John" ] .
foaf:mbox_sha1sum a owl:InverseFunctionalProperty .
```

Outline

Inside SELECT clause:

```
SELECT ?Item (?Pr * 1.1 AS ?NewP )
WHERE { ?Item ex:price ?Pr . }
```

Note: cannot assign values to variables inside the expression.

Data:

```
ex:lemonade1 ex:price 3 .
ex:icetea1 ex:price 3.
ex:coke1 ex:price 3.50 .
ex:coffee1 ex:price "n/a" .
```

Result (leaves errors unbound):

```
--------------------------
| ?Item         | ?NewP |
--------------------------
| ex:lemonade1 | 3.3   |
| ex:icetea1   | 3.3   |
| ex:coke1     | 3.85  |
| ex:cofee1    |       |
--------------------------
```

Assignment of New Values II

Alternatively, using BIND:

```
SELECT ?Item ?NewP
WHERE { ?Item ex:price ?Pr .
        BIND (?Pr * 1.1 AS ?NewP) }
```

Data:

```
ex:lemonade1 ex:price 3 .
ex:icetea1 ex:price 3.
ex:coke1 ex:price 3.50 .
ex:coffee1 ex:price "n/a" .
```

Result (leaves errors unbound):

```
--------------------------
| ?Item          | ?NewP |
--------------------------
| ex:lemonade1 | 3.3   |
| ex:icetea1   | 3.3   |
| ex:coke1     | 3.85  |
| ex:cofee1    |       |
--------------------------
```

Note: BIND is evaluated in-place!

```
SELECT ?Item ?NewP
WHERE { BIND (?Pr * 1.1 AS ?NewP)
        ?Item ex:price ?Pr . }
```

Data:

```
ex:lemonade1 ex:price 3 .
ex:icetea1 ex:price 3.
ex:coke1 ex:price 3.50 .
ex:coffee1 ex:price "n/a" .
```

Result is empty:

```
------------------------
| ?Item        | ?NewP |
------------------------
```

Providing Inline Data with VALUES

```
:drink1  rdfs:label "Latte" ;  ex:price  4 .
:drink2  rdfs:label "Capuccino" ; ex:price 3.5 .
:drink3  rdfs:label "Dark Roast" ; ex:price 2 .
:drink4  rdfs:label "Espresso" ; ex:price 3.5 .
```

Providing Inline Data with VALUES

```
:drink1  rdfs:label "Latte" ;  ex:price  4 .
:drink2  rdfs:label "Capuccino" ; ex:price 3.5 .
:drink3  rdfs:label "Dark Roast" ; ex:price 2 .
:drink4  rdfs:label "Espresso" ; ex:price 3.5 .
```

Use VALUES keyword to enumerate tuples of values to be assigned to variables.

```
SELECT ?drink ?name ?price
WHERE {
  ?drink rdfs:label ?name ;
         ex:price ?price .
  VALUES (?drink ?name)
  { (UNDEF "Latte")
     (:drink2 UNDEF)
     (:drink5 "Espresso")
  }  }
```

Providing Inline Data with VALUES

```
:drink1  rdfs:label "Latte" ;  ex:price  4 .
:drink2  rdfs:label "Capuccino" ; ex:price 3.5 .
:drink3  rdfs:label "Dark Roast" ; ex:price 2 .
:drink4  rdfs:label "Espresso" ; ex:price 3.5 .
```

Use VALUES keyword to enumerate tuples of values to be assigned to variables.

```
SELECT ?drink ?name ?price
WHERE {
  ?drink rdfs:label ?name ;
         ex:price ?price .
  VALUES (?drink ?name)
  { (UNDEF "Latte")
    (:drink2 UNDEF)
    (:drink5 "Espresso")
  }  }
```

```
?drink  | ?name       | ?price |
-------------------------------
:drink1 | "Latte"     | 4      |
:drink2 | "Capuccino" | 3.5    |
```

Outline

Aggregates I

Count items:

```
SELECT (COUNT(?Item) AS ?C)
WHERE { ?Item ex:price ?Pr . }
```

Data:

```
ex:smoothie1 ex:price 4 ;
             a ex:Colddrink .
ex:icetea1 ex:price 3 ;
           a ex:Colddrink .
ex:coke1   ex:price 3.50 ;
           a ex:Colddrink .
ex:tea1    ex:price 3 ;
           a ex:Hotdrink .
ex:coffee1 ex:price "n/a" ;
           a ex:Hotdrink .
```

Results:

```
------
| ?C |
------
| 5  |
------
```

Count categories:

```
SELECT (COUNT(?Ty) AS ?C)
WHERE { ?Item rdf:type ?Ty . }
```

Data:

```
ex:smoothie1 ex:price 4 ;
             a ex:Colddrink .
ex:icetea1 ex:price 3 ;
           a ex:Colddrink .
ex:coke1   ex:price 3.50 ;
           a ex:Colddrink .
ex:tea1    ex:price 3 ;
           a ex:Hotdrink .
ex:coffee1 ex:price "n/a" ;
           a ex:Hotdrink .
```

Results:

```
------
| ?C |
------
| 5  |
------
```

Count distinct categories:

```
SELECT (COUNT(DISTINCT ?Ty) AS ?C)
WHERE { ?Item rdf:type ?Ty . }
```

Data:

```
ex:smoothie1 ex:price 4 ;
             a ex:Colddrink .
ex:icetea1 ex:price 3 ;
           a ex:Colddrink .
ex:coke1   ex:price 3.50 ;
           a ex:Colddrink .
ex:tea1    ex:price 3 ;
           a ex:Hotdrink .
ex:coffee1 ex:price "n/a" ;
           a ex:Hotdrink .
```

Results:

```
------
| ?C |
------
| 2  |
------
```

Aggregates with Grouping

Count item per categories:

```
SELECT ?Ty (COUNT(?Item) AS ?C)
WHERE { ?Item rdf:type ?Ty . }
GROUP BY ?Ty
```

Data:

```
ex:smoothie1 ex:price 4 ;
             a ex:Colddrink .
ex:icetea1 ex:price 3 ;
           a ex:Colddrink .
ex:coke1   ex:price 3.50 ;
           a ex:Colddrink .
ex:tea1    ex:price 3 ;
           a ex:Hotdrink .
ex:coffee1 ex:price "n/a" ;
           a ex:Hotdrink .
```

Results:

```
---------------------
| ?Ty          | ?C |
---------------------
| ex:Colddrink | 3  |
| ex:Hotdrink  | 2  |
---------------------
```

Filtering Groups

Count item per categories, for those categories with more than two items:

```
SELECT ?Ty (COUNT(?Item) AS ?C)
WHERE { ?Item rdf:type ?Ty . }
GROUP BY ?Ty
HAVING COUNT(?Item) > 2
```

Data:

```
ex:smoothie1 ex:price 4 ;
             a ex:Colddrink .
ex:icetea1 ex:price 3 ;
           a ex:Colddrink .
ex:coke1   ex:price 3.50 ;
           a ex:Colddrink .
ex:tea1    ex:price 3 ;
           a ex:Hotdrink .
ex:coffee1 ex:price "n/a" ;
           a ex:Hotdrink .
```

Results:

```
---------------------
| ?Ty          | ?C |
---------------------
| ex:Colddrink | 3  |
---------------------
```

Other Aggregates

- SUM
- AVG
- MIN
- MAX
- GROUP_CONCAT – concatenate values with a given separator string
- SAMPLE – 'pick' one non-deterministically

Outline

- Subqueries: SELECT query inside a graph pattern.

"List all distinct titles of papers authored by at most 6 co-authors of Pascal Hitzler"

```
#Try at http:/data.semanticweb.org/snorql
PREFIX swp: <http://data.semanticweb.org/person/>
SELECT DISTINCT ?title
WHERE {
  ?paper foaf:maker ?person ; rdfs:label ?title .
  { SELECT DISTINCT ?person
     WHERE {
       ?doc foaf:maker swp:pascal-hitzler, ?person .
       FILTER (?person != swp:pascal-hitzler)
     } LIMIT 6
  }
}
```

Property Path Expressions

Allows one to query using arbitrary length of paths in the graphs.
"List all names of people who transitively co-authors with Pascal Hitzler"

```
PREFIX swp: <http://data.semanticweb.org/person/>
SELECT DISTINCT ?name
WHERE {
  swp:pascal-hitzler (^foaf:maker/foaf:maker)+/foaf:name ?name
}
```

That is, we find the name of:

1. people who co-authors with Pascal Hitzler;
2. people who co-authors with the people from (1)
3. people who-co-authors with the people from (2)
4. etc.

Property Path Syntax Forms

The forms are somewhat similar to regular expression.

1. `iri` – an IRI, a path of length one.
2. `^path` – inverse of `path`
3. `path1 / path2` – concatenation of `path1` followed by `path2`
4. `path1 | path2` – alternative between `path1` and `path2` (try all possibilities)
5. `path*` – zero or more concatenation of `path`
6. `path+` – one or more concatenation of `path`
7. `path?` – zero or one of `path`
8. `!(iri1|...|irin)` – an IRI not one of `iri1`,..., `irin`.
9. `!(^iri1|...|^irin)` – an IRI not one of reverse of `iri1`, ..., `irin`. Can be combined with the negated path expression in (8)
10. `(path)` – grouping of path with brackets to control precedence

Precedence from highest to lowest: IRI, negated property sets, groups, unary operators, unary inverse links, concatenation binary operator, binary operator for alternatives

Outline

Need to clarify:

- User: "Which answers can I expect from my query?"
- Developer: "Which behavior is expected from my SPARQL implementation?"
- Marketing: "Is our product already conformant with SPARQL standard?"

All Kinds of Semantics

Recall:

- Logic-based semantics:
  - Model-theoretic semantics: Which interpretations satisfy my knowledge base?
  - Proof-theoretic semantics: Which derivations can be obtained from my knowledge base?
- Programming languages:
  - Axiomatic semantics: Which logical statements hold for my program?
  - Operational semantics: What happens during the execution of my program?
  - Denotational semantics: How can we describe the input/output function of the program in an abstract way?
- What about query languages?

Semantics of Query Languages

- Query Entailment
  - Query as a description of allowed results
  - Data as a set of logical statements (set of axioms/theory)
  - Results as logical entailment

  e.g., RDF(S), OWL DL as query languages; conjunctive queries; etc.
- Query Algebra
  - Query as instruction for computing results
  - Queried data as input
  - Results as output

  e.g., Relational algebra for SQL, SPARQL algebra

SPARQL Algebra I

```
{ ?book ex:price ?price .
  FILTER (?price < 15)
  OPTIONAL { ?book ex:title ?title }
  { ?book ex:author ex:Shakespeare } UNION
  { ?book ex:author ex:Marlowe }
}
```

The semantics of a SPARQL query is given by:

1. Transformation into a SPARQL algebra expression.
2. Evaluation of the algebra expression.

SPARQL Algebra II

```
{ ?book ex:price ?price .
  OPTIONAL { ?book ex:title ?title }
  { ?book ex:author ex:Shakespeare } UNION
  { ?book ex:author ex:Marlowe }
  FILTER (?price < 15)
}
```

Note: filters applies to the whole group in which they occur.

SPARQL Algebra III

```
{ ?book <http://ex.org/price> ?price .
  OPTIONAL { ?book <http://ex.org/title> ?title }
  { ?book <http://ex.org/author> <http://ex.org/Shakespeare> } UNION
  { ?book <http://ex.org/author> <http://ex.org/Marlowe> }
  FILTER (?price < 15)
}
```

1. Expand abbreviated IRIs.

SPARQL Algebra IV

```
{ Bgp(?book <http://ex.org/price> ?price)
  OPTIONAL { Bgp(?book <http://ex.org/title> ?title) }
  { Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>) } UNION
  { Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>) }
  FILTER (?price < 15)
}
```

2. Replace triple patterns with Bgp(·)

```
{ LeftJoin(Bgp(?book <http://ex.org/price> ?price),
           Bgp(?book <http://ex.org/title> ?title),
           true)
  { Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>) } UNION
  { Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>) }
  FILTER (?price < 15)
}
```

3. Introduce LeftJoin(·) for the optional parts. Indicate with "true" if the optional part has no filter.

```
{ LeftJoin(Bgp(?book <http://ex.org/price> ?price),
           Bgp(?book <http://ex.org/title> ?title),
           true)
  Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
        Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
  FILTER (?price < 15)
}
```

4. Combine alternatives with Union(·). Note: has higher precedence than conjunction of graph patterns and it's left-associative.

```
{ Join(
     LeftJoin(Bgp(?book <http://ex.org/price> ?price),
              Bgp(?book <http://ex.org/title> ?title),
              true),
     Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
           Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
   )
  FILTER (?price < 15)
}
```

5. Apply Join(·) to combine non-filter elements.

SPARQL Algebra VIII

```
Filter(?price < 15,
   Join(
     LeftJoin(Bgp(?book <http://ex.org/price> ?price),
              Bgp(?book <http://ex.org/title> ?title),
              true),
     Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
           Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
   ))
```

6. Translate a group with filters into expression with Filter(·) operator.

- Bgp(P) – match/evaluate pattern P
- Join(M_1, M_2) – conjunctive join of solutions of M_1 and M_2
- Union(M_1, M_2) – union of solutions of M_1 and M_2
- LeftJoin(M_1, M_2, F) – optional join (left join) of M_1 and M_2 with filter constraint F (**true** if no filter given)
- Filter(F, M) – filter solutions with constraint F
- Z – empty pattern (identity for join operation)

Evaluation of BGPs

A solution mapping of a BGP P, denoted Bgp(P) over the active graph G is a partial function μ such that:

1. the domain of μ, denoted dom(μ), is exactly the set of variables in P
2. there exists an assignment σ from blank nodes in P to IRIs, blank nodes, or RDF literals such that the RDF graph $\mu(\sigma(P))$ is a subgraph of G.

Note:

- A solution mapping corresponds to one row in the result table.
- Compare this with the condition for RDF simple entailment!
- μ is a partial function: unbound variables are those that have no assigned value.
- for a partial function μ to be a solution, the existence of σ as above is needed.

The result of evaluating a BGP P over G, denoted $[\![\text{Bgp}(P)]\!]_G$ is a multiset of solution mappings

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- A multiset A over an underlying set S can be defined as a set $A = \{\langle s, A(s)\rangle \mid s \in S\}$. Here, we slightly abuse the notation for the multiset A by using it as a function where $A(s)$ is the multiplicity of s in the multiset of A.
- A multiplicity $A(s)$ of an element s is the number of occurrences of s in the multiset A.
- For every multiset A and any element s in A, $A(s) \in \mathbb{Z}^+ \cup \{\omega\}$ where $\omega > n$ for every positive integer $n \in \mathbb{Z}^+$
- For any other s not occurring in A, $A(s) = 0$.
- Alternative notation: the multiset $A = \{\langle a, 2\rangle, \langle b, 1\rangle\}$ can be written as $\wr a, a, b \int$

Multiset operations, etc.

- Equality $\wr a, a, b \int = \wr b, a, a \int = \wr a, b, a \int = \{\langle a, 2\rangle, \langle b, 1\rangle\}$
- Membership: $\langle a, 2\rangle \Subset \wr a, a, b \int$, $\langle b, 1\rangle \Subset \wr a, a, b \int$, $\langle a, 1\rangle \not\Subset \wr a, a, b \int$, $\langle c, 0\rangle \not\Subset \wr a, a, b \int$, $\langle c, 2\rangle \not\Subset \wr a, a, b \int$.
  We write $a \in A$ if $A(a) > 0$, and $a \notin A$ otherwise.
- Union: $\wr a, a, a, b \int \cup \wr a, c \int = \wr a, a, a, b, c \int$
  For multisets A, B, the union $A \cup B = \{\langle s, n\rangle \mid n = \max(A(s), B(s)) > 0\}$
- Intersection: $\wr a, a, a, b \int \cap \wr a, b, b, c \int = \wr a, b \int$
  $A \cap B = \{\langle s, n\rangle \mid n = \min(A(s), B(s)) > 0\}$
- Sum: $\wr a, a, a, b \int \uplus \wr a, b, b, c \int = \wr a, a, a, a, b, b, b, c \int$
  $A \uplus B = \{\langle s, n\rangle \mid n = A(s) + B(s) > 0\}$

Solution Mapping Example

```
ex:pascal foaf:maker [
     a  ex:ConferencePaper ;
     dc:title "GeoLink Ontology" ] .
ex:pascal foaf:maker [ r
     a  ex:JournalPaper ;
     dc:title "Paraconsistent DL" ] .
```

Bgp(`?who foaf:maker _:x . _:x dc:title ?what .`)

Solution Mapping Example

```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(`?who foaf:maker _:x . _:x dc:title ?what .`)

Solution Mapping Example

```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(?who foaf:maker _:x . _:x dc:title ?what .)

μ_1 : ?who $\mapsto$ ex:pascal, ?what $\mapsto$ "GeoLink Ontology"

σ_1 : _:x $\mapsto$ _:a

Solution Mapping Example

```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(?who foaf:maker _:x . _:x dc:title ?what .)

$$\begin{aligned}
\mu_1 &: \quad \texttt{?who} \mapsto \texttt{ex:pascal}, \quad \texttt{?what} \mapsto \texttt{"GeoLink Ontology"} \\
\sigma_1 &: \quad \texttt{_:x} \mapsto \texttt{_:a} \\
\mu_2 &: \quad \texttt{?who} \mapsto \texttt{ex:pascal}, \quad \texttt{?what} \mapsto \texttt{"Paraconsistent DL"} \\
\sigma_2 &: \quad \texttt{_:x} \mapsto \texttt{_:b}
\end{aligned}$$

Solution Mapping Example

```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(`?who foaf:maker _:x . _:x dc:title ?what .`)

μ_1 : `?who` ↦ `ex:pascal`, `?what` ↦ `"GeoLink Ontology"`

σ_1 : `_:x` ↦ `_:a`

μ_2 : `?who` ↦ `ex:pascal`, `?what` ↦ `"Paraconsistent DL"`

σ_2 : `_:x` ↦ `_:b`

Two solution mappings (μ_1 and μ_2), each with multiplicity 1

Solution Mapping Example

```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(`?who foaf:maker _:x . _:x dc:title _:y .`)

Solution Mapping Example

```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(?who foaf:maker _:x . _:x dc:title _:y .)

μ_1 : ?who $\mapsto$ ex:pascal

σ_1 : _:x $\mapsto$ _:a, _:y $\mapsto$ "GeoLink Ontology"

Solution Mapping Example

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```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(?who foaf:maker _:x . _:x dc:title _:y .)

μ_1 : ?who $\mapsto$ ex:pascal

σ_1 : _:x $\mapsto$ _:a, _:y $\mapsto$ "GeoLink Ontology"

μ_2 : ?who $\mapsto$ ex:pascal

σ_2 : _:x $\mapsto$ _:b, _:y $\mapsto$ "Paraconsistent DL"

Solution Mapping Example

```
ex:pascal foaf:maker _:a .
_:a  rdf:type  ex:ConferencePaper .
_:a  dc:title "GeoLink Ontology" .
ex:pascal foaf:maker _:b .
_:b  rdf:type  ex:JournalPaper .
_:b  dc:title "Paraconsistent DL" .
```

Bgp(?who foaf:maker _:x . _:x dc:title _:y .)

μ_1 : ?who $\mapsto$ ex:pascal

σ_1 : _:x $\mapsto$ _:a, _:y $\mapsto$ "GeoLink Ontology"

μ_2 : ?who $\mapsto$ ex:pascal

σ_2 : _:x $\mapsto$ _:b, _:y $\mapsto$ "Paraconsistent DL"

One solution mapping with multiplicity 2, since $\mu_1 = \mu_2$

Compatibility of Solution Mappings

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- Evaluation of more complex patterns (Union, Join, LeftJoin, Filter, etc.) is done based on the solution mapping of its BGP components.
- The involved solution mappings often need to be compatible to each other.

Compatibility of Solutions

Two solutions μ_1 and μ_2 are compatible iff for every x for which both $\mu_1(x)$ and $\mu_2(x)$ are defined, $\mu_1(x) = \mu_2(x)$ holds.

- That is, μ_1 and μ_2 are compatible iff they agree on their shared variables.
- $\mu_1 = \{\texttt{?x} \mapsto \texttt{ex:a}, \texttt{?y} \mapsto \texttt{ex:b}\}$ and $\mu_2 = \{\texttt{?y} \mapsto \texttt{ex:b}, \texttt{?z} \mapsto \texttt{ex:c}\}$ are compatible.
- $\mu_1 = \{\texttt{?x} \mapsto \texttt{ex:a}\}$ and $\mu_2 = \{\texttt{?y} \mapsto \texttt{ex:b}\}$ are compatible.
- $\mu_1 = \{\texttt{?x} \mapsto \texttt{ex:a}, \texttt{?y} \mapsto \texttt{ex:b}\}$ and $\mu_2 = \{\texttt{?y} \mapsto \texttt{ex:c}, \texttt{?z} \mapsto \texttt{ex:d}\}$ are NOT compatible.

Union of Compatible Solution Mappings

- Two compatible solution mappings may need to be merged/combined when defining operations such as Join, etc.
- Union of two compatible solution mappings corresponds to union of two matching table rows.

Union of Compatible Solutions

Let μ_1 and μ_2 be two compatible solution mappings. Their union is denoted by $\mu_1 \cup \mu_2$ and defined as

$$(\mu_1 \cup \mu_2)(x) = \begin{cases} \mu_1(x) & \text{if } x \in \text{dom}(\mu_1) \\ \mu_2(x) & \text{otherwise} \end{cases}$$

If we view μ_1 and μ_2 as sets of bindings, then $\mu_1 \cup \mu_2$ is really just the union of both sets and it is still a well-defined mapping since for every variable x occurring in $\text{dom}(\mu_1) \cap \text{dom}(\mu_2)$, we have that $\mu_1(x) = \mu_2(x)$.

Evaluation of Union(·)

Evaluation of Union(P_1, P_2) over a graph G is denoted by $[\![\text{Union}(P_1, P_2)]\!]_G$ and defined as:

$$[\![\text{Union}(P_1, P_2)]\!]_G = [\![P_1]\!]_G \uplus [\![P_2]\!]_G$$

Note that $[\![P_1]\!]_G$ and $[\![P_2]\!]_G$ are both multisets of solution mappings.

Evaluation of Join(P_1, P_2) over a graph G is denoted by $[\![\text{Join}(P_1, P_2)]\!]_G$ and defined as:

$$[\![\text{Join}(P_1, P_2)]\!]_G = \biguplus_{\substack{\langle \mu_1, m_1 \rangle \in [\![P_1]\!]_G \\ \langle \mu_2, m_2 \rangle \in [\![P_2]\!]_G}} \{\langle \mu_1 \cup \mu_2, m_1 m_2 \rangle \mid \mu_1 \text{ and } \mu_2 \text{ are compatible}\}$$

Example Evaluation of Join(·)

Suppose

$$\llbracket P_1 \rrbracket_G = \{\langle(\mu_1 \colon \texttt{?x} \mapsto \texttt{ex:a}, \texttt{?y} \mapsto \texttt{ex:b}), 2\rangle, \langle(\mu_2 \colon \texttt{?x} \mapsto \texttt{ex:c}), 1\rangle\}$$

$$\llbracket P_2 \rrbracket_G = \{\langle(\mu_3 \colon \texttt{?y} \mapsto \texttt{ex:b}, \texttt{?z} \mapsto \texttt{ex:c}), 2\rangle, \langle(\mu_4 \colon \texttt{?y} \mapsto \texttt{ex:d}), 1\rangle, \langle(\mu_5 \colon \texttt{?z} \mapsto \texttt{ex:c}), 1\rangle\}$$

Then,

$$\begin{aligned}
&\llbracket \text{Join}(P_1, P_2) \rrbracket_G \\
&= \{\langle \mu_1 \cup \mu_3, 2*2\rangle\} \uplus \{\langle \mu_1 \cup \mu_5, 2*1\rangle\} \uplus \{\langle \mu_2 \cup \mu_3, 1*2\rangle\} \uplus \{\langle \mu_2 \cup \mu_4, 1*1\rangle\} \\
&\quad \uplus \{\langle \mu_2 \cup \mu_5, 1*1\rangle\} \\
&= \{\langle(\texttt{?x} \mapsto \texttt{ex:a}, \texttt{?y} \mapsto \texttt{ex:b}, \texttt{?z} \mapsto \texttt{ex:c}), 4\rangle\} \uplus \{\langle(\texttt{?x} \mapsto \texttt{ex:a}, \texttt{?y} \mapsto \texttt{ex:b}, \texttt{?z} \mapsto \texttt{ex:c}), 2\rangle\} \\
&\quad \uplus \{\langle(\texttt{?x} \mapsto \texttt{ex:c}, \texttt{?y} \mapsto \texttt{ex:b}, \texttt{?z} \mapsto \texttt{ex:c}), 2\rangle\} \uplus \{\langle(\texttt{?x} \mapsto \texttt{ex:c}, \texttt{?y} \mapsto \texttt{ex:d}), 1\rangle\} \\
&\quad \uplus \{\langle(\texttt{?x} \mapsto \texttt{ex:c}, \texttt{?z} \mapsto \texttt{ex:c}), 1\rangle\} \\
&= \{\langle(\texttt{?x} \mapsto \texttt{ex:a}, \texttt{?y} \mapsto \texttt{ex:b}, \texttt{?z} \mapsto \texttt{ex:c}), 6\rangle, \langle(\texttt{?x} \mapsto \texttt{ex:c}, \texttt{?y} \mapsto \texttt{ex:b}, \texttt{?z} \mapsto \texttt{ex:c}), 2\rangle, \\
&\quad \langle(\texttt{?x} \mapsto \texttt{ex:c}, \texttt{?y} \mapsto \texttt{ex:d}), 1\rangle, \langle(\texttt{?x} \mapsto \texttt{ex:c}, \texttt{?z} \mapsto \texttt{ex:c}), 1\rangle\}
\end{aligned}$$

Evaluating Filter($\cdot$)

Given a filter condition F and a solution mapping μ whose domain includes all variables in F, $\mu(F)$ is a Boolean expression obtained by replacing variables in F with IRIs/literals/bnodes according to μ. Furthermore, $[\![\mu(F)]\!]$ is the Boolean result of evaluating $\mu(F)$.

Evaluation of Filter(F, P) over G where F is a filter condition and P is an algebra object is denoted with $[\![\text{Filter}(F, P)]\!]_G$ and defined as

$$[\![\text{Filter}(F, P)]\!]_G = \left\{ \langle \mu, n \rangle \mid [\![P]\!]_G(\mu) = n > 0 \text{ and } [\![\mu(F)]\!] = \textbf{true} \right\}$$

Evaluation of LeftJoin($\cdot$)

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Let P_1, P_2 be algebra objects, F be a filter condition over a graph G, and $M_1 = [\![P_1]\!]_G$ and $M_2 = [\![P_2]\!]_G$.

Then, the evaluation of LeftJoin(P_1, P_2, F) over G is denoted with $[\![\text{LeftJoin}(P_1, P_2, F)]\!]_G$ and defined as:

$$\begin{aligned}
&[\![\text{LeftJoin}(P_1, P_2, F)]\!]_G \\
&= [\![\text{Filter}(F, \text{Join}(P_1, P_2))]\!]_G \\
&\quad \uplus \left\{\langle \mu_1, M_1(\mu_1)\rangle \mid \mu_1 \in M_1 \text{ and there is no } \mu_2 \in M_2 \text{ compatible with } \mu_1\right\} \\
&\quad \uplus \left\{\langle \mu_1, M_1(\mu_1)\rangle \mid \mu_1 \in M_1 \text{ and for all } \mu_2 \in M_2 : [\![(\mu_1 \cup \mu_2)(F)]\!] = \textbf{false}\right\}
\end{aligned}$$

Evaluation Example

```
@prefix ex: <http://ex.org/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
ex:Hamlet          ex:author ex:Shakespeare ;
                   ex:price  "10.50"^^xsd:decimal .
ex:Macbeth         ex:author ex:Shakespeare .
ex:Tamburlaine     ex:author ex:Marlowe ;
                   ex:price  "17"^^xsd:integer .
ex:DoctorFaustus   ex:author ex:Marlowe ;
                   ex:price  "12"^^xsd:integer ;
                   ex:title  "The Tragical History of Doctor Faustus" .
ex:RomeoJulia      ex:author ex:Brooke ;
                   ex:price  "9"^^xsd:integer .
```

```
{
  ?book ex:price ?price .
  FILTER (?price < 15)
  OPTIONAL { ?book ex:title ?title }
  { ?book ex:author ex:Shakespeare }
  UNION
  { ?book ex:author ex:Marlowe }
}
```

Evaluation Example

```
@prefix ex: <http://ex.org/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
ex:Hamlet         ex:author ex:Shakespeare ;
                  ex:price  "10.50"^^xsd:decimal .
ex:Macbeth        ex:author ex:Shakespeare .
ex:Tamburlaine    ex:author ex:Marlowe ;
                  ex:price  "17"^^xsd:integer .
ex:DoctorFaustus  ex:author ex:Marlowe ;
                  ex:price  "12"^^xsd:integer ;
                  ex:title  "The Tragical History of Doctor Faustus" .
ex:RomeoJulia     ex:author ex:Brooke ;
                  ex:price  "9"^^xsd:integer .
```

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book
ex:Tamburlaine
ex:DoctorFaustus

Evaluation Example

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book
ex:Tamburlaine
ex:DoctorFaustus

book
ex:Macbeth
ex:Hamlet

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book
ex:Tamburlaine
ex:DoctorFaustus
ex:Hamlet
ex:Macbeth

Evaluation Example

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book	price
ex:Hamlet	10.5
ex:Tamburlaine	17
ex:DoctorFaustus	12
ex:RomeoJulia	9

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book	price
ex:Hamlet	10.5
ex:Tamburlaine	17
ex:DoctorFaustus	12
ex:RomeoJulia	9

book	title
ex:DoctorFaustus	"The Tragical History of Doctor Faustus"

Evaluation Example

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```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book	price	title
ex:Hamlet	10.5	
ex:Tamburlaine	17	
ex:DoctorFaustus	12	"The Tragical History of Doctor Faustus"
ex:RomeoJulia	9	

Evaluation Example

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book
ex:Tamburlaine
ex:DoctorFaustus
ex:Hamlet
ex:Macbeth

join with

book	price	title
ex:Hamlet	10.5	
ex:Tamburlaine	17	
ex:DoctorFaustus	12	"The Tragical History of Doctor Faustus"
ex:RomeoJulia	9	

Evaluation Example

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book	price	title
ex:Hamlet	10.5	
ex:Tamburlaine	17	
ex:DoctorFaustus	12	"The Tragical History of Doctor Faustus"

```
Filter(?price < 15,
  Join(
    LeftJoin(Bgp(?book <http://ex.org/price> ?price),
             Bgp(?book <http://ex.org/title> ?title),
             true),
    Union(Bgp(?book <http://ex.org/author> <http://ex.org/Shakespeare>),
          Bgp(?book <http://ex.org/author> <http://ex.org/Marlowe>))
))
```

book	price	title
ex:Hamlet	10.5	
ex:DoctorFaustus	12	"The Tragical History of Doctor Faustus"

Other SPARQL Algebra Operations

- All other SPARQL constructs and solution modifiers are associated with their own particular algebra operations.
- These operations are recursively evaluated.
- See formal definition at `https://www.w3.org/TR/sparql11-query/#sparqlDefinition`

Outline

Use keyword SERVICE to specify a remote endpoint. More than one remote endpoints can be specified in a query.

```
PREFIX dbr: <http://dbpedia.org/resource/>
PREFIX dbo: <http://dbpedia.org/ontology/>
SELECT (SUM(?pop) AS ?P )
{ SERVICE <http://dbpedia.org/sparql/>
   { SELECT DISTINCT ?C ?pop
      WHERE {
        ?C dbo:populationTotal ?pop ;
           dbo:country dbr:United_States .
        [] <http://dbpedia.org/property/city> ?C .
      }
      ORDER BY DESC ( ?pop )
      LIMIT 3
   }
}
```

SPARQL Update

- DELETE removes triples. INSERT inserts triples.
- Can be done via standard HTTP protocol.
- Security issues not handled by SPARQL standards!

```
PREFIX ex: <http://example.org/>
DELETE { ?Item ex:price ?Pr }
INSERT { ?Item ex:price ?NewPr }
WHERE { ?Item ex:price ?Pr
         BIND (?Pr * 1.1 AS ?NewPr ) }
```

SPARQL Entailment Regimes

- SPARQL on its own is only capable of simple entailment.
  - BGP evaluation corresponds to simple entailment between two RDF graphs.
- To allow, e.g., RDF, RDFS or OWL entailments, SPARQL engine needs to be aware of the corresponding semantics of those lagnuages.
- SPARQL standards defines several entailment regimes, which specify how an entailment relation can be used to redefine the evaluation of BGPs in a SPARQL query.
- Specification is at `https://www.w3.org/TR/sparql11-entailment/`, providing
  - RDF entailment regime
  - RDFS entailment regime
  - D-entailment regime – correspond to datatype entailment
  - OWL 2 RDF-based Semantics entailment regime
  - OWL 2 Direct Semantics entailment regime
  - RIF Core entailment regime

Example

Consider data:

```
(1) ex:book1 rdf:type ex:Publication .
(2) ex:book2 rdf:type ex:Article .
(3) ex:Article rdfs:subClassOf ex:Publication .
(4) ex:publishes rdfs:range ex:Publication .
(5) ex:MITPress ex:publishes ex:book3 .
```

Query: `SELECT ?prop WHERE { ?prop rdf:type rdf:Property }`

Example

Consider data:

```
(1) ex:book1 rdf:type ex:Publication .
(2) ex:book2 rdf:type ex:Article .
(3) ex:Article rdfs:subClassOf ex:Publication .
(4) ex:publishes rdfs:range ex:Publication .
(5) ex:MITPress ex:publishes ex:book3 .
```

Query: `SELECT ?prop WHERE { ?prop rdf:type rdf:Property }`

- Normal SPARQL query (i.e., simple entailment): empty answer.

Example

Consider data:

```
(1) ex:book1 rdf:type ex:Publication .
(2) ex:book2 rdf:type ex:Article .
(3) ex:Article rdfs:subClassOf ex:Publication .
(4) ex:publishes rdfs:range ex:Publication .
(5) ex:MITPress ex:publishes ex:book3 .
```

Query: `SELECT ?prop WHERE { ?prop rdf:type rdf:Property }`

- Normal SPARQL query (i.e., simple entailment): empty answer.
- With RDF entailment regime, we have the following answer:

prop
rdf:type
rdf:type
rdfs:subClassOf
rdfs:range
ex:publishes

Example

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Consider data:

```
(1) ex:book1 rdf:type ex:Publication .
(2) ex:book2 rdf:type ex:Article .
(3) ex:Article rdfs:subClassOf ex:Publication .
(4) ex:publishes rdfs:range ex:Publication .
(5) ex:MITPress ex:publishes ex:book3 .
```

Query: `SELECT ?pub WHERE { ?pub rdf:type ex:Publication }`

Consider data:

```
(1) ex:book1 rdf:type ex:Publication .
(2) ex:book2 rdf:type ex:Article .
(3) ex:Article rdfs:subClassOf ex:Publication .
(4) ex:publishes rdfs:range ex:Publication .
(5) ex:MITPress ex:publishes ex:book3 .
```

Query: `SELECT ?pub WHERE { ?pub rdf:type ex:Publication }`

Normal SPARQL query (i.e., with simple entailment):

pub
ex:book1

Consider data:

```
(1) ex:book1 rdf:type ex:Publication .
(2) ex:book2 rdf:type ex:Article .
(3) ex:Article rdfs:subClassOf ex:Publication .
(4) ex:publishes rdfs:range ex:Publication .
(5) ex:MITPress ex:publishes ex:book3 .
```

Query: `SELECT ?pub WHERE { ?pub rdf:type ex:Publication }`

With RDF entailment:

pub
ex:book1

Consider data:

```
(1) ex:book1 rdf:type ex:Publication .
(2) ex:book2 rdf:type ex:Article .
(3) ex:Article rdfs:subClassOf ex:Publication .
(4) ex:publishes rdfs:range ex:Publication .
(5) ex:MITPress ex:publishes ex:book3 .
```

Query: `SELECT ?pub WHERE { ?pub rdf:type ex:Publication }`

With RDFS entailment:

pub
ex:book1
ex:book2
ex:book3