TECHNISCHE UNIVERSITÄT DRESDEN

FOUNDATIONS OF SEMANTIC WEB TECHNOLOGIES

SPARQL 1.1

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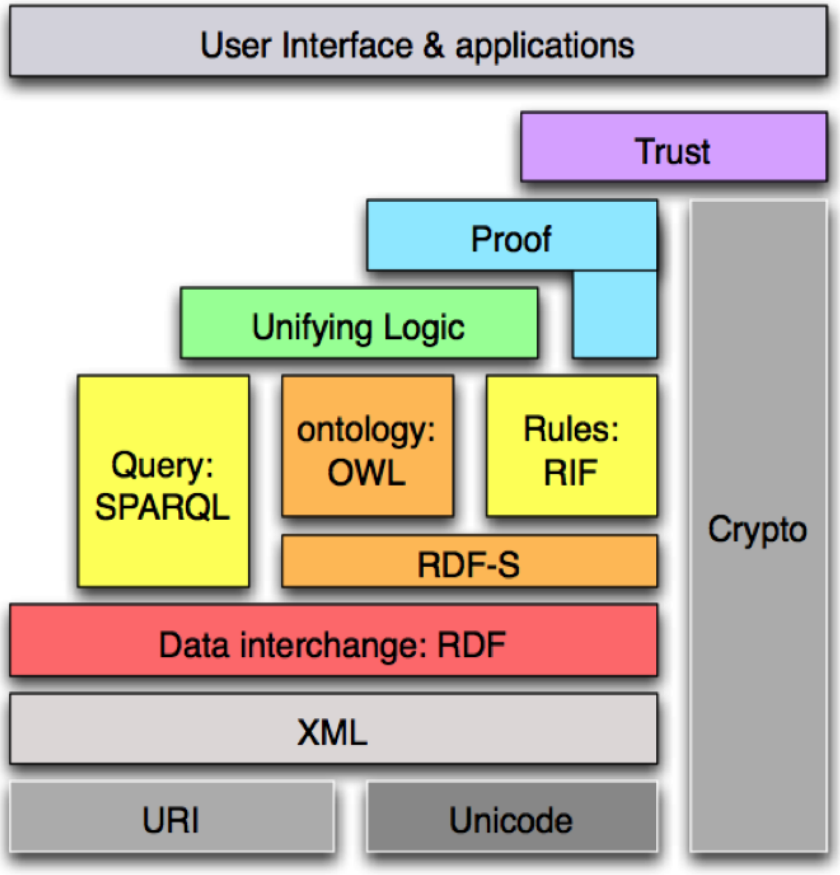
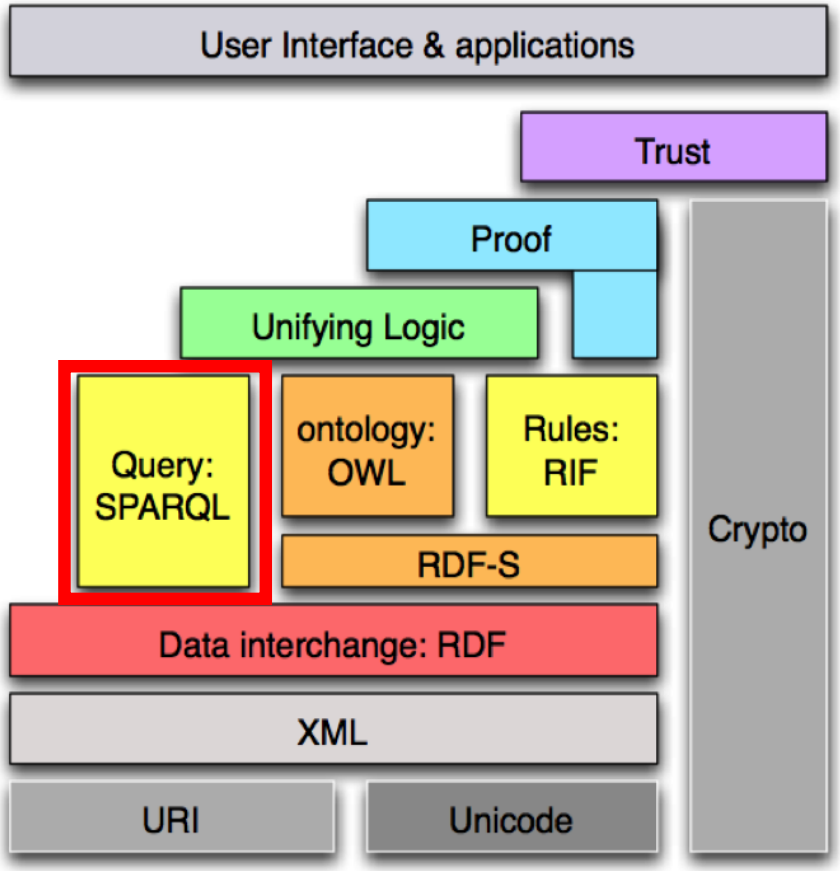
DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Content

The SPARQL Query Language



The SPARQL Query Language



Agenda

1. Recap
2. SPARQL 1.1 Query Extensions
   - Expressions in Selection and Bindings
   - Aggregates
   - Subqueries
   - Property Paths
   - Negation
3. SPARQL Protocol
4. SPARQL Update
5. SPARQL Service Descriptions
6. Summary

Agenda

Example Pattern

Example

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

Parts of the SPARQL Grammar

```
GroupGraphPattern          ::= '{' TriplesBlock?
                                 ( ( GraphPatternNotTriples
                                   | Filter ) '.' ? TriplesBlock? )*
                               '}'
GraphPatternNotTriples     ::= OptionalGraphPattern
                             | GroupOrUnionGraphPattern
                             | GraphGraphPattern
OptionalGraphPattern       ::= 'OPTIONAL' GroupGraphPattern
                               GroupGraphPattern
GroupOrUnionGraphPattern   ::= GroupGraphPattern ( 'UNION'
                                GroupGraphPattern )*
Filter                     ::= 'FILTER' Constraint
```

Correspondence Pattern vs. Grammar

Example

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

Corresponding Grammar Elements

```
{ TriplesBlock
  Filter
  OPTIONAL { TriplesBlock }
  { TriplesBlock } UNION
  { TriplesBlock } }
```

Correspondence Pattern vs. Grammar

Grammar Elements

```
{ TriplesBlock
  Filter
  OPTIONAL { TriplesBlock }
  { TriplesBlock } UNION
  { TriplesBlock } }
```

Corresponding Grammar Elements

```
{ TriplesBlock
  Filter
  OptionalGraphPattern
  GroupOrUnionGraphPattern }
```

Corresponding Grammar Elements

```
GroupGraphPattern
```

translate(`GroupGraphPattern` G)

Input: a `GroupGraphPattern` G = $(e_1, \ldots, e_n)$
Output: a SPARQL algebra expression A

```
 1: A := Z { the empty pattern}
 2: F := ∅ { filter}
 3: for i = 1, ..., n do
 4:     if e_i is FILTER( f ) then
 5:         F := F ∪ {f}
 6:     else if e_i is OPTIONAL { P } then
 7:         if translate(P) is Filter(F', A') then
 8:             A := LeftJoin(A, A', F')
 9:         else
10:             A := LeftJoin(A, translate(P), true)
11:     else
12:         A := Join(A, translate(e_i))
13: if F ≠ ∅ then
14:     A := Filter(⋀_{f∈F} f, A)
15: return A
```

translate(`GroupOrUnionGraphPattern` G)

Input: a `GroupOrUnionGraphPattern` G
with elements $e_1, \ldots, e_n$

Output: a SPARQL algebra expression A

```
1: for i = 1, ..., n do
2:     if A is undefined then
3:         A := translate(e_i)
4:     else
5:         A := Union(A, translate(e_i))
6: return A
```

Translation into SPARQL Algebra

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

Simplification of the SPARQL Algebra

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

Semantics of the SPARQL Algebra Operators

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

Agenda

Expressions in the Selection and Bindings

Solutions can be extended by evaluated expressions with `(expression AS ?var)` used for the assignment:

- In the `SELECT` clause
- In the `GROUP BY` clause
- Within `BIND` in a group graph pattern

Solutions from a group can further be joined with solutions given via `VALUES`

Example BIND (without Prefix Declarations)

Data

```
ex:Book ex:title "SPARQL Tutorial" ; ex:price 42 ; ex:discount
10 .
```

Query

```
SELECT ?title ?price WHERE
{ ?b ex:title ?title; ex:price ?p ; ex:discount ?r
 BIND ((?p-?r) AS ?price) }
```

Result

$?title \mapsto$ "SPARQL Tutorial", $?price \mapsto 32$

$\rightsquigarrow$ Algebra: Extend(Bgp(...), ?price, (?p-?r))

Example SELECT Expressions (without Prefix Declarations)

Data

```
ex:Book ex:title "SPARQL Tutorial" ; ex:price 42 ; ex:discount
10 .
```

Query

```
SELECT ?title ((?p-?r) AS ?price) WHERE
{ ?b ex:title ?title; ex:price ?p ; ex:discount ?r }
```

Result

$?title \mapsto$ "SPARQL Tutorial", $?price \mapsto 32$

$\rightsquigarrow$ Algebra: Extend(Bgp(...), ?price, (?p-?r))

Example VALUES

Data

```
ex:Book1 ex:title "SPARQL Tutorial".
ex:Book2 ex:title "SemWeb".
```

Query

```
SELECT ?title WHERE {
  ?b ex:title ?title
  VALUES ?b { ex:Book1 }
}
```

Result

$?title \mapsto$ "SPARQL Tutorial"

$\rightsquigarrow$ Bindings are conjunctively joined

Aggregates

- Aggregates allow for grouping of solutions and the computation of values over the groups

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Example

```
SELECT     (COUNT(?student) AS ?c) ?lecture
WHERE      { ?student ex:attends ?lecture }
GROUP BY   ?lecture
HAVING     ?c > 5
```

Aggregates

- Aggregates allow for grouping of solutions and the computation of values over the groups

Example

```
SELECT     (COUNT(?student) AS ?c) ?lecture
WHERE      { ?student ex:attends ?lecture }
GROUP BY   ?lecture
HAVING     ?c > 5
```

- `GROUP BY` groups the solutions (here into students who attend the same lecture)
- `COUNT` is an aggregate function that counts the solutions within a group (here the number of students in the lecture)
- `HAVING` filters aggregated values

Aggregates in SPARQL 1.1

SPARQL 1.1 supports the following aggregate functions, which are evaluated over the values in a group:

- `COUNT` – counts the solutions
- `MIN` – finds the minimal value
- `MAX` – finds the maximal value
- `SUM` – sums up the values
- `AVG` – computes the average
- `GROUP_CONCAT` – string concatenation, Example: `GROUP_CONCAT(?x ; separator=", ")`
- `SAMPLE` – picks a random value

Exercise Aggregates

Data

```
ex:Paul ex:hasMark 2.0 .
ex:Paul ex:hasMark 3.0 .
ex:Mary ex:hasMark 2.0 .
ex:Peter ex:hasMark 3.5 .
```

Query

```
SELECT ?student (AVG(?note) as ?avg)
WHERE { ?student ex:hasMark ?note }
GROUP BY ?student
HAVING (?avg > 2.0)
```

Solution Aggregates

Solution Aggregates

student	avg
ex:Paul	2.5
ex:Peter	3.5

Subqueries

Query

```
SELECT ?name WHERE {
  ?x foaf:name ?name .
  { SELECT ?x (COUNT(*) AS ?count)
    WHERE { ?x foaf:knows ?y . }
    GROUP BY ?x
    HAVING (?count = 3)
  }
}
```

- Results for the inner query are conjunctively joined with the results of the outer query

Regular Expressions in Patterns

Property Paths are constructed using regular expressions over predicates

- Paths with arbitrary length: `?s ex:p+ ?o`, `?s ex:p* ?o`
- Alternative paths: `?s` (`ex:`p_1|`ex:`p_2) `?o`
- Negation of paths: `?s !ex:p ?o`
- Inverse paths: `?s ^ex:p ?o` same as `?o ex:p ?s`
- Sequence of paths: `?s ex:`p_1 / `ex:`p_2 `?o`
- Length zero or one path: `?s ex:p? ?o`

Regular Expressions in Patterns

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- Paths with arbitrary length: `?s ex:p+ ?o`, `?s ex:p* ?o`
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- Length zero or one path: `?s ex:p? ?o`

- Property paths are, where possible, translated into standard SPARQL constructs
- Some new operators are still necessary

Property Path Example

Query 1

```
PREFIX ...
SELECT ?xName WHERE {
  ?x rdf:type foaf:Person .
  ?x foaf:name ?xName
  ?x foaf:knows/foaf:knows/foaf:name "Bill Gates" .
}
```

Query 2

```
PREFIX ...
SELECT ?s WHERE {
  ?s  rdf:type  ?type .
  ?type rdfs:subClassOf* ex:SomeClass .
}
```

Negation in Queries

- Two forms of negation with conceptual and small semantic differences
  1. Test non-matches for a pattern
  2. Removal of matching patterns

1. Filter

```
SELECT ?x WHERE {
  ?x rdf:type foaf:Person .
  FILTER NOT EXISTS { ?x foaf:name ?name }
}
```

2. Minus

```
SELECT ?x WHERE {
  ?x rdf:type foaf:Person .
  MINUS { ?x foaf:name ?name }
}
```

Evaluation of Negation via Filter

Data

```
_:x rdf:type foaf:Person .
_:x foaf:name "Peter" .
_:y rdf:type foaf:Person .
```

Query Pattern

```
{ ?x rdf:type foaf:Person .
  FILTER NOT EXISTS { ?x foaf:name ?name } }
```

1. $[\![\text{Bgp}(\text{1. Pattern})]\!]_G$: μ_1 : ?x $\mapsto$ _:x, μ_2 : ?x $\mapsto$ _:y
2. For each solution, we instantiate the second pattern
   - Solution is removed if the instantiated pattern matches (μ_1)
   - otherwise we keep the solution (μ_2)

Evaluation of Negation via Minus

Data

```
_:x rdf:type foaf:Person .
_:x foaf:name "Peter" .
_:y rdf:type foaf:Person .
```

Query Pattern

```
{ ?x rdf:type foaf:Person .
  MINUS { ?x foaf:name ?name } }
```

$[\![\text{Bgp(1. Pattern)}]\!]_G$: $\Omega_1 = \{\mu_1 : \texttt{?x} \mapsto \texttt{\_:x}, \mu_2 : \texttt{?x} \mapsto \texttt{\_:y}\}$

$[\![\text{Bgp(2. Pattern)}]\!]_G$: $\Omega_2 = \{\mu_3 : \texttt{?x} \mapsto \texttt{\_:x}, \texttt{?name} \mapsto \texttt{"Peter"}\}$

$[\![\text{Minus}(\Omega_1, \Omega_2)]\!]_G$: $\Omega = \{\mu \mid \mu \in \Omega_1$ and $\forall \mu' \in \Omega_2$ μ and μ' are incompatible or $\text{dom}(\mu) \cap \text{dom}(\mu') = \emptyset\}$

$\mu_1 \notin \Omega$:

μ_1 compatible with μ_3 and non-disjoint domains

$\mu_2 \in \Omega$: μ_2 incompatible with μ_3

Differences Minus and Filter Negation

Data

```
ex:a ex:b ex:c .
```

Query Pattern

```
{ ?s ?p ?o FILTER NOT EXISTS { ?x ?y ?z } }
```

- Filter pattern matches always (variables disjoint) $\rightsquigarrow$ every solution is removed

Query Pattern

```
{ ?s ?p ?o MINUS { ?x ?y ?z } }
```

- Minus does not remove any solutions since the domain of the solutions is disjoint

Agenda

SPARQL Protocol

- Specifies how queries can be sent to a SPARQL endpoint in the Web and how results are returned
- Specifies how errors are communicated
- Query
  - `GET` Query etc. is part of the URL: `http://server/endpoint1?query=...`
  - `POST` Query is in the body of the HTTP request, e.g., via an HTML form
- Update
  - `http://server/endpoint2?update=...`
  - `POST` with content-type application/sparql-update
  - `POST` via HTML form
- Query and Update are separate services

Graph Store HTTP Protocol

- Application protocol for distributed updating and fetching of RDF graph content via HTTP
  - IRIs identify a graph in a graph store
  - `GET` to receive the graph content
  - `PUT` to send a query that modifies a graph
  - `DELETE` to delete a graph
  - `POST` to merge submitted RDF data into an existing graph

Agenda

SPARQL Update

- For manipulation of graphs or graph content
- Based on the idea of a graph store (Quads)
  - Addition and removal of graphs
  - Addition and removal of triples in a graphs
- `LOAD`, `DROP`, `CREATE`
- `INSERT`, `DELETE` for data/triples
- No transactions, a query can consist of several atomic parts

Example Query

```
DELETE { ?person foaf:givenName "Bill" }
INSERT { ?person foaf:givenName "William" }
WHERE {
  ?person a foaf:Person .
  ?person foaf:givenName "Bill"
}
```

Agenda

Service Descriptions

- Method and vocabulary for describing SPARQL endpoints
- Client/User can request information about the SPARQL service, e.g.,
  - supported extension functions,
  - used data set or
  - supported inference mechanisms

HTTP Request

```
GET /sparql/ HTTP/1.1
Host: www.example.org
Accept: text/turtle
```

Possible Response (beginning)

```
HTTP/1.1 200 OK
Date: Fri, 09 Oct 2009 17:31:12 GMT
Server: Apache/1.3.29 (Unix) PHP/4.3.4 DAV/1.0.3
Connection: close
Content-Type: text/turtle

@prefix sd:
<http://www.w3.org/ns/sparql-service-description#> .
@prefix ent: <http://www.w3.org/ns/entailment/> .
@prefix prof: <http://www.w3.org/ns/owl-profile/> .
...
```

Possible Response (continued)

```
<http://ex.org/Distance> a sd:Function .

[] a sd:Service ;
  sd:endpoint <http://ex.org/sparql/> ;
  sd:supportedLanguage sd:SPARQL11Query ;
  sd:resultFormat
    <http://www.w3.org/ns/formats/RDF_XML>,
    <http://www.w3.org/ns/formats/Turtle> ;
  sd:extensionFunction <http://ex.org/Distance> ;
  sd:feature sd:DereferencesURIs ;
  sd:defaultEntailmentRegime ent:RDFS ;
```

Possible Response (continued)

```
sd:defaultDatasetDescription [
    a sd:Dataset ;
    sd:defaultGraph [
      a sd:Graph ;
      void:triples 100
    ] ;
    sd:namedGraph [
      a sd:NamedGraph ;
      sd:name <http://ex.org/named-graph> ;
      sd:entailmentRegime ent:OWL-RDF-Based ;
      sd:supportedEntailmentProfile prof:RL ;
      sd:graph [
        a sd:Graph ;
        void:triples 2000
      ]
    ]
] .
```

Agenda

Summary

- We have learned about the main SPARQL 1.1 extensions
- SPARQL 1.1 is a recommendation since March 2013
- SPARQL UPDATE allows for modifying graphs
- Protocol specifies the client server communication
- Service Descriptions describe a SPARQL service (machine readable)
- Further result formats: JSON, CVS, TSV (not covered)

Outlook:

- Entailment Regimes: SPARQL with inferred results

Public SPARQL Endpoints

DBPedia structured Wikipedia Data (> 100 million triples):
`http://dbpedia.org/sparql`

DBTune 14 billion RDF triple about music
`http://dbtune.org/jamendo/store/user/query`

CKAN Dataset repository with SPARQL service
`http://semantic.ckan.net/`
`http://semantic.ckan.net/snorql/`

Linked Movie Database `http://data.linkedmdb.org/` and
`http://data.linkedmdb.org/sparql`

SPARQL Editor with examples about space data `http://api.talis.com/stores/space/items/tutorial/spared.html`

Semantic Web Dog Food Information about authors, publications and conferences `http://data.semanticweb.org/snorql`