

Querying Semantic Web Data with SPARQL (and SPARQL 1.1)

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“The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation.”

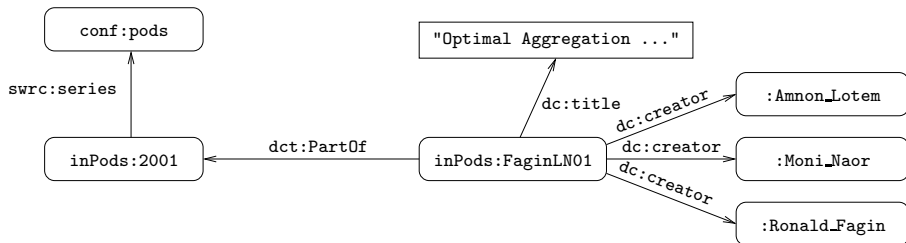
[Tim Berners-Lee et al. 2001.]

Specific goals:

- ▶ Build a description language with standard semantics
 - ▶ Make semantics machine-processable and understandable
- ▶ Incorporate logical infrastructure to reason about resources
- ▶ W3C proposals: **Resource Description Framework (RDF) and SPARQL**

An example of an RDF graph: DBLP

```
    : <http://dblp.13s.de/d2r/resource/authors/>
  conf: <http://dblp.13s.de/d2r/resource/conferences/>
inPods: <http://dblp.13s.de/d2r/resource/publications/conf/pods/>
  swrc: <http://swrc.ontoware.org/ontology#>
    dc: <http://purl.org/dc/elements/1.1/>
    dct: <http://purl.org/dc/terms/>
```



Querying RDF: SPARQL

- ▶ SPARQL is the W3C recommendation query language for RDF (January 2008).
 - ▶ SPARQL is a recursive acronym that stands for *SPARQL Protocol and RDF Query Language*
- ▶ SPARQL is a graph-matching query language.
- ▶ A SPARQL query consists of three parts:
 - ▶ Pattern matching: optional, union, filtering, ...
 - ▶ Solution modifiers: projection, distinct, order, limit, offset, ...
 - ▶ Output part: construction of new triples,

SPARQL in a nutshell

SPARQL in a nutshell

```
SELECT ?Author
```

SPARQL in a nutshell

```
SELECT ?Author
WHERE
{

}
```

SPARQL in a nutshell

```
SELECT ?Author
WHERE
{
  ?Paper      dc:creator      ?Author .
  ?Paper      dct:PartOf      ?Conf .
  ?Conf       swrc:series      conf: pods .
}
```

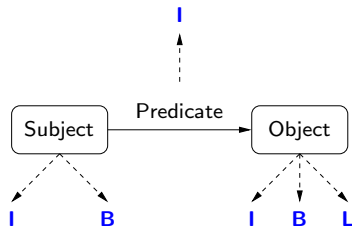

Outline of the talk

- ▶ RDF and SPARQL
- ▶ New features in SPARQL 1.1
 - ▶ Entailment regimes for RDFS and OWL
 - ▶ Navigational capabilities: Property paths
 - ▶ An operator to distribute the execution of a query
- ▶ Take-home message

Outline of the talk

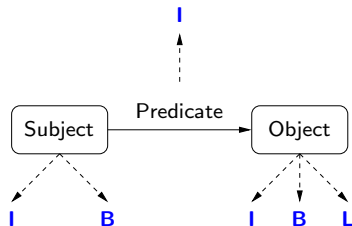
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RDF formal model



- I** : set of IRIs
- B** : set of blank nodes
- L** : set of literals

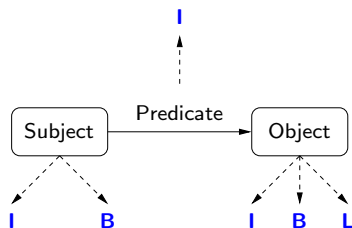
RDF formal model



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$(s, p, o) \in (\mathbf{I} \cup \mathbf{B}) \times \mathbf{I} \times (\mathbf{I} \cup \mathbf{B} \cup \mathbf{L})$ is called an **RDF triple**

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A finite set of RDF triples is called an **RDF graph**

Proviso

- ▶ We do not consider blank nodes in RDF graphs
 - ▶ $(s, p, o) \in \mathbf{I} \times \mathbf{I} \times (\mathbf{I} \cup \mathbf{L})$ is called an RDF triple
- ▶ We consider blank nodes in queries
 - ▶ Each blank node is assumed to start with $_:$, for example $_:b$ and $_:b_1$

SPARQL: An algebraic syntax

V: set of variables

- ▶ Each variable is assumed to start with ?

Triple pattern: $t \in (\mathbf{I} \cup \mathbf{B} \cup \mathbf{V}) \times (\mathbf{I} \cup \mathbf{V}) \times (\mathbf{I} \cup \mathbf{B} \cup \mathbf{L} \cup \mathbf{V})$

- ▶ Examples: $(?X, \text{name}, \text{john})$, $(?X, \text{name}, ?Y)$, $(?X, \text{name}, _ : b)$

Basic graph pattern (bgp): Finite set of triple patterns

- ▶ Examples: $\{(?X, \text{knows}, ?Y), (?Y, \text{name}, \text{john})\}$,
 $\{(?X, \text{knows}, _ : b), (_ : b, \text{name}, \text{john})\}$

SPARQL: An algebraic syntax (cont'd)

Recursive definition of SPARQL graph patterns:

- ▶ Every basic graph pattern is a graph pattern
- ▶ If P_1, P_2 are graph patterns, then $(P_1 \text{ AND } P_2)$, $(P_1 \text{ OPT } P_2)$, $(P_1 \text{ UNION } P_2)$ are graph pattern
- ▶ If P is a graph pattern and R is a *built-in condition*, then $(P \text{ FILTER } R)$ is a graph pattern

SPARQL query:

- ▶ If P is a graph pattern and W is a finite set of variables, then $(\text{SELECT } W P)$ is a SPARQL query

Mappings: building block for the semantics

Definition

A mapping is a partial function:

$$\mu : \mathbf{V} \longrightarrow (\mathbf{I} \cup \mathbf{L})$$

The evaluation of a graph pattern results in a set of mappings.

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Semantics of SPARQL: Basic graph patterns

Additional notation: $\sigma : \mathbf{B} \rightarrow (\mathbf{I} \cup \mathbf{L})$ is an instance mapping.

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Let P be a basic graph pattern

- ▶ $\text{var}(P)$: set of variables mentioned in P

Definition

The evaluation of P over an RDF graph G , denoted by $\llbracket P \rrbracket_G$, is the set of mappings μ :

- ▶ $\text{dom}(\mu) = \text{var}(P)$
- ▶ there exists an instance mapping σ such that $\mu(\sigma(P)) \subseteq G$

Semantics of basic graph patterns: Some examples

Notation: t is used to represent $\{t\}$

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graph

$(R_1, \text{name}, \text{john})$

$(R_1, \text{email}, \text{J@ed.ex})$

$(R_2, \text{name}, \text{paul})$

bgp

$(?X, \text{name}, ?Y)$

evaluation

	?X	?Y
μ_1 :	R_1	john
μ_2 :	R_2	paul

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$\mu_2:$

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$(?X, \text{name}, \text{_:b})$

	$?X$
μ_3 :	R_1
μ_4 :	R_2

Compatible mappings

Definition

Mappings μ_1 and μ_2 are compatible if they agree in their common variables:

If $?X \in \text{dom}(\mu_1) \cap \text{dom}(\mu_2)$, then $\mu_1(?X) = \mu_2(?X)$.

Example

	?X	?Y	?Z	?V
μ_1 :	R_1	john		
μ_2 :	R_1		J@edu.ex	
μ_3 :			P@edu.ex	R_2

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$\mu_1 \cup \mu_2$:	R_1	john	J@edu.ex	
$\mu_1 \cup \mu_3$:	R_1	john	P@edu.ex	R_2

- μ_2 and μ_3 are not compatible

Sets of mappings and operations

Let Ω_1 and Ω_2 be sets of mappings.

Definition

Join: extends mappings in Ω_1 with compatible mappings in Ω_2

- ▶ $\Omega_1 \bowtie \Omega_2 = \{\mu_1 \cup \mu_2 \mid \mu_1 \in \Omega_1, \mu_2 \in \Omega_2 \text{ and } \mu_1, \mu_2 \text{ are compatible}\}$

Difference: selects mappings in Ω_1 that cannot be extended with mappings in Ω_2

- ▶ $\Omega_1 \setminus \Omega_2 = \{\mu_1 \in \Omega_1 \mid \text{there is no mapping in } \Omega_2 \text{ compatible with } \mu_1\}$

Definition

Union: includes mappings in Ω_1 and in Ω_2

$$\blacktriangleright \Omega_1 \cup \Omega_2 = \{\mu \mid \mu \in \Omega_1 \text{ or } \mu \in \Omega_2\}$$

Left Outer Join: extends mappings in Ω_1 with compatible mappings in Ω_2 **if possible**

$$\blacktriangleright \Omega_1 \bowtie \Omega_2 = (\Omega_1 \bowtie \Omega_2) \cup (\Omega_1 \setminus \Omega_2)$$

Semantics of SPARQL: AND, UNION, OPT and SELECT

Given an RDF graph G

Definition

$$\llbracket (P_1 \text{ AND } P_2) \rrbracket_G =$$

$$\llbracket (P_1 \text{ UNION } P_2) \rrbracket_G =$$

$$\llbracket (P_1 \text{ OPT } P_2) \rrbracket_G =$$

$$\llbracket (\text{SELECT } W P) \rrbracket_G =$$

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$$\begin{aligned} \llbracket (P_1 \text{ AND } P_2) \rrbracket_G &= \llbracket P_1 \rrbracket_G \bowtie \llbracket P_2 \rrbracket_G \\ \llbracket (P_1 \text{ UNION } P_2) \rrbracket_G &= \llbracket P_1 \rrbracket_G \cup \llbracket P_2 \rrbracket_G \\ \llbracket (P_1 \text{ OPT } P_2) \rrbracket_G &= \llbracket P_1 \rrbracket_G \bowtie \llbracket P_2 \rrbracket_G \\ \llbracket (\text{SELECT } W P) \rrbracket_G &= \{ \mu|_W \mid \mu \in \llbracket P \rrbracket_G \} \end{aligned}$$

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$$\llbracket (\text{SELECT } W P) \rrbracket_G = \{ \mu|_W \mid \mu \in \llbracket P \rrbracket_G \}$$

$\text{dom}(\mu|_W) = \text{dom}(\mu) \cap W$ and

$\mu|_W(?X) = \mu(?X)$ for every $?X \in \text{dom}(\mu|_W)$

Example

$(R_1, \text{name}, \text{john})$
 $(R_1, \text{email}, \text{J@ed.ex})$
 $(R_2, \text{name}, \text{paul})$

$((?X, \text{name}, ?Y) \text{ OPT } (?X, \text{email}, ?E))$

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?X	?Y
R_1	john
R_2	paul

Semantics of SPARQL: An example

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?X	?Y
R_1	john
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?X	?Y	?E
R_1	john	J@ed.ex

?X	?E
R_1	J@ed.ex

► from the **Join**

Semantics of SPARQL: An example

Example

$(R_1, \text{name}, \text{john})$
 $(R_1, \text{email}, \text{J@ed.ex})$
 $(R_2, \text{name}, \text{paul})$

$((?X, \text{name}, ?Y) \text{ OPT } (?X, \text{email}, ?E))$

?X	?Y
R_1	john
R_2	paul

?X	?Y	?E
R_2	paul	

?X	?E
R_1	J@ed.ex

► from the **Difference**

Semantics of SPARQL: An example

Example

$(R_1, \text{name}, \text{john})$
 $(R_1, \text{email}, \text{J@ed.ex})$
 $(R_2, \text{name}, \text{paul})$

$((?X, \text{name}, ?Y) \text{ OPT } (?X, \text{email}, ?E))$

?X	?Y
R_1	john
R_2	paul

?X	?Y	?E
R_1	john	J@ed.ex
R_2	paul	

?X	?E
R_1	J@ed.ex

► from the **Union**

Filter expressions (value constraints)

Filter expression: (P FILTER R)

- ▶ P is a graph pattern
- ▶ R is a built-in condition

We consider in R :

- ▶ equality = among variables and RDF terms
- ▶ unary predicate bound
- ▶ boolean combinations (\wedge , \vee , \neg)

Satisfaction of value constraints

A mapping μ satisfies a condition R ($\mu \models R$) if:

Satisfaction of value constraints

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- ▶ R is $?X = c$, $?X \in \text{dom}(\mu)$ and $\mu(?X) = c$
- ▶ R is $?X = ?Y$, $?X, ?Y \in \text{dom}(\mu)$ and $\mu(?X) = \mu(?Y)$
- ▶ R is $\text{bound}(?X)$ and $?X \in \text{dom}(\mu)$

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- ▶ usual rules for Boolean connectives

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- ▶ usual rules for Boolean connectives

Definition

FILTER : selects mappings that satisfy a condition

$$\llbracket (P \text{ FILTER } R) \rrbracket_G = \{ \mu \in \llbracket P \rrbracket_G \mid \mu \models R \}$$

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 - ▶ An operator to distribute the execution of a query
- ▶ Take-home message

A new version of SPARQL has just been released (March 2013):
SPARQL 1.1

Some new features in SPARQL 1.1:

- ▶ Entailment regimes for RDFS and OWL
- ▶ Navigational capabilities: Property paths
- ▶ An operator (SERVICE) to distribute the execution of a query

Also in this version: Nesting of SELECT expressions, aggregates
and some forms of negation (NOT EXISTS, MINUS)

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Syntax of RDFS

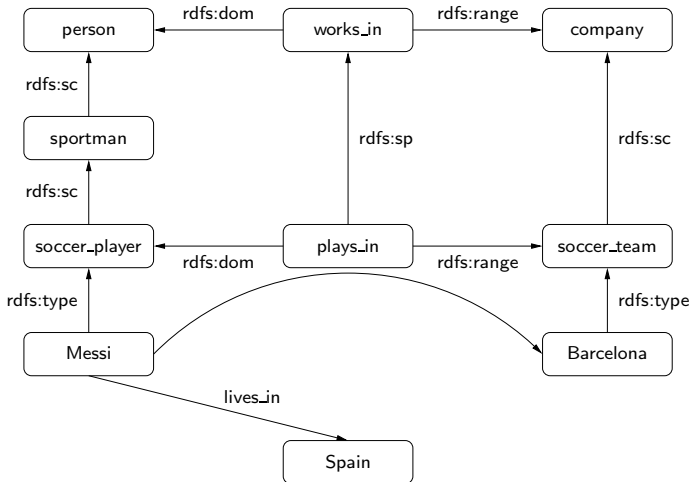
RDFS extends RDF with a schema vocabulary: `subPropertyOf` (`rdfs:sp`), `subClassOf` (`rdfs:sc`), `domain` (`rdfs:dom`), `range` (`rdfs:range`), `type` (`rdfs:type`).

Syntax of RDFS

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How do we evaluate a query over RDFS data?

A simple SPARQL query: (Messi, rdfs:type, person)



Checking whether a triple t is in a graph G is the basic step when answering queries over RDF.

- ▶ For the case of RDFS, we need to check whether t is implied by G

The notion of entailment in RDFS can be defined as for first-order logic.

This notion can also be characterized by a set of inference rules.

An inference system for RDFS

Sub-property : $\frac{(\mathcal{A}, \text{rdfs:sp}, \mathcal{B}) (\mathcal{B}, \text{rdfs:sp}, \mathcal{C})}{(\mathcal{A}, \text{rdfs:sp}, \mathcal{C})}$

$\frac{(\mathcal{A}, \text{rdfs:sp}, \mathcal{B}) (\mathcal{X}, \mathcal{A}, \mathcal{Y})}{(\mathcal{X}, \mathcal{B}, \mathcal{Y})}$

Subclass : $\frac{(\mathcal{A}, \text{rdfs:sc}, \mathcal{B}) (\mathcal{B}, \text{rdfs:sc}, \mathcal{C})}{(\mathcal{A}, \text{rdfs:sc}, \mathcal{C})}$

$\frac{(\mathcal{A}, \text{rdfs:sc}, \mathcal{B}) (\mathcal{X}, \text{rdfs:type}, \mathcal{A})}{(\mathcal{X}, \text{rdfs:type}, \mathcal{B})}$

Typing : $\frac{(\mathcal{A}, \text{rdfs:dom}, \mathcal{B}) (\mathcal{X}, \mathcal{A}, \mathcal{Y})}{(\mathcal{X}, \text{rdfs:type}, \mathcal{B})}$

$\frac{(\mathcal{A}, \text{rdfs:range}, \mathcal{B}) (\mathcal{X}, \mathcal{A}, \mathcal{Y})}{(\mathcal{Y}, \text{rdfs:type}, \mathcal{B})}$

Theorem (H03,MPG09,GHM11)

The previous system of inference rules characterize the notion of entailment in RDFS (without blank nodes).

Thus, a triple t can be deduced from an RDF graph G ($G \models t$) iff t can be deduced from G by applying the inference rules a finite number of times.

An entailment regime for RDFS in SPARQL 1.1

Basic graph patterns are evaluated by considering RDFS entailment.

Definition

The evaluation of a bgp P over an RDF graph G , denoted by $\llbracket P \rrbracket_G$, is the set of mappings μ :

- ▶ $\text{dom}(\mu) = \text{var}(P)$
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The semantics of AND, UNION, OPT, FILTER and SELECT are defined as before.

- ▶ RDFS entailment is only used at the level of bgps

Entailment regimes in SPARQL 1.1: Some observations

- ▶ SPARQL 1.1 can be used to query not only data but also schema information
 - ▶ For example: `(?X, rdfs:sc, person)`

Entailment regimes in SPARQL 1.1: Some observations

- ▶ SPARQL 1.1 can be used to query not only data but also schema information
 - ▶ For example: $(?X, \text{rdfs:sc}, \text{person})$
- ▶ Basic graph patterns can also be evaluated by considering OWL entailment.
 - ▶ $G \models \mu(\sigma(t))$ has to be defined according to the semantics of OWL

Entailment regimes in SPARQL 1.1: Some observations (cont'd)

- ▶ What are the consequences of considering entailment only at the level bgps?

Example

Let G be a graph consisting of $(\text{john}, \text{rdfs:type}, \text{student})$ together with:

$(\text{student}, \text{rdfs:sc}, u)$	}	axiom $\text{student} \sqsubseteq (\text{undergrad} \sqcup \text{grad})$
$(u, \text{owl:union}, l)$		
$(l, \text{rdf:first}, \text{undergrad})$		
$(l, \text{rdf:rest}, r)$		
$(r, \text{rdf:first}, \text{grad})$		
$(r, \text{rdf:rest}, \text{rdf:nil})$		

What should be the answer to

$P = ((?X, \text{rdfs:type}, \text{undergrad}) \text{ UNION } (?X, \text{rdfs:type}, \text{grad}))?$

- ▶ Under the current semantics: $\llbracket P \rrbracket_G = \emptyset$

Entailment regimes in SPARQL 1.1: Some observations (cont'd)

- ▶ It is possible to define a certain-answers semantics for SPARQL 1.1.
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- ▶ The semantics do not coincide as the following operator can be expressed in the language:

$$\llbracket (P_1 \text{ MINUS } P_2) \rrbracket_G = \llbracket P_1 \rrbracket_G \setminus \llbracket P_2 \rrbracket_G$$

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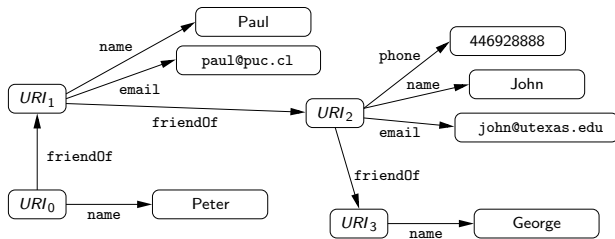
Open issues

- ▶ How natural is the semantics of SPARQL 1.1? Is it a good semantics? Why?
- ▶ Under which (natural) restrictions these two semantics coincide?

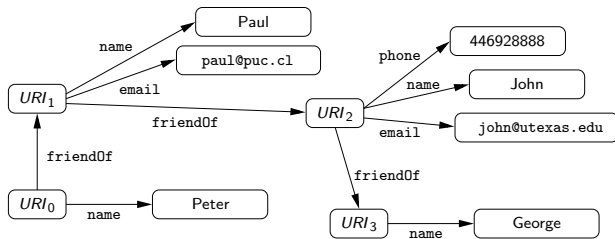
Outline of the talk

- ▶ RDF and SPARQL
- ▶ New features in SPARQL 1.1
 - ▶ Entailment regimes for RDFS and OWL
 - ▶ **Navigational capabilities: Property paths**
 - ▶ An operator to distribute the execution of a query
- ▶ Take-home message

SPARQL provides limited navigational capabilities

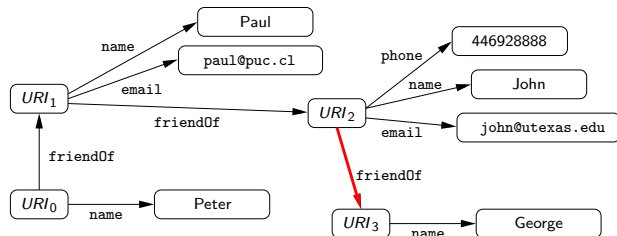


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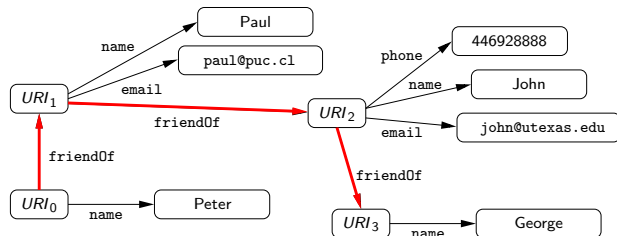
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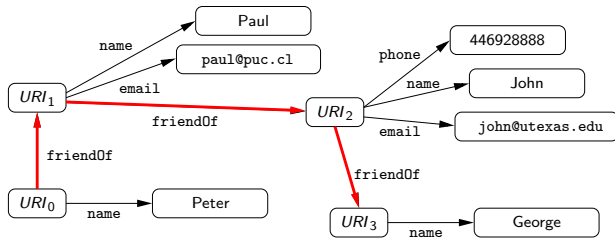
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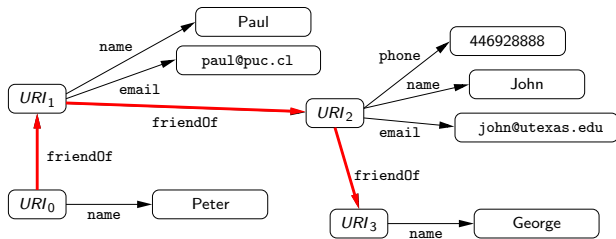


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A possible solution: Property paths



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```
(SELECT ?X ((?X, (friendOf)*, ?Y) AND (?Y, name, George)))
```

Navigational capabilities in SPARQL 1.1: Property paths

Syntax of property paths:

$$\text{exp} := a \mid \text{exp}/\text{exp} \mid \text{exp}|\text{exp} \mid \text{exp}^*$$

where $a \in \mathbf{I}$

Navigational capabilities in SPARQL 1.1: Property paths

Syntax of property paths:

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where $a \in \mathbf{I}$

Other expressions are allowed:

$\hat{\text{exp}}$: inverse path

$!(a_1 | \dots | a_n)$: an IRI which is not one of a_i ($1 \leq i \leq n$)

Evaluating property paths

The evaluation of a property path over an RDF graph G is defined as follows:

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Property paths in SPARQL 1.1

New element in SPARQL 1.1: A triple of the form (x, \textit{exp}, y)

- ▶ *exp* is a property path
- ▶ x (resp. y) is either an element from **I** or a variable

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Example

- ▶ $(?X, (\textit{rdfs:sc})^*, \textit{person})$: Verifies whether the value stored in $?X$ is a subclass of \textit{person}
- ▶ $(?X, (\textit{rdfs:sp})^*, ?Y)$: Verifies whether the value stored in $?X$ is a subproperty of the value stored in $?Y$

Semantics of property paths

Evaluation of $t = (?X, \text{exp}, ?Y)$ over an RDF graph G is the set of mappings μ such that:

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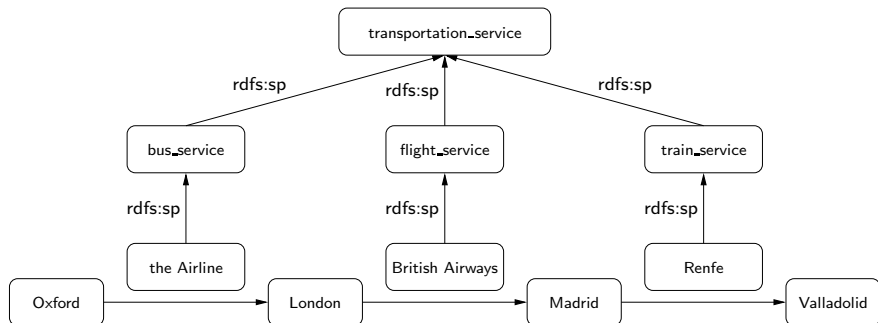
Other cases are defined analogously.

Example

- ▶ $((?X, KLM/(KLM)^*, ?Y) \text{ FILTER } \neg(?X = ?Y))$: It is possible to go from $?X$ to $?Y$ by using the airline KLM, where $?X, ?Y$ are different cities

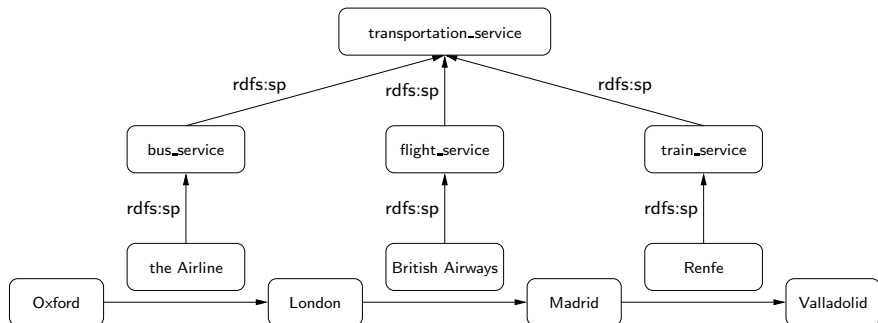
SPARQL 1.1: Entailment regimes and property paths

List the pairs a, b of cities such that there is a way to travel from a to b .



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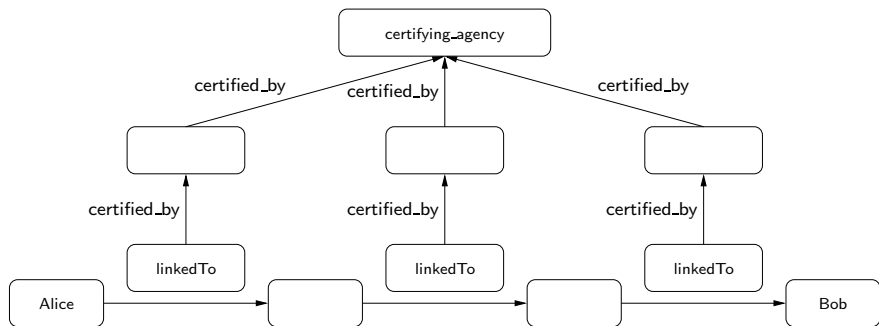


In SPARQL 1.1: $(?X, \text{transportation_service}^*, ?Y)$

Navigational capabilities in SPARQL 1.1: Some observations

- ▶ Previous query can be expressed in SPARQL 1.1 as the intermediate form of navigation involves RDFS vocabulary.

Not expressible: List pairs a, b of persons that are connected through a path of nodes certified by certifying_agency [RK13]:



- ▶ Some proposals solve the aforementioned issues: nSPARQL [PAG10], nested monadically defined queries [RK13], triple algebra [LRV13]
 - ▶ RDFS entailment can be handled in these proposals by using navigational capabilities

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Open issues

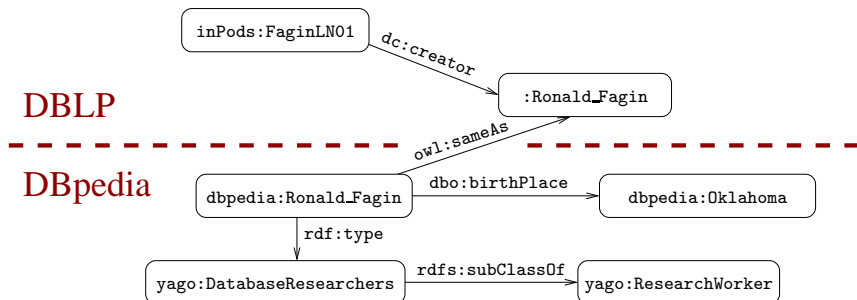
- ▶ How can OWL entailment be handled in these proposals?
- ▶ What navigational capabilities should be added to SPARQL 1.1?
- ▶ There is a need for query languages that can return paths

Outline of the talk

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RFD graphs can be interconnected

```
      : <http://dblp.l3s.de/d2r/resource/authors/>
dbpedia: <http://dbpedia.org/resource/>
  rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
  rdfs: <http://www.w3.org/2000/01/rdf-schema#>
  owl: <http://www.w3.org/2002/07/owl#>
  yago: <http://dbpedia.org/class/yago/>
  dbo: <http://dbpedia.org/ontology/>
```



Querying interconnected RDF graphs

Retrieve the authors that have published in PODS and were born in Oklahoma:

```
SELECT ?Author
WHERE
{
  ?Paper      dc:creator      ?Author .
  ?Paper      dct:PartOf      ?Conf .
  ?Conf       swrc:series      conf:pods .
  SERVICE <http://dbpedia.org/sparql> {
    ?Person   owl:sameAs     ?Author .
    ?Person   dbo:birthPlace   dbpedia:Oklahoma . }
}
```


Federation in SPARQL 1.1

New rule to generate graph patterns:

- ▶ If P is a graph pattern and $c \in (\mathbf{I} \cup \mathbf{V})$, then $(\text{SERVICE } c P)$ is a graph pattern.

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- ▶ If P is a graph pattern and $c \in (\mathbf{I} \cup \mathbf{V})$, then $(\text{SERVICE } c P)$ is a graph pattern.

We will define the semantics of this new operator.

- ▶ This corresponds with the official semantics for $(\text{SERVICE } c P)$ with $c \in \mathbf{I}$
- ▶ $(\text{SERVICE } ?X P)$ is allowed in the official specification of SPARQL 1.1, but its semantics is not defined

Semantics of SERVICE

$ep(\cdot)$: Partial function from \mathbf{I} to the set of all RDF graphs

- ▶ If $c \in \text{dom}(ep)$, then $ep(c)$ is the RDF graph associated with the endpoint accessible via c

Semantics of SERVICE

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Definition (BACP13)

The evaluation of $P = (\text{SERVICE } c P_1)$ over an RDF graph G is defined as:

- ▶ if $c \in \text{dom}(ep)$, then $\llbracket P \rrbracket_G = \llbracket P_1 \rrbracket_{ep(c)}$
- ▶ if $c \in \mathbf{I} \setminus \text{dom}(ep)$, then $\llbracket P \rrbracket_G = \{\mu_\emptyset\}$ (where μ_\emptyset is the mapping with empty domain)
- ▶ if $c \in \mathbf{V}$, then

$$\llbracket P \rrbracket_G = \bigcup_{a \in \text{dom}(ep)} \left(\llbracket P_1 \rrbracket_{ep(a)} \bowtie \{\mu_{c \rightarrow a}\} \right),$$

where $\mu_{c \rightarrow a}$ is a mapping such that $\text{dom}(\mu_{c \rightarrow a}) = \{c\}$ and $\mu_{c \rightarrow a}(c) = a$

Are variables useful in SERVICE queries?

Consider the query:

```
(?X, service_address, ?Y) AND (SERVICE ?Y (?N, email, ?E))
```

Are variables useful in SERVICE queries?

Consider the query:

`(?X, service_address, ?Y) AND (SERVICE ?Y (?N, email, ?E))`

There is a simple strategy to compute the answer to this query.

- ▶ Can this strategy be generalized?

How can we evaluate SERVICE queries?

We need some notion of boundedness

- ▶ A variable $?X$ is **bound** in a graph pattern P if for every RDF graph G and every $\mu \in \llbracket P \rrbracket_G$, it holds that $?X \in \text{dom}(\mu)$ and $\mu(?X)$ is mentioned in G

First attempt: Graph pattern P can be evaluated if for every sub-pattern $(\text{SERVICE } ?X P_1)$ of P , it holds that $?X$ is bound in P

- ▶ $?Y$ is bound in $(?X, \text{service_address}, ?Y)$ AND $(\text{SERVICE } ?Y (?N, \text{email}, ?E))$

The first attempt: Too restrictive

Consider the query:

```
(?X, service_description, ?Z) UNION  
  ((?X, service_address, ?Y) AND (SERVICE ?Y (?N, email, ?E)))
```

?Y is not bound in this query, but there is a simple strategy to evaluate it.

The first attempt: Not appropriate for nested SERVICE operators

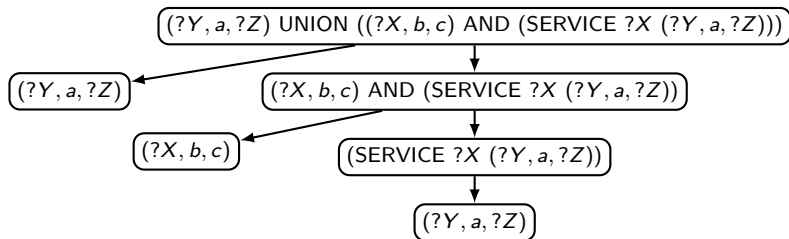
Consider the query:

$$(?U_1, \text{related_with}, ?U_2) \text{ AND } \left[\text{SERVICE } ?U_1 \left((?N, \text{email}, ?E) \text{ OPT } \left(\text{SERVICE } ?U_2 (?N, \text{phone}, ?F) \right) \right) \right]$$

Solving the problems ...

Notation: $\mathcal{T}(P)$ is the *parse tree* of P , in which every node corresponds to a sub-pattern of P

Parse tree of $(?Y, a, ?Z) \text{ UNION } ((?X, b, c) \text{ AND } (\text{SERVICE } ?X (?Y, a, ?Z)))$:



A more appropriate notion of boundedness

Definition (BACP13)

A graph pattern P is service-bound if for every node u of $\mathcal{T}(P)$ with label $(\text{SERVICE } ?X P_1)$, it holds that:

- ▶ there exists a node v of $\mathcal{T}(P)$ with label P_2 such that v is an ancestor of u in $\mathcal{T}(P)$ and $?X$ is bound in P_2
- ▶ P_1 is service-bound

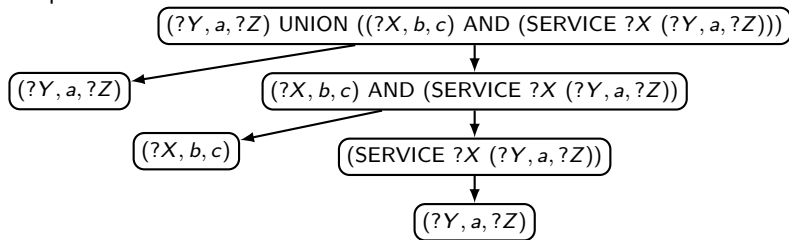
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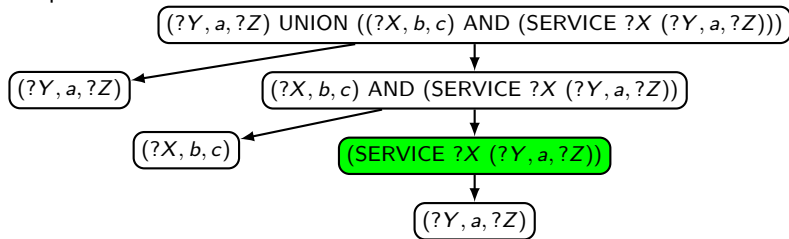
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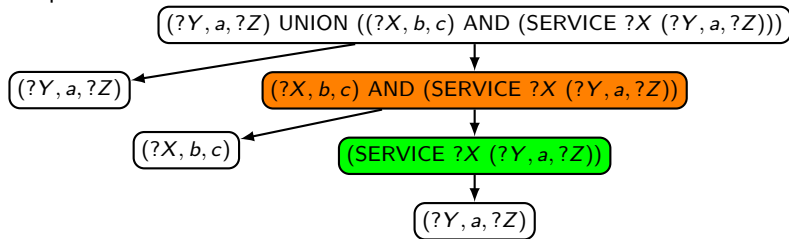
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(?Y, a, ?Z)

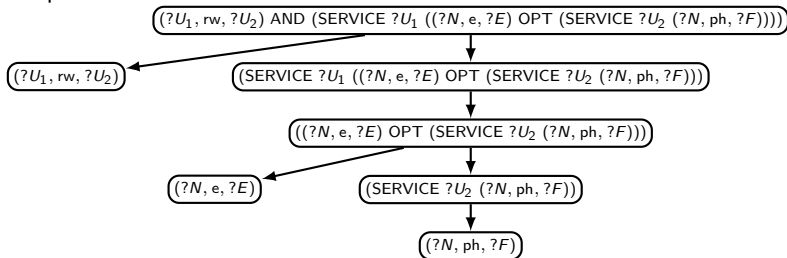
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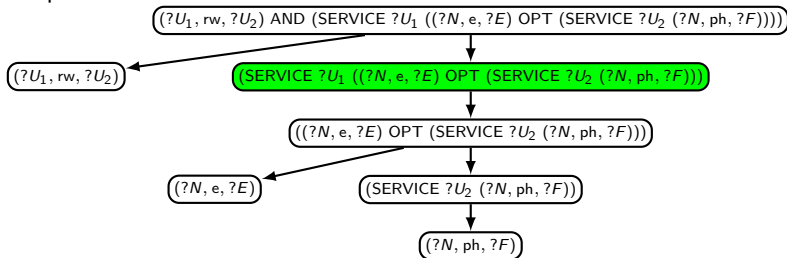
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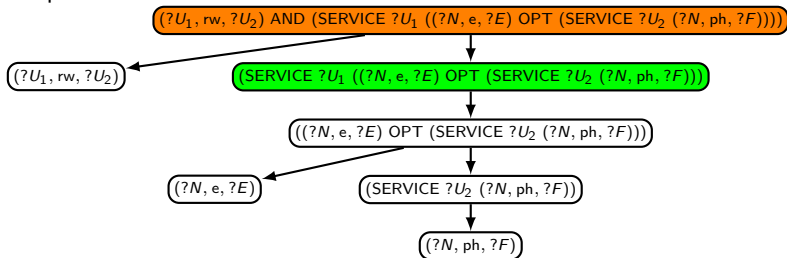
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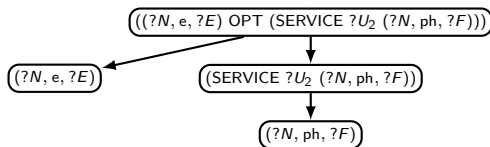
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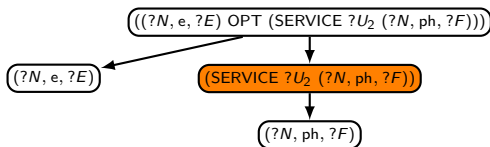
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Examples:



A more appropriate notion of boundedness (cont'd)

But we still have a problem:

Proposition (BACP13)

The problem of verifying, given a graph pattern P , whether P is service-bound is undecidable.

We consider a (syntactic) sufficient condition for service-boundedness.

An appropriate notion: Service-safeness

The set of strongly bound variables in P , denoted by $SB(P)$, is recursively defined as follows:

- ▶ if P is a bgp, then $SB(P) = \text{var}(P)$
- ▶ if $P = (P_1 \text{ AND } P_2)$, then $SB(P) = SB(P_1) \cup SB(P_2)$
- ▶ if $P = (P_1 \text{ UNION } P_2)$, then $SB(P) = SB(P_1) \cap SB(P_2)$
- ▶ if $P = (P_1 \text{ OPT } P_2)$, then $SB(P) = SB(P_1)$
- ▶ if $P = (P_1 \text{ FILTER } R)$, then $SB(P) = SB(P_1)$
- ▶ if $P = (\text{SERVICE } c P_1)$, then $SB(P) = \emptyset$

An appropriate notion: Service-safeness (cont'd)

Definition (BACP13)

A graph pattern P is **service-safe** if for every node u of $\mathcal{T}(P)$ with label $(\text{SERVICE } ?X P_1)$, it holds that:

- ▶ there exists a node v of $\mathcal{T}(P)$ with label P_2 such that v is an ancestor of u in $\mathcal{T}(P)$ and $?X \in \text{SB}(P_2)$
- ▶ P_1 is **service-safe**

If P is service-safe, then there is a strategy to evaluate P without considering all possible SPARQL endpoints.

An appropriate notion: Service-safeness (cont'd)

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If P is service-safe, then there is a strategy to evaluate P without considering all possible SPARQL endpoints.

Open issue

Is service-safeness the right condition to ensure that a query containing the SERVICE operator can be executed? Why?

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Take-home message

- ▶ RDF is the framework proposed by the W3C to represent information in the Web
- ▶ SPARQL is the W3C recommendation query language for RDF (January 2008)
- ▶ SPARQL 1.1 is the new version of SPARQL (March 2013)
- ▶ SPARQL 1.1 includes some interesting and useful new features
 - ▶ Entailment regimes for RDFS and OWL, navigational capabilities and an operator to distribute the execution of a query
 - ▶ There are some interesting open issues about these features

Thank you!

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