# Querying Semantic Web Data with SPARQL (and SPARQL 1.1)

Marcelo Arenas

PUC Chile & University of Oxford

# Semantic Web

"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."

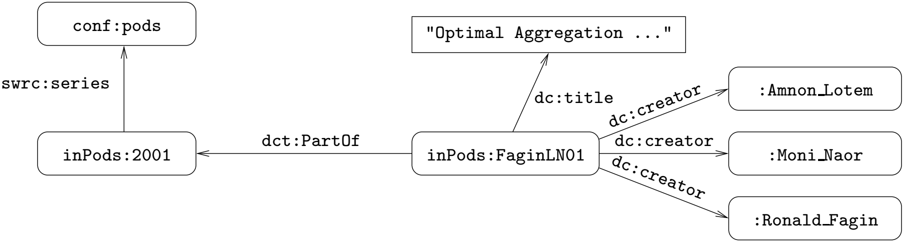
[Tim Berners-Lee et al. 2001.]

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.l3s.de/d2r/resource/authors/>
   conf: <http://dblp.l3s.de/d2r/resource/conferences/>
 inPods: <http://dblp.l3s.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

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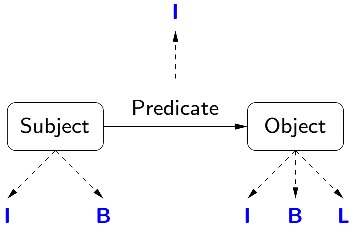
# RDF formal model

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**B** : set of blank nodes
**L** : set of literals

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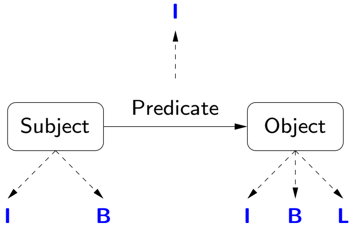


$\mathbf{I}$ : set of IRIs
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$(s, p, o) \in (\mathbf{I} \cup \mathbf{B}) \times \mathbf{I} \times (\mathbf{I} \cup \mathbf{B} \cup \mathbf{L})$ is called an RDF triple

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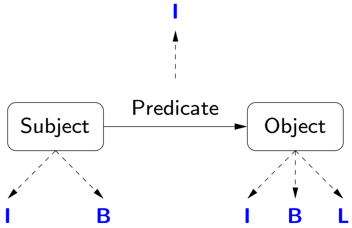


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A finite set of RDF triples is called an RDF graph

# RDF formal model

**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:

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

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

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 $[\![P]\!]_G$, is the set of mappings $\mu$:

- $\text{dom}(\mu) = \text{var}(P)$
- there exists an instance mapping $\sigma$ 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 | bgp | evaluation |
|---|---|---|
| $(R_1$, name, john$)$<br>$(R_1$, email, J@ed.ex$)$<br>$(R_2$, name, paul$)$ | $(?X$, name, $?Y)$ | see table below |

| | $?X$ | $?Y$ |
|---|---|---|
| $\mu_1$: | $R_1$ | john |
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| | $?X$ |
|---|---|
| $\mu_3$: | $R_1$ |
| $\mu_4$: | $R_2$ |

# Compatible mappings

## Definition

Mappings $\mu_1$ and $\mu_2$ are compatible if they agree in their common variables:

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

## Example

| | $?X$ | $?Y$ | $?Z$ | $?V$ |
|---|---|---|---|---|
| $\mu_1$ : | $R_1$ | john | | |
| $\mu_2$ : | $R_1$ | | J@edu.ex | |
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- $\mu_2$ and $\mu_3$ are not compatible

# Sets of mappings and operations

Let $\Omega_1$ and $\Omega_2$ be sets of mappings.

**Definition**

Join: extends mappings in $\Omega_1$ with compatible mappings in $\Omega_2$

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

Difference: selects mappings in $\Omega_1$ that cannot be extended with mappings in $\Omega_2$

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

# Sets of mappings and operations

## Definition

Union: includes mappings in $\Omega_1$ and in $\Omega_2$

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

Left Outer Join: extends mappings in $\Omega_1$ with compatible mappings in $\Omega_2$ **if possible**

- $\Omega_1 ⟕ \Omega_2 = (\Omega_1 \bowtie \Omega_2) \cup (\Omega_1 \smallsetminus \Omega_2)$

# Semantics of SPARQL: AND, UNION, OPT and SELECT

Given an RDF graph $G$

**Definition**

$$\begin{aligned}
[\![(P_1 \text{ AND } P_2)]\!]_G &= \\
[\![(P_1 \text{ UNION } P_2)]\!]_G &= \\
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\end{aligned}$$

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\end{aligned}
$$

$\text{dom}(\mu_{|W}) = \text{dom}(\mu) \cap W$ and
$\mu_{|W}(?X) = \mu(?X)$ for every $?X \in \text{dom}(\mu_{|W})$

# Semantics of SPARQL: An example

## Example

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

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

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|---|---|
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|---|---|---|
| | | |

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|---|---|---|
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| $?X$ | $?E$ |
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- from the Join

## Example

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| $?X$ | $?E$ |
|---|---|
| $R_1$ | J@ed.ex |

- from the Difference

# Semantics of SPARQL: An example

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- from the Union

# Filter expressions (value constraints)

Filter expression: $(P \text{ FILTER } R)$

- $P$ 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 ($\wedge$, $\vee$, $\neg$)

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

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- usual rules for Boolean connectives

**Definition**

FILTER : selects mappings that satisfy a condition

$$[\![(P \text{ FILTER } R)]\!]_G \quad = \quad \{\mu \in [\![P]\!]_G \mid \mu \models R\}$$

# 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 1.1

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).

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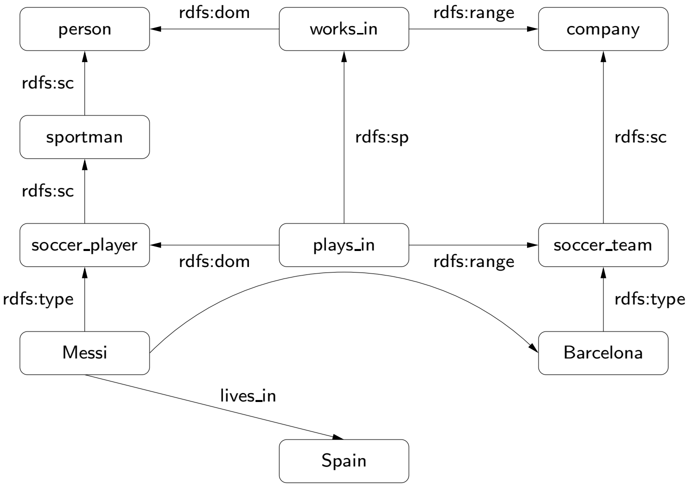
RDFS extends RDF with a schema vocabulary: subPropertyOf (rdfs:sp), subClassOf (rdfs:sc), domain (rdfs:dom), range (rdfs:range), type (rdfs:type).

How do we evaluate a query over RDFS data?

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



# Semantics of RDFS

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 : $\dfrac{(\mathcal{A},\ \text{rdfs:sp},\ \mathcal{B})\ (\mathcal{B},\ \text{rdfs:sp},\ \mathcal{C})}{(\mathcal{A},\ \text{rdfs:sp},\ \mathcal{C})}$

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

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

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

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

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

# Entailment in RDFS

**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 $[\![P]\!]_G$, is the set of mappings $\mu$:

- $\text{dom}(\mu) = \text{var}(P)$
- there exists an instance mapping $\sigma$ such that for every $t \in P$: $G \models \mu(\sigma(t))$

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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: $(?X, \text{rdfs:sc}, \text{person})$

# 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

- 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:

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

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: $[\![P]\!]_G = \emptyset$

# 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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$$[\![(P_1 \,\mathrm{MINUS}\, P_2)]\!]_G \quad = \quad [\![P_1]\!]_G \smallsetminus [\![P_2]\!]_G$$

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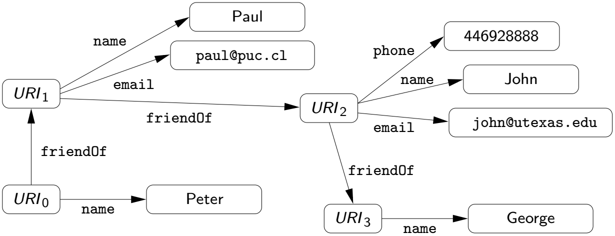
## Open issues

- 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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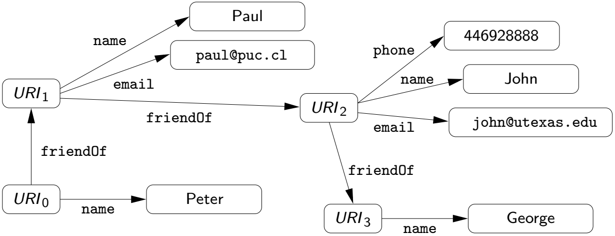


(SELECT $?X$ (($?X$, friendOf, $?Y$) AND ($?Y$, name, George)))

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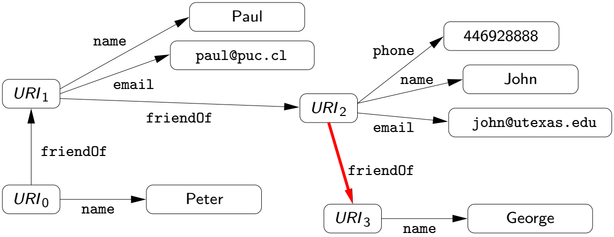


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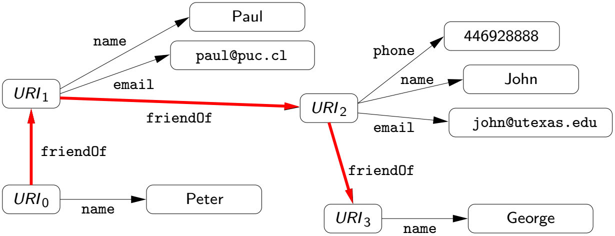


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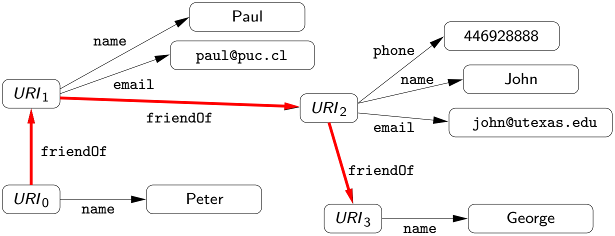
# A possible solution: Property paths



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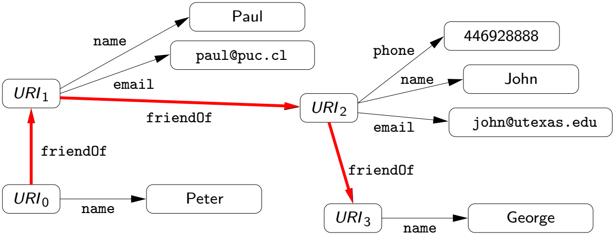


(SELECT $?X$ (($?X$, (friendOf)$^*$, $?Y$) AND ($?Y$, name, George)))

# Navigational capabilities in SPARQL 1.1: Property paths

Syntax of property paths:

$$exp \quad := \quad a \;\mid\; exp/exp \;\mid\; exp|exp \;\mid\; exp^*$$

where $a \in \mathbf{I}$

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$$exp \quad := \quad a \;\mid\; exp/exp \;\mid\; exp|exp \;\mid\; exp^*$$

where $a \in \mathbf{I}$

Other expressions are allowed:

| | | |
|---|---|---|
| $\hat{}exp$ | : | inverse path |
| $!(a_1 \mid \ldots \mid a_n)$ | : | an IRI which is not one of $a_i$ $(1 \leq i \leq n)$ |

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[\![exp_1|exp_2]\!]_G &= [\![exp_1]\!]_G \cup [\![exp_2]\!]_G \\
[\![exp^*]\!]_G &= \{(a,a) \mid a \text{ is an IRI in } G\} \cup [\![exp]\!]_G \cup \\
&\qquad [\![exp/exp]\!]_G \cup [\![exp/exp/exp]\!]_G \cup \cdots
\end{aligned}$$

# Property paths in SPARQL 1.1

New element in SPARQL 1.1: A triple of the form $(x, exp, y)$

- *exp* is a property path
- $x$ (resp. $y$) is either an element from $\mathbf{I}$ or a variable

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- *exp* is a property path
- $x$ (resp. $y$) is either an element from $\mathbf{I}$ or a variable

**Example**

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

# Semantics of property paths

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

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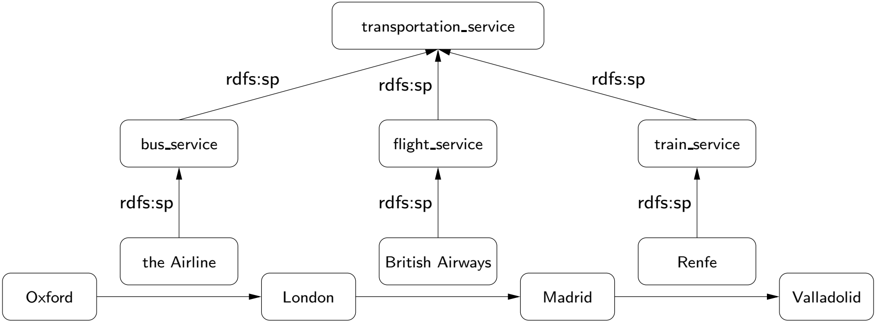
Other cases are defined analogously.

**Example**

- $((?X, \text{KLM}/(\text{KLM})^*, ?Y)$ 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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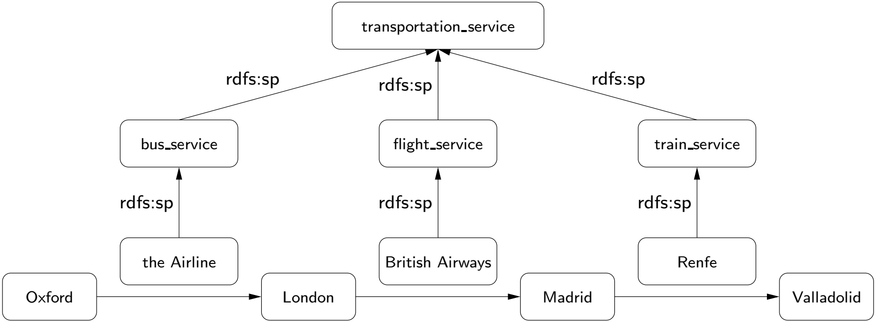
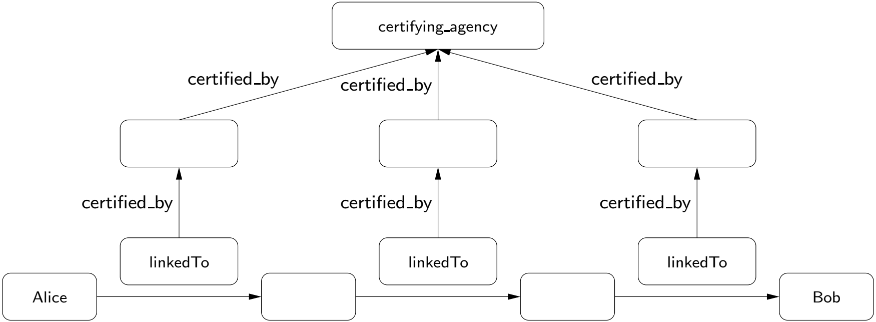



In SPARQL 1.1: $(?X, \text{transportation\_service}^*, ?Y)$

# 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]:



# Navigational capabilities in SPARQL 1.1: Some observations (cont'd)

- 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

## Navigational capabilities in SPARQL 1.1: Some observations (cont'd)

- 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

### 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

- RDF and SPARQL
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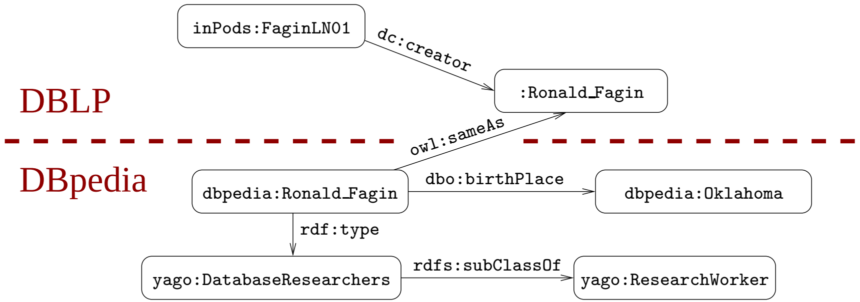
# RFD graphs can be interconnected

```
       : <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 (SERVICE $c$ $P$) is a graph pattern.

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New rule to generate graph patterns:

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

We will define the semantics of this new operator.

- This corresponds with the official semantics for (SERVICE $c$ $P$) with $c \in \mathbf{I}$
- (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 **I** to the set of all RDF graphs

- If $c \in \text{dom}(\text{ep})$, then $\text{ep}(c)$ 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 $c \in \text{dom}(\text{ep})$, then $[\![P]\!]_G = [\![P_1]\!]_{\text{ep}(c)}$
- if $c \in \mathbf{I} \setminus \text{dom}(\text{ep})$, then $[\![P]\!]_G = \{\mu_\emptyset\}$ (where $\mu_\emptyset$ is the mapping with empty domain)
- if $c \in \mathbf{V}$, then

$$[\![P]\!]_G \quad = \quad \bigcup_{a \in \text{dom}(\text{ep})} \left( [\![P_1]\!]_{\text{ep}(a)} \bowtie \{\mu_{c \to a}\} \right),$$

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

# Are variables useful in SERVICE queries?

Consider the query:

$$(?X, \text{service\_address}, ?Y) \text{ AND } (\text{SERVICE } ?Y \ (?N, \text{email}, ?E))$$

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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 $\mu \in [\![P]\!]_G$, 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 (SERVICE $?X$ $P_1$) of $P$, it holds that $?X$ is bound in $P$

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

# The first attempt: Too restrictive

Consider the query:

$$(?X, \text{service\_description}, ?Z) \text{ UNION}$$
$$\Big((?X, \text{service\_address}, ?Y) \text{ AND } (\text{SERVICE } ?Y \ (?N, \text{email}, ?E))\Big)$$

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

# The first attempt: Not appropriate for nested SERVICE operators

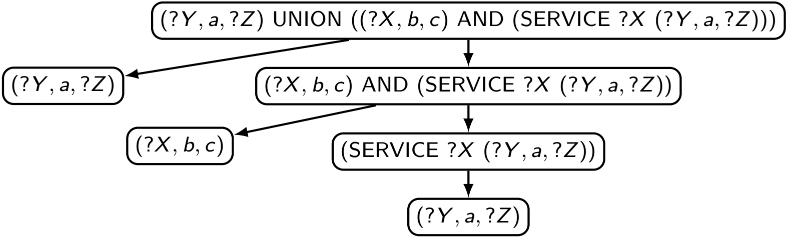
Consider the query:

$$(?U_1, \text{related\_with}, ?U_2) \;\; \text{AND} \;\; \Big[ \text{SERVICE } ?U_1 \; \Big( (?N, \text{email}, ?E) \;\; \text{OPT} \;\; (\text{SERVICE } ?U_2 \; (?N, \text{phone}, ?F)) \Big) \Big]$$

# 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 $(?Y, a, ?Z)$ UNION $((?X, b, c)$ AND (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 (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 $P_2$
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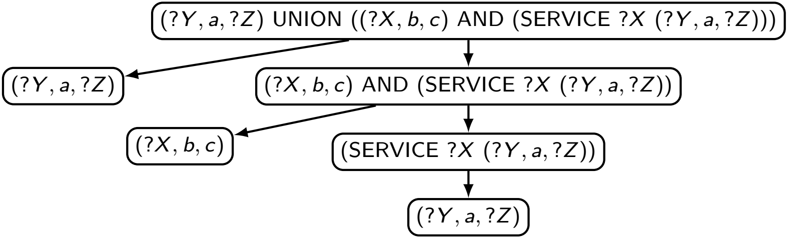

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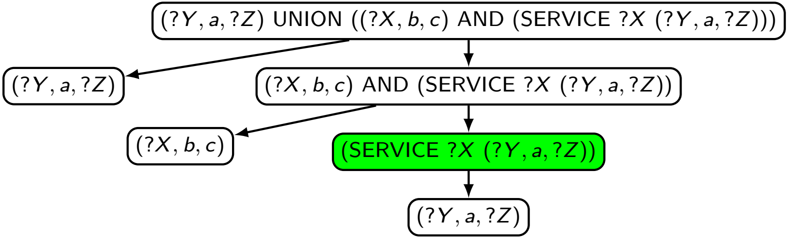

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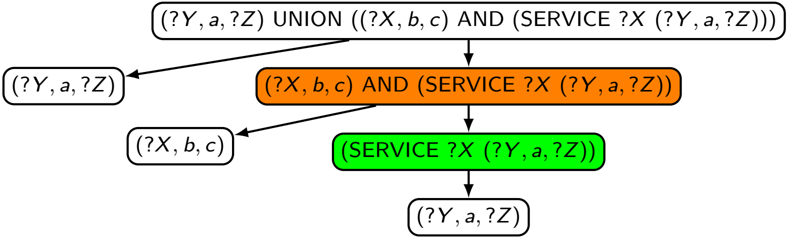

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Examples:

$\boxed{(?Y, a, ?Z)}$

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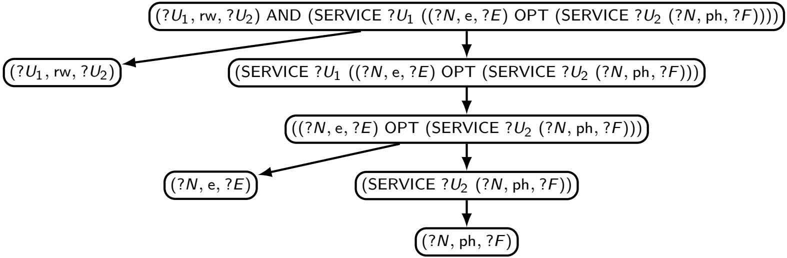

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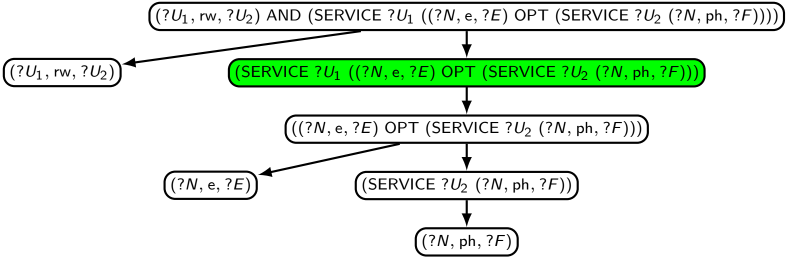
- $P_1$ is service-bound

Examples:



# A more appropriate notion of boundedness

## Definition (BACP13)

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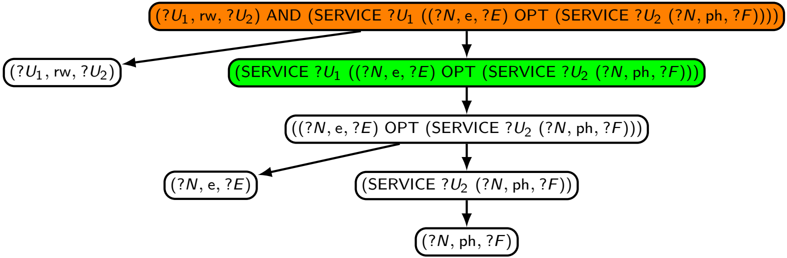

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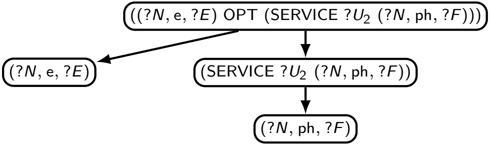

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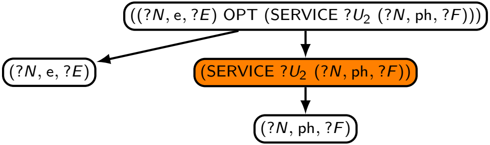

# A more appropriate notion of boundedness (cont'd)

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 $\text{SB}(P)$, is recursively defined as follows:

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

# 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 (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)

## Definition (BACP13)

A graph pattern $P$ is service-safe if for every node $u$ of $\mathcal{T}(P)$ with label (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.

## Open issue

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

# 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

# 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)
- SPARLQ 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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