Learning Commonalities in SPARQL*

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Introduction

Least general generalization (`lgg`)

- Machine Learning in the early 70's by Gordon Plotkin
- Knowledge representation domain in the early 90's
- Recently in semantic web

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- Query optimization: identify candidate views, or potiential query sharing
- Query approximation: a set of queries by a single query
- Social network context: recommending users asking for enough related things

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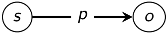
Goal

To study the problem in the *entire* conjunctive fragment of SPARQL setting.

Outline

RDF graphs

- Specification of RDF graphs with triples:
  $(\mathrm{s}, \mathrm{p}, \mathrm{o}) \in (\mathcal{U} \cup \mathcal{B}) \times \mathcal{U} \times (\mathcal{U} \cup \mathcal{L} \cup \mathcal{B})$



- Built-in property URIs to state RDF statements

RDF statement	Triple
Class assertion	$(\mathrm{s}, \mathrm{rdf{:}type}, \mathrm{o})$
Property assertion	$(\mathrm{s}, \mathrm{p}, \mathrm{o})$ with $\mathrm{p} \neq \mathrm{rdf{:}type}$

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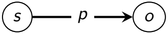

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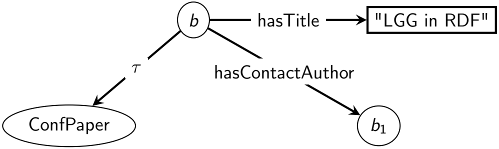

Adding ontological knowledge to RDF graphs

- Built-in property URIs to state RDF Schema statements, i.e., ontological constraints.

RDFS statement	Triple
Subclass	$(\mathrm{s}, \preceq_{\mathrm{sc}}, \mathrm{o})$
Subproperty	$(\mathrm{s}, \preceq_{\mathrm{sp}}, \mathrm{o})$
Domain typing	$(\mathrm{s}, \hookleftarrow_{d}, \mathrm{o})$
Range typing	$(\mathrm{s}, \hookrightarrow_{r}, \mathrm{o})$

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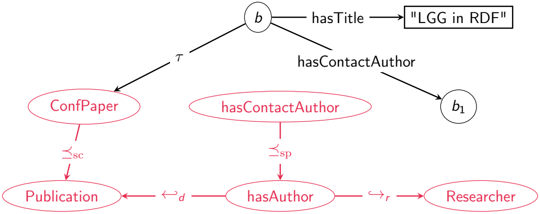

Deriving the implicit triples

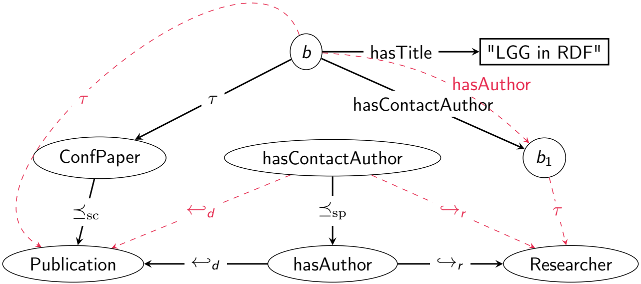

Figure: RDF graph $\mathcal{G}$

How to derive implicit triples of an RDF graph ?

Sample set of entailment rules

Rule [W3C-RDFS, 2014]	Entailment rule
`rdfs2`	$(\mathrm{p}, \hookleftarrow_d, \mathrm{o}), (\mathrm{s}_1, \mathrm{p}, \mathrm{o}_1) \rightarrow (\mathrm{s}_1, \tau, \mathrm{o})$
`rdfs3`	$(\mathrm{p}, \hookrightarrow_r, \mathrm{o}), (\mathrm{s}_1, \mathrm{p}, \mathrm{o}_1) \rightarrow (\mathrm{o}_1, \tau, \mathrm{o})$
`rdfs7`	$(\mathrm{p}_1, \preceq_{\mathrm{sp}}, \mathrm{p}_2), (\mathrm{s}, \mathrm{p}_1, \mathrm{o}) \rightarrow (\mathrm{s}, \mathrm{p}_2, \mathrm{o})$
`rdfs9`	$(\mathrm{s}, \preceq_{\mathrm{sc}}, \mathrm{o}), (\mathrm{s}_1, \tau, \mathrm{s}) \rightarrow (\mathrm{s}_1, \tau, \mathrm{o})$
`rdfs5`	$(\mathrm{p}_1, \preceq_{\mathrm{sp}}, \mathrm{p}_2), (\mathrm{p}_2, \preceq_{\mathrm{sp}}, \mathrm{p}_3) \rightarrow (\mathrm{p}_1, \preceq_{\mathrm{sp}}, \mathrm{p}_3)$
`rdfs11`	$(\mathrm{s}, \preceq_{\mathrm{sc}}, \mathrm{o}), (\mathrm{o}, \preceq_{\mathrm{sc}}, \mathrm{o}_1) \rightarrow (\mathrm{s}, \preceq_{\mathrm{sc}}, \mathrm{o}_1)$
`ext1`	$(\mathrm{p}, \hookleftarrow_d, \mathrm{o}), (\mathrm{o}, \preceq_{\mathrm{sc}}, \mathrm{o}_1) \rightarrow (\mathrm{p}, \hookleftarrow_d, \mathrm{o}_1)$
`ext2`	$(\mathrm{p}, \hookrightarrow_r, \mathrm{o}), (\mathrm{o}, \preceq_{\mathrm{sc}}, \mathrm{o}_1) \rightarrow (\mathrm{p}, \hookrightarrow_r, \mathrm{o}_1)$
`ext3`	$(\mathrm{p}, \preceq_{\mathrm{sp}}, \mathrm{p}_1), (\mathrm{p}_1, \hookleftarrow_d, \mathrm{o}) \rightarrow (\mathrm{p}, \hookleftarrow_d, \mathrm{o})$
`ext4`	$(\mathrm{p}, \preceq_{\mathrm{sp}}, \mathrm{p}_1), (\mathrm{p}_1, \hookrightarrow_r, \mathrm{o}) \rightarrow (\mathrm{p}, \hookrightarrow_r, \mathrm{o})$

Table: Sample RDF entailment rules $\mathcal{R}$

Semantics of RDF graphs

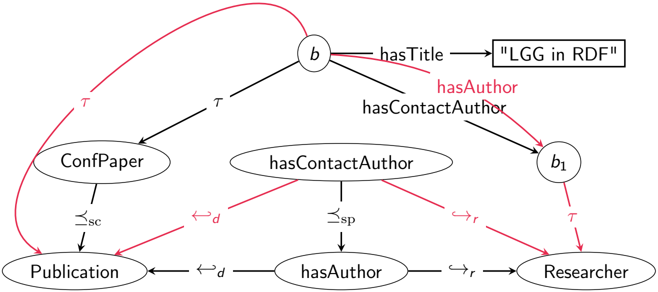

Figure: Saturated RDF graph $\mathcal{G}^{\infty}$

Basic graph pattern queries (BGPQ)

- BGPQ : conjunctive fragment of SPARQL queries, is the counterpart of the select-project-join queries for databases
- $(\mathtt{s}, \mathtt{p}, \mathtt{o}) \in (\mathcal{V} \cup \mathcal{U}) \times (\mathcal{V} \cup \mathcal{U}) \times (\mathcal{V} \cup \mathcal{U} \cup \mathcal{L})$

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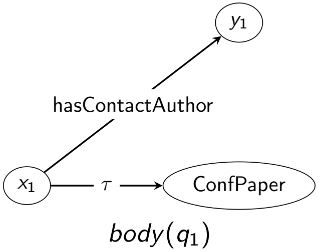


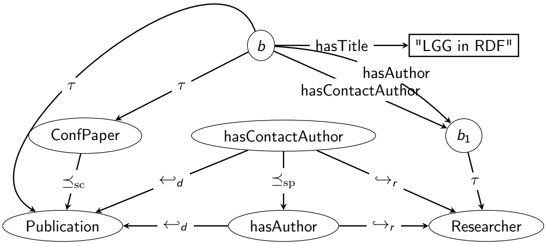
Figure: Sample BGPQ $q_1(x_1)$

Entailing and answering queries

Query entailment

$\mathcal{G} \models_{\mathcal{R}} q \iff \mathcal{G}^{\infty} \models q$

$q(x_1, x_2)$



$\mathcal{G}^{\infty}$

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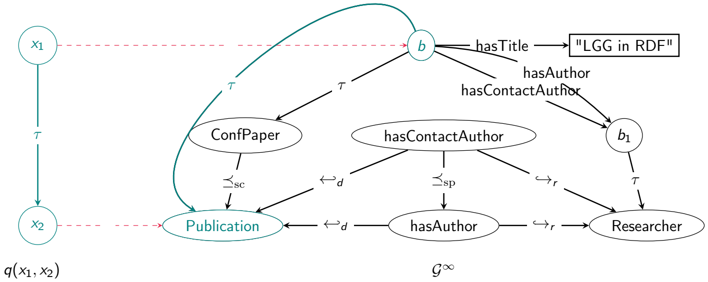
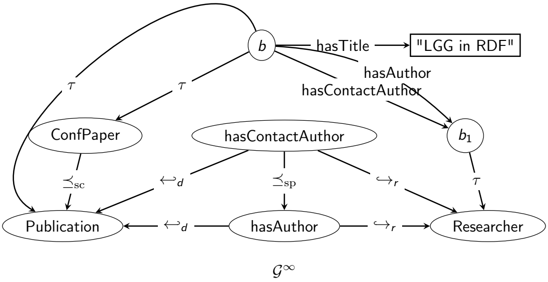


Entailing and answering queries

Query answering

$q(\mathcal{G}) = \{(\bar{x})_\phi \mid \mathcal{G} \models^{\phi}_{\mathcal{R}} body(q)\}$



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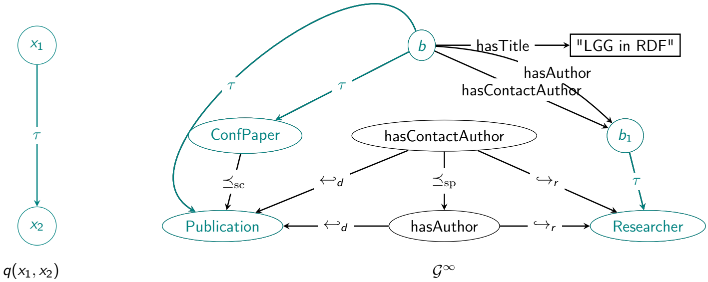
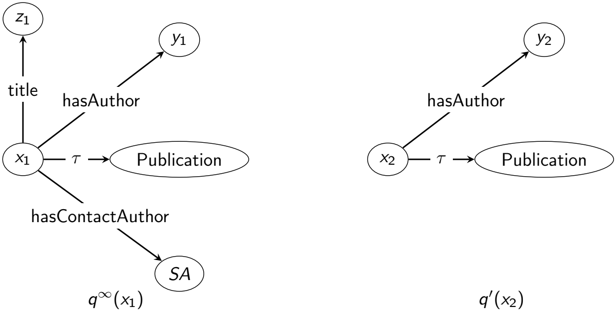


Entailing between BGPQs

$$q \models_{\mathcal{R}} q' \iff q^{\infty} \models q'$$



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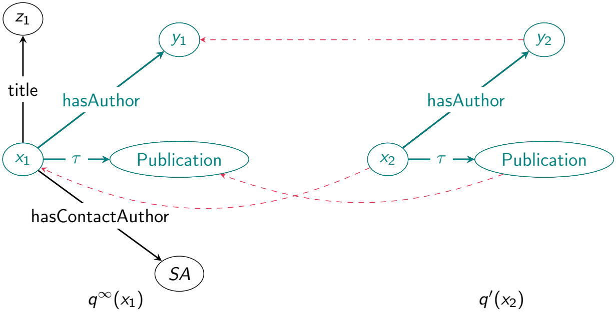

Outline

Towards defining lgg in SPARQL conjunctive fragment

A *least general generalization* (`lgg`) of n descriptions $d_1, \ldots, d_n$ is a most specific description d generalizing every $d_{1 \leq i \leq n}$ for some generalization/specialization relation between descriptions (G.Plotkin).

`lgg` in our SPARQL setting

- descriptions are BGP Queries
- relation generalization/specialization is entailment between queries

Defining the $\texttt{lgg}$ of queries

$\texttt{lgg}$ of BGPQs

Let $q_1, \ldots, q_n$ be BGPQs with the same arity and $\mathcal{R}$ a set of RDF entailment rules.

- A *generalization* of $q_1, \ldots, q_n$ is a BGPQ q_g such that $q_i \models_{\mathcal{R}} q_g$ for $1 \leq i \leq n$.
- A *least general generalization* of $q_1, \ldots, q_n$ is a generalization $q_{\texttt{lgg}}$ of $q_1, \ldots, q_n$ such that for any other generalization q_g of $q_1, \ldots, q_n$: $q_{\texttt{lgg}} \models_{\mathcal{R}} q_g$.

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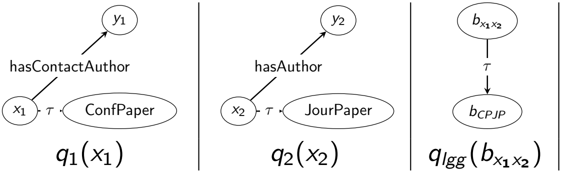

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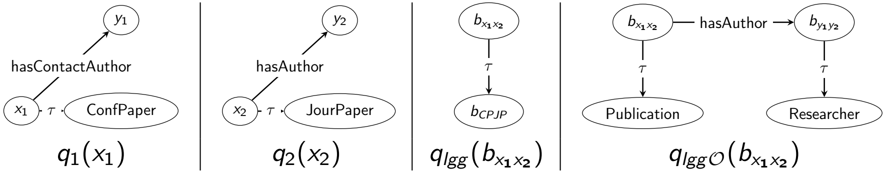


Entailment relation between BGPQs w.r.t. background knowledge

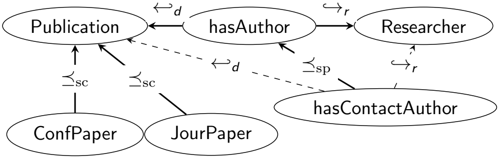
Entailment between BGPQs w.r.t. $\mathcal{R}, \mathcal{O}$

Given a set $\mathcal{R}$ of RDF entailment rules, a set $\mathcal{O}$ of RDFS statements, and two BGPQs q_1 and q_2 with the same arity, q_1 *entails* q_2 *w.r.t.* $\mathcal{O}$, denoted $q_1 \models_{\mathcal{R},\mathcal{O}} q_2$, iff ${q_1}^{\infty}_{\mathcal{O}} \models q_2$ holds.

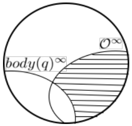
Well-founded relation : $q_1 \models_{\mathcal{R},\mathcal{O}} q_2$

- **Query entailment**: if $\mathcal{G} \models_{\mathcal{R}} q_1$ holds then $\mathcal{G} \models_{\mathcal{R}} q_2$ holds,
- **Query answering**: $q_1(\mathcal{G}) \subseteq q_2(\mathcal{G})$ holds.

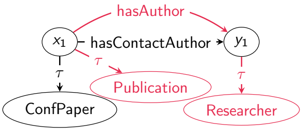
BGPQ saturation w.r.t. RDFS constraints



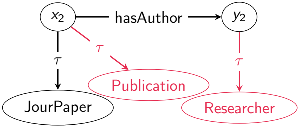
$\mathcal{O}$



$(body(q) \cup \mathcal{O})^\infty$



$q_1{}^\infty_\mathcal{O}(x_1)$



$q_2{}^\infty_\mathcal{O}(x_2)$

Defining the lgg of queries w.r.t. background knowledge

Definition (lgg of BGPQs w.r.t. RDFS constraints)

Let $\mathcal{R}$ be a set of RDF entailment rules, $\mathcal{O}$ a set of RDFS statements, and $q_1, \ldots, q_n$ n BGPQs with the same arity.

- A *generalization of* $q_1, \ldots, q_n$ *w.r.t.* $\mathcal{O}$ is a BGPQ q_g such that $q_i \models_{\mathcal{R},\mathcal{O}} q_g$ for $1 \leq i \leq n$.
- A *least general generalization of* $q_1, \ldots, q_n$ *w.r.t.* $\mathcal{O}$ is a generalization $q_{\mathtt{lgg}}$ of $q_1, \ldots, q_n$ w.r.t. $\mathcal{O}$ such that for any other generalization q_g of $q_1, \ldots, q_n$ w.r.t. $\mathcal{O}$: $q_{\mathtt{lgg}} \models_{\mathcal{R},\mathcal{O}} q_g$.

Theorem

An lgg of BGPQs w.r.t. RDFS statements may not exist for some set of RDF entailment rules; when it exists, it is unique up to entailment ($\models_{\mathcal{R},\mathcal{O}}$).

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Result : lgg of n BGPQ queries vs lgg of two BGPQ queries

$$
\begin{aligned}
\ell_3(q_1, q_2, q_3) &\equiv_{\mathcal{R},\mathcal{O}} \ell_2(\ell_2(q_1, q_2), q_3) \\
\cdots &\quad \cdots \\
\ell_n(q_1, \ldots, q_n) &\equiv_{\mathcal{R},\mathcal{O}} \ell_2(\ell_{n-1}(q_1, \ldots, q_{n-1}), q_n) \\
&\equiv_{\mathcal{R},\mathcal{O}} \ell_2(\ell_2(\cdots \ell_2(\ell_2(q_1, q_2), q_3) \cdots, q_{n-1}), q_n)
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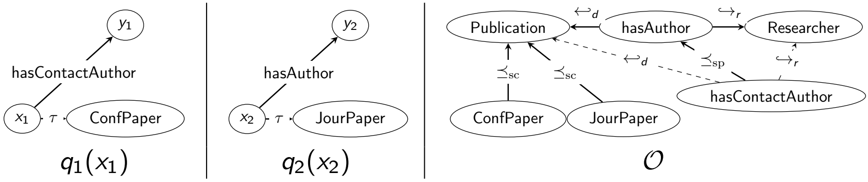
$$

We focus on computing lgg of two BGPQ queries

Defining the lgg of queries



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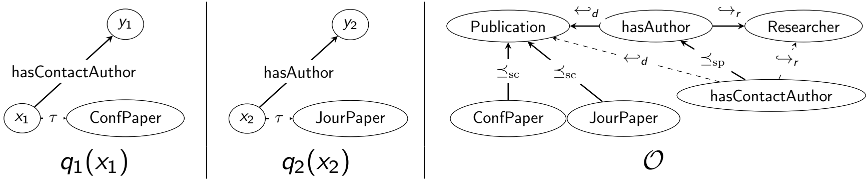

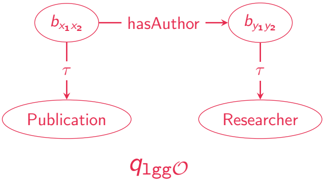

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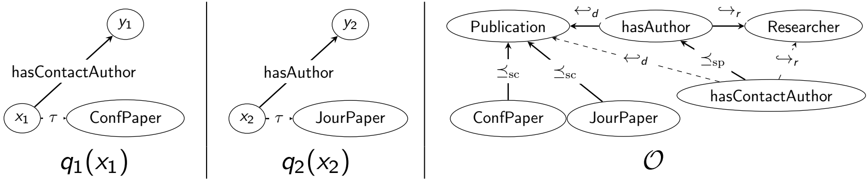
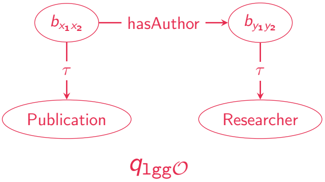




How to compute this query ?

The cover of SPARQL queries

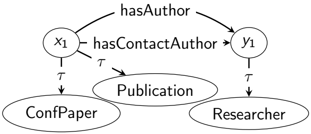
Definition (Cover query)

Let q_1, q_2 be two BGPQs with the same arity n.
<u>If</u> there exists the BGPQ q such that

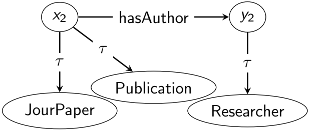
- $head(q_1) = q(x_1^1, \ldots, x_1^n)$ and $head(q_2) = q(x_2^1, \ldots, x_2^n)$ iff $head(q) = q(v_{x_1^1 x_2^1}, \ldots, v_{x_1^n x_2^n})$
- $(t_1, t_2, t_3) \in body(q_1)$ and $(t_4, t_5, t_6) \in body(q_2)$ iff $(t_7, t_8, t_9) \in body(q)$ with, for $1 \leq i \leq 3$, $t_{i+6} = t_i$ if $t_i = t_{i+3}$ and $t_i \in \mathcal{U} \cup \mathcal{L}$, otherwise t_{i+6} is the variable $v_{t_i t_{i+3}}$

<u>then</u> q is the *cover query* of q_1, q_2.

The cover of SPARQL queries



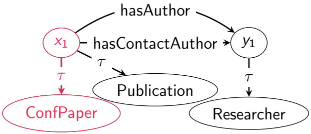
$q_1{}^{\infty}_{\mathcal{O}}(x_1)$



$q_2{}^{\infty}_{\mathcal{O}}(x_2)$

$$q(V_{x1x2})$$

The cover of SPARQL queries



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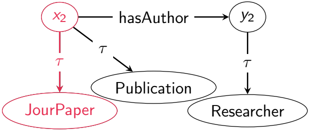

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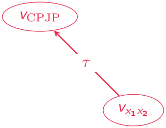
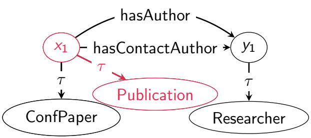
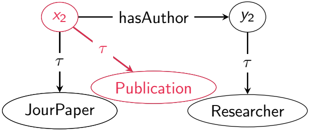


$q(V_{x1x2})$

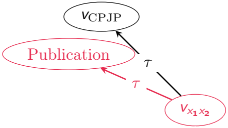
The cover of SPARQL queries



$q_{1}{}^{\infty}_{\mathcal{O}}(x_1)$

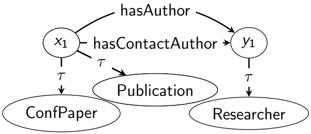


$q_{2}{}^{\infty}_{\mathcal{O}}(x_2)$

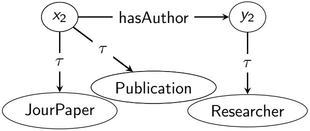


$q(V_{x1x2})$

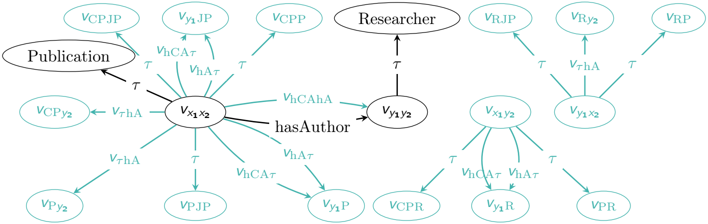
The cover of SPARQL queries



$q_1{}^{\infty}_{\mathcal{O}}(x_1)$



$q_2{}^{\infty}_{\mathcal{O}}(x_2)$



$q(V_{x1x2})$

Cover graph vs lgg

Theorem

Given a set $\mathcal{R}$ of RDF entailment rules, a set $\mathcal{O}$ of RDFS statements and two BGPQs q_1, q_2 with the same arity,

1. the cover query q of ${q_1}^{\infty}_{\mathcal{O}}, {q_2}^{\infty}_{\mathcal{O}}$ exists iff an `lgg` of q_1, q_2 w.r.t. $\mathcal{O}$ exists;
2. the cover query q of ${q_1}^{\infty}_{\mathcal{O}}, {q_2}^{\infty}_{\mathcal{O}}$ is an `lgg` of q_1, q_2 w.r.t. $\mathcal{O}$.

Corollary

A cover query-based `lgg` of two BGPQs q_1 and q_2 is computed in $O(|body({q_1}^{\infty}_{\mathcal{O}})| \times |body({q_2}^{\infty}_{\mathcal{O}})|)$ and its size is $|body({q_1}^{\infty}_{\mathcal{O}})| \times |body({q_2}^{\infty}_{\mathcal{O}})|$.

Outline

lgg of DBPedia queries

$q_{\texttt{lgg}}^{\mathcal{O}_{\texttt{DBpedia}}} \models q_{\texttt{lgg}}$

lgg of:	$Q_1 Q_2$	$Q_1 Q_3$	$Q_1 Q_4$	$Q_2 Q_3$	$Q_4 Q_5$	$Q_5 Q_6$	$Q_5 Q_7$	$Q_7 Q_8$
Time to compute $q_{\texttt{lgg}}$	3	3	5	4	4	5	6	5
$\lvert q_{\texttt{lgg}}(\mathcal{G}_{\texttt{DBpedia}})\rvert$	477,455	34,747,102	34,901,117	34,747,102	1,977	1,221	35	70
Time to compute $q_{\texttt{lgg}}^{\mathcal{O}_{\texttt{DBpedia}}}$	13	14	14	15	15	14	17	18
$\lvert q_{\texttt{lgg}}^{\mathcal{O}_{\texttt{DBpedia}}}(\mathcal{G}_{\texttt{DBpedia}})\rvert$	10,637	7,874,768	456,690	4,537,824	1,701	780	34	36
Gain in precision	97.77	77.33	98.69	86.94	13.96	36.11	2.85	48.57

Table: Characteristics of cover query-based lggs of test queries, w/ or w/o using the DBpedia RDFS constraints; times are in ms.

lgg3 of :	$Q_1 Q_2 Q_3$	$Q_1 Q_2 Q_4$	$Q_1 Q_3 Q_4$	$Q_2 Q_3 Q_4$	$Q_4 Q_7 Q_8$	$Q_5 Q_7 Q_8$	$Q_6 Q_7 Q_8$
Time to compute $q_{\texttt{lgg}}$	5	4	5	6	10	11	12
$\lvert q_{\texttt{lgg}}(\mathcal{G}_{\texttt{DBpedia}})\rvert$	34,747,102	34,901,117	34,901,117	34,901,117	70	1,977	4,969
Time to compute $q_{\texttt{lgg}}^{\mathcal{O}_{\texttt{DBpedia}}}$	19	20	20	24	27	27	33
$\lvert q_{\texttt{lgg}}^{\mathcal{O}_{\texttt{DBpedia}}}(\mathcal{G}_{\texttt{DBpedia}})\rvert$	7,874,768	615,339	7,874,779	4,537,824	36	1,701	335
Gain in precision	77.33	98.23	77.43	86.99	48.57	13.96	93.25

Table: Characteristics of cover query-based lggs of 3 test queries, w/ or w/o using the DBpedia RDFS constraints; times are in ms.

Outline

Introduction

Preliminaries

Finding commonalities between SPARQL conjunctive queries

Experiments

Related work

Conclusion

Related work

Structural approaches

- RDF
  - Rooted graphs, ignore RDF entailment :
    - [Colucci et al., 2016].
- SPARQL : tree queries
  - [Lehmann and Bühmann, 2011].
- Description Logics
  - [Zarrieß and Turhan, 2013].
  - [Baader et al., 1999].

Approaches independent of the structure

- RDF
  - [Hassad et al., 2017].
  - [Petrova et al., 2017].
- Conceptual Graphs
  - [Chein and Mugnier, 2009].
- First Order Clauses
  - [Nienhuys-Cheng and de Wolf, 1996].
  - [Plotkin, 1970].

Conclusion

- We revisited the problem of computing a least general generalization of general BGPQs w.r.t. background knowledge.
- We defined **new** entailment relationship between BGPQs w.r.t. background knowledge.
- We studied the added-value of considering background knowledge when learning lggs.

Perspective:

- Heuristics in order to compute `lgg` without redundants triples.
- To continue experimentations using queries logs.

Thank you !

Questions?

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