Schema Mappings and Data Exchange for Graph Databases

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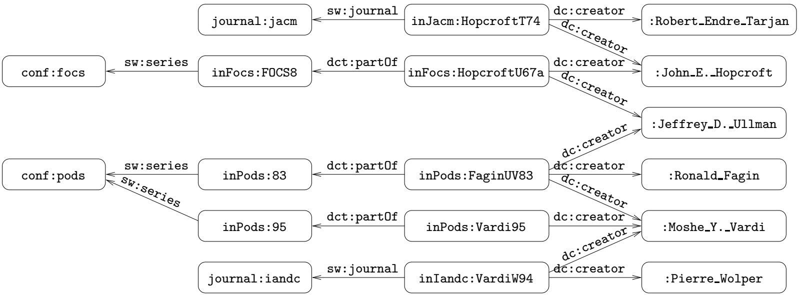
Graph structured data is now everywhere



RDF Linked Data representation of DBLP (real data!)

- DBpedia (RDF representation of Wikipedia)
- Bio2RDF, GeoNames, FreeBase, FOAF, ...
- Facebook, Twitter, ...

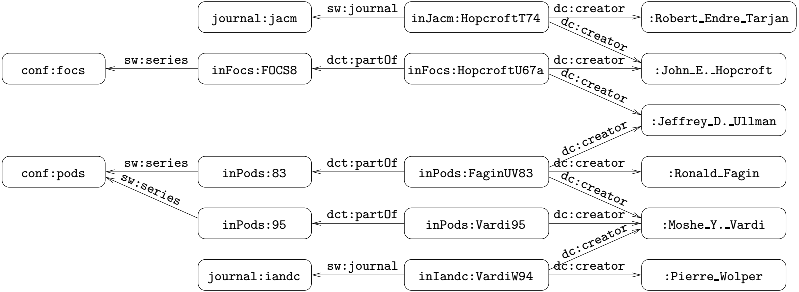
Formalisms to exchange graph databases

First define a *graph mapping language*, then

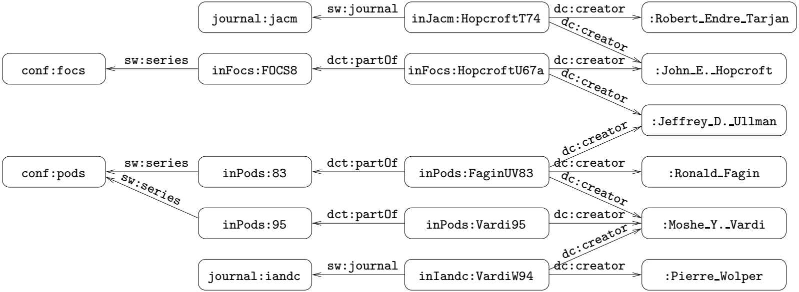
- Exchanging graph databases
- Computing solutions and answering target queries
- Advanced schema mapping operations
  - composition
  - inversion
  - ...

Outline

Graph query languages

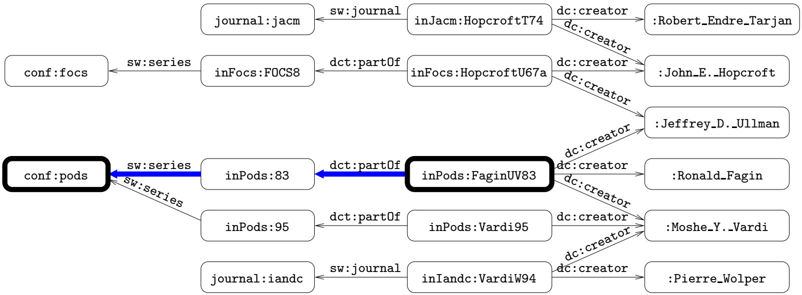


Graph query languages



RPQ: $\texttt{partOf} \cdot \texttt{series}$

Graph query languages



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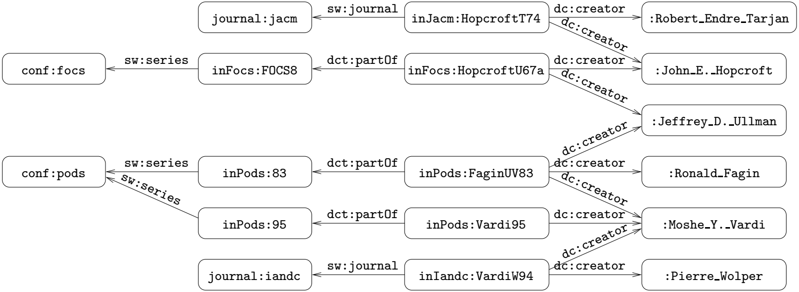

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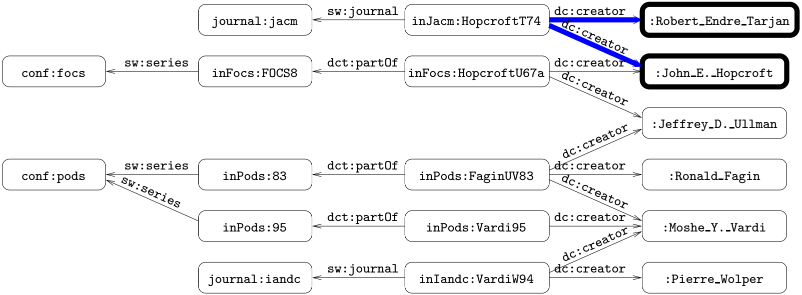

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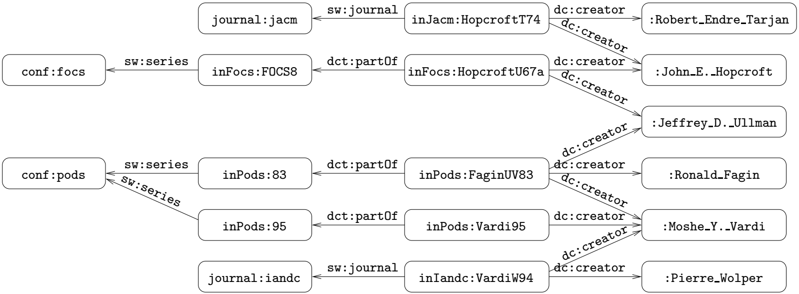

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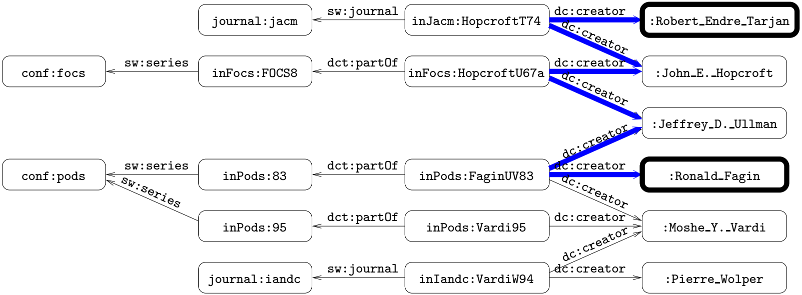

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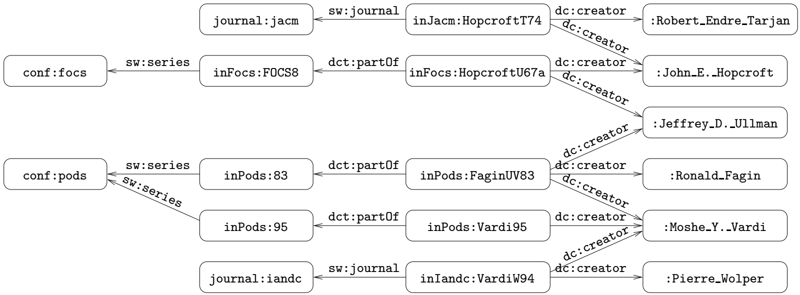
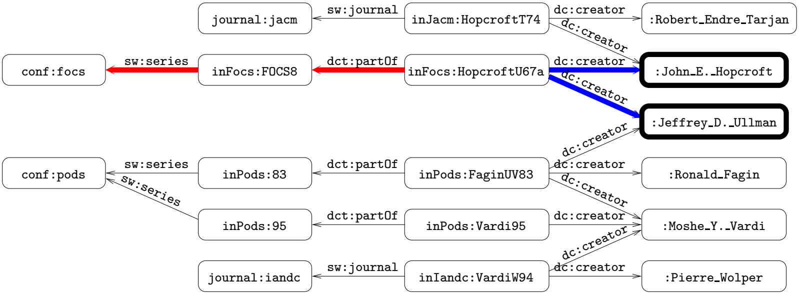


NRE: $\texttt{creator}^{-} \cdot [\, \texttt{partOf} \cdot \texttt{series} \,] \cdot \texttt{creator}$

Graph query languages



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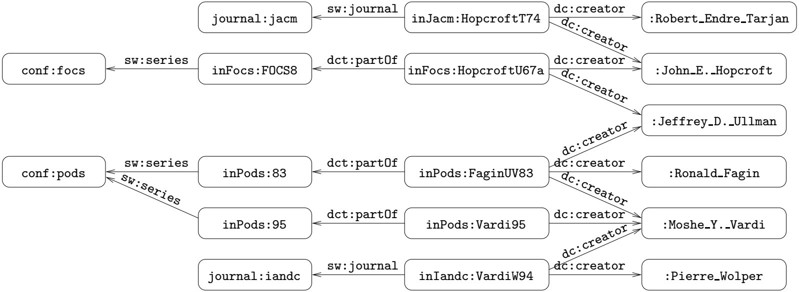

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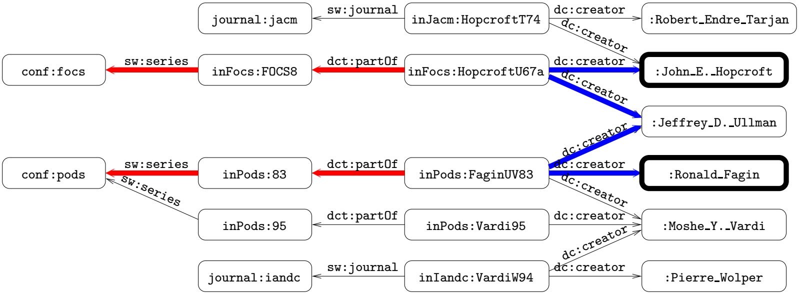

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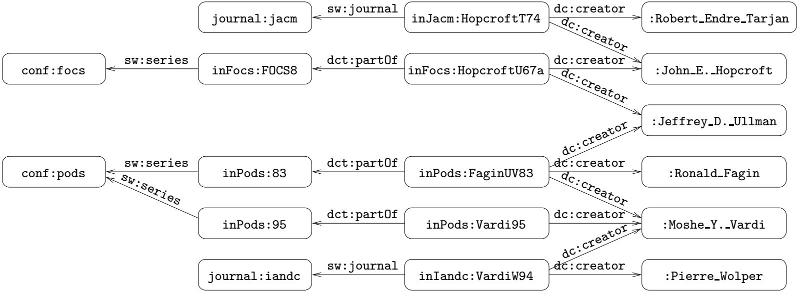
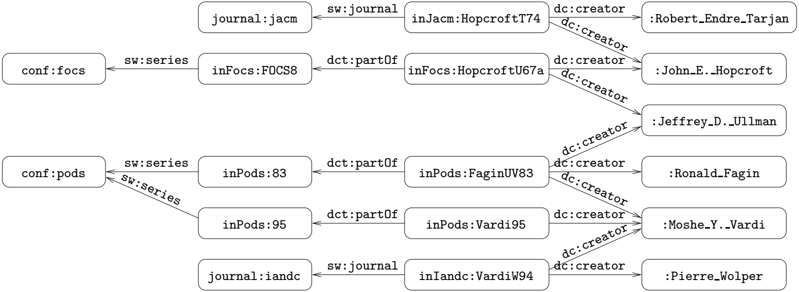


Conjunctions over RPQs, 2RPQs, and NREs

$$\exists \bar{y}\big(\ (u_1, r_1, u_1') \wedge \cdots \wedge (u_k, r_k, u_k')\ \big)$$

CRPQs, C2RPQs, CNREs

Graph query languages



$$\exists u \exists v \big((x, \mathtt{creator}^-, u) \wedge (u, \mathtt{partOf} \cdot \mathtt{series}, v) \wedge (u, \mathtt{creator}, y) \big)$$

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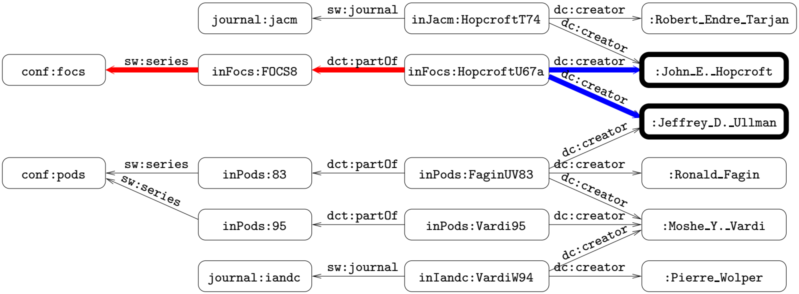

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Review on expressiveness

$$\begin{array}{rcl} \text{NREs} & \not\subseteq & \text{C2RPQs} \\ \text{(binary) CRPQs} & \not\subseteq & \text{NREs} \end{array}$$

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Example

$$(\texttt{creator}^{-} \cdot [\, \texttt{partOf} \cdot \texttt{series} \,] \cdot \texttt{creator})^{+}$$

cannot be expressed as a C2RPQ

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tree-shaped binary C2RPQs $\equiv$ $(\ )^{*}$-$[\ ]$ *alternation-free* NREs

Review on complexity

Evaluation problem for NREs can be solved in $O(|G| \times |expr|)$

- via a PDL-like recursive labeling procedure

NREs properly extends a linear-time fragment of C2RPQs maintaining the complexity of evaluation

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Evaluation problem for CRPQs is NP-complete

- it is in NP for CNREs

Graph mapping language

Consider two (disjoint) graph alphabets $\Sigma_{\mathbf{S}}$ and $\Sigma_{\mathbf{T}}$

- *Graph mapping:* $\mathcal{M} = (\Sigma_{\mathbf{S}}, \Sigma_{\mathbf{T}}, \mathcal{T})$ s.t. $\mathcal{T}$ contains rules

$$\varphi_{\mathbf{S}}(\bar{x}) \longrightarrow \psi_{\mathbf{T}}(\bar{x})$$

$\varphi_{\mathbf{S}}$ and $\psi_{\mathbf{T}}$ are *CNREs* over $\Sigma_{\mathbf{S}}$ and $\Sigma_{\mathbf{T}}$, resp.

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- *L_1-to-L_2 mapping:* $\varphi_{\mathbf{S}} \in L_1$ and $\psi_{\mathbf{T}} \in L_2$
- *L-GAV mapping:* $\varphi_{\mathbf{S}} \in L$ and $\psi_{\mathbf{T}}$ is (x, a, y) with $a \in \Sigma_{\mathbf{T}}$

Graph mapping language: example

2RPQ-GAV:

$$(x, (\texttt{creator}^- \cdot \texttt{creator})^+, y) \longrightarrow (x, \texttt{connected}, y)$$

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C2RPQ-to-CRPQ:

$$(y, \texttt{creator}^{-}, x) \wedge (x, \texttt{partOf} \cdot \texttt{series}, w) \longrightarrow (y, \texttt{makes}, x) \wedge (x, \texttt{inConf}, w)$$

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Solutions in graph data exchange

- Let $\mathcal{M} = (\Sigma_{\mathbf{S}}, \Sigma_{\mathbf{T}}, \mathcal{T})$ be a graph mapping
- Let $G_{\mathbf{S}}$ be a source graph database
- $G_{\mathbf{T}}$ is a *solution* for $G_{\mathbf{S}}$ under $\mathcal{M}$ if
  - for every $\varphi_{\mathbf{S}}(\bar{x}) \to \psi_{\mathbf{T}}(\bar{x})$ in $\mathcal{T}$ and
  - for every tuple $\bar{a}$ of values in $G_{\mathbf{S}}$, we have that

if $\bar{a}$ is in the evaluation of $\varphi_{\mathbf{S}}$ over $G_{\mathbf{S}}$, then
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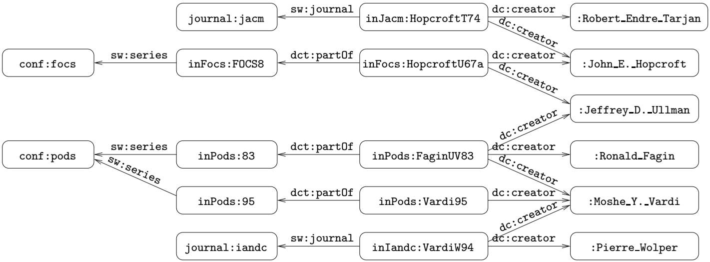
$\mathrm{Sol}_{\mathcal{M}}(G_{\mathbf{S}})$ is the set of solutions for $G_{\mathbf{S}}$ under $\mathcal{M}$.

Example



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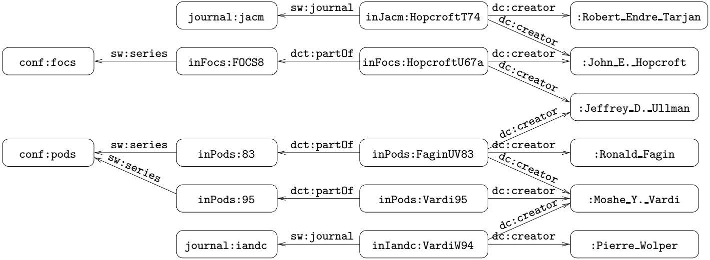

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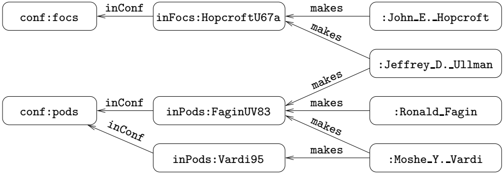

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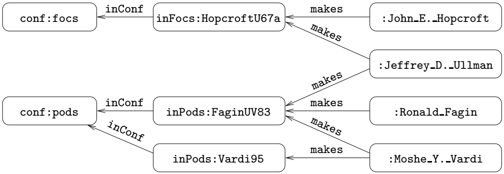

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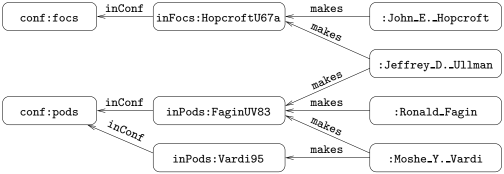

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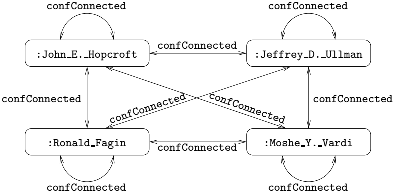

Interesting expressive power

Example

Copy from source to target all paths of the form

$$a(aa)^*b$$

changing the first a by a', remaining aa by a'', and b by b'

We can express this by NRE-mappings

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$$\begin{aligned} a \cdot [(aa)^* b] &\rightarrow a' \\ [(a^- a^-)^* a^-] \cdot aa \cdot [(aa)^* b] &\rightarrow a'' \end{aligned}$$

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Any regular source path can be *synchronized* in the same way

Outline

Graph mapping language

Computing solutions & answering queries

Composing graph schema mappings

Graph patterns as universal representatives

Graph patterns are graphs such that

- Nodes can be labeled with *null values*
- Edges can be labeled with (nested) regular expressions

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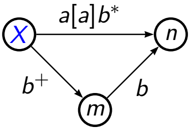

Graph patterns: semantics

Semantics of graph patterns in terms of homomorphisms:

Given a pattern π, graph database G is in $\text{rep}(\pi)$ iff there exists homomorphism h from nulls in π to nodes in G s.t.

for every (u, expr, v) in π there is a path in G from $h(u)$ to $h(v)$ that satisfies expr.

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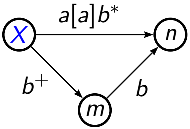
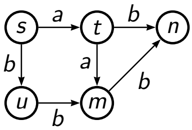


G:



$X \longrightarrow s$

$G \in \text{rep}(\pi)$

Computing universal representatives

Definition

$\pi_{\mathbf{T}}$ is a *universal representative* for graph $G_{\mathbf{S}}$ under $\mathcal{M}$ if

$$\mathsf{Sol}_{\mathcal{M}}(G_{\mathbf{S}}) = \mathsf{rep}(\pi_{\mathbf{T}})$$

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Proposition

- *Given graph $G_{\mathbf{S}}$ and mapping $\mathcal{M}$, a universal representative always exists and can be computed in polynomial space*
- *For fixed $\mathcal{M}$ it can be computed in polynomial time*

just a simple adaptation of the chase procedure...

Feasible universal representative computation

Universal representatives can be in general of size exponential in the size of the mapping

Proposition

Computing universal representatives is $\mathbf{FP}^{\mathbf{NP}[\log]}$-hard even restricted to inputs ensuring univ representatives of polynomial size

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Proposition

Given NRE-to-CNRE mapping $\mathcal{M}$ *a universal representative can be computed in* $O(|G_{\mathbf{S}}|^2 \times |\mathcal{M}|)$ *(tight bound)*

Certain answers

Definition

$$\underline{\text{certain}}_{\mathcal{M}}(Q_{\mathbf{T}}, G_{\mathbf{S}}) = \bigcap_{G_{\mathbf{T}} \in \text{Sol}_{\mathcal{M}}(G_{\mathbf{S}})} Q_{\mathbf{T}}(G_{\mathbf{T}})$$

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Observation: if $\pi_{\mathbf{T}}$ is a unviersal representative, then

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CertAns

Input: Graph $G_{\mathbf{S}}$, mapping $\mathcal{M}$, target query $Q_{\mathbf{T}}$, and tuple $\bar{a}$

Ouput: Is $\bar{a}$ in $\underline{\text{certain}}_{\mathcal{M}}(Q_{\mathbf{T}}, G_{\mathbf{S}})$?

Complexity of computing certain answers

Theorem

(1) CertAns *is in EXPSPACE for CNRE-to-CNRE mappings and CNRE queries*

(2) CertAns *is EXPSPACE-hard for CRPQ-to-CRPQ mappings and CRPQ queries*

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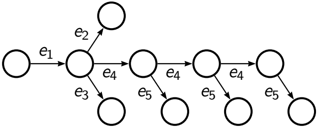

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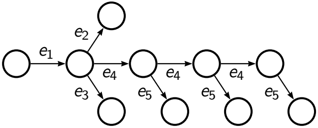
  $e_1 \cdot [e_2] \cdot [e_3] \cdot (e_4 \cdot [e_5])^*$



  need to run over (a restricted class of) trees

Even data complexity is hard

$\textsc{CertAns}(\mathcal{M}, Q_{\mathbf{T}})$

Input: Graph $G_{\mathbf{S}}$, and tuple $\bar{a}$

Ouput: Is $\bar{a}$ in $\underline{\text{certain}}_{\mathcal{M}}(Q_{\mathbf{T}}, G_{\mathbf{S}})$?

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1. $\textsc{CertAns}(\mathcal{M}, Q_{\mathbf{T}})$ *is coNP-complete for every CNRE-to-CNRE mapping and CNRE query.*
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In the paper:

- Structural properties ensuring tractable data complexity

Tractable query answering

High complexity if we allow conjunctions in rules or regular expressions in the right-side

- Need to focus on GAV mappings.

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By just computing a universal representative we obtain

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For NRE-GAV mappings and NRE queries, CertAns *can be solved in time*

$$O(|G_{\mathbf{S}}|^2 \times |\mathcal{M}| \times \ |expr|)$$

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Outline

Composing mappings

$\mathbf{S}_A$ $\mathbf{S}_B$ $\mathbf{S}_C$

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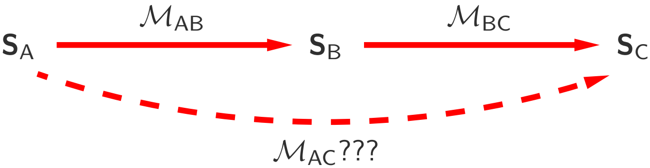
$$\mathbf{S}_{\mathrm{A}} \xrightarrow{\mathcal{M}_{\mathrm{AB}}} \mathbf{S}_{\mathrm{B}} \xrightarrow{\mathcal{M}_{\mathrm{BC}}} \mathbf{S}_{\mathrm{C}}$$

Composing mappings



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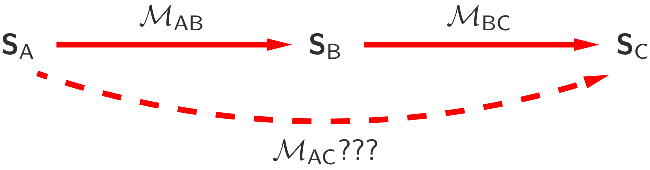

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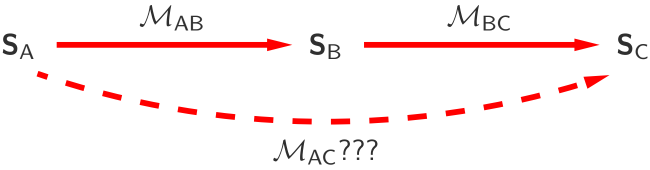

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- how to compute the composition?
- what is the language needed to express it?
- is there a language closed under composition?

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Example

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The composition of NRE-GAV mappings can always be specified by an NRE-GAV mapping

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Corollary

The composition of tree-shaped C2RPQ-GAV mappings can always be specified by an NRE-GAV mapping

Composition in the presence of conjunctions

Known result in relational data exchange:

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Open question:
What is the language needed to compose CRPQ-GAV mappings?

Concluding remarks

We have initiated the study of Graph Data Exchange

- Some techniques can be adapted from the relational case
- Query answering is highly complex
- Schema mapping operators is a challenging topic
- NREs add expressive power compared with 2RPQs maintaining the complexity plus giving good properties for composition

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  - Good candidate to start: GraphXPath
- More natural (and expressive) synchronization between paths

$$(a/a')(aa/a'')^*(b/b')$$

Schema Mappings and Data Exchange for Graph Databases

Pablo Barceló   Jorge Pérez   Juan Reutter

Universidad de Chile, PUC Chile

Outline