When Can We Answer Queries Using Result-Bounded Data Interfaces?

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Problem: Answering Queries Using Web Services

Directory service

Find researchers from a department

DBLP service

Find papers from a researcher

- We have several Web services that expose data

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Directory service

*Find **researchers** from a **department***

DBLP service

*Find **papers** from a **researcher***

Query

*Find all **papers** written by **researchers** from my **department**?*

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Directory service	DBLP service	Query
		
*Find **researchers** from a **department***	*Find **papers** from a **researcher***	*Find all **papers** written by **researchers** from my **department**?*

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→ How can we **rephrase** the query against the Web services?

Formalizing the Problem

Service schema:

DBLP(author, title, year)

- Model each service as a relation

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Constraints: express logical relationships between the services

Every researcher from the directory is in DBLP

$\Sigma : \forall d\, a\ \mathrm{Directory}(d, a) \rightarrow \exists t\, y\ \mathrm{DBLP}(a, t, y)$

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What is a monotone plan?

- Access the services by giving bindings
- Evaluate monotone relational algebra
- The plan is correct if it returns $Q(D)$ on any database D that satisfies Σ

Example:

$T_1 \Leftarrow$ Directory $\Leftarrow$ MyDept;

$T_2 \Leftarrow$ DBLP $\Leftarrow \pi_{\text{person}}(T_1)$;

$T_3 \Leftarrow \pi_{\text{title}}(T_2)$;

Return T_3

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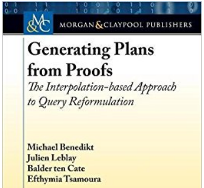

Extensive literature about how to reformulate queries to monotone plans and about the complexity depending on the constraint language

New Challenge: Result Bounds

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Formalization: DBLP(author, title, year) has a **result bound** of 1000

- If an access matches ≤ 1000 tuples then they are **all** returned
- If it matches > 1000 tuples then we get 1000 of them (random)

→ **How to reformulate queries using result-bounded services?**

Formal Problem Statement

Input:

- Service schema S of relation names and attributes with <u>input attributes</u> and optionally a result bound
  - $\rightarrow$ Directory(<u>department</u>, person)
  - $\rightarrow$ DBLP(<u>author</u>, title, year) with bound 1000
- Conjunctive query Q
  - $\rightarrow$ $Q(t) : \exists a\, y\ \text{Directory}(\text{MyDept}, a) \wedge \text{DBLP}(a, t, y)$
- Constraints Σ
  - $\rightarrow$ $\forall d\, a\ \text{Directory}(d, a) \rightarrow \exists t\, y\ \text{DBLP}(a, t, y)$

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We study:

→ What is the complexity of deciding plan existence, depending on the constraint language?

→ In which ways are result-bounded services useful?

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→ Let's see the **schema simplification results** and proof techniques

Existence-Check Simplification

Idea: use result-bounded services to check the existence of tuples

- Schema: DBLP(author, title, year) with bound 1000
- Query Q: *Has Michael Benedikt published something?*
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- Add two IDs in Σ to relate $\text{DBLP}_{\text{check}}$ and DBLP:

$$\forall a\ \text{DBLP}_{\text{check}}(a) \leftrightarrow \exists t\, y\ \text{DBLP}(a, t, y)$$

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  $$\forall a\ \text{DBLP}_{\text{check}}(a) \leftrightarrow \exists t\, y\ \text{DBLP}(a, t, y)$$
- Forbid direct accesses to DBLP (so the result bound is irrelevant)

Existence-Check Simplification Results

Theorem

Any schema $\mathbf{S}$ *with constraints* Σ *in* ***Inclusion dependencies*** *(IDs) is* ***existence-check simplifiable***

$\rightarrow$ Under IDs, result-bounded services only serve as existence checks

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→ Under IDs, result-bounded services only serve as existence checks

As the existence-check approximation has no result bounds, we can reduce to the classical setting and deduce:

Corollary

For any schema S *with result bounds, ID constraints* Σ*, and query* Q*, deciding the existence of a monotone plan is* EXPTIME-*complete*

FD Simplification

Result-bounded services can do more than existence checks:

- Schema S: directory that returns addresses and phone numbers
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We call *S* and Σ FD-simplifiable if any query that has a plan on *S* and Σ still has one on the FD approximation:

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- For each relation **Dir2**(<u>**name**</u>, **address**, **phone**) with result bound, create a new relation Dir2_{FD}(<u>**name**</u>, **address**) that outputs the attributes **determined** in Σ by the input attributes

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- Forbid accesses on Dir2 and add IDs with Dir2_{FD} like before

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Any schema S with constraints Σ in Functional dependencies (FDs) is FD simplifiable

→ Under FDs, result-bounded services are only useful to access outputs that are functionally determined (i.e., we are guaranteed to have only one result)

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Again, there are no result bounds left in the FD approximation, so we can use this result to show:

Corollary

For any schema S with result bounds, FD constraints Σ, and query Q, deciding the existence of a monotone plan is NP-complete

Choice Simplification

With expressive constraints, the FD approximation is not enough:

Lemma

There is a service schema S, query Q, and TGDs Σ such that Q is not FD-simplifiable (hence, not existence-check-simplifiable)

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A less drastic simplification is the choice simplification:

- For every service with a result bound, change the bound to be 1

$\rightarrow$ Intuition: It's important to get some tuple if one exists

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Any schema S with constraints Σ in equality-free first-order logic (e.g., TGDs) is choice simplifiable

Thus, plan existence is decidable for decidable FO fragments, e.g., frontier-guarded TGDs (FGTGDs):

Corollary

For any schema S with result bounds, query Q, and FGTGDs Σ deciding the existence of a monotone plan is 2EXPTIME-complete

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For any schema **S** *with result bounds, query* **Q***, and* ***FGTGDs*** Σ *deciding the existence of a monotone plan is* **2EXPTIME-*complete***

We can also show choice approximability for another fragment:

Theorem

Any schema **S** *with constraints* Σ *that are* ***FDs*** *and* ***unary IDs*** (UIDs) *is* ***choice simplifiable***

→ This implies that plan existence is **decidable** for FDs and UIDs

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- Show that result-bounds can be axiomatized in simpler ways:
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- Reduce to query containment under constraints

  → Study the result of the translation to show complexity bounds

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- Better complexity bounds using a linearization technique for query containment under IDs + side information

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*Plan existence is **decidable** for **guarded two-variable FO + counting***

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Thanks for your attention!

References

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