Determining Relevance of Accesses at Runtime

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DBWeb Seminar, 7 February 2011

Definition (Deep Web, Hidden Web, Invisible Web)

All the content on the Web that is not directly accessible through hyperlinks. In particular: HTML forms, Web services.

Size estimate: 500 times more content than on the surface Web! [Bergman, 2001]. Hundreds of thousands of deep Web databases [He et al., 2007]

Querying the deep Web

- A large part of deep Web data (phone directories, library catalogs, etc.) is essentially relational
- Access to deep Web necessary goes through restricted query interfaces, named here access methods
- Typically: for a given form interface to relational data, some input attributes must be bound, other attributes are free
- Given a query (say, conjunctive) over base relations, answering it using restricted interfaces may 1) not be possible 2) require an unbounded number of calls to query interfaces
- Large body of work on the computation of static query plans under access limitations [Rajaraman et al., 1995, Duschka and Levy, 1997, Li, 2003, Nash and Ludäscher, 2004, Calì and Martinenghi, 2008b]: not our concern here

When is an access relevant?

Consider:

- a schema $\mathcal{S}$, with access methods for schema relations
- a query Q over $\mathcal{S}$
- some pre-existing knowledge Conf of the content of relations of $\mathcal{S}$
- an access method over a base relation $R \in \mathcal{S}$, and a binding $\vec{b}$ of the input attributes to constants; the corresponding access is denoted $R(\vec{b}, ? \dots ?)$ (or $R(\vec{b})?$ if there are only input attributes)

We want to know if $R(\vec{b}, ? \dots ?)$ is relevant to Q in Conf, i.e., if it may bring us knowledge on the truth value of Q.

Simplifying assumption: no views, accesses are directly on base relations

Motivating example

Schema (input attributes in blue)

```
Employee(EmpId, Title, LastName, FirstName, OffId)
Office(OffId, StreetAddress, State, Phone)
Approval(State, Offering)
Manager(EmpId, EmpId)
```

Query

```
SELECT DISTINCT 1 FROM Employee E, Office O, Approval A
WHERE E.Title='loan officer' AND E.OffId=O.OffId
  AND O.State='Illinois' AND A.State='Illinois' AND A.Offering='30'
```

Is the access "Manager(12345,?)" relevant to the query?

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Is the access "Manager(12345,?)" relevant to the query?

Different notions of relevance

The relevance of a =“Manager(12345,?)” depends on several factors:

Initial configuration
: If we already know of a loan officer in Illinois, a is not relevant. Otherwise, it might be.

Dependence of accesses
: If it is possible to “guess” employee ids at random (independent accesses), a is not relevant. If all employee ids used must appear as the result of a previous access (dependent accesses), a may be relevant.

Immediate and long-term relevance
: By itself, a cannot make the query true if it was not true already: it is not immediately relevant. But it may provide employee ids that will be used to build a witness to the query, i.e., it is long-term relevant.

Problem studied

Algorithms for, complexity of determining if an access is relevant to a query in a given configuration:

- independent vs dependent case
- immediate relevance vs long-term relevance
- query language

We focus on combined complexity, but we also present data complexity results.

Outline

Relevance of an Access

Formal Definitions

Relevance and Query Containment

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Framework

We assume given:

- a relational schema $\mathcal{S} = \{S_1 \dots S_n\}$ (each attribute has an abstract domain);
- a set of access methods $\mathcal{A} = \{A_1 \dots A_m\}$ where each A_i is the given of:
  1. one relation S_i of $\mathcal{S}$
  2. a subset of the attributes of S_i that are input attributes
  3. either of the dependent or independent types

Configurations and accesses

- A configuration Conf is an instance of the relational schema.
- Given a configuration Conf, a well-formed access a is the given of:
  - an access method A_k
  - an assignment of input attributes of A_k to constants such that either:
    - A_k is independent
    - or all values of the binding are constants of Conf of the proper domain
- A configuration Conf and a well-formed access a leads (non-deterministically) to a new configuration Conf′ with:
  1. $\mathsf{Conf} \subseteq \mathsf{Conf}'$
  2. $\mathsf{Conf}' - \mathsf{Conf}$ only contains tuples of the accessed relation, and all these tuples agree with the binding

Configuration paths

A well-formed path between configurations Conf and Conf$'$ is a sequence of configurations

$$(\mathsf{Conf} =)\mathsf{Conf}_0 \to^{a_1} \mathsf{Conf}_1 \to^{a_2} \dots \quad \mathsf{Conf}_{n-1} \to^{a_n} \mathsf{Conf}_n (= \mathsf{Conf}')$$

such that for all $i \geqslant 1$, a_i is a well-formed access that leads from Conf_{i-1} to Conf_i. We say Conf$'$ is reachable from Conf.

The truncation of this path is the path

$$(\mathsf{Conf} =)\mathsf{Conf}_0 \to^{a_2} \mathsf{Conf}'_2 \to^{a_3} \dots \quad \mathsf{Conf}_{n-1} \to^{a_k} \mathsf{Conf}'_k$$

with k maximum such that the path is still well-formed, and Conf'_i contains all facts of Conf_i except those produced by a_1.

Queries

- Only Boolean queries
- Two query languages, subsets of the relational calculus:

  Conjunctive queries (CQs) $\exists, \wedge$

  Positive queries (PQs) $\exists, \wedge, \vee$

- Queries should be consistent with attribute domains
- Constants in the query are assumed to also be part of the configuration
- We note $\mathsf{Conf} \models Q$ when Q is true in Conf

Immediate and long-term relevance

Query Q, configuration Conf, access a.

- a is immediately relevant (IR) for Q in Conf if there exists a configuration Conf$'$ such that:
  - a may lead from Conf to Conf$'$
  - Conf $\not\models Q$
  - Conf$' \models Q$
- a is long-term relevant (LTR) for Q in Conf if there exists a well-formed path p starting with a and leading to some Conf$'$, whose truncation p' leads from Conf to Conf$''$ such that:
  - Conf$' \models Q$
  - Conf$'' \not\models Q$

Simple example

Example

$Q = R(x, y) \wedge S(y, z)$. Conf $= \varnothing$. $a = R(?, ?)$. Access method on S.

- a is not IR for Q in Conf.
- a is LTR for Q in Conf.

First observations

- For a fixed arity k, relevance for a query of output arity k reduces to relevance for Boolean queries.
- Determining relevance for Q in Conf requires checking that Conf $\not\models Q$, which is coNP-hard for CQs.

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Containment under access limitations

Schema $\mathcal{S}$, set of access methods $\mathcal{A}$, configuration Conf.

Definition

Query Q_1 is contained in Q_2 under $\mathcal{A}$ starting from Conf, denoted $Q_1 \sqsubseteq_{\mathcal{A},\mathsf{Conf}} Q_2$ if for every configuration Conf′ reachable from Conf,

$$\mathsf{Conf}' \models Q_1 \Rightarrow \mathsf{Conf}' \models Q_2.$$

Notion introduced (in a restricted form) in [Calì and Martinenghi, 2008a], shown to be coNEXPTIME for conjunctive queries. No lower bound given.

Access limitations impact containment

Example ([Calì and Martinenghi, 2008a])

- $Q_1 = R(x)$, $Q_2 = S(x)$
- Dependent access methods $\mathcal{A} = \{R(\cdot)?, S(?)\}$
- $Q_1 \sqsubseteq_{\mathcal{A},\varnothing} Q_2$ while $Q_1 \not\sqsubseteq Q_2$.

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From containment to relevance

Let $\mathcal{Q}$ be one of CQs, PQs.

Proposition

There is a polynomial-time many-one reduction from query containment of queries in $\mathcal{Q}$ under access limitations to the complement of LTR of dependent accesses for queries in $\mathcal{Q}$.

Immediate application: LTR is Σ_2^P-hard for PQs.

From relevance to containment

Proposition

There is a reduction from LTR of dependent accesses to the complement of query containment, which is:

- *a polynomial-time many-one reduction for PQs;*
- *a nondeterministic polynomial-time Turing reduction for CQs.*

The weaker form of reduction comes from the need for disjunction. Enough to show matching complexity results for containment and LTR in most cases.

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Proposition

IR for CQs or PQs is DP-complete in combined complexity. If the query is fixed, the problem is in AC^0.

Proof sketch.

Upper bound: the problem is shown to be in NP (by a short-witness argument) as soon as the query is known not to be true.

Lower bound: coding of satisfiability/unsatisfiability pair as a single query.

Data complexity: the algorithm can be implemented as a first-order formula.

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Lower bound: coding of satisfiability/unsatisfiability pair as a single query.

Data complexity: the algorithm can be implemented as a first-order formula.

Long-term relevance

Proposition

In the absence of dependent accesses, the combined complexity of LTR for CQs or PQs is Σ_2^P-complete. If the query is fixed, the problem is in AC^0.

Proof sketch.

The upper bound is straightforward. The lower bound is a consequence of a the hardness of determining whether a tuple is critical for a query in a relational database [Miklau and Suciu, 2007]. □

Long-term relevance

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Immediate relevance

Only one access involved in immediate relevance: dependence does not play a role. We are still DP-complete in combined complexity, and AC^0 in data complexity.

Long-term relevance

- Naïve idea: a witness path can be shortened by generating all needed constants in the initial access. Fails for accesses with only input attributes, or in the presence of domain constraints.
- Upper bound arguments: show that the access path must be tree-like [Calì and Martinenghi, 2008a, Chaudhuri and Vardi, 1997] (non trivial)
- Lower bound arguments: reduction from corridor tiling [Johnson, 1990] (non trivial either!)
- For conjunctive queries: additional trick needed to code Boolean operation with their truth values

Complexity results

Theorem

- *LTR for CQs is NEXPTIME-complete in combined complexity.*
- *LTR for PQs is 2NEXPTIME-complete in combined complexity.*
- *LTR for PQs is PTIME if the query is fixed.*

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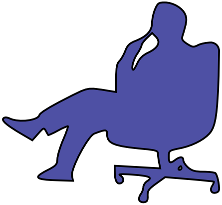
In brief

- Strong connection between long-term relevance and containment under access limitations
- Combined complexity:

	IR	LTR	Containment
Indep. accesses (CQs)	DP-c	Σ_2^P-c	coNP-c
Indep. accesses (PQs)	DP-c	Σ_2^P-c	Π_2^P-c
Dep. accesses (CQs)	DP-c	NEXPTIME-c	coNEXPTIME-c
Dep. accesses (PQs)	DP-c	2NEXPTIME-c	co2NEXPTIME-c

- Data complexity: everything is in PTIME (AC^0 for independent accesses).
- Not presented: a number of simpler cases (low arity, non-repeated relations, etc.)

Perspectives



- Extension to other query languages, especially UCQs
- Adding views, integrity constraints, and exactness constraints to the setting
- Other notions of relevance:
  - LTR: ∃ an instance, ∃ a path, such that the query is true after the path and not after the truncation of the path
  - ∃ an instance, ∀ paths such the query is true after the path, it is not after the truncation of the path
  - ∀ instances, ∃ a path, such that the query is true after the path and not after the truncation of the path

Merci.

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