



# Value Joins are Expensive over (Probabilistic) XML

E. Kharlamov, W. Nutt, [P. Senellart](#)





Probabilistic XML

Querying Probabilistic XML

The Complexity of Joins

Essential Joins

Conclusion



# Uncertain data

Numerous sources of **uncertain data**:

- Measurement errors
- Data integration from contradicting sources
- Imprecise mappings between heterogeneous schemata
- Imprecise automatic process (information extraction, natural language processing, etc.)
- Imperfect human judgment



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Uncertainty modeled here as **probabilities**

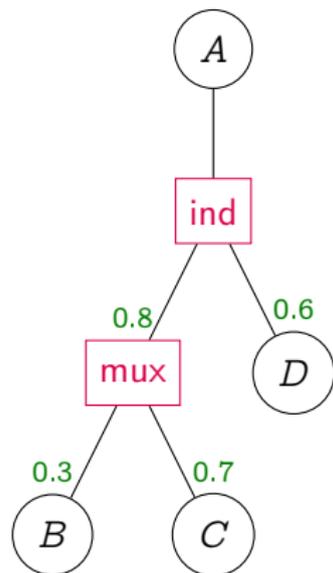


## Why XML?

- Extensive literature about probabilistic relational databases [Dalvi et al., 2009, Widom, 2005, Koch, 2009]
- Different typical querying languages: conjunctive queries vs tree-pattern queries (possibly with joins)
- Cases where a tree-like model might be appropriate:
  - No schema or few constraints on the schema
  - Independent modules **annotating** freely a content warehouse
  - Inherently tree-like data (e.g., mailing lists, parse trees) with naturally occurring queries involving the descendant axis

# Local dependencies

[Nierman and Jagadish, 2002, Kimelfeld et al., 2008]



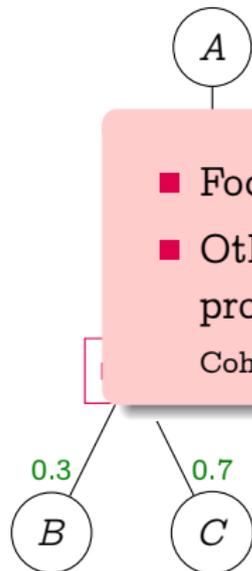
- Tree with **ordinary** (circles) and **distributional** (rectangles) nodes
- Distributional nodes specify how their **children** can be **randomly selected**:
  - ind** independently of one another;
  - det** deterministically;
  - mux** mutually exclusively.
- **Possible-world semantics**: every possible selection of children of distributional nodes, with associated probability
- No long-distance probabilistic dependencies in the tree!

# Local dependencies

[Nierman and Jagadish, 2002, Kimelfeld et al., 2008]

- Tree with **ordinary** (circles) and **distributional** (rectangles) nodes
- Distributional nodes specify how their

- Focus here on such **local dependencies**
- Other **more expressive** (and less tractable) probabilistic XML models exist [Abiteboul et al., 2009, Cohen et al., 2008, Kharlamov et al., 2010, Benedikt et al., 2010]



... possible selection of children of distributional nodes, with associated probability

- No long-distance probabilistic dependencies in the tree!



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# Semantics of queries

Semantics of a (Boolean) query = **probability**:

1. Generate **all possible worlds** of a given probabilistic document
2. In each world, **evaluate the query**
3. **Add up** the probabilities of the worlds that make the query true



# Semantics of queries

Semantics of a (Boolean) query = **probability**:

1. Generate **all possible worlds** of a given probabilistic document (possibly exponentially many)
2. In each world, **evaluate the query**
3. **Add up** the probabilities of the worlds that make the query true

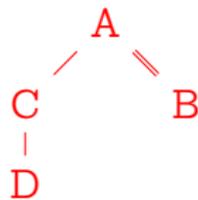
**EXPTIME** algorithm! We usually want to do better, i.e., to apply directly the algorithm on the probabilistic document?

Focus on **data complexity**



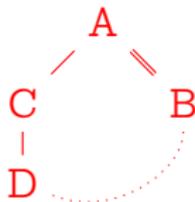
# Boolean query languages on trees

Tree-pattern queries (TP) `/A[C/D]//B`



Tree-pattern queries with joins (TPJ) for `$x` in `$doc/A/C/D`

`return $doc/A//B[.= $x]`



Monadic second-order queries (MSO) generalization of TP, does not cover TPJ unless the size of the alphabet is bounded

Monadic second-order queries with joins (MSOJ) MSO + SameLabel predicate



## The $\#P$ and $FP^{\#P}$ complexity classes

- A (counting) problem is in  $\#P$  if there is a  $P$ TIME non-deterministic Turing machine whose number of accepting paths, given as input the input of the problem, is the output of the problem.
- A problem is  $\#P$ -hard if any  $\#P$  problem can be  $P$ TIME-reduced to it (via a Turing reduction).  $\#2DNF$ , the problem of counting the number of assignments satisfying a formula in 2-DNF, is  $\#P$ -complete.



## The $\#P$ and $FP^{\#P}$ complexity classes

- A (counting) problem is in  $\#P$  if there is a  $PTIME$  non-deterministic Turing machine whose number of accepting paths, given as input the input of the problem, is the output of the problem.
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- A (computation) problem is in  $FP^{\#P}$  if it is computable by a  $PTIME$  Turing machine with access to a  $\#P$  oracle.
- A problem is  $FP^{\#P}$ -hard if any  $FP^{\#P}$  problem can be  $PTIME$ -reduced to it (via a Turing reduction). Equivalently, a computation problem is  $FP^{\#P}$ -hard if it is  $\#P$ -hard.



# Motivating Observation

- **Linear algorithm** for computing the probability of a TP query [Kimelfeld and Sagiv, 2007, Kimelfeld et al., 2009] and even of an MSO query [Cohen et al., 2009]
- Very simple TPJ queries have **#P-hard complexity** over probabilistic XML [Abiteboul et al., 2010]
- **Where is the boundary?** **How hard** are queries with joins?
- Algorithm to decide whether a query is hard?



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# The complexity of TPJ

## Proposition

*The data complexity of TPJ evaluation is:*

- *$P$ TIME over XML;*
- *$FP\#P$ -complete over probabilistic XML.*

**Main idea:** TPJ on trees is basically the same thing as conjunctive queries on relations.



# The complexity of MSOJ

## Proposition

*The data complexity of MSOJ evaluation is:*

- $\Sigma_k^P$ -complete and  $\Pi_k^P$ -complete over XML for all  $k \geq 0$ ;
- #P-hard over probabilistic XML.

**Main idea:** MSOJ on trees is basically the same thing as MSO on relations.



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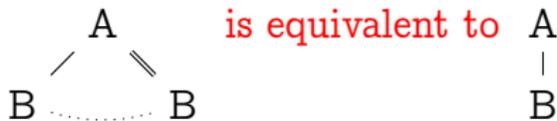
# Essential Joins

## Definition

A TPJ (resp., MSOJ) query is **essentially join-free** if it is equivalent to a TP (resp., MSO) query.

If a query is not essentially join-free, it is said to **have essential joins**.

## Example





# A Test for Essential Joins

## Theorem

*A TPJ query  $q$  is essentially join-free if it is equivalent to the query obtained from  $q$  by removing all join conditions.*

**Main idea:** characterization of query containment of TP queries as query evaluation on a representative document, due to [Miklau and Suciu, 2004]



# Deciding Essential Joins

## Theorem

*Deciding essential joins is:*

- $\Pi_2^P$ -complete for TPJ;
- undecidable for MSOJ.

**Main idea:** similar construction to the one used in [Deutsch and Tannen, 2001] for  $\Pi_2^P$ -completeness of TPJ query containment



# A (Weak) Dichotomy for TPJ

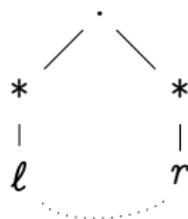
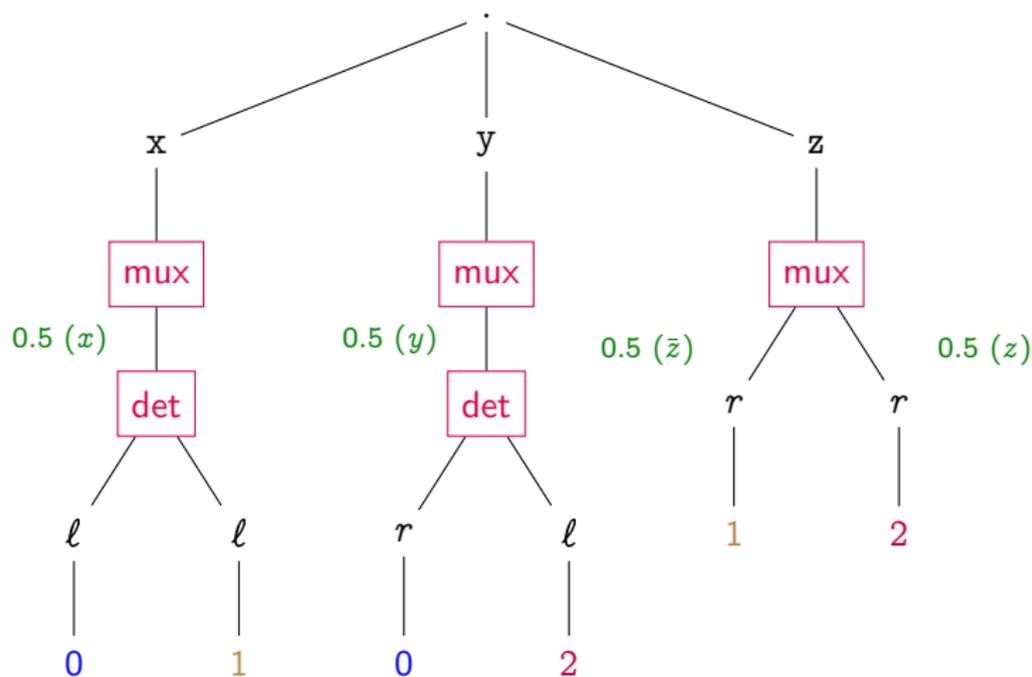
## Theorem

Let  $q$  be a TPJ query with a single join. Then:

- if  $q$  is essentially join-free, then query evaluation of  $q$  over PrXML is *PTIME*;
- otherwise, it is  $FP^{\#P}$ -complete.

# Hardness Proof Idea

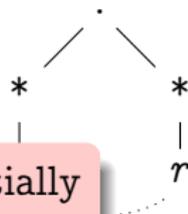
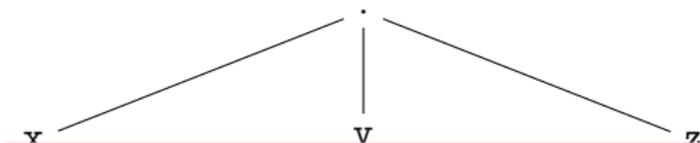
Reduction from #2DNF. Example:  $\varphi = xy \vee x\bar{z} \vee yz$ .





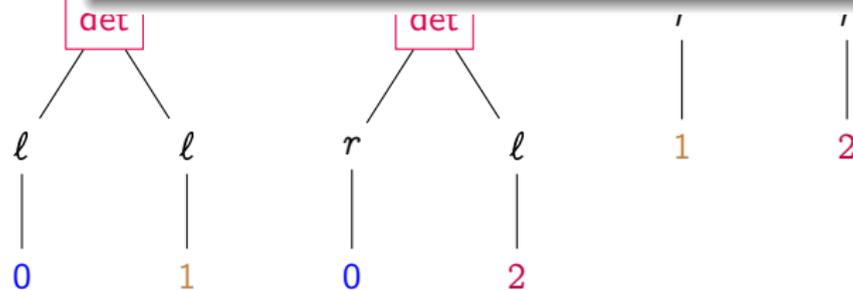
# Hardness Proof Idea

Reduction from #2DNF. Example:  $\varphi = xy \vee x\bar{z} \vee yz$ .



General case (arbitrary with a single join, not essentially join-free): replace  $l$  and  $r$  with the **necessarily distinguishable** paths of the tree leading to the join variables. Quite technical!

0.5 (x)





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- Join-free queries: everything is **linear**
- Complexity of join queries:

	TPJ	MSOJ
XML	$P$ TIME	$\Sigma_k^P$ -complete, $\Pi_k^P$ -complete $\forall k \geq 0$
PrXML	$FP^{\#P}$ -complete	$\#P$ -hard, in $FPSPACE$

- Deciding essential joins
  - can be done in  $\Pi_2^P$  for TPJ
  - is **undecidable** for MSOJ
- Being **essentially join-free** is the tractability criterion for TPJ queries with a single join

See **combined complexity** results in the paper.



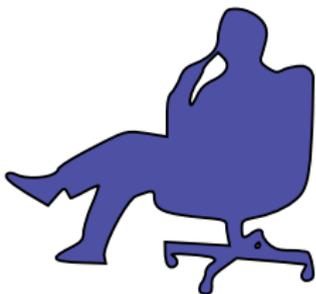
# Open Problems



- A number of **complexity gaps** to fill in
- Extension of the **dichotomy** result to **arbitrary** TPJ queries
- Approximation techniques (A. Souihli's talk at the PhD Workshop in 30min)



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- A number of **complexity gaps** to fill in
- Extension of the **dichotomy** result to **arbitrary** TPJ queries
- Approximation techniques (A. Souihli's talk at the PhD Workshop in 30min)
- Investigating the connection with the (much more complicated) **dichotomy of conjunctive queries over relational data** [Dalvi and Suciu, 2007]
- Things are easier over trees because of the structure of the data; what about **bounded tree-width relations**?
- Joins are correlation in the query. What about data correlations (**long-distance dependencies**)?

Merci.

Wabdam

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