

Probabilistic XML: Survey and Challenges

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The Hong Kong University of Science and Technology
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- 1 Motivation
- 2 Probabilistic XML Survey
- 3 Challenges

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

Objective

Not to pretend this imprecision does not exist, and manage it as rigorously as possible throughout a long, automatic and human, potentially complex, process.

Especially:

- Use **probabilities** to represent the confidence in the data
- Query data and retrieve **probabilistic** results
- Allow adding, deleting, modifying data in a **probabilistic** way
- (If possible) Keep throughout the process **lineage/provenance** information, so as to ensure **traceability**

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- Extensive literature about probabilistic relational databases [DRS09, Wid05, Koc09]
- 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

Remark

Some results can be transferred from one model to the other. In other cases, connection much trickier (see later)!

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2 Probabilistic XML Survey

- Models
- Querying
- Other Problems of Interest

3 Challenges

1 Motivation

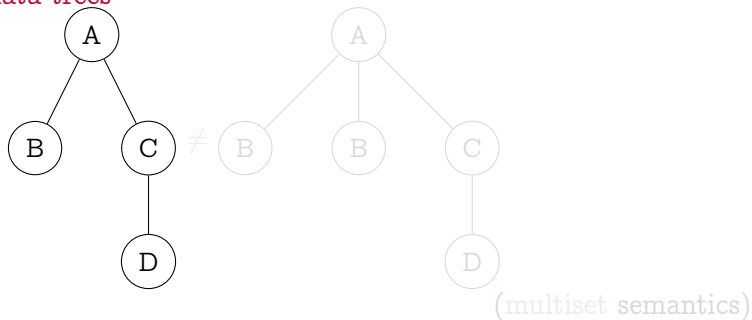
2 Probabilistic XML Survey

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Trees and possible worlds

Unordered data trees

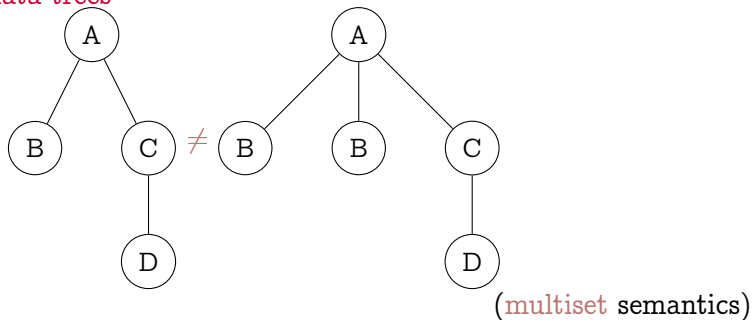


Sample space: Set of all such data trees.

Probabilistic XML database: (Succinct) representation of a discrete probability distribution over this sample space (= a set of possible worlds).

Trees and possible worlds

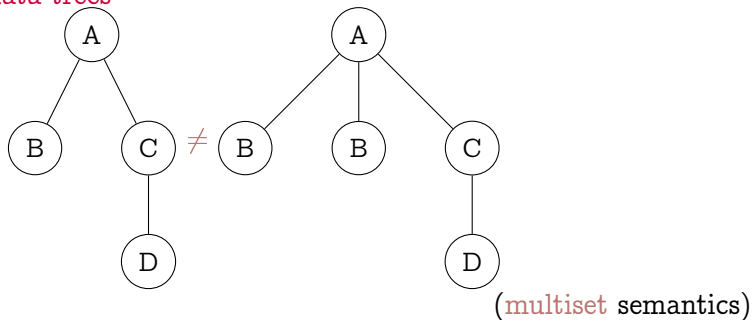
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Sample space: Set of all such data trees.

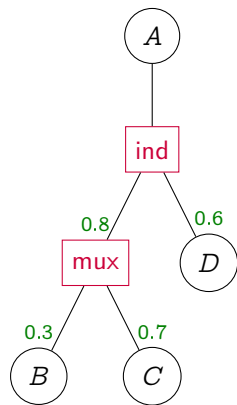
Probabilistic XML database: (Succinct) representation of a discrete probability distribution over this sample space (= a set of possible worlds).

Unordered data trees



Sample space: Set of all such data trees.

Probabilistic XML database: (Succinct) representation of a **discrete probability distribution** over this sample space (= a set of possible worlds).



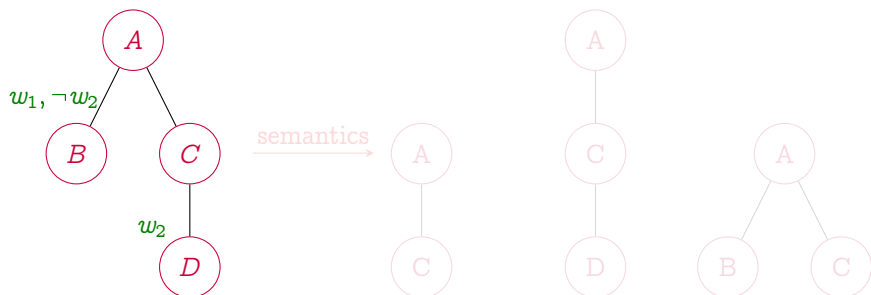
- Tree with **ordinary** (circles) and **distributional** (rectangles) nodes
- Distributional nodes specify how their **children** can be **randomly selected** (here, independently or in a mutually exclusive way)
- **Possible-world semantics**: every possible selection of children of distributional nodes, with associated probability
- No long-distance probabilistic dependencies in the tree!

- det** all children of the node are **deterministically** selected
- ind** children of the node are chosen **independently** of one another, according to their probabilities
- mux** children of the node are chosen in a **mutually exclusive** way, depending of their probabilities, that must sum up to 1 or less
- exp** the distribution of all possible choices of children is **explicitly** given: each subset of the set of the children is associated with a probability, these probabilities summing up to 1

Remark

Clearly, det is a particular case of ind, and det mux are particular cases of exp. ind can be simulated with a hierarchy of mux and exp.

Arbitrary dependencies: event conjunctions [AS06]



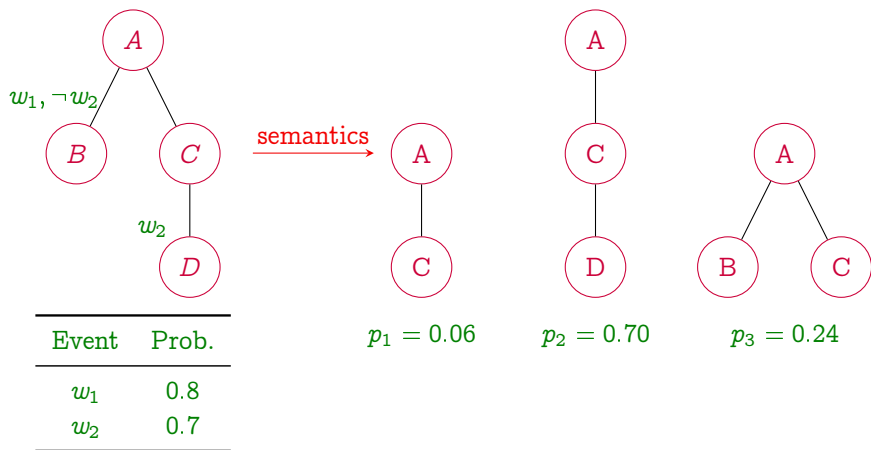
Event	Prob.
w_1	0.8
w_2	0.7

$$p_1 = 0.06$$

$$p_2 = 0.70$$

$$p_3 = 0.24$$

- Conjunctions of independent events on each node of the tree [IL84]
- Expresses arbitrarily complex dependencies
- Both ind and mux can be seen as particular cases (but not exp!)



- Conjunctions of independent events on each node of the tree [IL84]
- Expresses **arbitrarily complex** dependencies
- Both ind and mux can be seen as particular cases (but not exp!)

- Event variables: can represent the **provenance** of data
- Typically:
 - 1 At each (probabilistic) update, a **new** event variable is introduced
 - 2 Query results are given with probabilities, but also with the **lineage** of the query [FGT08]
- Allow to keep **track**, with no additional cost, of the provenance of data!

Previously studied XML models

ProTDB [NJ02] ind + mux

Probabilistic XML [vKdKA05] mux + det, with alternation between the two kinds of nodes

SP trees [AS06], PEPX [LSC06] ind without hierarchies of distributional nodes

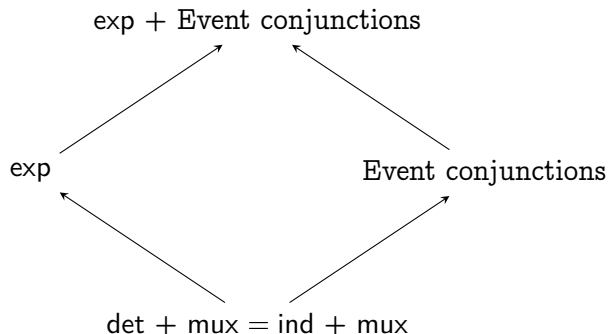
PXML [HGS03] exp without hierarchies, extended to graphs

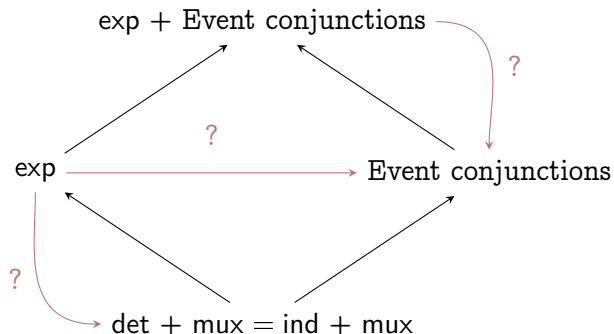
Probabilistic interval XML [HGS07] exp without hierarchies, when intervals are collapsed into points

Prob-trees [AS06, SA07] Event conjunctions

Theorem ([AS06, KKS08, AKSS09])

- 1 *ind alone, or mux alone, are not a complete representation system.*
- 2 *det + mux is enough to have full expressive power. Consequently, ind + mux, exp alone, or event conjunctions, have full expressive power.*
- 3 *Hierarchies (allowing a distributional node below another distributional node) are important.*





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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

EXPTIME algorithm! Can we do better, i.e., can we apply directly the algorithm on the probabilistic document?

We shall talk about **data complexity** of query answering.

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! Can we do better, i.e., can we apply directly the algorithm on the probabilistic document?

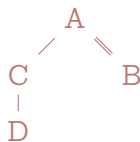
We shall talk about **data complexity** of query answering.

Boolean query languages on trees

Single-path queries (SP) `/A//B/C` (no branching)

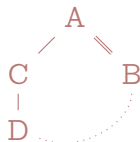


Tree-pattern queries (TP) `/A[C/D]//B`



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, do not cover TPJ

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

- A (counting) problem is in $\#P$ if there is a 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 Karp reduction). $\#2DNF$, the problem of counting the number of assignments satisfying a formula in 2-DNF, is $\#P$ -complete.
- A (computation) problem is in $FP^{\#P}$ if it is computable by a Turing machine with access to a $\#P$ oracle.
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	Local dependencies	Arbitrary dependencies
SP	PTIME	$\text{FP}^{\#P}$ -complete [KKS08]
TP	PTIME [KS07, KKS08, KKS09]	$\text{FP}^{\#P}$ -complete
TPJ	$\text{FP}^{\#P}$ -complete	$\text{FP}^{\#P}$ -complete
MSO	PTIME [CKS09]	$\text{FP}^{\#P}$ -complete

Remark

Project-free queries are tractable with arbitrary dependencies. [SA07]

Local dependencies

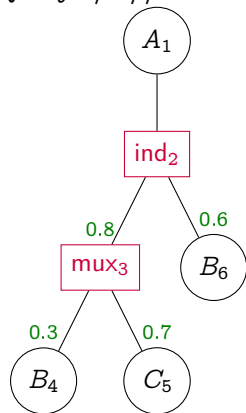
Arbitrary dependencies

TP PTIME [KS07, KKS08, KKS09]

TPJ FP^{#P}-complete

Bottom-up dynamic programming algorithm.

Query: /A//B



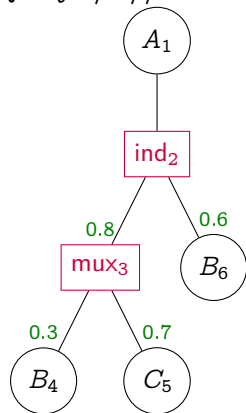
	A_1	ind_2	mux_3	B_4	C_5	B_6
/B				1	0	1
//B				1	0	1
/A//B				0	0	0

mux convex sum

ind inclusion-exclusion

Bottom-up dynamic programming algorithm.

Query: /A//B



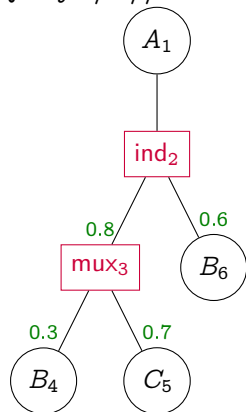
	A_1	ind_2	mux_3	B_4	C_5	B_6
/B			0.3	1	0	1
//B			0.3	1	0	1
/A//B			0	0	0	0

mux convex sum

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Bottom-up dynamic programming algorithm.

Query: /A//B



	A_1	ind_2	mux_3	B_4	C_5	B_6
/B		0.696	0.3	1	0	1
//B		0.696	0.3	1	0	1
/A//B		0	0	0	0	0

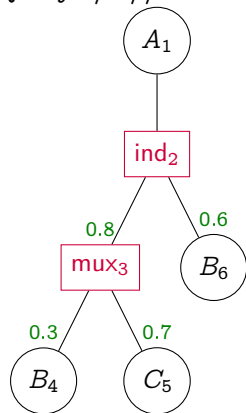
mux convex sum

ind inclusion-exclusion

$$\begin{aligned}
 \Pr(\text{ind}_2 \models /B) &= 1 - (1 - 0.8 \times \Pr(\text{mux}_3 \models /B)) \times (1 - 0.6 \times \Pr(B_6 \models /B)) \\
 &= 1 - (1 - 0.8 \times 0.3) \times (1 - 0.6) = 0.696
 \end{aligned}$$

Bottom-up dynamic programming algorithm.

Query: /A//B



	A_1	ind_2	mux_3	B_4	C_5	B_6
/B	0	0.696	0.3	1	0	1
//B	0.696	0.696	0.3	1	0	1
/A//B	0.696	0	0	0	0	0

mux convex sum

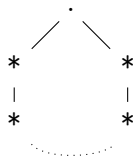
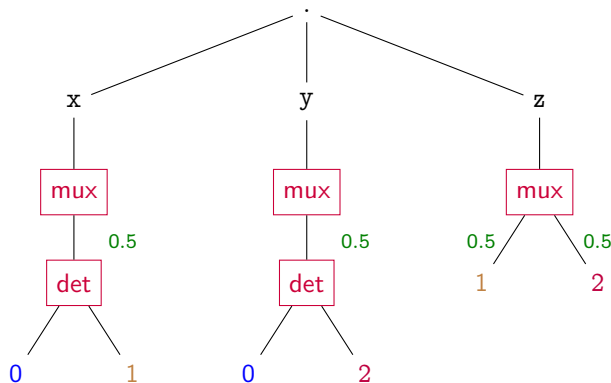
ind inclusion-exclusion

General case:

- Branching patterns: need to consider all **conjunctions of subbranches** of a pattern (exponentially many!)
- Works also with **exp**, but more complicated inclusion-exclusion
- Number of optimizations possibles
- **Bottomline**: it works because bottom-up evaluation is possible
- **Generalization [CKS09]**: MSO queries can be converted (non efficiently) into bottom-up tree automata, therefore MSO is also tractable

TPJ $\text{FP}^{\#P}$ -hard for local dependencies

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



Aggregate Queries: sum, count, avg, countd, min, max, etc.
Distributions? Possible values? Expected value?

Summary of results

- Computing expected values of sum and count **tractable** with arbitrary dependencies. Everything else **intractable**.
- Computing expected values of every of these aggregate functions is **tractable** with local dependencies.
- Computing distributions and possible values is **tractable** for count, min, max, **intractable** for the others.

Always possible to approximate query answers with **Monte Carlo sampling**.

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- Determining the probability that a probabilistic document with local dependencies matches a schema is **tractable** (uses the transformation of schemas into bottom-up automaton).
- Determining the probability that a probabilistic document with arbitrary dependencies matches a schema is **intractable**.

Updates defined by a query (cf. XUpdate, XQuery Update).

Semantics: for all matches of a query, insert or delete a node in the tree at a place located by the query.

Results

- Updates are **intractable** with local dependencies: the result of an update can require an exponentially larger representation size
- Insertions are **tractable** with arbitrary dependencies; deletions are **intractable**.

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Missing complexity results

- Tractable reduction from exp to arbitrary dependencies?
- Tractable reduction from exp to mux + ind?
- More systematic study of **updates** (different semantics: insert once if there is at least one match).
- **Combined complexity** results.



Work in progress with U. Oxford and U. Bozen-Bolzano

Relational case

(Block-independent disjoint model, [DS07])

- Some conjunctive queries are **PTIME**
- Others are **#P-hard**
- Complex conditions to separate the two

XML case (Local dependencies)

- Tree pattern queries are **PTIME**
- Tree pattern queries with (non-trivial) joins are **#P-hard**

- Why does the XML case seem simpler?
- Is there some insight to be gained from one case to the other?
- Translating XML data and queries to the relational case yields queries with self-joins, a less well-understood setting

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XML case (Local dependencies)

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- Most probabilistic database models assume **discrete** probabilistic distributions
- Sensor networks, unknown values: need for **continuous** distributions! (uniform, Gaussian, Poisson, etc.)
- Some existing works on query answering over continuous distributions [CKP03, DGM⁺04] but no clear semantics
- **Claim:** this is not more difficult than the discrete case, as long as integration/differentiation are easy (symbolically or numerically) for the considered distributions
- Discrete distributions can be modeled as **Diracs**



Work in progress with U. Bozen-Bolzano

Tractable extensions of the local dependency model

- Arbitrary dependencies: **not tractable**
- Local dependencies: **not practical**
- Somewhere in between?
 - What makes the arbitrary dependency model hard?
 - How can the local dependency model be generalized, while remaining tractable?
- And can we go further? cf. XML schemas
 - Trees of unbounded depth
 - Trees of unbounded width
 - Infinite trees?



Work in progress with U. Oxford

But where do probabilities come?!

- Do the numbers assigned as probabilities in PDBMS really make sense?
- In some cases, sources of “good” probabilities:
 - Statistics
 - Conditional Random Fields
- What about the rest? Does it really make sense to model uncertainty with probabilities?

A system that just works

- Nothing else than toy systems exist for probabilistic XML
- What should it be based upon:
 - a probabilistic relational DBMS?
 - a native XML DBMS?
- Systems issue: distribution, indexing, etc.
- And need for a killer application!
 - Probabilistic content warehouse?
 - Parse trees of natural language sentences?
 - Concise representation of a large corpus of XML documents?






PhD started on this topic in October 2009





Merci.





The logo for Webdam is written in a stylized, blue, cursive font with a thick black outline. The letters are rounded and connected, giving it a friendly and approachable appearance.





Foundations of Web data management

<http://webdam.inria.fr/>

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