Probabilistic XML: Survey and Challenges

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1 Motivation

2 Existing Work

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
Managing this imprecision

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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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*
Why XML?

- 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) 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)!
Outline

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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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Trees and possible worlds

Unordered data trees

\[ A \]
\[ B \]
\[ C \]
\[ D \] \neq

\[ A \]
\[ B \]
\[ B \]
\[ C \]
\[ D \]

(multiset semantics)

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!
- Minor generalizations of ind and mux also exist
Conjunctions of independent events on each node of the tree [IL84]

Expresses arbitrarily complex dependencies

Bonus: events can track lineage [FGT08]
Arbitrary dependencies \cite{AS06}

\begin{itemize}
  \item Conjunctions of independent events on each node of the tree \cite{IL84}
  \item Expresses \textit{arbitrarily complex} dependencies
  \item Bonus: events can track lineage \cite{FGT08}
\end{itemize}

<table>
<thead>
<tr>
<th>Event</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w_1$</td>
<td>0.8</td>
</tr>
<tr>
<td>$w_2$</td>
<td>0.7</td>
</tr>
</tbody>
</table>

$p_1 = 0.06$, $p_2 = 0.70$, $p_3 = 0.24$
## Summary of results (data complexity)

<table>
<thead>
<tr>
<th>Local dependencies</th>
<th>Arbitrary dependencies</th>
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<tbody>
<tr>
<td><strong>Expressiveness</strong></td>
<td><strong>Full expressive power</strong> [AS06, KKS08]</td>
</tr>
<tr>
<td><strong>Compactness</strong></td>
<td><strong>AD exponentially more compact than LD</strong> [Sen07, KKS08]</td>
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### Queries

- **tree-pattern**
  - PTIME [KKS09]
- **with joins**
  - FP\#P-complete
- **project-free**
  - PTIME
- **TP + HAVING**
  - PTIME [CKS08]
- **Tree automaton (typing, MSO)**
  - PTIME [CKS09]

### Updates

- **Intractable** [AKSS09]
- **Insertions tractable, Deletions intractable** [SA07]
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Link with probabilistic relational models

Relational case
(Block-independent disjoint model, \([\text{DS07}]\))

- Some conjunctive queries are \textsc{PTIME}
- Others are \textsc{#P-hard}
- Complex conditions to separate the two

XML case (Local dependencies)

- Tree pattern queries are \textsc{PTIME}
- Tree pattern queries with (non-trivial) joins are \textsc{#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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Continuous probability distributions

- 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**
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?
But where do probabilities come from?!

- 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?
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?
Merci.
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Comprendre le Web caché. Understanding the Hidden Web.

Jennifer Widom.
Trio: A system for integrated management of data, accuracy, and lineage.