On the Complexity of Managing Probabilistic XML Data

Pierre Senellart Serge Abiteboul

Principles Of Database Systems, 13th June 2007

Outline

Imprecise Data and Imprecise Tasks

Observations

- Many tasks generate imprecise data, with some confidence value.
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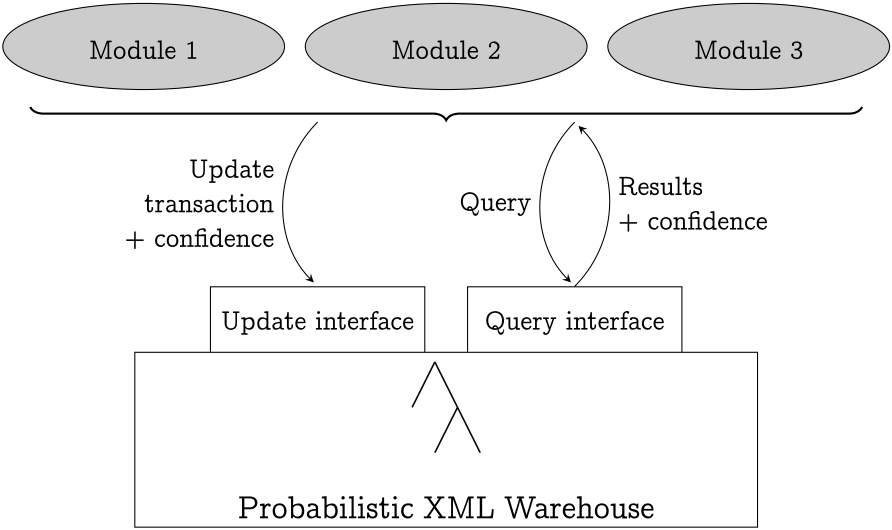

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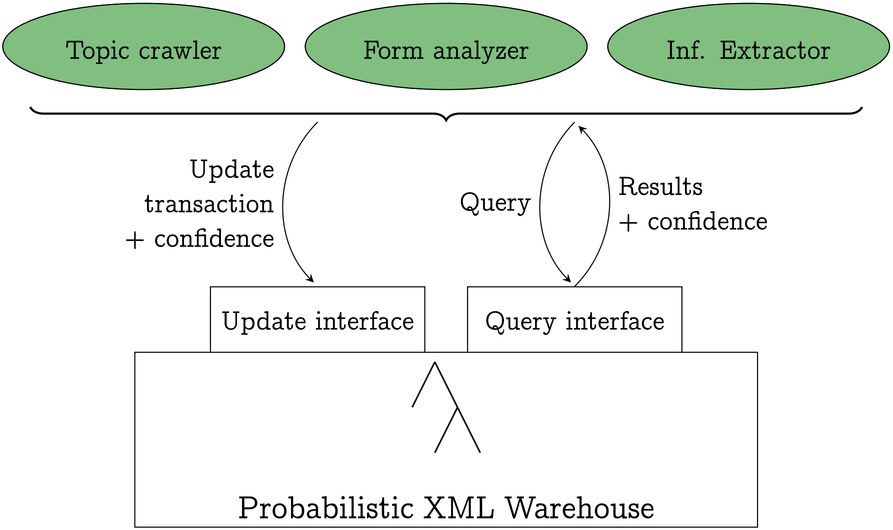

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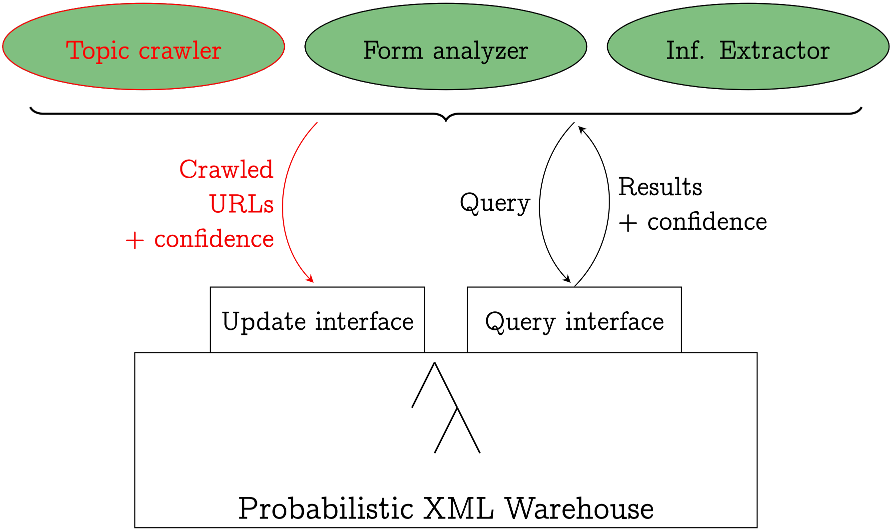

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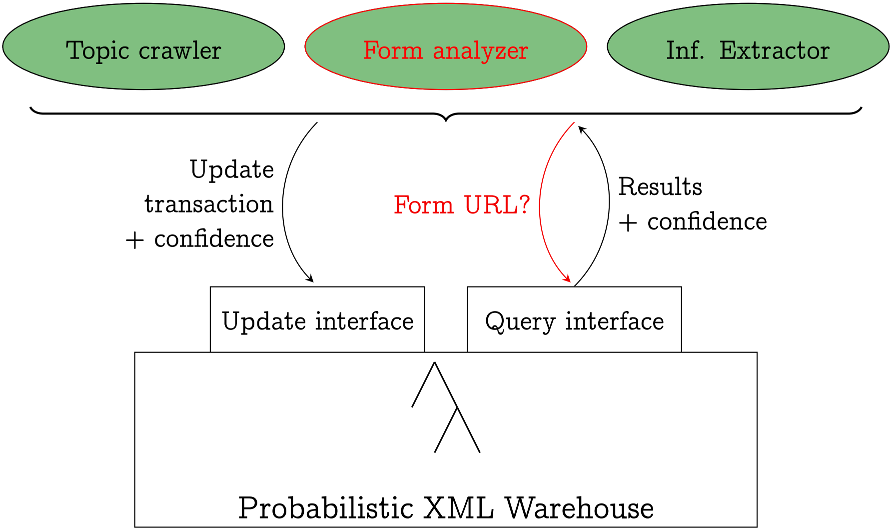

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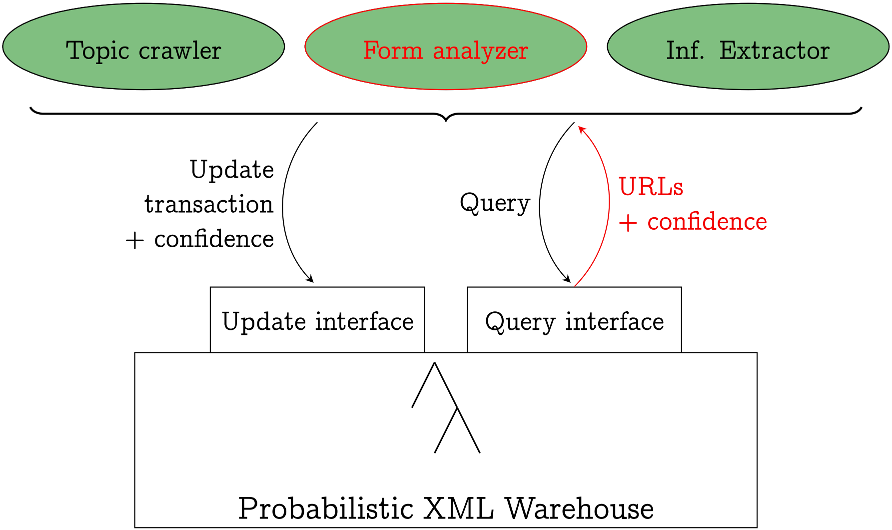

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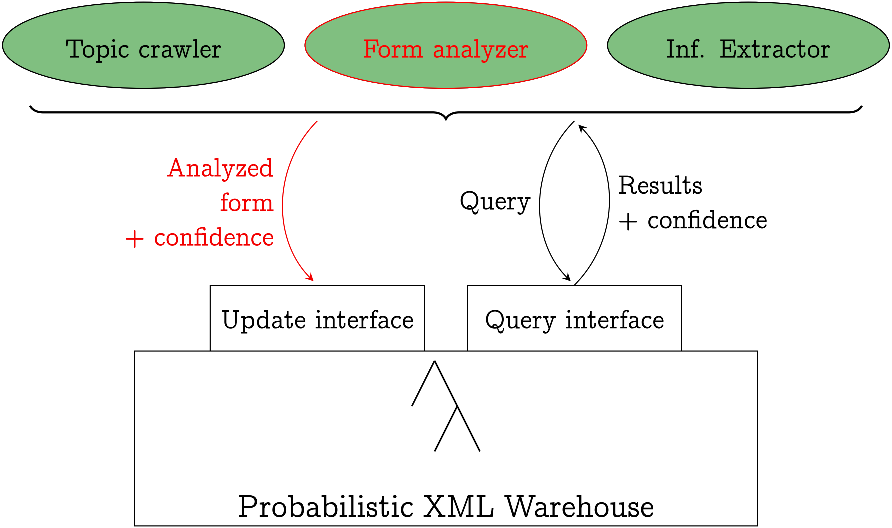

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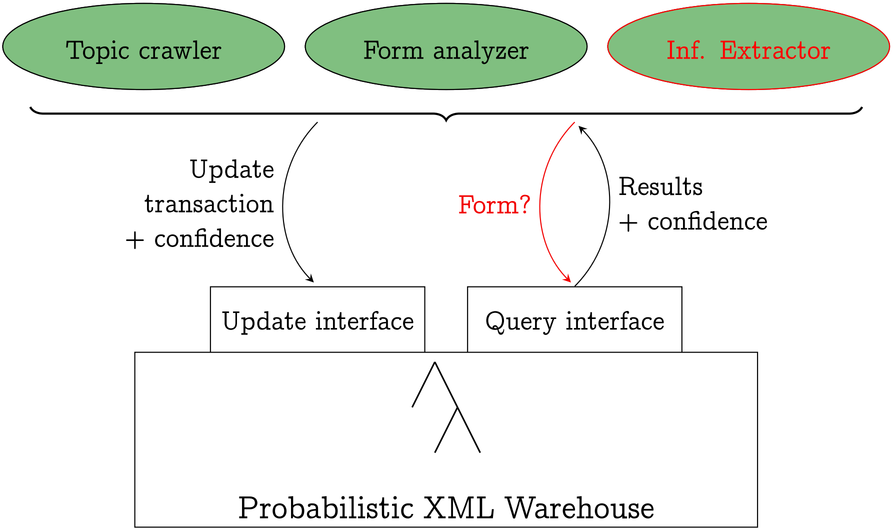

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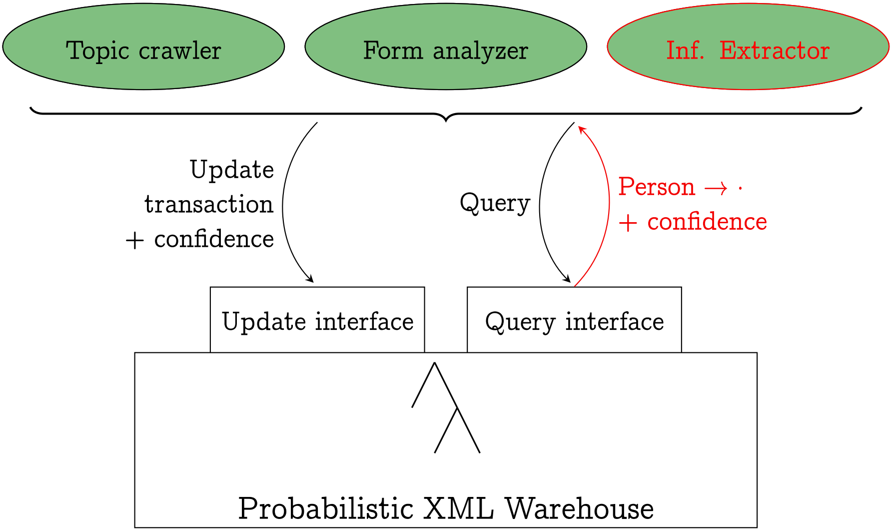

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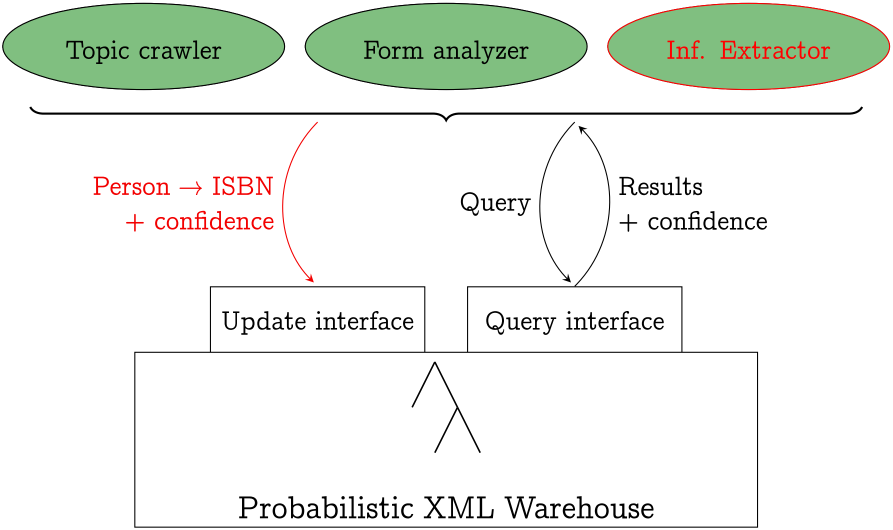

Probabilistic Trees

Framework

- Unordered data trees
- Details: no attributes, no mixed content...

(multiset semantics)

Sample space: Set of all such data trees.

Probabilistic tree (prob-tree): Representation of a discrete probability distribution over this sample space.

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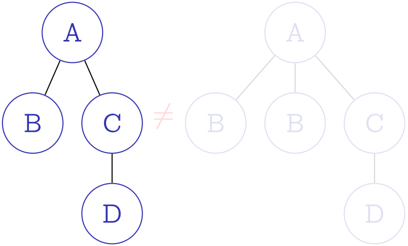

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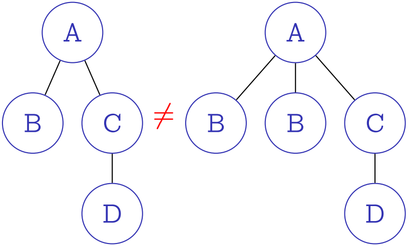

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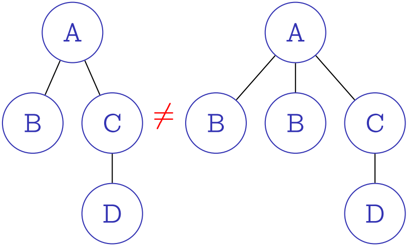

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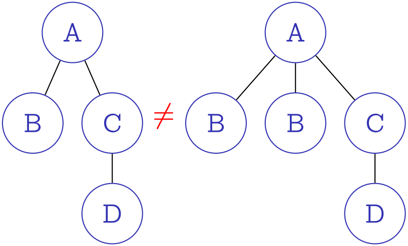

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Prob-tree model defined in [Abiteboul & Senellart 2006]. Here, we tackle complexity questions about it:

- What is the complexity of queries and updates?
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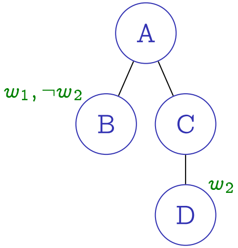
The Prob-Tree Model

- Data tree with event conditions (conjunction of probabilistic events or negations of probabilistic events) assigned to each node.
- Probabilistic events are boolean random variables, assumed to be independent, with their own probability distribution.
- Representation *à la* [Imieliński & Lipksi 1984].



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w_1	0.8
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Semantics of a Prob-Tree T: Set of Possible Worlds $[\![T]\!]$ (probability distribution over the set of data trees).

$p_1 = 0.06$ $p_2 = 0.70$ $p_3 = 0.24$

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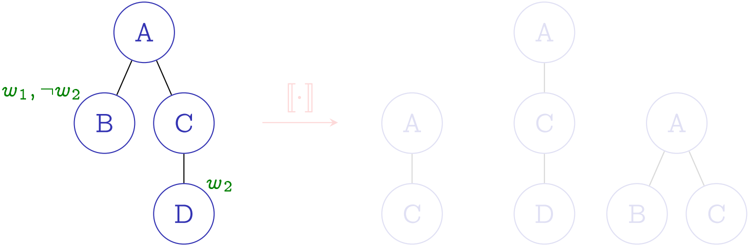

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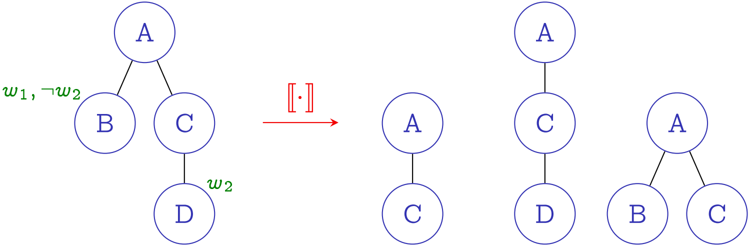

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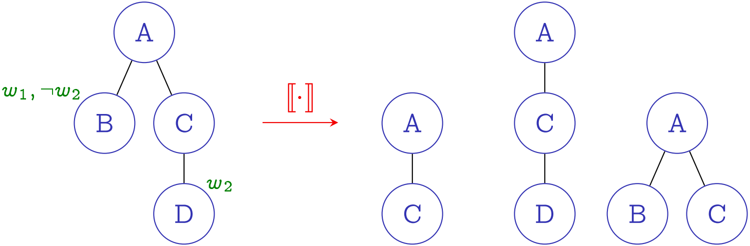

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Locally Monotone Queries

Query: function that maps a data tree t to a set of subtrees of t containing its root.

Definition

A query Q is locally monotone if, for any data trees u, t' and t such that $u \leqslant t' \leqslant t$, $u \in Q(t) \iff u \in Q(t')$.

Examples

- Tree-pattern queries with joins are locally monotone.
- "Return the root node if it has no A child, nothing otherwise." is not locally monotone.

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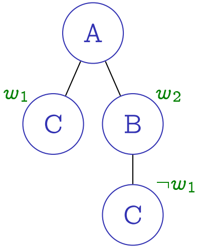

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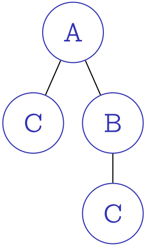

Underlying data tree.

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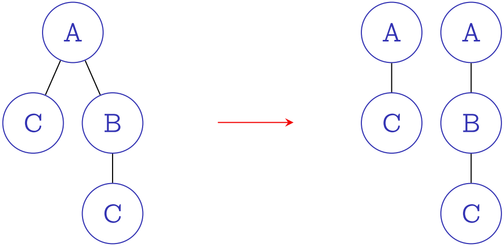

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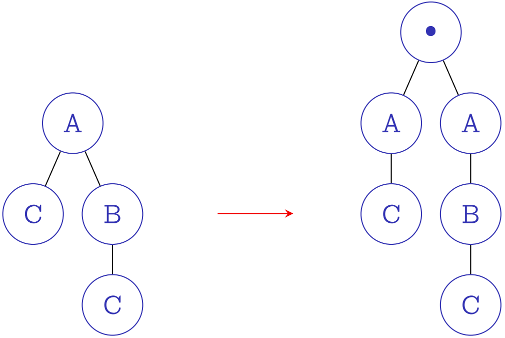

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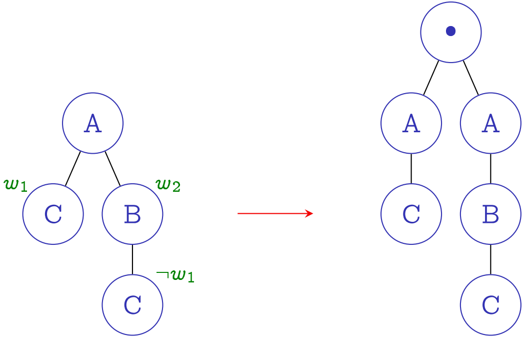

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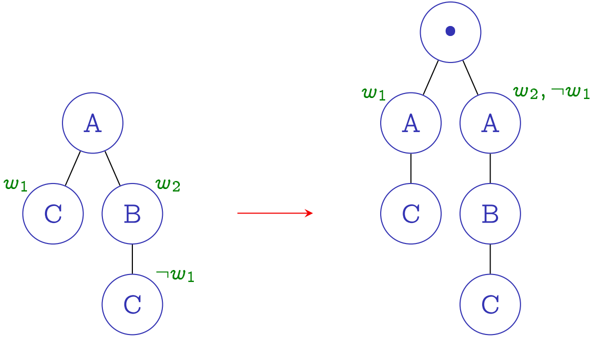

Consistence of Queries on Prob-Trees

Theorem

$$
\begin{tikzcd}
\textit{Prob-Tree} \arrow[r, "query"] \arrow[d, "semantics"] & \textit{Prob-Tree} \arrow[d, "semantics"] \\
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What about updates?

- We consider sets of elementary insertions and deletions.
- Defined with respect to a query (mapping between nodes of the query and nodes to insert/delete).
- More involved definitions. . .
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Complexity Results

T: prob-tree with underlying data tree t.
$\mathbf{time}(Q(t))$: complexity of the query Q over the data tree t.

Upper bounds for operations on T:

Operation	Complexity
Query	$\mathbf{time}(Q(t))$ + polynomial in the size of T, $Q(t)$
Insertion	$\mathbf{time}(Q(t))$ + polynomial in the size of T, $Q(t)$
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If the query language is not trivial, the result of a deletion may necessarily be exponential.

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Two Notions of Equivalence

What does it mean for two prob-trees to represent the same information?

Two different notions:

Structural Equivalence: we keep the same event variables.

Semantic Equivalence: we only consider the possible worlds semantics.

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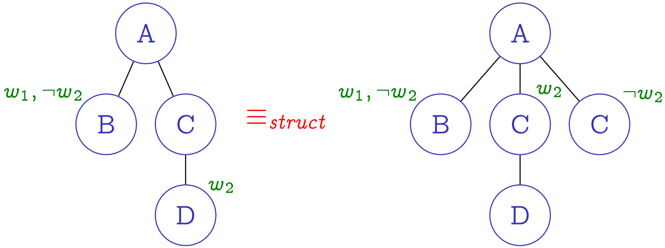

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Theorem

Structural Equivalence is a ***coRP*** *problem: there exists a randomized polynomial-time algorithm that returns* `true` *if two prob-trees are equivalent, and* `false` *with probability* $\geqslant 1/2$ *otherwise.*

Based on the notion of count-equivalence:

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Two propositional formulas ψ, ψ' in DNF are count-equivalent ($\psi \stackrel{\pm}{\equiv} \psi'$) if, for every valuation of the variables of ψ and ψ', the same number of disjuncts of ψ and ψ' are satisfied.

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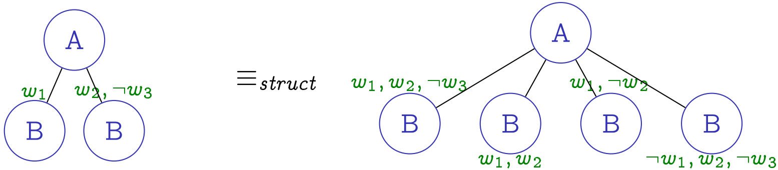

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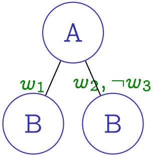
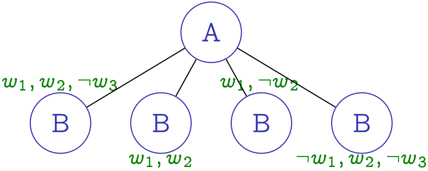


$\equiv_{struct}$



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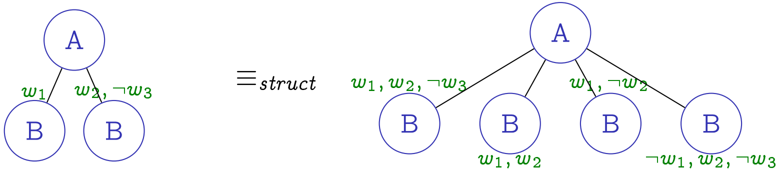

$$\iff \quad w_1 \lor (w_2 \land \neg w_3) \quad \stackrel{+}{\equiv} \quad (w_1 \land w_2 \land \neg w_3) \lor (w_1 \land w_2) \lor (w_1 \land \neg w_2) \lor (\neg w_1 \land w_2 \land \neg w_3)$$

$$\iff \quad X_1 + X_2(1 - X_3) \quad = \quad X_1X_2(1 - X_3) + X_1X_2 + X_1(1 - X_2) + (1 - X_1)X_2(1 - X_3)$$

(see [Green, Karvounarakis & Tannen 2007]).

Polynomial-time randomized algorithm for determining if a multivariate polynomial is zero [Schwartz 1980].

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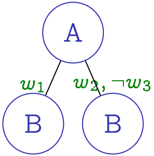
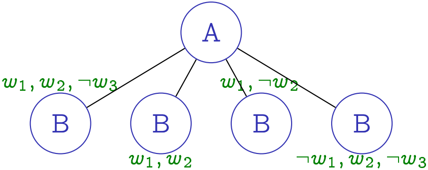


$\equiv_{struct}$



$$\Longleftrightarrow \quad w_1 \lor (w_2 \land \neg w_3) \quad \stackrel{+}{\equiv} \quad (w_1 \land w_2 \land \neg w_3) \lor (w_1 \land w_2) \lor (w_1 \land \neg w_2) \lor (\neg w_1 \land w_2 \land \neg w_3)$$

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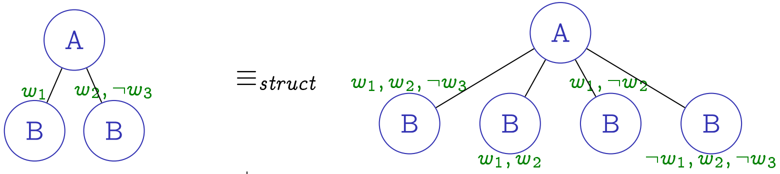

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Two prob-trees T and T' are semantically equivalent ($T \equiv_{sem} T'$) if $[\![T]\!] = [\![T']\!]$.

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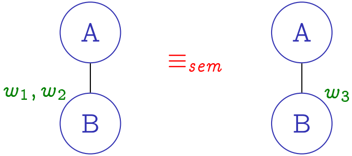

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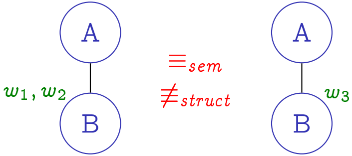

Semantic and Structural Equivalence

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1. *If* $T \equiv_{struct} T'$, *then* $T \equiv_{sem} T'$
2. *If* $T \equiv_{sem} T'$ *for every possible probability distribution, then* $T \equiv_{struct} T'$.

Complexity of semantic equivalence: open issue. Easy **EXPTIME** upper bound.

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Restriction to a Probability Threshold

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- $[\![T]\!]_{|\geqslant p}$: set of possible worlds in $[\![T]\!]$ whose probabilities are greater than p.

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- Unavoidable exponential complexity for deletions.
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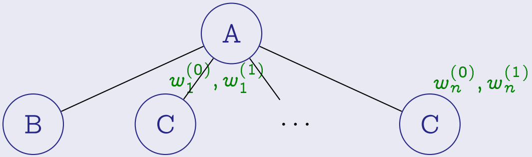
Merci.

Proof of the Exponential Complexity of Deletion

Proof.

Deletion d: "If the root has a C-child, then delete all B-children of the root."

$T =$



$\forall i, \pi(w_i) = 1/2$

Then, it can be shown that if $T' \equiv_{struct} d(T)$, at least 2^n literals appear in T'.

$\square$

◂ Return to theorem

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