Structurally Tractable Uncertain Data

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Uncertain data management

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→ We need uncertain data management

Example model: TID

- Consider a relational instance

Date	Animal
Wed 3rd	Kangaroo
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  - → Semantics: a probability distribution on regular instances
- What about queries? (Boolean CQs)
  - → Semantics: compute the probability that the query holds

Big problem: Tractability

- Evaluate the fixed Boolean CQ: $\exists xy \, R(x) \, S(x,y) \, T(y)$
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$\rightarrow$ #P-hard [Dalvi and Suciu, 2007] (instead of AC^0)

Existing approaches:

- Avoid hard queries [Dalvi and Suciu, 2012]
- Use sampling to get approximate answers

The general idea

Input instances are not arbitrary!

$\rightarrow$ Impose structural restrictions on instances

$\rightarrow$ Prove fixed-parameter tractability results

This talk

- Parameter: instance treewidth
- Bound it by a constant

$\rightarrow$ MSO queries have linear data complexity [Courcelle, 1990]

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- Parameter: instance treewidth
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→ MSO queries have linear data complexity [Courcelle, 1990]

→ Also holds on TID instances (with unit cost arithmetics)
(joint work with Pierre Bourhis and Pierre Senellart)

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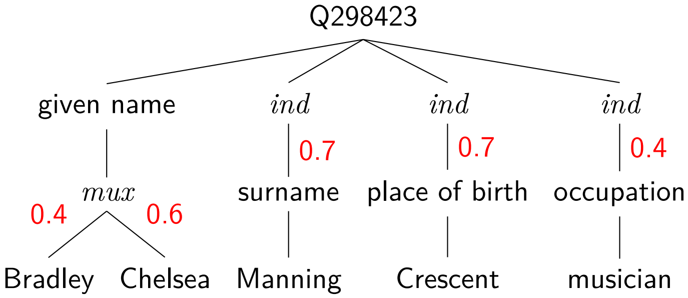
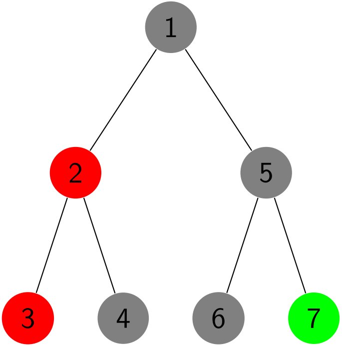
Uncertain tree example

- A possible PrXML tree, from Wikidata facts:



→ Probabilities reflect contributor trustworthiness

Formalizing uncertain trees



A valuation of a tree decides whether to keep or discard node labels.

Example query:
"Is there both a red and green node?"

Valuation: $\{1, 2, 3, 4, 5, 6, 7\}$

The query is true

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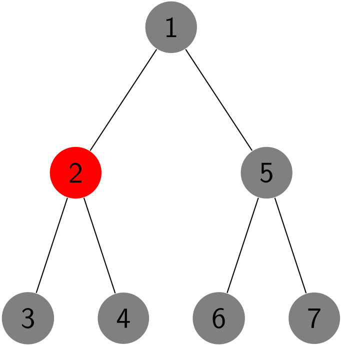

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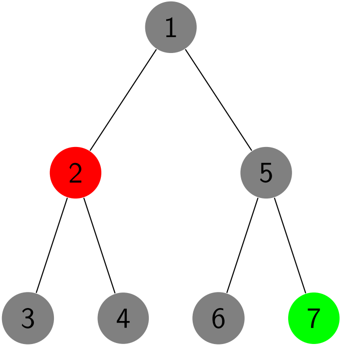

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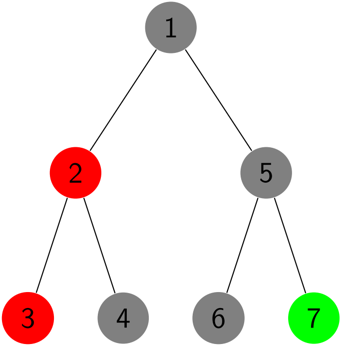
Provenance formulae and circuits



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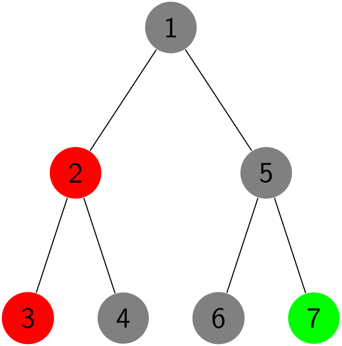

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→ Provenance formula of a query q on an uncertain tree T:

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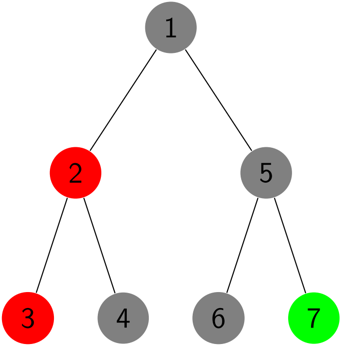

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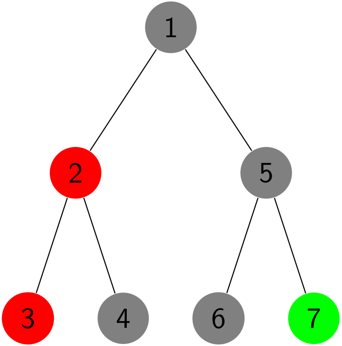
- Provenance circuit of q on T [Deutch et al., 2014]
  - Boolean circuit C
  - with input gates $g_1 \ldots g_7$

  → $\nu(T)$ satisfies q iff $\nu(C)$ is true

Example



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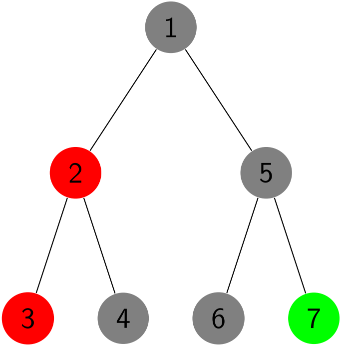

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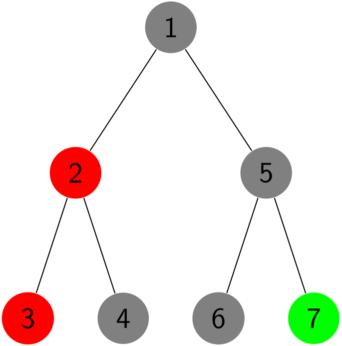

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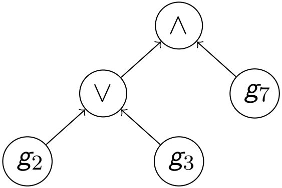

Our main result on trees

Theorem

For any fixed MSO query q (first order + quantify on sets) we can compute a provenance circuit C for any input tree T in linear time in the input T.

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→ Relates to message passing [Lauritzen and Spiegelhalter, 1988]

→ Already known [Cohen et al., 2009]

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Treewidth intuition

Generalize from trees to treelike instances:

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- Treewidth: measure on instances
    - Trees have treewidth 1
    - Cycles have treewidth 2
    - k-cliques and k-grids have treewidth $k-1$
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$\rightarrow$ Treelike instances can be encoded to trees

Treewidth formal definition

Instance:

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a	b
b	c
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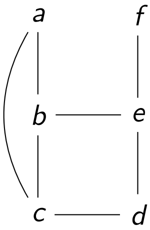

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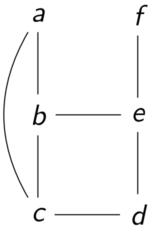

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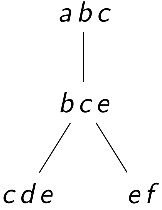

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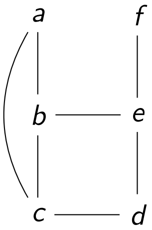

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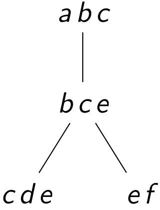

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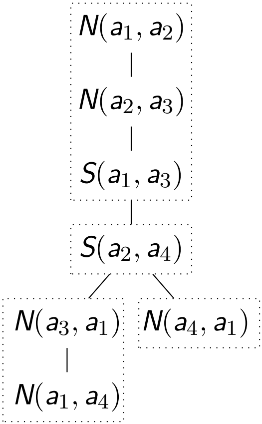

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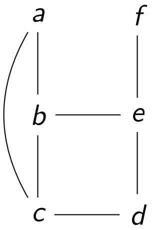

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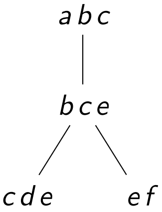

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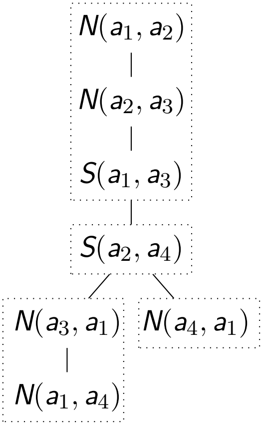

→ Treelike: constant bound on the maximal bag size

Our main result on treelike instances

Theorem

*For any fixed MSO query q and bound $k \in \mathbb{N}$,
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Corollary

MSO queries have linear data complexity on treelike TID instances.

Further results

- Support other models with dependencies between facts:
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  - Block-independent disjoint (BID): mutually exclusive facts
  - pc-tables: events and Boolean annotations
- Support other tasks:
  - Counting query results encodes to probabilistic evaluation
  - General connection to semiring provenance [Green et al., 2007]

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- Negation:
  - Semiring provenance usually defined for positive queries
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- Structural restrictions:
  - Are real-world instances tree-like?
  - Are there other possible restrictions?
  - Experiments?

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- Compiling to automata has high combined complexity

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$\rightarrow$ Connect to tractable languages (e.g., guarded Datalog)

- What about incorporating new evidence?

$\rightarrow$ Connect to work on conditioning [Tang et al., 2012]

Other projects and directions

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Thanks for your attention!

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Semiring provenance [Green et al., 2007]

- Semiring $(K, \oplus, \otimes, 0, 1)$
  - $(K, \oplus)$ commutative monoid with identity 0
  - $(K, \otimes)$ commutative monoid with identity 1
  - $\otimes$ distributes over $\oplus$
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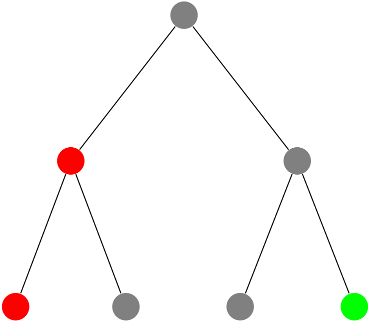
  - 0 absorptive for $\otimes$
- Idea: Maintain annotations on tuples while evaluating:
  - Union: annotation is the sum of union tuples
  - Select: select as usual
  - Project: annotation is the sum of projected tuples
  - Product: annotation is the product

Tree automata

Tree alphabet: 



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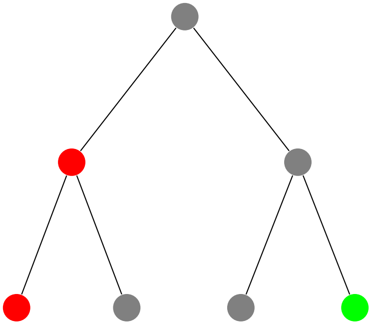

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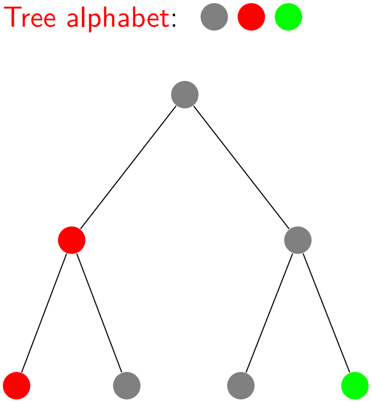

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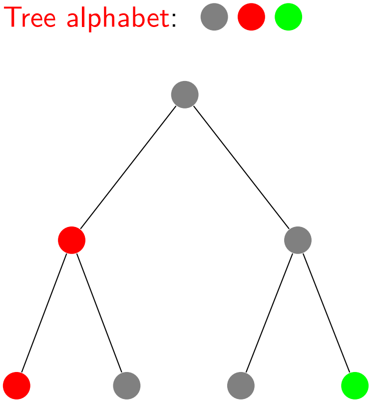

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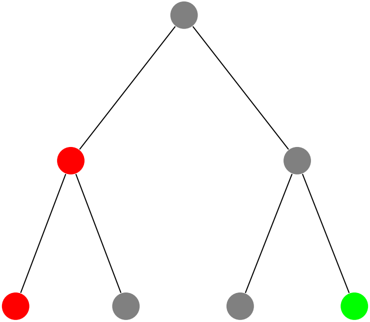
- Final states: $\{\top\}$

Tree automata

Tree alphabet: 



- bNTA: bottom-up nondeterministic tree automaton
- "Is there both a red and green node?"
- States: $\{\bot, G, R, \top\}$
- Final states: $\{\top\}$
- Initial function:

 $\bot$  R  G

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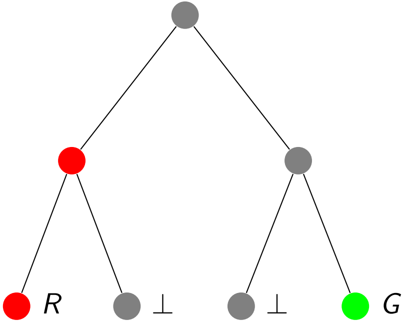

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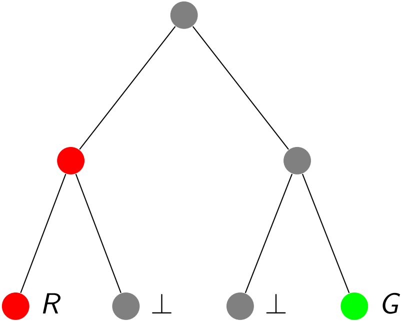

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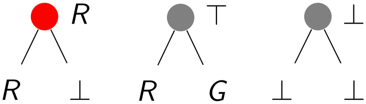

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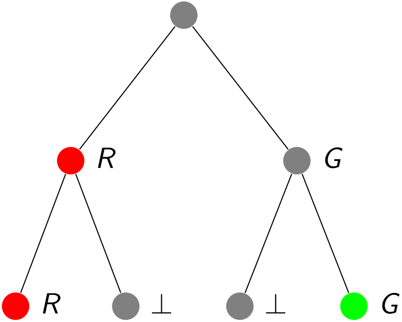

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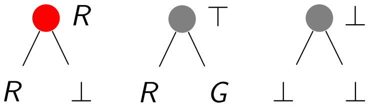

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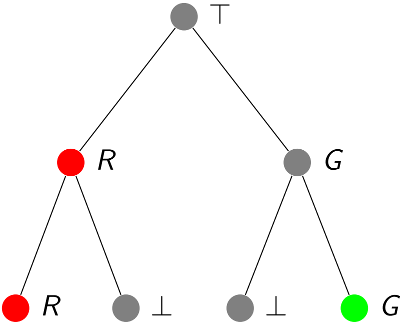

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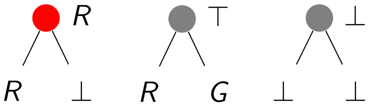
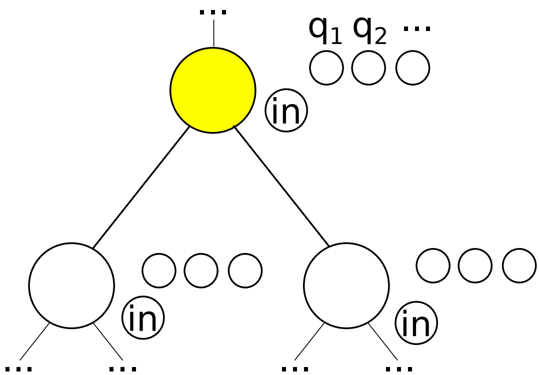


Constructing the provenance circuit

→ Construct a Boolean provenance circuit bottom-up



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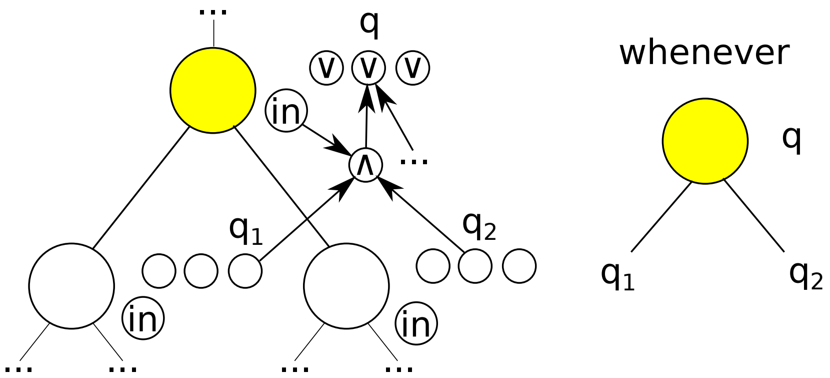

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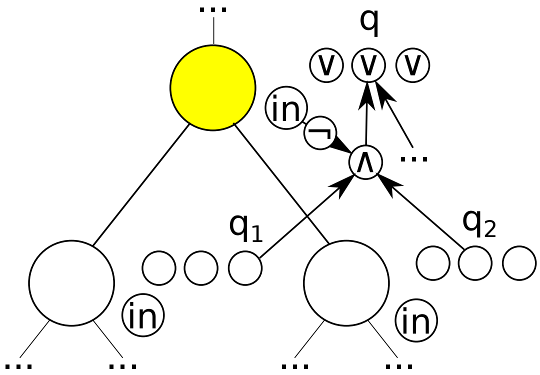

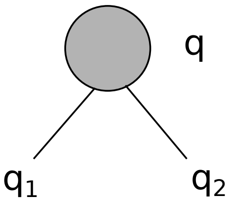

Example: block-independent disjoint (BID) instances

name	**city**	**iso**	*p*
pods	melbourne	au	0.8
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icalp	tokyo	jp	0.1
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$\rightarrow$ For a treelike instance, linear time!

Supporting coefficients

- In the world of trees
  - The same valuation can be accepted multiple times
  - $\rightarrow$ Number of accepting runs of the bNTA
- In the world of treelike instances
  - The same match can be the image of multiple homomorphisms

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→ Add assignment facts to represent possible assignments

→ Encode to a bNTA that guesses them

Supporting exponents

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  - The same fact can be used multiple times
  - Annotate nodes with a multiplicity
  - The bNTA is monotone for that multiplicity
  - Use each input gate as many times as we read its fact
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  - The same fact can be the image of multiple atoms
  - Maximal multiplicity is query-dependent but instance-independent

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→ Encodes CQs to bNTAs that read multiplicities

  - Consider all possible CQ self-homomorphisms
  - Count the multiplicities of identical atoms
  - Rewrite relations to add multiplicities
  - Usual compilation on the modified signature