Regular tree patterns: a uniform formalism for update queries and functional dependencies in XML

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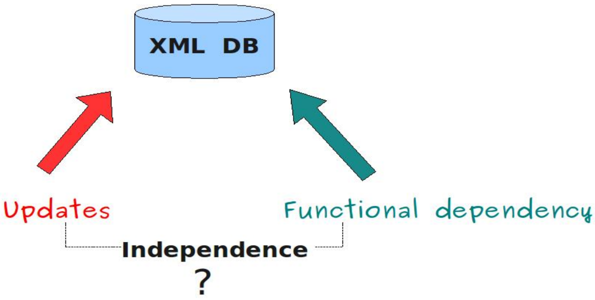
Updates in XML 2010

Outline

Introduction: the problem of independence



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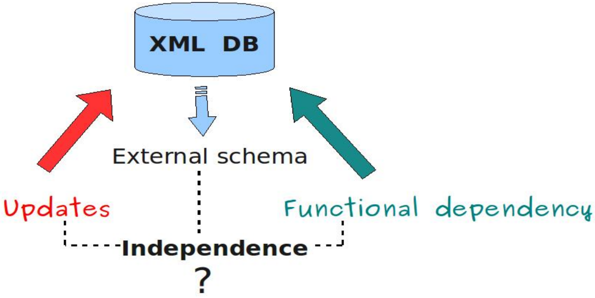

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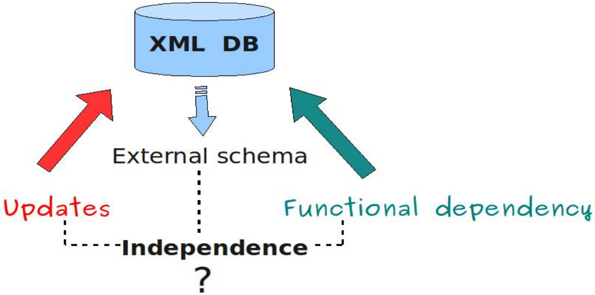
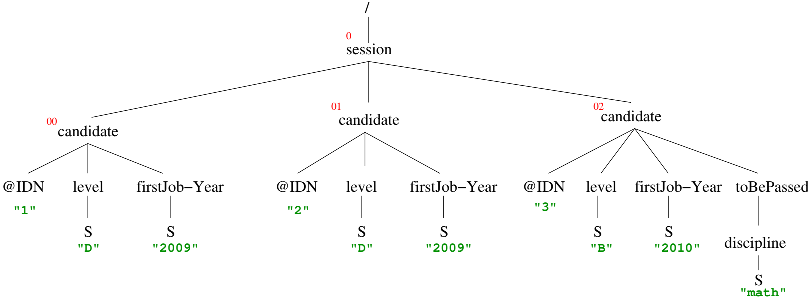


Goal

Detecting independence will help us to avoid a new verification of the functional dependency

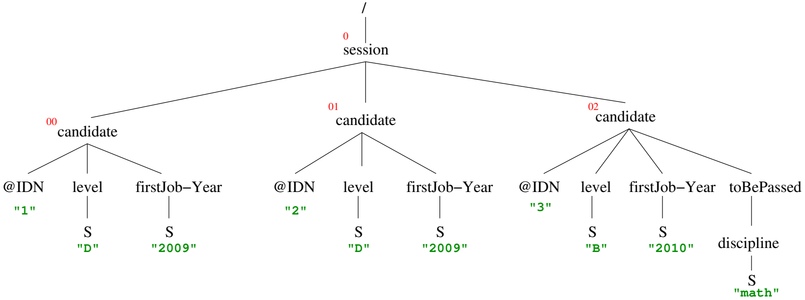
Introduction: example



XML documents $\mathcal{D}$=(D, λ, val)

- $D \subset \mathbb{N}^*$: a tree domain denoted by $\mathcal{N}(\mathcal{D})$
- $\lambda : D \to \Sigma = El \cup A \cup \{S\}$
- val: $D \to D \cup I^*$

Introduction: example



A functional dependency (satisfied before the update)

“Two candidates with a job and a same academic level, have got their first job the same year.”

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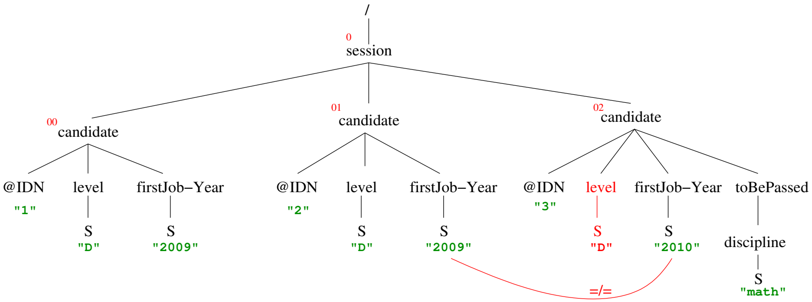

An update

“ Update the level of each candidate having to pass some remaining exams“

A functional dependency (not satisfied after updating)

“Two candidates with a job and a same academic level, have got their first job the same year.”

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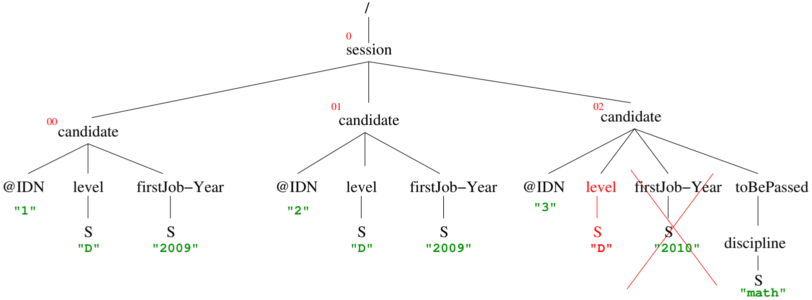

Schema :$\mathcal{S}c$

candidate :(level,(firstJob-Year|toBePassed))

The functional dependency “Two candidates with a job and a same academic level, have got their first job the same year” remains satisfied after the update

Related work

- Some works in the area:
  -[W. Fan & al, 2000 - 2002] "*Integrity constraints for XML*"
  -[P. Buneman & al, 2003] "*Reasoning about Keys for XML*"
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- Similar works using updates:
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Expressing functional dependencies

The most commonly used model is based on simple linear paths.

Example:

"Two candidates with a job and a same academic level, have got their first job the same year"

(/session ,({candidate/level} → candidate/firstJobYear))

Expressing functional dependencies

The most commonly used model is based on simple linear paths.

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"Two candidates with a job and a same academic level, have got their first job the same year"

$$(\underbrace{/session}_{\text{context}},(\underbrace{\{candidate/level\}}_{\text{condition}} \rightarrow \underbrace{candidate/firstJobYear}_{\text{target}}))$$

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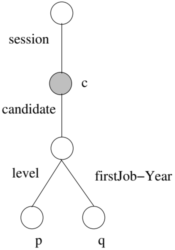


Our chosen model :

Regular tree patterns (RTPs)

Regular tree pattern: the definition

Σ is a finite alphabet of labels.

Definition ($\mathcal{R} = (\mathcal{T}, \overrightarrow{s})$: n-ary regular tree pattern over Σ)

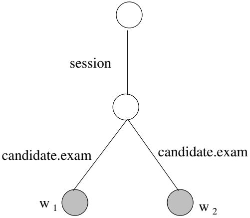
- $\mathcal{T} = (\Sigma, N, M, \mathcal{E})$ is the regular tree template composed of
  - a tree (N, M) with N as tree domain and $M \subseteq N \times N$ as associated set of edges.
  - an application $\mathcal{E} : M \longrightarrow REG(\Sigma)$
- $\overrightarrow{s}$=(w_1, ..., w_n) is the tuple of selected nodes.

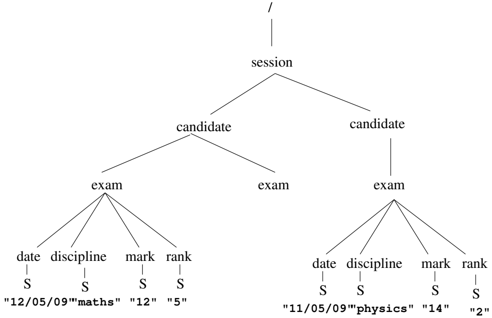
Regular tree pattern: the evaluation(1)

Let $\mathcal{R} = (\mathcal{T}, \overrightarrow{s})$ be a regular tree pattern with $\mathcal{T} = (\Sigma, N, M, \mathcal{E})$ and $\mathcal{D} = (D, \lambda, val)$ be an XML document

Mapping:

A mapping of $\mathcal{R}$ in $\mathcal{D}$ is a one-to-one function $\pi : N \longrightarrow D$





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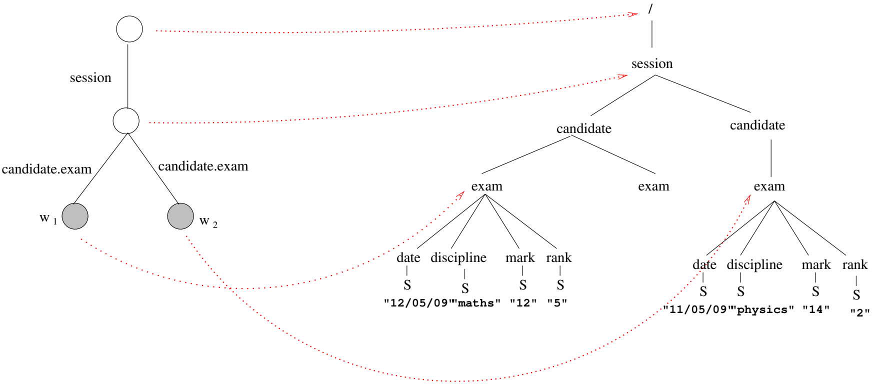

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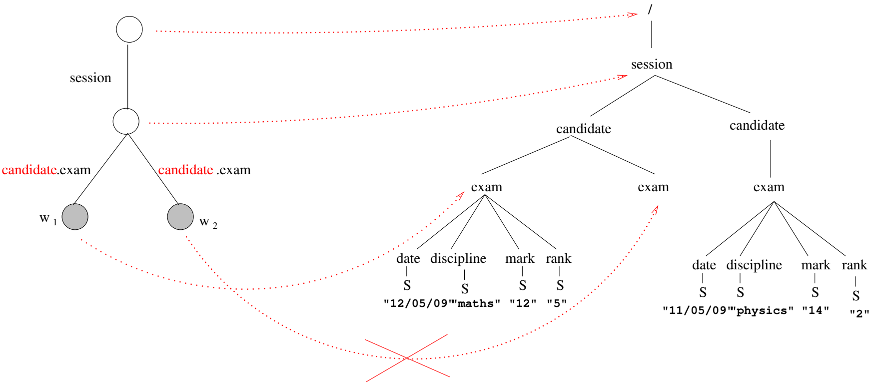

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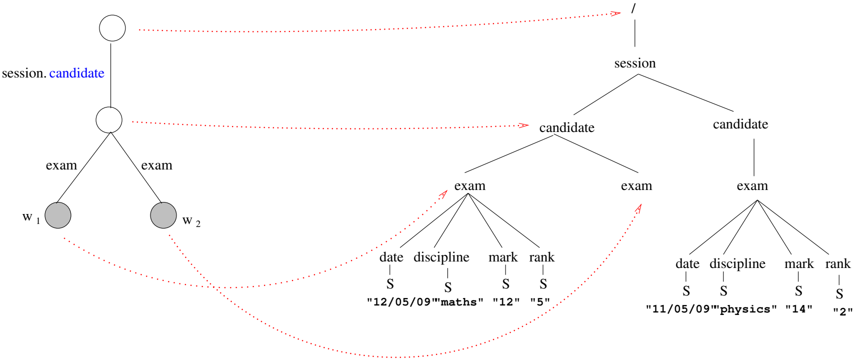

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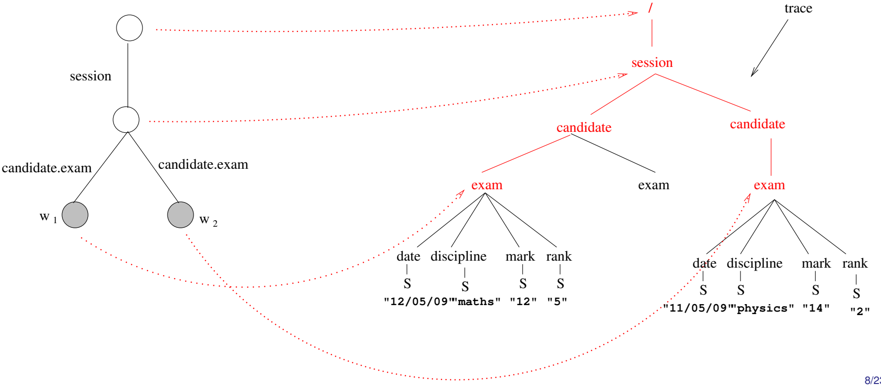

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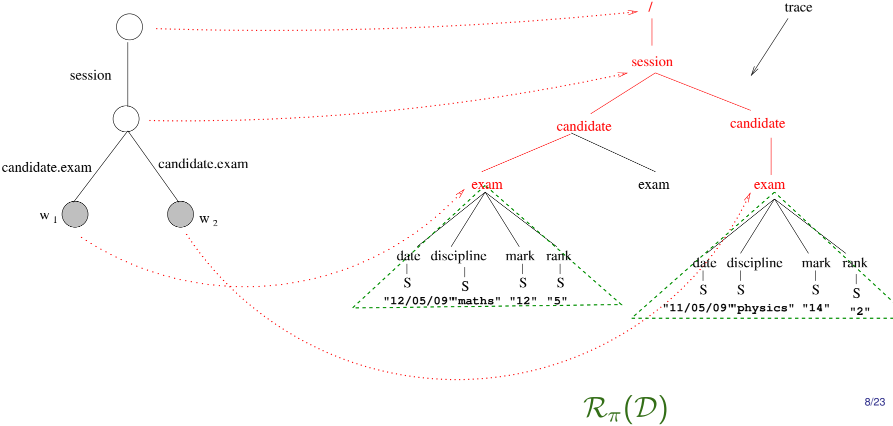

Regular tree pattern: the evaluation(2)

Evaluation of $\mathcal{R}$ over $\mathcal{D}$

- Let $\mathcal{P}$ be the set of all mappings of $\mathcal{R}$ in $\mathcal{D}$
- The evaluation of $\mathcal{R}$ over $\mathcal{D}$ according to $\pi \in \mathcal{P}$ is defined by : $\mathcal{R}_{\pi}(\mathcal{D})$=$(\mathcal{D}(\pi(w_1)), \ldots, \mathcal{D}(\pi(w_n)))$
  where $\overrightarrow{s}$=$(w_1, ..., w_n)$,
  and $\mathcal{D}(\pi(w_k))$ sub-tree rooted at $\pi(w_k)$.

Regular tree pattern: the evaluation(2)

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  where $\overrightarrow{s}=(w_1, ..., w_n)$,
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- The evaluation of $\mathcal{R}$ over $\mathcal{D}$ is then : $\mathcal{R}(\mathcal{D})= \bigcup_{\pi \in \mathcal{P}} \mathcal{R}_\pi(\mathcal{D})$

Modelling functional dependencies by RTPs

Definition

An XML functional dependency is an expression $fd = (\mathcal{F}D, c)$ where:

- $\mathcal{F}D = (\mathcal{T}, \overrightarrow{s} = \{p_1[E_1], p_2[E_2], ..., p_n[E_n], q[E_{n+1}]\})$ is a regular tree pattern.
  $p_1, ..., p_n$ and q are associated with an equality type $E_i \in \{V, N\}$ (i=1,..., n+1)
- c (context node) is an ancestor node of $p_1, p_2, ..., p_n$ (condition nodes) and of q (target node)

V is the value equality: ($w_1 \equiv_v w_2 \Leftrightarrow \mathcal{D}(w_1)$ and $\mathcal{D}(w_2)$ have the same value.)

N is the node equality: $w_1 \equiv_N w_2$ iff $w_1 = w_2$

Satisfaction of a functional dependency

Definition

A document $\mathcal{D}$ satisfies the functional dependency $(\mathcal{F}D, c)$ iff:

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IF for two traces, $\tau_1 = \mathtt{trace}_{\pi_1}(\mathcal{F}D, \mathcal{D})$ and $\tau_2 = \mathtt{trace}_{\pi_2}(\mathcal{F}D, \mathcal{D})$, with
(a) $\pi_1(c) =_N \pi_2(c)$
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(b) $\forall i = 1, ..., n$, $\pi_1(p_i) =_{E_i} \pi_2(p_i)$,

THEN $\pi_1(q) =_{E_{n+1}} \pi_2(q)$

Modelling update classes by RTPs

We use the same model for updates.

- F. Gire and H. Idabal "Updates and Views Dependencies in Semi-structured Databases" IDEAS 2008

An update q is a composition of

$\longrightarrow$ a node selection process ($\mathcal{U}$)

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$\mathcal{U}$ selects the nodes to be modified so it defines a **class of updates**

Modelling update classes by RTPs

An update class $\mathcal{U}$:

“For each candidate still having to pass some remaining exams, update his level“

Modelling update classes by RTPs

An update class $\mathcal{U}$:

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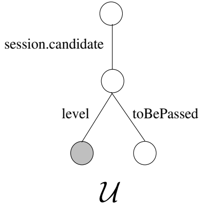

Modelling update classes by RTPs

An update class $\mathcal{U}$:

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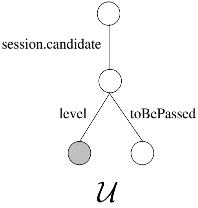

- $q_1 \in \mathcal{U}$: "For each candidate still having to pass some remaining exams, decrease his level to the level just below"
- $q_2 \in \mathcal{U}$: "For each candidate still having to pass some remaining exams, add a child node 'comment' to the 'level' node"

Independence Problem

Given

- Let *fd* be a functional dependency
- Let $\mathcal{U}$ be a class of updates
- Let $\mathcal{S}c$ be a Schema (given by an automaton $\mathcal{A}_{\mathcal{S}c}$)

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Independence problem :

fd is independent w.r to $\mathcal{U}$ in the context of $\mathcal{S}c$ iff:
$\forall\, \mathcal{D} \in \mathtt{valid}(\mathcal{S}c), \forall\, q \in \mathcal{U}$ *with* $q(\mathcal{D}) \in \mathtt{valid}(\mathcal{S}c)$,

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IF $\mathcal{D}$ satisfies fd THEN $q(\mathcal{D})$ satisfies fd as well.

Independence problem is PSPACE-hard

Proposition

Deciding whether a functional dependency *fd* is independent with respect to an update class $\mathcal{U}$ is a PSPACE-hard problem

Independence problem is PSPACE-hard

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Deciding whether a functional dependency *fd* is independent with respect to an update class $\mathcal{U}$ is a PSPACE-hard problem

Proof We reduce the well-known PSPACE-hard problem of the inclusion of two regular expressions, into the problem of independence.

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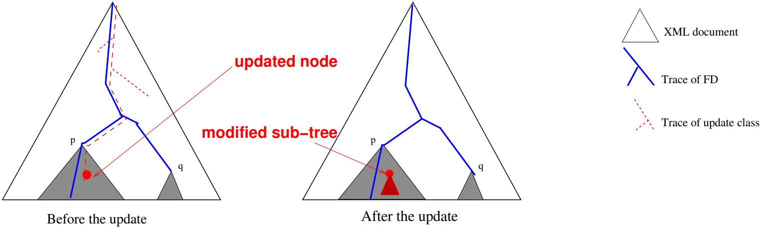
So there is a node n of $\mathcal{D}$ whose update by q generates a witness of the violation of fd in $q(\mathcal{D})$.

Independence problem: static analysis

First case

n belongs to one of the sub-trees rooted at condition or target nodes



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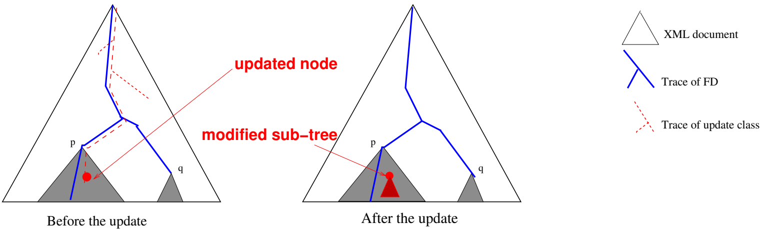
$\longrightarrow$ its update doesn't modify the trace of $\mathcal{F}D$ in $\mathcal{D}$



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n belongs to one of the sub-trees rooted at condition or target nodes

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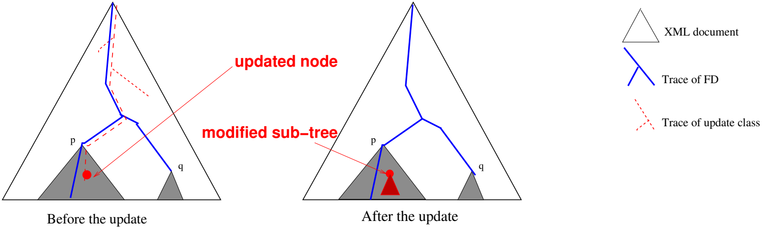
→ but the modified value of this subtree generates the violation of fd in q($\mathcal{D}$).



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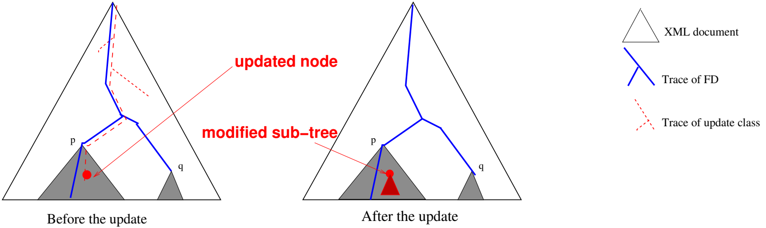

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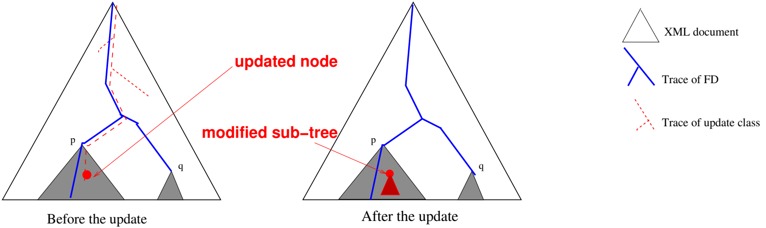

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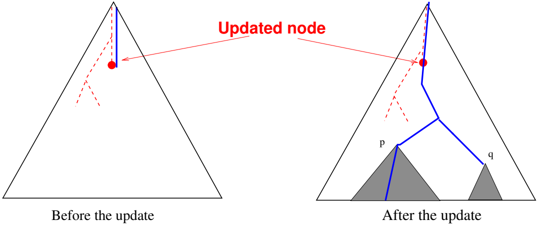
$\mathcal{N}(\pi'(\overrightarrow{s}_{\mathcal{U}})) \cap \mathcal{N}(\mathcal{F}D_{\pi}(\mathcal{D})) \neq \emptyset$

Independence problem: static analysis

Second case

the updated node n generates a new trace of $\mathcal{F}D$ in q($\mathcal{D}$) that contributes to the violation of *fd*



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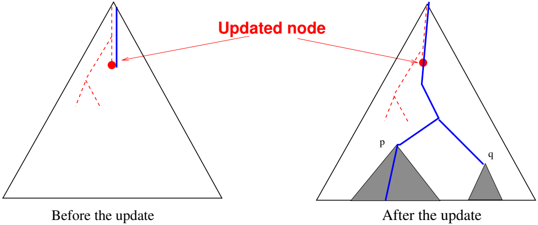

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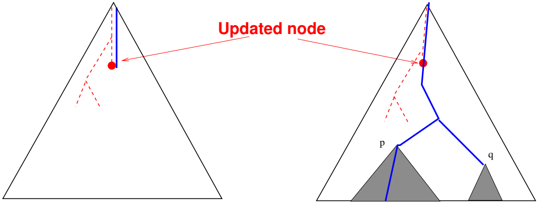

Before the update

After the update

$\exists$ a mapping π of $\mathcal{F}D$ on $q(\mathcal{D})$ and $\exists$ a mapping π' of $\mathcal{U}$ on $q(\mathcal{D})$ such that:

$\mathcal{N}(\pi'(\overrightarrow{s}_{\mathcal{U}})) \cap \mathcal{N}(trace_{\pi}(\mathcal{F}D, q(\mathcal{D}))) \neq \emptyset$

An independence criterion

Definition

Let $\mathcal{L}$ be the language of XML documents $\mathcal{D}$ satisfying:
(i) $\mathcal{D} \in \texttt{valid}(\mathcal{S}c)$
(ii) $\exists\ \tau_{\mathcal{F}D} = trace_{\pi}(\mathcal{F}D, \mathcal{D})$, w.r to a mapping π of $\mathcal{F}D$ on $\mathcal{D}$,
and $\exists\ \tau_{\mathcal{U}} = trace_{\pi'}(\mathcal{U}, \mathcal{D})$,w.r to a mapping π' of $\mathcal{U}$ on $\mathcal{D}$, such that:
$\mathcal{N}(\pi'(\overrightarrow{s}_{\mathcal{U}})) \bigcap (\mathcal{N}(trace_{\pi}(\mathcal{F}D, \mathcal{D})) \cup \mathcal{N}(\mathcal{F}D_{\pi}(\mathcal{D}))) \neq \emptyset$

An independence criterion

Definition

Let $\mathcal{L}$ be the language of XML documents $\mathcal{D}$ satisfying:
(i) $\mathcal{D} \in \texttt{valid}(\mathcal{S}c)$
(ii) $\exists\ \tau_{\mathcal{F}D} = trace_{\pi}(\mathcal{F}D, \mathcal{D})$, w.r to a mapping π of $\mathcal{F}D$ on $\mathcal{D}$,
and $\exists\ \tau_{\mathcal{U}} = trace_{\pi'}(\mathcal{U}, \mathcal{D})$,w.r to a mapping π' of $\mathcal{U}$ on $\mathcal{D}$, such that:
$\mathcal{N}(\pi'(\overrightarrow{s}_{\mathcal{U}})) \bigcap (\mathcal{N}(trace_{\pi}(\mathcal{F}D, \mathcal{D})) \cup \mathcal{N}(\mathcal{F}D_{\pi}(\mathcal{D}))) \neq \emptyset$

Proposition[Independence criterion *IC*]

If $\mathcal{L}$ is empty then *fd* is independent w.r to $\mathcal{U}$ in the context of $\mathcal{S}c$.

Checking criterion *IC* & Complexity

- A regular Bottom-Up automaton $\mathcal{A}$ recognizing $\mathcal{L}$ can be built from the automaton $\mathcal{A}_{\mathcal{S}c}$ and the regular tree patterns $\mathcal{F}D$ and $\mathcal{U}$

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- The size $|\mathcal{A}|$ of the automaton $\mathcal{A}$ is in $O(a_{\mathcal{U}} a_{\mathcal{F}D} \times |\Sigma|^2 \times |\mathcal{A}_{\mathcal{S}c}| \times |\mathcal{U}| \times |\mathcal{F}D|)$, where $a_{\mathcal{U}}$ and $a_{\mathcal{F}D}$ are the maximal arities of $\mathcal{U}$ and $\mathcal{F}D$ respectively

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- The independence criterion *IC* is polynomial: the emptiness of the language $\mathcal{L}$ is testable in $O(a_{\mathcal{U}}^2\ a_{\mathcal{F}D}^2 \times |\Sigma|^4 \times |\mathcal{A}_{\mathcal{S}c}|^2 \times |\mathcal{U}|^2 \times |\mathcal{F}D|^2)$ time.

Conclusion

Main results :

- An uniform formalism based on RTPs
- The independence Problem is PSPACE-hard
- A sufficient criterion for checking the independence testable in polynomial time

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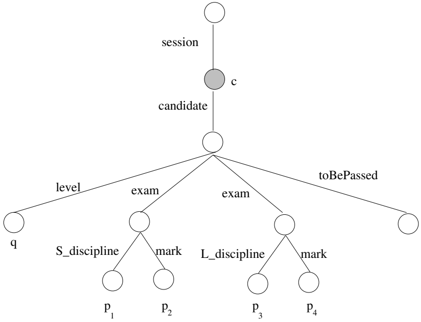
To do :

- Axiomatisation and verification problems
- Necessary and sufficient condition in the case of special fds
- Implementation

THANKS

Advantages of our model

"Two candidates with the same mark in at least two disciplines and also having some remaining exams to pass, receive the same level".



$\mathcal{S}c$:

- exam : ((S_discipline|L_discipline), mark).

- L_disciplines appear after S_disciplines.

- Labels of two edges outgoing from a same node can share a common prefix.
- Leaves of $\mathcal{F}D$ are not only condition or target nodes.
- The order is relevant.