



# XPath query containment and rewriting using views

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# View-based rewriting of XML queries

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# Part I

## **Introduction**

## XML and XPath

### XML

- XML trees: rooted, ordered, unranked node-labeled trees
- Node labels come from an (in)finite alphabet  $S$ .
- We denote with  $T_S$  all XML trees over alphabet  $S$ .

### XPath syntax

- **XPath**: A language for navigating and selecting nodes from XML documents.
- XPath expressions are a sequence of XPath steps:  
*axis :: nodetest[*predicate*]*.
- **axis**: is a forward or backward axis (navigation).
- **nodetest**: is a label or a wildcard.
- **predicate**: is another step relative to the context where defined.

## Tree pattern queries (twigs)

- We focus on XPath expressions with only the child and descendant axis.
- We model them as **pattern trees or twigs**.

### Pattern tree (twig)

- Each XPath step is a **node** of the tree pattern.
- Steps along child axis are indicated with single lines edges (**child edges**).
- Steps along descendant axis are indicated with double lines edges (**descendant edges**).
- Predicates are denoted as subtrees of the corresponding step.
- The last step of the expression is called **selection node** and is denoted by underlining the nodetest.

## Embedding & evaluation of XPath

### Embedding

- An **embedding** from an XPath query  $p$  to an XML tree  $t$ , is a function  $e : V_p \rightarrow V_t$ , with the following properties:
  - **root preserving**:  $e(r_p) = r_t$ ,
  - **label preserving**:  $\forall n \in V_p$ , if  $n.label \neq *$ , then  $n.label = e(n).label$ ,
  - **structure preserving**:  $\forall e' = (n_1, n_2) \in E_p$ , if  $e'$  is a **child** edge then  $e(n_2)$  is a child of  $e(n_1)$  in  $t$ ; otherwise  $e(n_2)$  is a descendant of  $e(n_1)$  in  $t$ .

### XPath query evaluation

Given an XPath query  $p$  and an XML tree  $t$ ,  $p(t) = \cup_{e \in EB} \{(t)_{sub}^{e(o_p)}\}$ , where  $EB$  is the set of all embeddings from  $p$  to  $t$ .

## Part II

# XPath query containment

## Introduction

### Definition

XPath query  $p$  is contained in  $q$ , denoted as  $p \subseteq q$ , if and only if  $p(t) \subseteq q(t)$ , for every XML tree  $t$ . (The definition can be easily extended for the case of a DTD existence).

### Theorem

*For XPath queries  $p, q$  there is a translation to boolean XPath queries  $p_0, q_0$ , such that  $p \subseteq q$  if and only if  $p_0 \subseteq q_0$  [17]*

### Techniques for checking containment

- Canonical models
- Homomorphism technique
- Automata technique
- Chase technique



## Canonical model technique

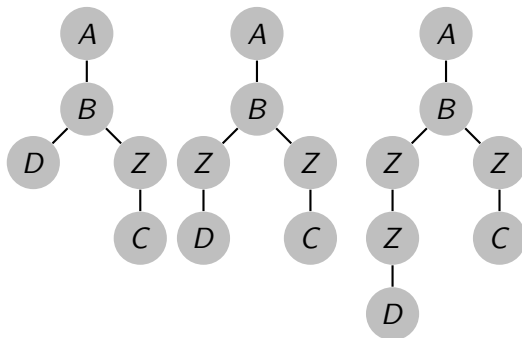
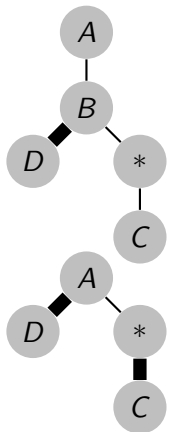
- We consider boolean tree pattern queries  $p, q$ .
- Intuition:  $p \not\subseteq q$  if and only if there is a counter example XML tree  $t$ , such that  $p(t) \not\subseteq q(t)$ .
- If there is such a counter example it will be in the set of canonical models for  $p$ .

### Canonical models for XPath query $p$

- Each canonical model is an XML tree  $t$  obtained from  $p$ .
- **Wildcards:** replace wildcard nodes in  $p$  with a new symbol say  $z$  not in  $p$  or  $q$ .
- **Descendant Edges:** replace a descendant with a chain of at most  $m(q) + 1$   $z$ -labeled nodes, where  $m(q)$  is the longest chain of child edges with wildcard-labeled nodes in  $q$ .

## Example

XPath queries  $P$ ,  $Q$  Canonical models for  $P$ ,  $M(Q) = 1$



All of

them match  $Q$ , therefore  $P \subseteq Q$ .

## Homomorphism technique

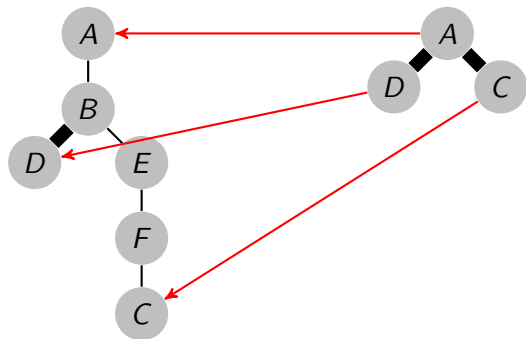
- Given two tree pattern queries  $p$ ,  $q$  then:  $p \subseteq q$  if and only if there is a homomorphism from  $q$  to  $p$ .
- This is not the case for XPath queries in  $XP(/, //, [], *)$  where homomorphism is not necessary for containment.

### Homomorphism from $q$ to $p$

- An **homomorphism** from an XPath query  $q$  to an XPath query  $p$ , is a function  $h : V_q \rightarrow V_p$ , with the following properties:
  - root preserving:**  $h(r_q) = r_p$ ,
  - label preserving:**  $\forall n \in V_q$ , if  $n.label \neq *$ , then  $n.label = h(n).label$ ,
  - structure preserving:**  $\forall e' = (n_1, n_2) \in E_q$ , if  $e'$  is a **child** edge then  $h(n_2)$  is a child of  $h(n_1)$  in  $p$ ; otherwise  $h(n_2)$  is a descendant of  $h(n_1)$  in  $p$ .

## Example

### Homomorphism from Q to P



There is a Homomorphism from Q to P, therefore  $P \subseteq Q$ .

## Automata technique (1/2)

- Intuition 1: Reduce the containment problem between XPath queries to the containment problem between tree automata or the languages that are accepted by these automata.
- Intuition 2: Compactly represent all counter examples that will imply no containment between two XPath queries and check if it is empty.

### Theorem

*Containment for XPath expression in  $XP(/, //)$  in the presence of a DTD is in PTIME [25, 28]*

### Proof.

- Construct tree automaton  $P$  that accepts trees matching  $p$ .
- Construct tree automaton  $NQ$  that accepts trees not matching  $q$ .



## Automata technique (2/2)

### Proof.

- Construct tree automaton  $D$  that accepts trees conforming to DTD.
- Construct tree automaton  $C = P \times NQ \times D$ , i.e. the cartesian product of  $P$ ,  $NQ$ ,  $D$ .
- $C$  accepts all XML trees that conform to DTD and are matched by  $p$  but not  $q$ .
- Therefore, if  $C$  is empty then  $p \subseteq q$ .
- Every tree automaton construction and checking emptiness of  $C$  is in PTIME.



## Chase technique (1/2)

- Has been applied on tree pattern queries to obtain PTIME algorithms for containment in the presence of DTDs.
- Considered DTDs **duplicate-free**, **choice-free**.
- Intuition: To decide  $p \subseteq q$  extract a set of constraints from DTD, chase query  $p$  with the constraints and try to establish a homomorphism from  $q$  to  $p$ .

### Constraints Extracted from a DTD

- **Functional (FC)**:  $a \downarrow b$ , node  $a$  has only one child with label  $b$ .
- **Parent-Child (PC)**:  $a \rightarrow b$ ,  $b$  when is desc. of  $a$  is always child.
- **Sibling (SC)**:  $a : B \downarrow c$ , node  $a$  with children in  $B$  has a  $c$  child.
- **Cousin (CC)**:  $a : b \downarrow_c c$ , node  $a$  with desc.  $b$  has also desc.  $c$ .
- **Intermediate (IC)**:  $a \rightarrow_c b$ ,  $c$  node is always in any path between  $a$ ,  $b$ .

## Chase technique (2/2)

### Theorem

Let  $D$  be a *duplicate-free* DTD and  $C$  be the set of SC and FC constraints extracted from  $D$ . Let  $p, q$  be XPath queries in  $XP(/, [])$  then the  $D$ -containment  $p \subseteq_D q$  can be computed in PTIME using the equivalence:  $p \subseteq_D q$  iff  $\text{chase}(p) \subseteq q$  [35]

### Theorem

Let  $D$  be a *acyclic* and *choice-free* DTD and  $C$  be the set of SC, PC, IC, CC, FC constraints extracted from  $D$ . Let  $p, q$  be XPath queries in  $XP(/, //, [])$  then the  $D$ -containment  $p \subseteq_D q$  can be computed in PTIME using the equivalence:  $p \subseteq_D q$  iff  $\text{chase}(p) \subseteq q$  [19]



## Example: chasing an XPath query

- Let  $q \equiv /a[b//i][b/d]/j$  be an XPath query in  $XP(/, //, [])$ .
- Consider the following (duplicate-free, acyclic and choice-free) DTD:

$$a \rightarrow b, f^*, g^+, h$$

$$b \rightarrow (c|d), l$$

$$c \rightarrow i; d \rightarrow i; l \rightarrow j$$

- Apply SC  $a: b \Downarrow h$  resulting in  $q \equiv /a[b//i][b/d][h]/j$
- Apply FC  $a \Downarrow b$  resulting in  $q \equiv /a[b//i][d][h]/j$
- Apply IC  $a \rightarrow_l j$  resulting in  $q \equiv /a[b//i][d][h]//l//j$
- Apply PC  $l \rightarrow j$  resulting in  $q \equiv /a[b//i][d][h]//l/j$

## Part III

# XPath query rewriting

## XPath query rewriting

- XPath query **rewriting existence** problem: Given an XPath query  $q$  and a materialized  $v$ , is there any rewriting  $e$  of  $q$  using  $v$  such that for every XML tree  $t$ :  $e(v(t)) = q(t)$ ?
- **Finding (minimal) rewriting**: if there is a positive answer to the rewriting existence problem, we seek to find the (minimal) rewriting query  $e$ .

### Problem Statement

- **Equivalent rewriting**: as defined above.
- **Maximally contained rewriting**: a rewriting  $e$  such that for every XML tree  $t$ :  $e(v(t)) \subseteq q(t)$  and  $e(v(t))$  is maximal.

## Rewriting existence: compensation pattern (1/2)

### Concatenation Operator

- **Concatenation Operator:**  $p \oplus q$ : an XPath pattern constructed by merging the root of  $p$  and the selection node of  $q$  into one node.
- Rewriting existence problem: Decide whether an XPath **compensation pattern**  $q'$  exists, such that  $q' \oplus v \equiv q$ .

### Theorem

*Let  $q, v$  be two tree pattern queries with selection nodes as roots, then  $q \subseteq v$  iff there exists a rewriting of  $q$  using  $v$  [37]*

### Theorem

*The rewriting existence problem is CoNP-Hard for  $XP(/, //, [], *)$  [37]*

## Rewriting existence: compensation pattern (2/2)

### Theorem

*For the subclasses of  $XP(/, //, [], *)$  the rewriting existence problem is in PTIME. [37]*

### Lemma

*Let  $v, q$  be in the subclasses of  $XP(/, //, [], *)$ , and let  $n_q$  be the node in the selection path of  $q$  with the same position as the selection node of  $v$  at  $v$ 's selection path. If a compensation pattern  $q'$  of  $q$  using  $v$  exist, the subpattern of  $q$  rooted at  $n_q$  (i.e.  $(q)_{sub}^{n_q}$ ) is a compensation pattern of  $q$  using  $v$  [37]*

## Rewriting existence: natural rewriting candidates (1/3)

### Natural rewriting candidate

- Let  $q$  be a tree pattern query, with  $q_{r//}$  we denote the tree pattern obtained from  $q$  by turning all edges that emanate from root to be descendant edges.
  - Given a query  $q$  and a view  $v$  then  $q'$  is a **natural rewriting candidate** if is either  $(q)_{sub}^{n_q}$  or  $((q)_{sub}^{n_q})_{r//}$ , where  $n_q$  is the node in the selection path of  $q$  with the same position as the selection node of  $v$  at  $v$ 's selection path [2]
- 
- What if none natural rewriting candidate is a rewriting of  $q$  using  $v$ ?
  - Under certain condition a natural rewriting candidate is a **potential rewriting**, that is if a rewriting of  $q$  using  $v$  exists then one such rewriting is among the two natural rewriting candidates.

## Rewriting existence: natural rewriting candidates (2/3)

### Conditions for completeness of natural rewriting candidates

- query  $q$ :
- if the selection path of  $q$  by node  $n_q$  has only child edges, then  $(q)_{sub}^{n_q}$  is a potential rewriting.
- if  $(q)_{sub}^{n_q}$  is **stable** (i.e. the label of root is not wildcard or if the length of the selection path of  $q$  is at least 1 and a node emanating from root has unique label in the subtree of  $q$  starting under the root node), then it is a potential rewriting.
- **View  $v$ :**
- if a descendant edge enters the selection node of  $v$ , then  $(q)_{sub}^{n_q}$  is a potential rewriting.
- if the selection path of  $v$  has only child edges, a potential rewriting exists among the two natural rewriting candidates.

## Rewriting existence: natural rewriting candidates (3/3)

### Conditions for completeness of natural rewriting candidates

- query  $q$  and View  $v$ :
- Let  $q$  be a tree pattern query and  $v$  be a view, such that the last descendant edge on the selection path of  $q$  is the  $k_{th}$  edge and the  $k_{th}$  edge at  $v$  selection path is a descendant edge, then  $(q)_{sub}^{n_q}$  is a potential rewriting.

### Theorem

*The rewriting existence problem for  $XP(/, //, [], *)$  under the before mentioned conditions is CoNP-Complete [2]*



## Finding minimal rewritings: compensation pattern (1/2)

### Theorem

For the subclasses of  $XP(/, //, [], *)$  the problem of finding minimal rewriting is in PTIME [37]

### Proof.

- finding the minimal rewriting of  $q$  using  $v$  is equivalent of finding the minimal rewriting of the subpattern of  $q$  at node  $n_q$  (i.e.  $(q)_{sub}^{n_q}$ ) using the subpattern of  $v$  at its selection node, say  $sn_v$  (i.e.  $(v)_{sub}^{sn_v}$ ).
- Given a query  $q$  and a node  $n$ , we denote with  $q - n$  the subpattern obtained by  $q$  by pruning the subpattern of  $q$  at node  $n$  (i.e.  $(q)_{sub}^n$ ).
- the minimal compensation pattern of  $q$  using  $v$  is the  $(q)_{sub}^{n_q} - R_{(v)_{sub}^{sn_v}}^{(q)_{sub}^{n_q}}$ .



## Finding minimal rewritings: compensation pattern (2/2)

### rewriting Redundant node set $R_v^q$

- Let  $q, v$  be tree pattern queries, such that  $v$ 's selection node is its root.
- let  $n$  be a node in  $q$  then  $(q)^n$  is a subpattern of  $q$  constructed by adding to the  $(q)_n^{sub}$  the root of  $q$  and the path, as in  $q$ , connecting that root to the root of  $(q)_n^{sub}$ .
- $C_q, C_v$  are sets including all children nodes of  $q, v$  roots respectively.
- $n_q \in C_q$  is **redundant** if there exists  $n_v \in C_v$  s.t.  
 $(q \oplus v)^{n_q} \equiv (q \oplus v)^{n_v}$ .
- $R_v^q$ : set of all redundant nodes.

### Proof.

- Computing  $R_v^q$  and checking pattern equivalence is in PTIME.



## Finding natural rewriting candidates: using stability

### Generalized Normal Form (GNF)

Given a tree pattern query  $q$  with  $d$  nodes on its selection path. Then  $q$  is in  $GNF_{/*}$  if for all  $1 \leq i \leq d$  one of the following holds:

- A child edge enters the  $i$  node of  $q$ .
- The subpattern of  $q$  at the  $i_{th}$  node is stable.
- The subpattern of  $q$  at the  $i_{th}$  node forms a path (not a tree).

### Theorem

*if  $q$  is in  $GNF_{/*}$ , then at least one of the natural rewriting candidate is a potential rewriting [2]*

## Finding natural rewriting candidates: looking only for the last descendant

### Theorem

*if the deepest descendant on the selection path of view  $v$  is at least as deep as the deepest descendant on the selection path of the query  $q$ , then  $(q)_{sub}^{n_q}$  is a potential rewriting, where  $n_q$  is the node in the selection path of  $q$  with the same position as the selection node of  $v$  at  $v$ 's selection path [2]*

### Pattern extension

Let  $q$  be a tree pattern query and  $l$  be a label, then the  **$l$ -extension** of  $q$  denoted with  $q^{+l}$  is obtained:

- Add a wildcard labeled child to every leaf of query  $q$ , but the selection node (in case it is leaf).
- Add a  $l$  labeled child to the selection node of  $q$ .

## Finding natural rewriting candidates: pattern extension & output lifting

### Output Lifting

Let  $q$  be a tree pattern query with  $d$  nodes on its selection path. Let  $1 \leq j \leq d$ , then the **output lifting** of  $q$  denoted with  $q^{j \rightarrow}$  is obtained: from  $q$  by considering as selection node the  $j$  node on the selection path of  $q$ .

### Theorem

Let  $q, v$  be tree pattern queries and for some  $k \leq j \leq d$ , where  $k$  is the number of nodes in  $v$  selection path and  $d$  the corresponding for  $q$ , the  $j$  node of  $q$  selection path is not wildcard labeled, then:

- there is a rewriting of  $q$  using  $v$  iff there is a rewriting of  $(q^{+m})^{j \rightarrow}$  using  $v^{+*}$ .
- $(q^{+m})^{j \rightarrow}$  using  $v^{+*}$  has a rewriting among natural candidates iff so do for  $q, v$  [2]

## Form of the rewriting

- Given a query  $q$  and a view  $v$  with one selection node we saw that the rewriting of  $q$  using  $v$  is **one** pattern that is formulated by combining a rewriting pattern with  $v$ .
- The question is whether the rewriting can be expressed as the **union** of tree pattern queries.
- The answer is **no!**

### Theorem

*Let  $q, v$  be tree pattern queries, then any equivalent rewriting of  $q$  using  $v$  will contain only one tree pattern query [33]*

## A general framework for XPath/query rewriting (1/2)

- Let  $q$  and  $v$  be a tree pattern query and a view respectively with **more than one** node as selection node.
- A rewriting of  $q$  using  $v$  is a mapping from the selection nodes of  $q$  to the selection nodes of  $v$ , called **selection node mapping (SNM)**.
- A rewriting is **correct** iff we can use it to establish an embedding from  $q$  to any XML tree  $t$ , utilizing also the embedding from  $v$  to  $t$ .
- Let  $L$  be the number of nodes in the longest star-path of  $q$  and  $m$  be the number of descendant edges in  $q$ .

## A General Framework for XPath query rewriting (2/2)

### $\vec{u}$ Extension of $Q$

Let  $\vec{u} = \langle u_1, \dots, u_m \rangle$ , where for all  $1 \leq i \leq m$ ,  $u_i \geq 0$  and  $z$  be a label not in  $q$ . Then the  $\vec{u}$  extension of  $q$  is an XML tree obtained from  $q$  as:

- replace all wildcard labeled nodes with the  $z$  label.
- replace the  $i_{th}$  descendant edge with a path containing  $u_i$   $z$  labeled nodes.

### Theorem

*A rewriting of  $q$  using  $v$  is correct iff it is correct on the  $\vec{u}$  extension of  $q$  for all  $\vec{u} = \langle u_1, \dots, u_m \rangle$ , where for all  $1 \leq i \leq m$ ,  $u_i \leq L + 1$  [29]*



## Maximally contained rewriting: MCR existence

### Useful Embedding

An embedding  $e$  from  $q$  to  $v$  is **useful** provided:

- $e$  is empty and the root of  $q$  is qualified with the descendant axis.
- **OR** (a) Each node in the selection path of  $q$  (if mapped) is mapped to a node in the selection path of  $v$
- **and** (b) For each path  $p$  in  $q$  **either**  $p$  is fully mapped by  $e$  **or** if  $x$  is the last node in  $p$ , where  $e$  is defined, and  $y$  is its successor node, then  $x$  is mapped to the selection node of  $v$  or to a descendant of that node or the edge between  $x, y$  is descendant.

### Theorem

*Let  $q, v$  be two tree pattern queries, then a MCR of  $q$  using  $v$  exists iff there is a useful embedding from  $q$  to  $v$  [19]*

## Maximally contained rewriting: MCR generation (1/2)

### Clip-away tree (CAT)

Given a useful embedding  $e$  from  $q$  to  $v$ , the CAT is obtained as follows:

- Find the **terminal nodes** in  $q$ , i.e. nodes  $x$  s.t.  $e(x)$  is defined and  $x$  has at least one child  $y$ , where  $e(y)$  is not defined.
- For each child  $y$  of every terminal node  $x$  in  $q$  **create a tree pattern** connecting a dummy root to the subtree of  $q$  rooted at node  $y$  (i.e.  $(q)_{sub}^y$ ) with an edge of the same type (child or desc.) as the edge between  $x$  and  $y$  in  $q$ .
- **Merge** the dummy roots of all the above tree patterns and **label** that root with the label of the selection node of  $v$ .

## Maximally contained rewriting: MCR generation (2/2)

### Algorithm

- 1 Compute all useful embeddings from  $q$  to  $v$ .
  - 2 Prune the set of useful embeddings with embeddings that will lead to redundant rewritings [19]
  - 3 Produce the set of CATs that correspond to each of useful embedding.
  - 4 The MCR is the union of the tree patterns (contained rewriting, CR) that are in the set of CATs.
- 
- The algorithm is **exponential**.
  - Note that the MCR is expressed as the **union of CRs** that are tree pattern queries.

## Part IV

# XPath query rewriting under integrity constraints

## Motivation

- Let  $q \equiv /a//c$  be an XPath query and  $v \equiv /a//b$  be a view in  $XP(/, //)$ .
- Consider the following (duplicate-free, acyclic and choice-free) DTD:

$$a \rightarrow d, e, f$$

$$d \rightarrow b; b \rightarrow c$$

$$c \rightarrow i; e \rightarrow i; f \rightarrow i$$

- The compensation pattern  $e \equiv /b//c$  can be used to rewrite  $q$  using  $v$ .
- To compute  $e$  we need to **chase** query  $q$  with the IC  $a \rightarrow_c b$ .
- Therefore,  $q \equiv /a//c \equiv /a//b//c$ .
- Note that  $e \equiv (q)_{sub}^b$ .

## Motivation

- Constraints **enable rewritings** in cases for which there would be no rewriting without the constraints.
- In what follows there is a **direct reduction** of the rewriting techniques of the schemaless case under the DTD existence.
- Some DTDs allow PTIME extraction of constraints and PTIME chase:

### PTIME cases For DTDs

- **Duplicate-free (DF) DTD**: At each right-hand side of any DTD rule each element name  $n$  appears at most once.
- **Acyclic & choice-free (ACF) DTD**: At each right-hand side of any DTD rule there is no alternation. Also, there is no recursion in the DTD.

## Equivalent rewriting for $XP(/, [], *)$ under DF DTDs

- Given a query  $q$  and a view  $v$  in  $XP(/, [], *)$  under a DF DTD.
- Applying the **compensation pattern** technique we can answer the rewriting existence problem and find a (minimal) rewriting.
- Though, this technique requires to be able to decide **containment** between tree patterns in this setting.

### Theorem

*Containment of queries in  $XP(/, [], *)$  in the presence of a duplicate-free DTD is CoNP-hard [24]*

- Two approaches:  
**incomplete but efficient**  
**complete but exponential**

## Equivalent rewriting for $XP(/, [], *)$ under DF DTDs

### PTIME containment

- Extract SC and FC constraints from DTD.
- Extend them to the wildcard case, resulting in **WSC** and **WFC** constraints.
- Define the **SIC** (single child constraints) and the **WSIC** as a stronger version of the FC, that capture some cases not captured by FCs.
- Decide containment using the **chase** technique based on the following theorem:

### Theorem

Let  $D$  be a duplicate-free DTD and  $C$  be the set of (W)FCs, (W)SCs, (W)SICs implied by  $D$ , then  $q \subseteq_{SAT(D)} p$  iff  $chase_C(q) \subseteq p$ , if  $chase_C(q)$  is 1-1 homomorphic to a subtree in  $SAT(D)$  (i.e. all trees conforming to  $D$ ) [4]



## Equivalent rewriting for $XP(/, [], *)$ under DF DTDs

- Chasing with (W)SC, (W)FC and (W)SIC constraints a tree pattern in  $XP(/, [], *)$  will not always yield a tree pattern 1-1 homomorphic to a subtree in  $SAT(D)$ .
- There is no set of constraints that can guarantee that [4].

### Complete containment

- Intuition: reduce query  $q$  into  $XP(/, [])$  utilizing the DTD  $D$ , so that  $chase_C(q)$  is always 1-1 homomorphic to a subtree in  $SAT(D)$  [35].
- Therefore, we can decide the containment  $q \subseteq_{SAT(D)} p$ .
- However, reduction of  $q$  from  $XP(/, [], *)$  to  $XP(/, [])$  by eliminating wildcard is **exponential** [4]

## Maximally contained rewriting for $XP(/, //, [])$ ACF DTD: MCR existence

- A **direct application** of the useful embedding as in the schemaless case will not work.
- The reason is that the CAT induced by the embedding composed with the view might result to an **unsatisfiable** rewriting w.r.t. the ACF DTD.

### Useful embedding DTD case

An embedding  $e$  from  $q$  to  $chase_C(v)$ , where  $C$  is the set of PC, SC, FC, CC, IC constraints implied from a ACF DTD  $D$ , is **useful** provided:

- is a useful embedding as in the schemaless case.
- **AND** For each node  $x$  in  $q$  that is not mapped by  $e$ , then there is a way in  $D$  starting from a rule that carries the label of the selection node of  $v$  to produce a node labeled as  $x$ .

## Maximally contained rewriting for $XP(/, //, [])$ ACF DTD: MCR existence

### Theorem

Let  $q, v$  be two tree pattern queries and  $D$  be an ACF DTD, then a MCR of  $q$  using  $v$  exists iff:

- ① there is a *useful embedding* from  $q$  to  $\text{chase}_C(v)$ , where  $C$  is the set of constraints implied from  $D$
- ② the rewriting composed by the CAT induced by this embedding and the view  $v$  is *satisfiable* under  $D$  [19]

## Maximally contained rewriting for $XP(/, //, [])$ ACF DTD: MCR generation

### Algorithm

- 1 Extract constraints  $C$  implied by ACF DTD  $D$ .
  - 2 Chase  $v$  with only the appropriate constraints from  $C$  as to establish a useful embedding from from  $q$  to  $chase_C(v)$ .
  - 3 Compute **useful embeddings** and prune this set to avoid redundant rewritings.
  - 4 Produce **the set** of CATs for each of useful embedding.
  - 5 The MCR **is the union** of the tree patterns (contained rewriting: CR) that are in the set of CATs [19]
- The algorithm will yield at most one useful embedding and therefore the MCR consists of only **one** tree pattern.
  - Note that there is no need to chase  $v$  will every constraint in  $C$  (for details see [19]).

## Extensions to equivalent rewriting

### Immediate Consequences of the previous techniques

- Equivalent query rewriting and containment for queries and views in  $XP(/, [], *)$  are in PTIME under ACF DTD.
- Equivalent query rewriting for queries and views in  $XP(/, //, [])$  is in PTIME under ACF DTD.

## Part V

# XPath/XQuery rewriting using multiple views

## Introduction

- Hidden hypothesis in the *single-view* rewriting context: the query cache (view) stores only copies of XML elements.
- Using **multiple** views in query rewriting allows exploiting node identifiers from the original XML tree to combine views.
- Given a query  $q$  and a set of views  $V$ , we seek to find a rewriting  $r$  obtained by **intersecting** materialized views in  $V$ .
- There is no interest in examining the **union** of these views due to the following theorem:

### Theorem

*If a tree pattern is equivalent to a union of tree patterns, then it is equivalent to a member of the union [12]*

## DAG pattern rewriting for $XP(/, //, [])$

Tree patterns extend to DAG patterns, representing the intersection of a set of views.

### DAG pattern

- For each view  $v$  the  $dag(v)$  is the tree pattern corresponding to  $v$ .
- $dag(v_1 \cap v_2)$  is obtained by coalescing the roots and selection nodes of  $dag(v_1)$  and  $dag(v_2)$ , provided there is no label conflict.

### Theorem

Any DAG pattern is equivalent to the union of its *interleavings* [12]



## DAG pattern rewriting for $XP(/, //, [])$

### Definition



**Interleaving** of a DAG pattern  $d$  is a tree pattern  $p_i$  whose selection path corresponds to a path in  $d$  from its root to its selection node (MB path) **and** if a predicate  $s$  appears below node  $n$  in MB path, then it also appears below the corresponding node  $n'$  in  $p_i$ 's selection path.

### Algorithm for finding a rewriting

- 1 Test equivalence from dag pattern  $d$  to query  $q$  (the opposite is trivial).
- 2 Compute interleavings  $p_i$  from  $d$  ( $d$  is equivalent to their union).
- 3 Test union-freeness, i.e. only one interleaving  $p$  such that  $p \equiv q$ . (rule based procedure that transforms  $d$ )
- 4 The rewriting is  $(q)_{sub}^n$ , where  $n$  is the selection node of  $p$  [12]

## Structural join rewriting for $XP(/, //, [], *)$

- A different approach based on **view selection** for rewriting a query using multiple views.
- How do we produce the set of views  $V$  to rewrite  $q$ ? **Use automata on tree patterns.**
- Then we can find compensation patterns for each view separately and then **join** the results from applying these patterns to the materialized XML fragment of the corresponding views.
- **Limitations:** We need algorithms to perform these joins **and** most of these algorithms impose certain encodings in the XML trees.

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