THE INDEX UPDATE PROBLEM FOR XML DATA IN XDBMS

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Abstract: Database Management Systems are a major component of almost every information system. In relational Database Management Systems (RDBMS) indexes are well known and essential for the performant execution of frequent queries. For XML Database Management Systems (XDBMS) no index standards are established yet; although they are required not less. An inevitable side effect of any index is that modifications of the indexed data have to be reflected by the index structure itself. This leads to two problems: first it has to be determined whether a modifying operation affects an index or not. Second, if an index is affected, the index has to be updated efficiently - best without rebuilding the whole index.
In recent years a lot of approaches were introduced for indexing XML data in an XDBMS. All approaches lack more or less in the field of updates. In this paper we give an algorithm that is based on finite automaton theory and determines whether an XPath based database operation affects an index that is defined universally upon *keys*, *qualifiers* and *a return value* of an XPath expression. In addition, we give algorithms how we update our KeyX indexes efficiently if they are affected by a modification. The *Index Update Problem* is relevant for all applications that use a secondary XML data representation (e.g. indexes, caches, XML replication/synchronization services) where updates must be identified and realized.

1 INTRODUCTION

The Extensible Markup Language (XML) has become the standard data format for exchanging information in information systems. XML is an easy and flexible way to express *semistructured data* - independent from platforms, programming languages and operating systems. The increasing usage of XML data demands the connection between XML technology and database management systems, because the latter provide a fast, robust, and application independent way of storing and accessing data. In recent years a multitude of *native* XML Database Management Systems (XDBMS) were introduced by commercial vendors (e.g. Tamino (Schöning, 2001), Xindice (Apache,)) and research projects (e.g. Natix (Fiebig et al., 2002), InfonyteDB (Infonyte GmbH, 2003), Timber (Jagadish et al., 2002)). Like in relational DBMS indexes are adopted to decrease the execution time of frequent queries and may increase the performance of an XDBMS up to factor 100,000 for realistic scenarios compared to a query execution without any index. In contrast to relational DBMS, where indexes and index structures are well known since decades, indexes in XDBMS are still an active field of research with no standards established yet. In RDBMS only atomic values of specified columns are reflected in an index; XML indexes have to cover both the structure of the data and the values of elements. A lot of approaches have been introduced in recent years dealing with indexes for querying XML data. The problem of updating an index is a minor focus of most publications. If at all, the authors describe how their data structure can be updated from a technical point of view. To the best of our knowledge, the problem whether an XML index i is affected by a modifying operation o is never faced before. We call this problem the *XML Index Update Problem (XIUP)*.

For expressing updates we have to select which nodes (elements, attributes, or content) in the given XML data have to be modified. *XPath* (World Wide Web Consortium (W3C),) is a selection language for such a purpose. Due to space restriction we cannot give an introduction to XPath. All examples in this paper are given in the abbreviated syntax of XPath. XPath itself cannot be used to modify the XML data.

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Therefore a language like *XUpdate* (e.g. (XML:DB XUpdate Working Group ,)) is needed to express update operations. XUpdate statements contain XPath expressions to identify the nodes to be modified.

In this paper we assume that an index is *selective*; i.e. it is defined to accelerate a specific query and not all queries in general. Index approaches that are not selective (e.g. Strong DataGuides (Goldman and Widom, 1997)) reflect the whole XML data and may lead to exhaustive space consumption. Additionally, every modifying database operation affects the non-selective index leading to an update. Therefore, the Index Update Problem for non-selective indexes is trivial. More about the characteristics of selective and non-selective index approaches can be found in previous works (B.C.Hammerschmidt et al., 2004a; B.C.Hammerschmidt et al., 2004b). We motivate the XIUP by two examples that operate on data from the *DBLP* computer science bibliography project (Ley, 2001). The full DBLP data consists of approximately 500,000 publications, mainly articles, inproceedings and books. The root node is called `dblp` and is the parent node of the different publications.

Example: The index i_1 is defined to accelerate XPath expressions of the shape of query q_1:

```
q1 = /dblp/book[author='x']
```

Index i_1 indexes all `book` elements by the value of their `author` child which is interpreted as a *key* for this query. In our index approach *KeyX* all keys are stored in a search tree offering logarithmic retrieval time. Thus, if an authors name is given, we find the corresponding books efficiently.

The XUpdate operation o_1 deletes all books that are written by the author Kempa.

```
o1 = <xupdate:remove
  select=/dblp/book[author='Kempa'] >
     </xupdate:remove>
```

Obviously one can see that the index i_1 is affected by o_1 because after executing o_1 there is no book author 'Kempa' anymore in the data. The key 'Kempa' has to be removed from the index to keep it consistent.

At first glance, it seems easy to determine the affection by comparing the contained XPath expressions which are equal in this example. But because XPath expressions may contain more complex navigational steps the decision can become more difficult; this is shown in the following example.

Example: Index i_2 indexes all child elements of the `dblp` element which have a `title` child that is used as key.

```
q2 = /dblp/*[title='x']
```

The modifying operation o_2 deletes all children of all `article` elements.

```
o2 = <xupdate:remove
        select=/dblp/article/*/>
     </xupdate:remove>
```

First, one can remark that the contained XPath expressions are not equal. Second, without any schema information like a DTD or XMLSchema we do not know if the `dblp` element is allowed to have an `article` element and that the `article` element may have a child named `title`. Due to the wildcard operator (*) it is not sufficient to perform a string comparison of both XPath fragments. With one or more descendant axis (//) this problem becomes even more complex.

In this work we define the *XML Index Update Problem (XIUP)* formally and introduce an efficient algorithm solving the XIUP for a fragment of XPath containing *node tests*, the *child* axis (/), the *descendant* axis (//), wildcards(*) and *qualifiers* ([]) without the `NOT` operator. This class is called $XP^{\{[],*,//\}}$. The algorithm calculates the intersection of two XPath expressions and checks its emptiness. For the more general XPath fragment $XP^{\{[],*,//,NOT\}}$ containing the operator `NOT` in qualifiers the XIUP is still decidable but becomes NP complete leading to inefficient algorithms with exponential runtime in the worst case. Further, we present algorithms for updating the key-oriented XML index (KeyX).

The remainder of this paper is organized as follows: In Section 2 we introduce and formalize an abstract definition of an index structure for XML data. Section 3 defines the XML Index Update Problem and reduces it to the *Intersection Problem* of XPath expressions. Finite automata that calculate the emptiness of the intersection are introduced in this section. In Section 4 we present the implementation of updates in KeyX. We survey related work in Section 5 and conclude the paper in Section 6.

2 INDEX AND UPDATE DEFINITION

This paper focusses on *selective* indexes like the IndexFabrics (Cooper et al., 2001), APEX (Chung et al., 2002) or our index approach called KeyX. Indexes that are non-selective (e.g. Strong DataGuide (Goldman and Widom, 1997)) are indexing the whole XML data. Therefore they are affected by every modifying operation. This leads to a trivial XIUP. Non-selective indexes perform best for read-only applications but fail when changes occur frequently.

In order to define indexes we have to define XPath based path expressions first. In this work we distinguish between simple and general path expressions.

Definition 1: Simple Path Expression:
A *simple path expression* p_s for a given alphabet Σ of element and attribute names is defined as follows:

$$p_s \quad ::= \quad p_s/p_s \mid p_s//p_s \mid * \mid n \mid .$$

with / denoting the child axis, // the descendant axis, $*$ an arbitrary element and n a specific element with the label $n \in \Sigma$; . is the current node. The set of all simple path expressions is denoted by P_s. □

Based on the definition of simple path expressions we define *general path expressions* which may include key comparisons and qualifiers:

Definition 2: General Path Expression
A *general path expression* p for the XPath fragment $XP^{\{[],*,//\}}$ is defined as follows:

$$\begin{array}{lcl} p & ::= & p/p \mid p//p \mid \mathbf{p}[\mathbf{q}]* \mid * \mid n \mid . \\ q & ::= & p \mid p\ AND\ p \mid p\ OR\ p \mid n\ op\ v \\ r & ::= & = \mid < \mid > \mid <= \mid >= \\ v & ::= & \textit{string} \mid \textit{int} \mid \textit{float} \end{array}$$

where *string*, *int*, and *float* are string, integer and float literals. □

The path expressions of $XP^{\{[],*,//\}}$ may have structural qualifiers (sometimes called predicates) and qualifiers with value comparisons. We call the latter *keys* because the can be compared to keys in relational indexes.
The grammar for the XPath fragment $XP^{\{[],*,//,NOT\}}$ has an additionally *NOT* operator in the rules for q.

The XIUP is relevant for any index approach. We focus on our general KeyX definition. An adoption to other index approaches can be made easily because an index is defined universally upon *keys*, *qualifiers* and one *return value*.

Example: For instance, the XPath query

```
q3 = /dblp/*[author='Kempa' AND
      year >2002][isbn]
```

selects all elements below `dblp` that match a given `author` name and a range of `year` values. Additionally, the selected elements must have at least one child named `isbn`. Because we have value comparisons for the `author` and `year` we call them *keys*.

The keys can be stored in an index's data structure optimized for fast key retrieval. *Qualifiers* may have any value, only their existence is requested (here `isbn`). Therefore, the value of qualifiers can be ignored. The return value path is the path to the elements that are selected by the XPath expression.

Definition 3: Index Declaration
Formally, a *selective index* i is defined as a triple $i = (K, Q, v)$ where K is a list of absolute simple path expressions $\in P_s$, referring to the key nodes. Q a list of absolute simple path expressions $\in P_s$, referring to the qualifier nodes and $v \in P_s$ is a simple path to the value nodes. □
The path expressions to the keys, qualifiers and the return value are extracted from a given XPath expression using the extraction function described in (B.C.Hammerschmidt et al., 2004a).

Example: The following index declaration defines an index suited for the query q_3:

```
i3 = (
  K = [/dblp/*/author, dblp/book/year],
  Q = [/dblp/*/isbn],
  v = dblp/*
)
```

In general, a selective index covers all queries with a result set being a subset of the path expression that defines the index. For instance, the index i_3 may also be used to answer the following query q_4 = `/dblp/book[author='Beda'][isbn]` because the result set of q_4 is a subset of q_3. Details about containment (subset) of XPath expressions can be found in (Miklau and Suciu, 2004).

Because relevant keys can be found in logarithmic time the linear process of comparing each element that is referenced by the key path is avoided.

Because one selective index covers only a limited number of queries we need a set of indexes to support a real application. The problem of finding a good set of indexes for a given set of querying and modifying database operations is part of the previous publication (B.C.Hammerschmidt et al., 2004b) dealing with this so called *Index Selection Problem*. Queries that are not covered by any index must be evaluated conventionally by the XPath engine of the underlying XDBMS.

Whenever a modifying operation adds or removes an element or the content value of an element that is referenced by at least one of the paths defining the index, an update of the index may be necessary to keep index and original data consistent. For instance, if we add a first `isbn` node to a `book` having already an `author` and a `year` the index i_{q_3} has to add this new book because it is now in the result set of q_3.

3 THE XML INDEX UPDATE PROBLEM

In this section we introduce the *XML Index Update Problem* (XIUP) and reduce it to the *Intersection Problem* of two XPath expressions.
An index i *covers* a query q if the nodes returned by the index structure are the same as the nodes returned by the database itself. Because the index is defined upon a return value and a set of keys and a set of qualifiers, the index may be out-dated if one of these nodes have changed. The key of an index is a structural and a content property. Therefore we have to update the index if a key appears, disappears or its value changes. Qualifiers and the return values

are only structural properties, the modification of their values does not touch the index.

The index is affected by a modifying operation if the path expressions defining the keys, qualifiers or the return value selects at least one node that is selected by the path expression of the modifying operation. Formally, this means that the *intersection* of the path expressions is not empty.

Definition 4: Affection
The *affection of two XPath expressions* p and $p' \in XP^{\{[],*,//\}}$ is defined as follows:

$$\{ \exists\, t \in T \mid p(t) \cap p'(t) \neq \emptyset \}$$

with $\emptyset$ denoting the empty set. T denotes the set of all XML data - any XML document that is well formed is in T. $p(t)$ with $t \in T$ is the set of nodes of t that is returned by the evaluation of p. We denote *Mod*$(p) \in T$ the set of all XML data where p returns a non-empty result set. □

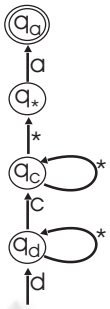
Informally, the affection asks if there can be an arbitrary XML document so that p and p' share at least one node in their result sets. Actually, we are not interested in that document but only if one may exist or not. We determine the existence of such a document by the use of finite automaton theory. A finite automaton is defined by its *states* and *transitions*. See (Hopcroft et al., 2001) for details about finite automaton theory. We give a procedure to create finite automaton for simple path expressions before we present the algorithm which checks affection.

Definition 5: Automaton for *Mod*(p)
We build an automaton A accepting *Mod*(p) as follows:

A is a tuple (Q,Σ, σ, q_0, F) with Q = NODES(p) a set of *states*, Σ a finite alphabet consisting of all element names. σ is a function $Q \times \Sigma \rightarrow Q$ defining the set of *transitions*. q_0 is the *initial state* whereas F is the set of *final states*. For each node $x \in$ NODES(p) with a child y, A has a transition $(y;'x') \rightarrow x$ with $'x' \in \Sigma$ the label of the node x. If the label of x is a wildcard (*) then any symbol $\in \Sigma$ is valid for the transition. For every descendant edge e from node x to node y, A has a transition $(y;'*') \rightarrow y$. These transitions lead to a nondeterministic automaton. The terminal state is ROOT(p). □

Example: The simple XPath expression $q_5 = /a/*//c//d$ leads to an automaton A with Q = $\{q_a$,q_*,q_b,q_c,$q_0\}$ and σ = $\{t_0$ ... $t_5\}$ with

t_0 = (q_0;'d') $\rightarrow q_d$,
t_1 = (q_d;'*') $\rightarrow q_d$,
t_2 = (q_d;'c') $\rightarrow q_c$,
t_3 = (q_c;'*') $\rightarrow q_c$,
t_4 = (q_c;'*') $\rightarrow q_*$ and finally
t_5 = (q_*;'a') $\rightarrow q_a$.
The initial state is q_0, q_a is the one final state. Please note that the transitions are not deterministic (e.g. t_3, t_4). The automaton for this example is illustrated in the Figure on the right hands side.



Because we regard the intersection of simple path expressions with all nodes having one child at maximum we can use standard finite automaton theory to calculate the existence of an intersection. The more complex tree automaton theory usually applied for processing XML is not required. The following algorithm checks the affection of two path expressions:

1. create automaton A accepting *Mod*(p);
2. create automaton A' accepting *Mod*(p');
3. create product autom. B acc. *Mod*$(p) \cap$ *Mod*(p');
4. $< q_{0_A} \times q_{0_{A'}} >$ = initial state of B;
5. $< q_{F_A} \times q_{F_{A'}} >$ = final state of B;
6. $CLOS$ = transitive closure of $< q_{0_A} \times q_{0_{A'}} >$
7. if ($< q_{F_A} \times q_{F_{A'}} > \in CLOS$) return true;
   else return false;

Figure 1: Pseudo code of the affection algorithm

In Step 1 the algorithm creates an automaton A accepting all XML data where p returns non-empty result sets . Analogue, Step 2 creates an automaton A' for path p'. In Step 3 the product automaton B of A and A' is created. B accepts all XML data where both path expressions p and p' evaluate to a non-empty result set. Informally, one can say that B simulates the simultaneous execution of A and A' accepting if and only if both automata are accepting.
If this is the case, at least one node of the XML data is selected by both p and p' and the index defined over p is affected by p' and must therefore be updated.
In the last steps of the algorithm it is checked if there is a path from the initial state to a final state of B by calculating the transitive closure of the initial state of B. Please note that the emptiness of the intersection is a property of the product automaton. It is determined without processing any concrete XML input

Algorithm: Update a KeyX index for an Insert operation

Input: 1. KeyX index with declaration $x = (K_p, Q_p, v_p)$
2. Insert operation with node i_n and path i_p

Output: The KeyX index x is updated concerning i_n.

Method: 1. if $isAffected(k_p^i - i_p, i_p^{'})$ with $i_p^{'} \in path(i_n)$ and $k_p^i \in K_p$ then
/* the Insert operation may contain an indexed key value */
$repairKeys(x, i_n, i_p)$
2. if $isAffected(q_p^i - i_p, i_p^{'})$ with $i_p^{'} \in path(i_n)$ and $q_p^i \in Q_p$ then
/* the Insert operation may contain a qualifier */
$repairQualifier(x, i_n, i_p)$
3. if $isAffected(v_p - i_p, i_p^{'})$ with $i_p^{'} \in path(i_n)$ then
/* the Insert operation may contain an indexed return value */
$repairValues(x, i_n, i_p)$

Figure 2: Update algorithm of KeyX for an **Insert** operation

Algorithm: Repair Keys after Insert operation

Pre: Insert operation may contain new indexed key value

Input: 1. KeyX index with declaration $x = (K_p, Q_p, v_p)$
2. Insert operation with node i_n and path i_p

Output: The keys of KeyX index x are updated concerning i_n.

Method: Foreach father node $f_n \in root(db).query(i_p)$ to be inserted in do

1. Foreach key value node $k_n^i \in i_n.query(k_p^i - f_p)$ do // k_n^i is a new partial key
(a) Foreach key value node $K_n \in k_n^i.query(K_p - k_p^i)$ do // K_n is the key of k_n^i
i. add return value node to index with $x.add(K_c, r_n)$ and $r_n \in K_n.query(v_p - K_p)$ if $r_n \in x.returnValues(K_n)$

Figure 3: Repair algorithm for **keys** after an Insert operation

4 UPDATE ALGORITHM FOR KeyX

This section introduces the update algorithm for the KeyX data structure for the insert operation. The algorithms for the replace and delete operations are omitted here for space reasons and are defined analogously. Every replace operation can be expressed by a delete operation followed by an insert operation.
The section is finished by presenting performance measurements of our implementation for the KeyX index system.

Algorithms updating the index structure
The algorithms presented in this section make use of some further methods and operations introduced first. The operation $'-'$ from the path interface can be applied to two simple paths $p_1 - p_2$. It returns the path from a node with path p_2 to a node with path p_1. The operation is extended for a tuple of paths as first or second parameter. In this case it returns a tuple of difference paths. The method $path$ applied to a node n returns a list of the paths to all sub-nodes of n. Additionally a method is needed to navigate to a path expression from a given context node. This is realized by method $query$. With $n.query(p)$ the path p is evaluated concerning the context node n. The result of this method is a list of nodes. Further, the method add and $returnValues$ from the interface of the KeyX implementation are used. With $x.add(K_c, r_n)$ a return node r_n can be added to the key value entry K_c in index x. The method $x.returnValues(K_n)$ returns the return values of the key nodes K_n taking the qualifiers of the index declaration into account. Generally all identifier with subscript p represents the path of a node, with subscript n the node itself and with subscript c the content of the node.
Now the update algorithm for an KeyX index concerning an insert operation can be presented in Figure 2.

In a first step the algorithm determines if a node is inserted which relate to an indexed key value, indexed qualifier node, or to an indexed return value node. If one of these cases is true the belonging key value nodes are extracted from the database and inserted with the relevant return value nodes into the index.

Algorithm: Repair Values after Insert operation

Pre: Insert operation may contain new values

Input: 1. KeyX index with declaration $x = (K_p, Q_p, v_p)$
2. Insert operation with node i_n and path i_p

Output: KeyX index x is updated for new values concerning i_n.

Method: Foreach father node $f_n \in root(db).query(i_p)$ to be inserted in do

1. Foreach return value node $r_n \in i_n.query(v_p - f_p)$ do // r_n is a possible new return value
   (a) Foreach key value node $K_n \in r_n.query(K_p - v_p)$ do // K_n is the key of r_n
      i. add return value node to index with $x.add(K_c, r_n)$ if $r_n \in x.returnValues(K_n)$

Figure 4: Repair algorithm for **values** after an Insert operation

The algorithm is sound and complete for the XPath fragment $XP^{\{[],*,//\}}$ because excluding qualifiers cannot be expressed in this class.
The more general class $XP^{\{[],*,//,NOT\}}$ allows to express qualifiers in p and p' that cannot be fulfilled simultaneously. For instance, if $p = /a[b]$ and $p' = /a[NOT(b)]$ it is obvious that there can be no element a having a child b and no child b at the same time. In this case, the algorithm is still complete but not sound meaning that an index affection is indicated where it is not the case. A redundant index update is effected.
A sound and complete algorithm in general cannot be as efficient because the XIUP for the XPath fragment $XP^{\{[],*,//,NOT\}}$ is NP hard (the NP-complete problem *3SAT* can easily be reduced to the XIUP by attaching child nodes representing the clauses from 3SAT to one root node). The proof of the NP-completeness of the XIUP is beyond the scope of this paper.

Measurements:
In order to judge our approach we measured the performance of the algorithm in Figure 2. KeyX and the algorithms of this paper are done in Java. We performed all tests on a Pentium 4 with 2.66 Ghz and 1 Gb main memory. In Test 1 we increased the number of keys in the index's definition. As the diagram in Figure 5 shows the execution time increases linearly. When increasing the number of keys *and* the length of the path expressions defining the index the execution time increases quadratically; this is shown in the second graph.

Even for very complex indexes with more than 20 keys and path expressions of the length about 20 the XIUP can be solved in less than 3 milliseconds. When an index is affected the underlying index structure has to be updated by inserting/removing a key or updating the reference of the return value. Compared to a total rebuild of an index which may take minutes for traversing the whole XML data this approach is a major improvement. For applications that frequently update an XML database (e.g. orders in an online shop) the approach offers a suitable index system.

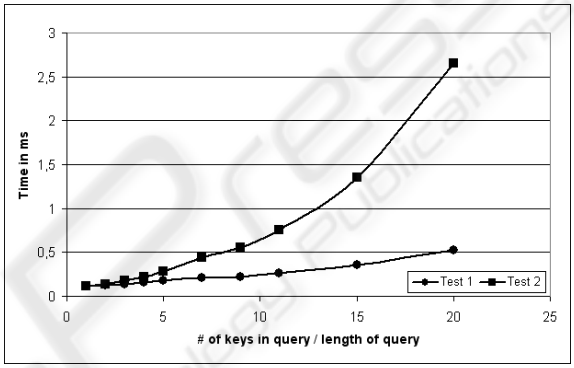


Figure 5: Measurements of the Index Affection algorithm

5 RELATED WORK IN INDEXING XML

In recent years a multitude of approaches for indexing XML were introduced. One common approach to index the structure of semistructured data are the so called *structural summaries*. One early approach are the *Strong DataGuides* (Goldman and Widom, 1997) providing a general index structure to accelerate path expressions starting at the root. References to elements that are reached by the same path expression are summarized in one node of the DataGuide. The creation of a DataGuide can be compared to the transformation of a nondeterministic finite state machine to a deterministic one by the fusion of equivalent states. DataGuides differ significantly from indexes in RDBMS: Instead of accelerating specific queries very efficiently they try to improve the evaluation of path expressions in general. In contrast to indexes in RDBMS where indexes are selected by the database administrator, structural summaries in XDBMS are

permanently enabled and thus not selective.

The idea of the DataGuide is extended in several works. The problem of non-selective and large DataGuides is faced in the work of Kaushik et al (Kaushik et al., 2002) introducing a selective structural summary.
The same problem motivates the *Adaptive Path Index (APEX)* (Chung et al., 2002) from Chung et al. APEX is a specific structural index optimized for frequent queries ignoring the values of elements. Therefore, it is less efficient for queries containing a key.
Structural summaries are the main data structure or part of further works, including the Forward-and-Backward-Index (Abiteboul et al., 1999) the T-Index (Milo and Suciu, 1999) (with the special cases 1-Index and 2-Index), the D(K)-Index (Chen et al., 2003), HOPI (Schenkel et al., 2004) and others (Barg and Wong, 2003; Halverson et al., 2003; Kaushik et al., 2004; Weigel et al., 2003). Although some of the work discuss how to update the index's data structure none of them explain how an affection is determined.

Numbering schemes (e.g. (Grust, 2002; H. Jiang and H. Lu and W. Wang and B. Ooi, 2003)) map each element of the XML data to one or more numbers that are mostly determined by post/preorder XML-tree traversing algorithms. The numbers are used for a faster retrieval of relationships between elements. For some numbering schemes a change in the structure means a recalculation of each assigned number - this can cost as much as rebuilding the total index. This problem is faced in the work (Kha et al., 2001) proposing a numbering schema that is optimized for updates leading to less number recalculation when the XML data is modified. Again, none of these paper faces the XIUP.

The *Index Fabric* (Cooper et al., 2001) is a balanced tree structure storing the encoded paths from the root to each node and its values. Therefore, the Index Fabric support queries with keys and qualifiers. The data structure of the Index Fabric - a Patricia trie - can be updated easily like any other search tree. But the question whether an index is affected by a modifying operation is not mentioned by the authors. Our index approach KeyX can be compared with the index Fabric. Compared to the Index Fabric KeyX supports more query types including multi-key queries and range queries.

Approaches that uses an underlying relational DBMS to store and index XML (e.g. (Bauer et al., 2003)) have in common that they can reuse existing and performant implementations of the relational world. However, XML queries have to be mapped to SQL queries leading to many expensive Join operations if a multi-key query is executed. This lead to performance degradation compared to native XDBMS.

Recapitulating, a lot of XML index approaches where introduced in the past. Early approaches even have underlying data structures that cannot be updated efficiently. Recent approaches use updatable data structures but - to the best of our knowledge - we are the first that present an algorithm that detects if an existing index must be updated in order to keep it consistent.

6 CONCLUSION

In this paper we defined the XML Index Update Problem (XIUP) and proposed an efficient algorithm solving the XIUP for the XPath fragments of the class $XP^{\{[],*,//\}}$. We showed that the XIUP for more general XPath expressions is NP complete but the algorithm is still identifies all required index updates. The XIUP is relevant for all approaches that try to index XML data. To the best of our knowledge we are the first who pay attention to the XIUP and introduced an efficient algorithm.

Future work will deal with efficient algorithms finding a (sub-)optimal sound-and-complete approximation for XPath fragments of the class $XP^{\{[],*,//,NOT\}}$. A major constraint is that any approximation has to be completed in order to identify required index updates and to keep the index and the data consistent.

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