Xregion: A New Approach to Storing XML Data in Relational Databases

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Abstract
In this paper, we propose a new structure-based approach, called Xregion, to storing XML data in relational databases. Our approach first partitions an XML document into several disjoint regions according to the cardinality of element nodes, and then maps these regions into separate relations. The experimental results demonstrate that the proposed approach dramatically improves the performance of queries on the XML data over the generic mapping approaches.

Key words: XML, DBMS, XQuery

1 Introduction

With increasing popularity of XML documents, it is crucial to store and query XML documents efficiently in order to exploit the full power of this new technology. A motivated application of this research can be an XML repository system that stores millions heterogeneous XML documents, which are well-formed but have no DTD or the DTDs of which are not known beforehand.

One promising approach to managing XML documents is to store and query them in a relational database. In this approach, XML data must be converted into a set of tuples and stored in relational tables, due to the difference between relational database structure and the hierarchical structure of XML documents. Queries posed on XML documents then need to be translated into SQL statements against those relational tables, and the query results need to be constructed in the desired XML format. Thus, the problem of query efficiency over XML documents shifts to the effectiveness of the database schemas in terms of query performance by SQL.

The database schema for XML storage varies among different XML-to-Relation mapping techniques. One of the mapping techniques, called generic mapping, is to design relational database schemas for XML documents without the knowledge of DTD or XML Schema information. Multiple generic mapping techniques have been studied, such as Edge Mapping [6] and Path Based Mapping [10] [14] [7].

The basic idea behinds existing XML generic mapping approaches is to model an XML document as a tree, and record the parent-child relationships among nodes in the XML tree as tuples in relational tables, with each tuple representing an edge or a node in the XML data tree. As a result of this decomposition, the hierarchical structure of an XML document is flattened to binary relationships scattered in the database tables. Although the generic mapping approach can be used to store any XML documents, with or without schema, into current relational database, querying performances of existing generic mapping approaches are still far from satisfactory, especially for large XML documents.

There are two main reasons of this inefficiency. First, XML data are scattered in relation schemas with a very high degree of fragmentation. At the query processing time, a great amount of join or θ join operations are required to restore the hierarchical structure of an XML document. Second, only parent-child binary relationships are stored in relation schemas, so it is very expensive to search ancestor information.

In this paper, we propose a new generic mapping technique, called *Xregion*, to store XML data in relational databases. Our solution for reducing the fragmentation is simple, but very effective. We first partition an XML document into several disjoint regions according to the cardinality of node occurrences, and then store these regions, including their parent information, into separate tables. An example for our mapping approach is given below.

The graph in the Figure 1 can be interpreted as a structure summary of a sample XML document for a university registration system. Each ellipse represents a node in the document while a double ellipse represents a node with repeated occurrences, i.e. set-valued node. For example, each course has one course number and one title, but many sections and many TAs. Therefore, both "section" and "TA" node are represented by a double ellipse.

Each set-valued node represents a distinct region in the structure summary, and each distinct node in a region is represented by a separate field in the table for the region. For example, R_{21} in Figure 1 is the region represented by the "course" node, and its corresponding

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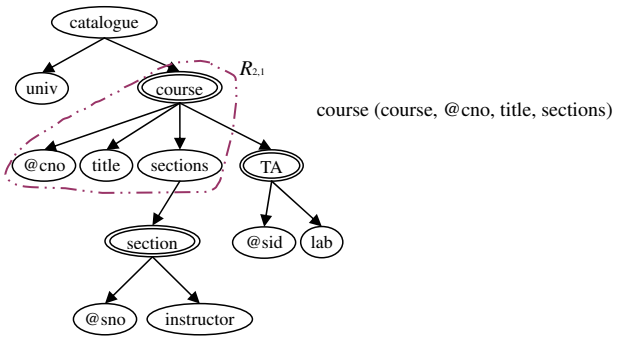


Figure 1: An example for Xregion.

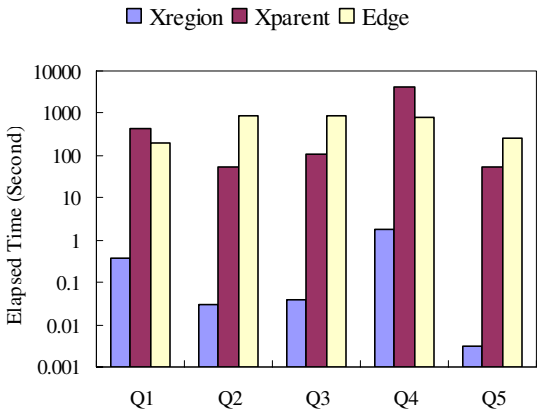


Figure 2: Elapsed time for querying evaluation using Xregion, XParent and Edge on an XML document(2GB)

relation schema is

course_table (course, @cno, title, sections).

The advantages to partition and store XML documents based on cardinality of node occurrences are as follows. First, since each region contains no further nested structure, i.e. no other set-valued nodes, it can be stored a set of tuples in one table. Second, we avoid the very expensive join operations required for query evaluation by other approaches, because all children nodes, except for the set-valued child nodes, of an element are stored in the same relation as the element. Since regular relations do not support set-valued attributes, we create a separate relation for each set-valued element and all its descendants with one-to-one relationships to the element. So in our system, XML documents are decomposed according to the nested level of the data, rather the binary relationships between nodes, which are widely used in the existing generic mapping methods.

We have implemented Xregion and several other existing generic mapping techniques, including XParent [7], Edge Mapping[6] and Xrel[14]. We have conducted extensive experiments using above approaches to storing two XML documents (200 MB and 2GB) into an Oracle database, and then compare their performance by evaluating 7 and 5 typical queries respectively. Figure2 describes the elapsed time for querying the database storing an XML document with size 2GB.

The figure demonstrates that the proposed approach dramatically improves the performance of queries on the XML data over the existing generic mapping technologies, by the order of one or two magnitudes. The improvement is particularly striking for large XML documents.

The rest of the paper is organized as follows. In Section 2, we review the current state of generic mapping approaches. In Section 3, we give formal definitions of the XML data models used in our approach. Section 4 formalizes the proposed approach, Xregion. Section 5 goes into the implementation details of the XML bulk loader system. The experimental setup and results are described in Section 6. Finally, in Section 7 we provide a summary and present future work.

2 Background

XML is becoming the standard for data interchange and representation on the Web and elsewhere. Its nested and self-describing nature makes its transmission, and presentation more intuitive than any other data standard. Figure 3 is an example XML document describing courses information.

An XML documents may have a DTD (Document Type Definition) or an XML Schema, which can be used to define and validate the data structure of the document. In this paper, we focus on the problem of storing XML documents into relational database without the knowledge of the DTDs or XML schemas.

The nested and self-describing nature of XML provides simple and flexible means for exchanging data among applications. However, it is not designed to facilitate efficient data storage or retrieval.

One method to store XML data is to employ current Relational Database Management Systems (RDBMS) for XML storage and retrieval. This takes advantage of the mature technologies already provided in current database systems, such as concurrency control, powerful query optimizers and indexing techniques.

When we look at mapping XML to a relational database, we are considering the difference between relational database structures and XML data structures. Conventional relational database systems do not sup-

```
<catalogue>
  <univ>ABC</univ>
  <course cno="291">
    <title>Database Systems</title>
    <sections>
      <section sno="H1" >
        <instructor>Dr. Lin</instructor>
      </section>
      <section sno="H2" >
        <instructor>Dr. Dean</instructor>
      </section>
    </sections>
  </course>
  <course cno="539">
    <title>Programming</title>
    <sections>
      <section sno="H1" >
       <instructor>Dr. Hanks</instructor>
      </section>
    </sections>
    <TA sid="123"> <lab>D01</lab> </TA>
    <TA sid="112"> <lab>D02</lab> </TA>
  </course>
</catalogue>
```

Figure 3: An example XML document for university courses

port the inherent hierarchical and semi structured format of XML data. Instead, the nested XML data need to be transformed into tables according to the database schemas generated by mapping approaches.

The design of database schema is crucial to the performance of query processing and result publishing, because it stipulates how XML data are stored into the underlying relational database systems. In the case that XML documents are very large or they are in huge numbers, it is imperative to convert those data to a format where they can be retrieved effectively.

To further understand XML relational storage models and their effectiveness in terms of query processing, we will now describe existing generic mapping approaches.

Edge Based Mapping: Florescu and Kossmann [6] proposed the Edge approach to modeling an XML document as a set of atomic structure units, which are edges on the data graph, and store each unit as a tuple in a relational table of RDBMS. They represented an XML document as an ordered and directed graph, in which every node is assigned an identifier *oid* and each edge is explicitly labeled by the name of incoming element type or attribute. All edges of an XML data graph are stored in a single table called the **Edge** table, which has the following structure.

Edge(source,ordinal,target,label,flag,value).

Each tuple in the Edge table represents one edge in the directed graph. An edge is defined by the *Source* and *Target* fields, which are *oid*s of the two nodes connected by the edge. The *Label* field records the label of an edge.

Src	Ord	Tgt	Label	Flag	Value
&0	1	&1	catalogue	ref	
&1	1	&2	univ	string	ABC
&1	1	&3	course	ref	
&3	1	&4	@cno	string	291
&3	1	&5	title	string	Database Systems
&3	1	&6	sections	ref	
&6	1	&7	section	ref	
&7	1	&8	@sno	string	H1
&7	1	&9	instructor	string	Dr. Lin
&6	2	&10	section	ref	
&10	1	&11	@sno	string	H2
&10	1	&12	instructor	string	Dr. Dean
&1	2	&13	course	ref	
&13	1	&14	@cno	string	539
&13	1	&15	title	string	Program.
&13	1	&16	sections	ref	
&16	1	&17	section	ref	
&17	1	&18	@sno	string	H1
&17	1	&19	instructor	string	Dr. Hanks
&13	1	&20	TA	ref	
&20	1	&21	@sid	string	123
&20	1	&22	lab	string	D01
&13	2	&223	TA	ref	
&23	1	&24	@sid	string	112
&23	1	&25	lab	string	D02

Table 1: A relational storage example using Edge approach.

The local order of the edge among its siblings is stored in the *Ordinal* field. The *Flag* field indicates whether the target node is an internal node ("ref") or a leave node with a value ("string" or "int"). The data graph for the example XML document is shown in Figure 4, and Table 1 is its corresponding Edge table.

Independent to XML DTDs, edge mapping approach can be applied to a wide range of XML documents or other semi-structured documents that have arbitrary graph structures. However, such a decomposition method makes the query evaluation very inefficient. It needs a number of self-join operations to restore the hierarchical structure of the XML data at query processing time, due to the high fragmentation of the data in relations. To improve the performance, Florescu and Kossmann [6] also proposed another variant of the Edge mapping, called Binary approach, though the result is not very satisfactory.

XParent: XParent [7] is a four-table path-based mapping system, which uses fixed schemas to store variant XML documents, according to the XPath model. **Element** table and **Data** table, respectively, are created for storing the element nodes and the values of attribute nodes and text nodes. Each tuple in these tables represents a node in the XML tree. The binary relationships among nodes are stored in the **DataPath** table. Another table, **LabelPath** table, stores all distinct label-paths and their depth. These four relational

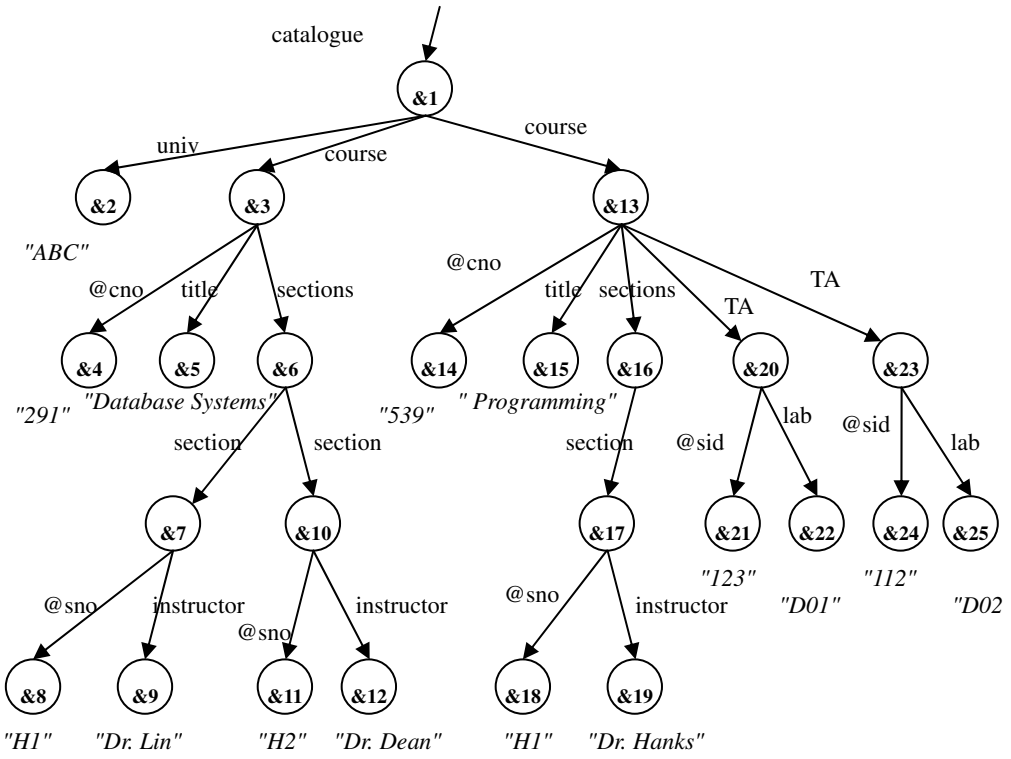


Figure 4: An XML data graph of Edge mapping

tables are as follows.

LabelPath (ID, Len, Path)
DataPath (Parentid, Childid)
Element (PathID, Did, Ordinal)
Data (PathID, Did, Ordinal, Value)

Compared with Edge Mapping, the path based mapping speeds up the query processing on simple XML queries by storing path expressions explicitly in relations. However, when processing queries with multiple paths or multiple conditions on different branches they still need a number of joins or self-joins to check nodes connections.

XRel: XRel proposed by M. Yoshikawa and T. Amagasa et al [14] is a generic mapping approach, which keeps both the simple path expressions and element positions in relations. The position of an element is recorded by the byte-offset of its start and end positions in the XML document. For example, the positions of node 1 (document root "catalogue") and node 19 ("instructor") in the XML tree shown in Figure 4 are (0, 450) and (299, 332) respectively. In addition to the **Element** table, another two tables are created to store attributes and text contents, i.e. **Attribute** table and **Text** table. Same as Edge and XParent approaches, each tuple in these relations represents one node in the XML tree. The basic XRel schemas are as follows.

Text (docID, pathID, start, end, value)
Attribute (docID, pathID, start, end, value)
Element (docID, pathID, start, end, ordinal, reverse_ord)

A contribution of XRel was that they introduced a new format for representing paths by using two characters to separate steps in a path expression, e.g. '#/catalogue#/course' instead of '/catalogue/course'. The advantage of this transformation is that it simplifies the query translation process for simple queries on paths with wildcards, and guarantees the correctness of string matching in query processing.

In XRel schemas, the containment relationships among nodes in an XML document can be captured by comparison between start and end positions. So for XRel, sometimes, it does not need to verify all the intermediate edge connections one by one between two nodes, e.g. node a→b→c→node d, and only need to check whether one node (d) is reachable from the other node (a). Thus XRel will use less join operations for searching ancestors of a node. However, this simplification in query processing does not improves the query performance as expected, and sometimes it is even worse especially for large documents.

Monet Model: Monet [10] is another path based XML relational storage model proposed by Schmidt et

al. The basic idea is similar to the Edge mapping, which identifies parent-child relations from the XML data graph. At the mapping stage, they apply a different approach by creating separate relational tables for every distinct path in the graph. Thus data stored in the same table has a strong structural relation and each table is relative small compared to Edge approach. However, similar argument with the Binary approach of Edge mapping, this approach might not be viable for large collections of XML documents, due to the limit of total number of tables in database systems. For example, the Monet approach created 2587 tables for a single XML document for Webster's Dictionary [10].

Other Mapping Approaches: In addition to generic mapping approach, several other XML-to-Relation mapping techniques have also been investigated recently.

Some of them use XML DTDs or XML schemas information for generate relational schemas [11] [8][9]. Others construct the database schema according to analysis and statistics on frequent structure or query work load, such as STORED system [4] and a cost based system LegoDB [2]. But it is difficult for them to deal with XML data that has irregular structures. In addition extra operations, such as gathering statistics and analyzing query work load, are also required.

Cooper, Sample and Franklin et al pursue a different direction to improve the performance of querying XML data in database. To facilitate the navigation and selection of nodes on the XML trees, they build a special index, Index Fabric [3], on top of RDBMSs for storing path information. The experimental results show that the fast index improves performance, but mainly for refined paths, which are specialized paths for tuning frequently occurring queries.

Xing, Guo and Wang use node grouping to mapping XML documents to databases which reduces the index space and thus significantly improve the query performance [13].

3 Xregion Data Model

In this section, we first formally define the XML data tree, XML structure tree, region and nested level, which forms the basis of the data model used in our mapping approach.

Given an XML document, we use *El* to denote the set of element names, *Attr* the set of attribute names, *Vert* the set of node identifiers, *Str* the set of possible string value of elements or attributes. (Note that the symbol '@' is added as the prefix of all attribute names.)

3.1 XML Data Tree

Following previous work on XML data, we model an XML document as a node-labeled tree, *XML data tree*, which is defined below. The XML data tree used in our approach is slight different from the XPath tree models [5] discussed in Section 2. We model the text of an element as the value of that element node, rather than a separate text node on the tree. For this reason, we adapt the formal definition of XML data tree from XNF [1] by modifying the total function "ele" and adding a new function "val".

Definition 1 [1] An XML tree T is defined as a tree *(V, lab, ele, val, attr, root)*:

- $V \subseteq Vert$ is a finite nonempty set of vertices.
- $lab: V \rightarrow El$.
- $ele: V \rightarrow V^*$
- $val: V \rightarrow Str \cup null$
- $attr$ is a partial function $V \times Attr \rightarrow Str$. For each $v \in V$, the $\{al \in Att \mid attr(v, al)\ is\ defined\}$ is a finite set.
- $root \in V$ is the root of XML data tree T.

Every element in the document is modeled as a node, characterized by a unique node identifier. All attributes of an XML document are modeled as children of their associated element nodes. Given an XML data tree, a *path* of a node is a sequence of ancestor labels starting from the root to the node. Figure 5 is a graphic depiction of the data tree for the sample XML document in Figure 3.

3.2 XML Structure Tree

An XML document contains both meta data and data itself, and its meta data, including all path and other information, can be described by the structure tree, which is a summary of the XML data tree.

Definition 2 Let Pt be the set of paths in an XML data tree. An XML structure tree S is defined as a tree *(Vs, Pt, multi, r)*:

- $Vs: Pt \rightarrow El \cup Attr$.
- $multi: Pt \rightarrow n$.
- $r \in Vs(Pt)$ is the root of XML structure tree S.

$multi(p_{t1})$ shows the maximum cardinality of a node identified by a path $p_{t1} \in Pt$. The parent-child relationship is captured by paths. Figure 6 shows an XML structure tree for the example XML document. All multi-valued nodes that occur repeatedly under their

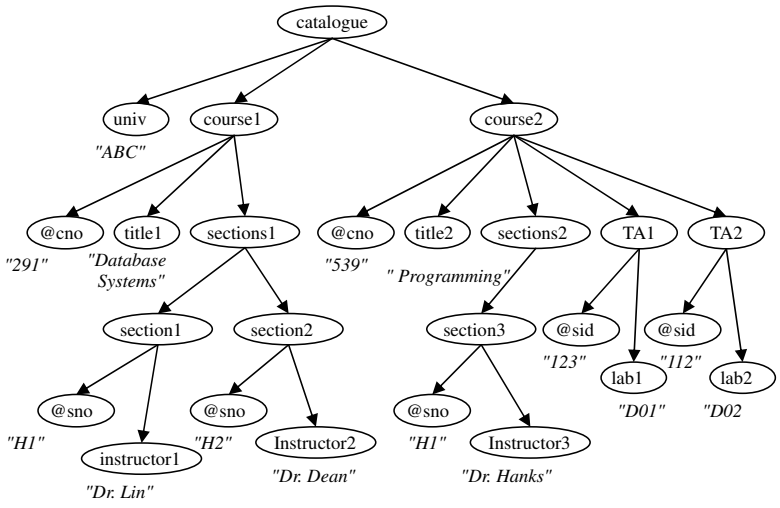


Figure 5: An XML data tree for the example XML document

parent nodes,
$\{p_{t1} \in Pt |\ multi(p_{t1}) > 1\}$, are identified by a double ellipse in this structure tree. For example, each course

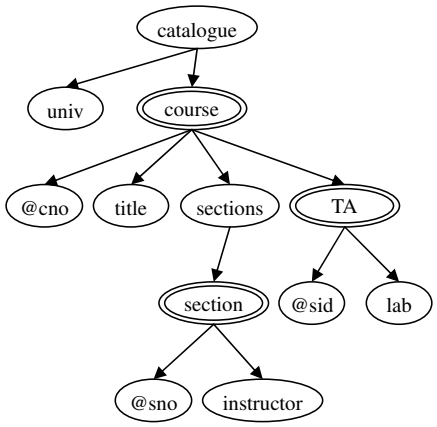


Figure 6: An XML Structure tree

has one course number and one title, but many sections and many TAs. Therefore, both course number "@cno" and "title" are represented by a single ellipse while "section" and "TA" are represented by a double ellipse.

Features of the XML structure tree are:

1. It represents the complete structure of a given XML document, i.e., it contains the structure of every element type in the XML document.

2. It is exactly as deep as the corresponding XML data tree.

3. Generally, the XML structure tree will be much smaller than the XML data graph.

From this graph we can see that the structured information for an XML document includes not just path information, but also cardinality of node occurrences. Because of the above features, we will use the structure tree as the basis for partitioning any given XML documents.

3.3 Region

The key idea of the proposed approach is to partition the input XML documents into disjoint regions according to the cardinality of node occurrences. The definition of the region is given below.

Definition 3 A region in a structure tree is a subtree R of the structure tree such that

1. the root of R is either a set-valued node (i.e., a double ellipse) or the root of the structure tree, and

2. all the subtrees of R rooted with set-valued node (i.e., a double ellipse) are removed.

Obviously, a structure tree with N double ellipses contains $N + 1$ disjoint regions. Each region consists of all and only those descendants that have one-to-one relationships with the set-valued element (region root), so we can map all nodes in a region into one relation with every node in this region represented by a separate field in the relation. The other feature of a region is that all the nodes in a region share the same ancestors and cousins outside of the region. Consequently, storing all the regions in separate tables may significantly

reduce the number of joins needed for query evaluation. Figure 7 shows all the regions for the sample document, and the responding relations for storing regions.

For example, the relation for the region "course" is:
Relation_course (course, @cno, title, sections)

3.4 Region Tree and Nested Level

In order to specify the table schema according to the regions, we define the *region tree* of a given document as the tree obtained from the structure tree by replacing each region with one node. Since each node in a region tree will be stored as one relation, a region tree is also called a relation tree. Figure 7 (b) describes the relation tree for the sample document.

Given a region tree *Tr*, the nested level of a region is then defined as the height of its corresponding region node in the region tree.

All nodes in a given region belong to the same nested level, although they are on different depths of the XML structure tree. For example, in Figure 7, while the node "section","instructor" and "TA" are on different depths in the structure tree, they are at the same nested level – the nested level 3. Thus we transform the complicated hierarchical structure of an XML document to a relatively simple nested structure among regions (relations).

Based on its topological position in the region tree, each region can then be labeled as $R_{i,j}$, where i denotes its nested level, and j the order of regions in their respective level, with the left most as 1. Consider Figure 7 (b) again. Relation "root" is labeled as $R_{1,1}$, Relation "course" is labeled as $R_{2,1}$, Relation "section" is labeled as $R_{3,1}$, and Relation "TA" is labeled as $R_{3,2}$.

3.5 Region Instance

Once all regions are identified, the XML data tree will be traversed to map all the instances of each region into the corresponding tables specified by the region.

Definition 4 Let *Pr*, *r_edge* be the set of paths and edges in a region R of an XML structure tree respectively, and *root* be the path of the region root. An instance I of the region R is defined as a tree *(Pi, edge, r, val)*, which is a subtree of the XML data tree.

1. $Pi \subseteq Pr$ is a finite set of paths.
2. $val: Pi \rightarrow Str \cup null$.
3. $edge \subseteq r\_edge$ is a finite set of edges.
4. $r = root$ is the root of sub tree I that represents the instance.

We call each occurrence of a region structure as an instance of the region, because it instantiates the abstract structure of a region with data in the XML document. When loading XML document into the database, each instance of a region is stored as one tuple in the table of this region.

For example, the I_1 and I_2, marked on the XML data tree shown in Figure 8, are two instances of the region "course".

4 Xregion Storage Schema

In this section, we specify the basic database schema of our proposed approach, Xregion. The basic idea of Xregion is to store all children nodes, including attributes, of an element in the same relation with the element, except its set-valued child nodes, in order to reduce the fragmentation degree of XML data in relations.

Given an XML document, we first build an XML document structure tree for it, partition the document structure tree into several regions, and then map all nodes of each region into a separate relational table. After processing all the nodes on the XML document structure tree of a given XML document, the mappings from XML structure to database schema are recorded in a database table as meta data. Because of the limit on the size of region trees, a limited number of tables are needed to store any number of XML documents.

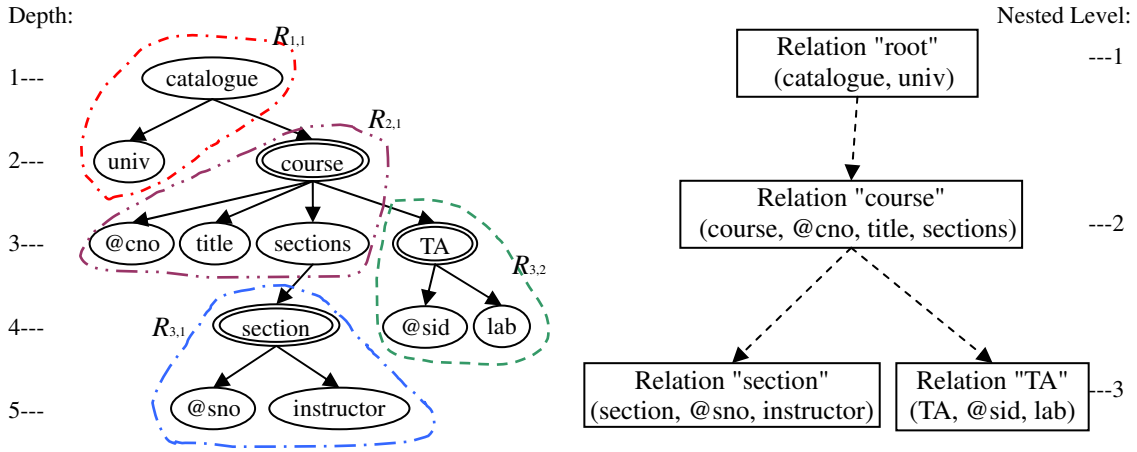
The XML data tree is then traversed to load the XML data into their corresponding tables in the database system. Every query to the XML data will be translated into a query to the underlying database, and then the XML query result will be constructed from the answer returned from the underlying database.

4.1 Basic Database Schema for Xregion

The underlying database for Xregion consists of one *meta table*, used to store all the meta information, such as paths, in the document structure trees and their corresponding mappings, and a limited number of *data tables*, named table_i_j for region $R_{i,j}$, where the upper limit of both i and j depends on the size of regions trees of stored XML documents.

Therefore, for an XML document with N regions, we need only $N + 1$ tables. With the increase of N, new data tables can be created accordingly.

For simplicity, we assume that the number of nodes in any region is limited to n, say $n = 20$. Should the number of nodes exceeds this limit, we can either increase the number of columns of the table for the region or to create a new table to store information for the extra nodes.



(a) Regions (b) Relation Tree

Figure 7: An example for *regions*. The structure tree is divided into four regions by its three set-valued nodes *course*, *section* and *TA*.

4.1.1 Data Tables

Each data table is used to store all the instances of the corresponding region, as well as the data needed to identify the parent information of any node in the region.

Since a region does not contain any set-valued node, each instance of a region can be represented by a tuples of n columns, one for the value of each node in the region.

To uniquely identify each tuple in the region, we will create one unique id, named *tuple_id*.

In Xregion, the parent of any node in a tuple of a given region table, is either in the same table, or is stored in the region table of upper level (parent of the region root). Therefore, we also create a column, called *parent_id*, or *p_id* for short, to store the tuple_id of the parent instance of the a given tuple in a region.

In order to preserve the order among all sibling nodes, we will introduce a column to record the ordinal position of the set-valued nodes, which are root nodes of each region. Finally, since a data table will be used to store multiple XML documents, we do need a column to store the document name.

In summary, each table table_i_j is defined as a table with $n + 4$ columns, that is,

table_i_j(doc_name, tuple_id, p_id, ordinal, col_1, ..., col_{n-1}, col_n).

Where doc_name is used to store the document name of the XML document, tuple_id is used to store the unique id of a tuple in the region, p_id is used to store the tuple_id of the parent node, ordinal is used to store the ordinal position of the tuple, and col_i, for $1 \leq i \leq n$, are used to store the value of the corresponding node in the region.

For convenience, we simplify the table for root region $R_{1,1}$ by removing the p_id, ordinal, since the root region does not have any parent and sibling. So the structure of the root table is:

table_1_1(doc_name, tuple_id, col_1, ..., col_{n-1}, col_n).

4.1.2 Meta Table

The meta table, named *meta_table*, is designed to store all the meta information from the document structure trees, one tuple for each path in the structure tree.

Since each path represents one node in the structure tree and each node is stored in the corresponding column of its region relation, the tuple shall contain the name of the region table, the column name in the region table, and the parent table name of the region table.

Of course, we shall also store, for each tuple, the name of the XML document.

In summary, the meta table consists of five columns, that is,

meta_table(doc_name, path, table_name, col_name, p_table).

It is easy to see that the aforementioned $N + 1$ tables store all the information about an XML document.

4.2 Example

Given an XML document to be imported into a RDBMS system, the database schemas generation process works as follows. First, the XML document is parsed to get

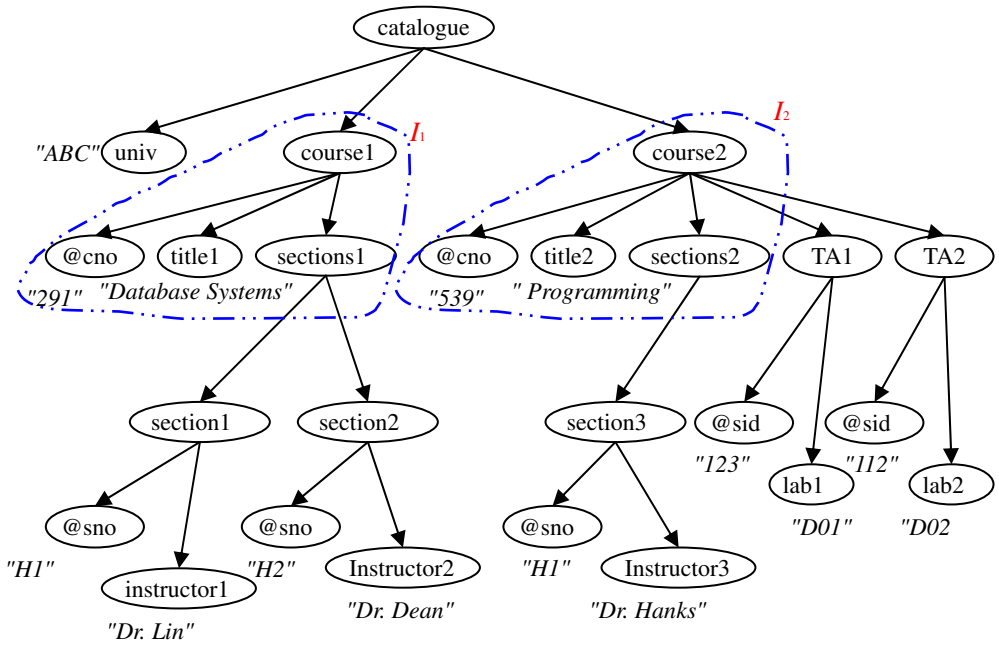


Figure 8: Two instances of region "course".

doc_name	tuple_id	col1	col2
course.xml	1	*catalogue*	ABC

Table 3: The table_1_1 (*root*)

doc_name	tuple_id	p_id	ord	col1	col2	col3
course.xml	7.0	5.0	1	*TA1*	123	D01
course.xml	8.0	5.0	2	*TA2*	112	D02

Table 5: The table_3_2 (*TA*)

the path summary of the document. Second, an XML document structure tree is built and all set-valued nodes are identified. Once the document structure tree is created, it is partitioned into regions represented by set-valued nodes. Then separate database schema is created for each region, and the relational table assignments are recorded in the meta_table.

After creating or assigning tables for each region on the XML document structure tree, the XML data tree is traversed in depth-first-order to load the XML data, instances of each region, into their corresponding tables in the database system.

All the data tables and meta table for the sample document described in Figure 3 are shown in Tables 2 - 6.

As shown in the Table 4, the two instances, I_1 and I_2 (Figure 8), of the "course" region are stored as two tuples in table_2_1.

In this example, the values of "tuple_id" of all the region instances are assigned based on the document order. Figure 9 describes the tuple orders for the example XML document. The "tuple_id" together with the "doc_name" field serves as the primary key of each

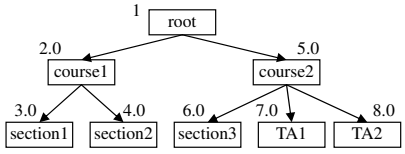


Figure 9: The tuple order.

data table. The "p_id" and "doc_name" field forms a foreign key refer to the parent table in the upper level.

4.3 Discussion

4.3.1 Storing Different XML Documents

It is not feasible to create different schemas for every individual XML document in a system that store a large number of XML documents, because some of the existing database systems still enforce a limit on the number of tables that the database system can hold. So we propose to let different XML documents share a set of relational tables in the system, and only create a new table

when there is no corresponding table_i_j table existed in the system. To distinguish data of different XML documents stored in the same table, we add a document identifier attribute to all the tables in the system.

Although different XML documents may have heterogeneous structures, the concept of nested level is the same. In Xregion, every data table conforms to the same general structure, which make it feasible for different XML documents to share and reuse the existing tables. So we can store XML data of different XML documents into the same table as long as they are at the same nested level of their own relation trees. Table 7 is a snapshot of table *table_3_1*, in which the data of "course.xml" and "test.xml" are stored.

4.3.2 Query Evaluation and Result Publishing

The meta_table of Xregion provides a standard interface for query processing and XML query result publishing. The mapping information of all component of an XML document are recorded as meta-data identified by paths and document name in the meta_table. At query processing time, the system looks up the meta_table and translates XML queries to SQL statements against the relational tables in the database system.

In Xregion, every instance of a region is stored as a tuple in its corresponding region table, any non-set-valued node in a instance is stored in the same tuple with its parent, and the parent of a set-valued node is stored in a record of its parent region table and is identified by the parent_id (p_id) of the set-valued node. So compared with other existing generic mapping approaches, Xregion is much more efficient in evaluating queries.

First, queries on nodes within a region is simplified to one or a limit number of selections on one region table, without the need of join operations, which are otherwise required by other existing mapping approaches. For example, SQL 4, 5 and 6 are translated SQL statements of Xregion, Edge and Xparent, respectively, for the XML query given below.

Example 1 Given the example XML document in Figure 3, find the course title of the course with a course number "291".

Q3: /catalogue/course[@cno="291"]/title

SQL 4: A translated SQL query statement for Q3 using Xregion.

```
SELECT  col3
FROM    table_2_1
WHERE   col2='291'
```

SQL 5 A translated SQL query statement for Q3 using Edge.

```
SELECT title.value
FROM   edge root,edge crs,edge cno,edge title
WHERE  root.label='catalogue'
AND    crs.label='course'
AND    title.label='title'
AND    cno.label='@cno'
AND    root.tgt=crs.src
AND    crs.tgt=title.src
AND    crs.tgt=cno.src
AND    cno='291';
```

SQL 6 A translated SQL query statement for Q3 using XParent.

```
SELECT title.value
FROM   data cno, data title,
       labelpath lp_cno, labelpath lp_title,
       datapath dp_cno, datapath dp_title
WHERE  lp_title.path='/catalogue/course/title'
       AND lp_ta.path='/catalogue/course/@cno'
       AND cno.pathid=lp_cno.id
       AND title.pathid=lp_title.id
       AND cno.value='291'
       AND title.did=dp_title.childid
       AND cno.did=dp_cno.childid
       AND dp_title.parentid=dp_cno.parentid;
```

As we can see, both Edge and XParent approaches require join operations to ensure that the "@cno" nodes and "title" nodes are belong to the same "course" elements. For Xregion, the "@cno" and its corresponding "title" are stored in the same tuple with "course", so it only need a single selection on "@cno" and a projection on "title".

Furthermore, Xregion makes the searching for ancestor information more efficient than existing mapping approaches. Xregion transforms the hierarchical structure of an XML document to a relatively simple nested structure among regions (relations), which are normally much shallower than the structure tree. So the process for searching ancestor of nodes is converted to search ancestor of regions, which reduces the number of join operations for complicated queries. It is this feature that makes efficient query evaluations possible.

As an example, SQL 7, 8 is a translated SQL statement of Xregion and Xparent, respectively, for the example XML query discussed in Section 2.

Example 2 Find the TAs who work with Dr. Hanks.

Q2:/catalogue/course[sections/section/instructor ="Dr. Hanks"]/TA

SQL 7: A translated SQL query statement for Q2 using Xregion.

```
SELECT ta.col1, ta.col2, ta.col3
FROM   table_3_1 inst,table_3_2 ta
WHERE  inst.col3='Dr. Hanks' AND
       ta.p_id=inst.p_id
```

SQL 8: A translated SQL query statement for Q2 using XParent.

```
SELECT ta.did
FROM  data ta, data inst,
      labelpath lp_ta, labelpath lp_inst,
      datapath dp_ta, datapath dp_inst,
      datapath dp_section, datapath dp_sections
WHERE lp_inst.path='/catalogue/course/
          sections/section/instructor'
   AND lp_ta.path = '/catalogue/course/TA'
   AND ta.pathid = lp_ta.id
   AND inst.pathid = lp_inst.id
   AND inst.value = 'Dr. Hanks'
   AND inst.did = dp_inst.childid
   AND dp_inst.parentid=dp_section.childid
   AND dp_section.parentid=
         dp_sections.childid
   AND ta.did = dp_ta.childid
   AND dp_sections.parentid=dp_ta.parentid
```

Using Xregion, we only need to check whether the "instructor" and "TA" are connected by same instances of their parent region *course*, whereas Xparent requires a number of joins to check the connection *instructor*←*section*←*sections*← *course*→*TA*, in order to make ensure that the pairs of nodes, "TA" and "Instructor", are connected by the same "course" nodes. Figure 10 is a graph depiction for tracing the nearest common ancestor "course" under Xregion and XParent schemas, which shows that XParent needs to check two more steps than Xregion for the example query.

XML query result publishing is another important aspect for evaluating an XML-to-Relation mapping approach. Most XML query languages return the query result in XML format, which consists of the value of the satisfied element nodes together with all their descendants.

Xregion also speeds up the XML query result publishing process. Because all children nodes, except for the set-valued child nodes, of an element are stored in the same relation as the element. So under Xregion schema, transforming the answer from relational database to XML format, does not involve expensive operations. For example, shown in the SQL 7, all the content of "TA" elements can be retrieved from a single table. However, for other existing approaches, they still need a number of join operations to construct the query result in XML format, due to the high fragmentation of the XML data stored in the database. For example, four more joins on Data tables and DataPath tables are involved for answering the above query by XParent approach.

5 Implementation

We have implemented a prototype of an XML importing system, called XML Loader, as per the mapping approach described in previous section, for storing XML documents into relational databases. Figure 11 describes the architecture of our XML importing system. There are three main modules: XML Parser, Schema Generator and XML Data Loader. The XML Parser reads the input XML document(s), extracts XML tag name and value of each node in the document, materializes the path for each node and detects all the set-valued nodes. The Schema Generator identifies regions for each set-valued node and creates the corresponding mapping schemas for the XML document. The Data Loader module takes the schema information generated in the Schema Generator module, composes tuples according to the relation assignment and loads those tuples into their corresponding tables in the underlying database. The whole programs have been completely written by us using the JAVA programming language(Java^{TM} 2 Platform, Standard Edition, v 1.4.1) and JDBC (Java Database Connectivity 2.0).

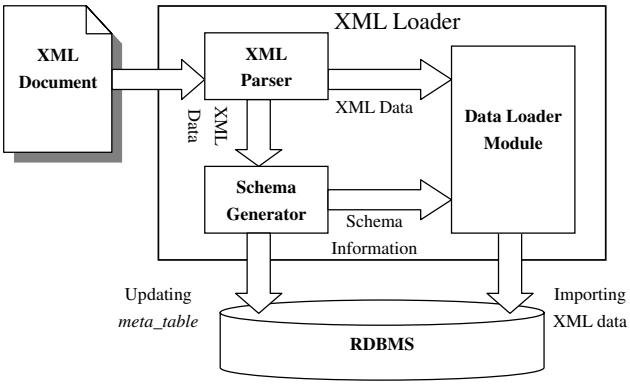


Figure 11: The prototype of the XML importing system.

XML Parser Module: our XML parser module is implemented based on the SAX interface. The major output of the XML Parser module is the completed paths set and set-valued nodes set, i.e. the document structure tree, of the input XML document. Since our parser does one sequential scan over the input XML document, we cannot navigate back and forth to retrieve the ancestor information of a given element node. So in implementation, we introduce a path stack to trace the local hierarchical structure and node occur-

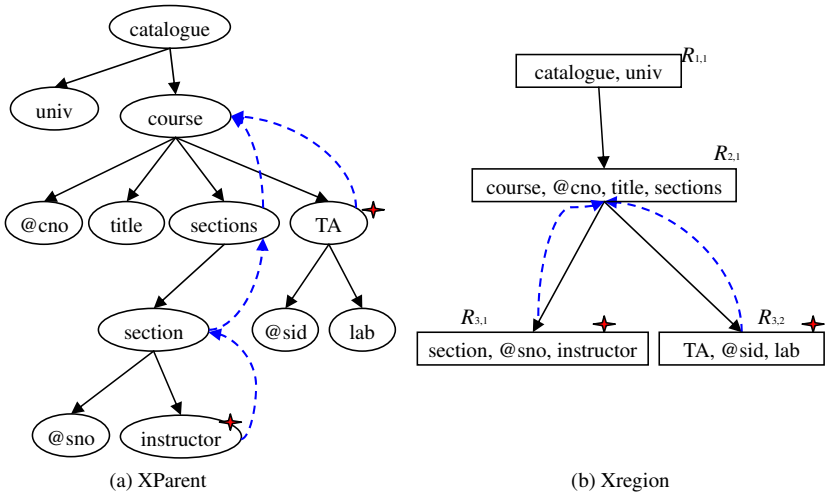


Figure 10: Ancestor tracing route for XParent VS Xregion

rence of an XML document. At any given time the peak of the stack is the parent information of the incoming node.

Schema Generator Module The Schema Generator module is the core component of our XML Loader system. Figure 12 shows a simplified view of the schema generation procedure. First, the XML document structure tree obtained from XML Parser module is partitioned into regions by set-valued nodes. Then relational tables are assigned to all regions according to their nested levels on the region tree. In the case that there is no corresponding table for a given region existed in the underlying database, a new table representing the region will also be created in the schema generating process. At the end of the schema generation procedure, the *meta_data* table will be updated for this new XML document.

Data Loader Module The Data Loader module reads the schema meta data generated by Schema Generator Module, identifies region instances and composes tuples with tuple_id and parent information, and loads the tuples into their corresponding tables.

In our system, an XML document is loaded into database incrementally by one-pass sequential scan. So it can process very large XML documents, as long as the size of the document supported by the underlying operating system.

The important feature of identifying region instance is that the procedure of constructing one region tuple may interleave the process of composing tuples of other regions, due to the nested structure of XML documents and sequential scan. For example, shown in Figure 14, the construction of a *course* tuple, is interrupted by that of two *section* tuples.

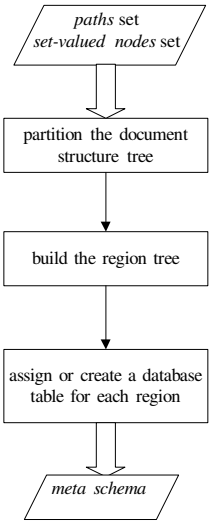


Figure 12: Schema Generator

In implementation, we design a special stack to keep all ongoing region instances, and only pop out a instance from the stack when the file reader encounters the end tag of its region root(the set-valued node), which indicates the completeness of this instance. As can be seen, the size of the stack is less than the depth of the region tree, which is much shallower than the XML data tree.

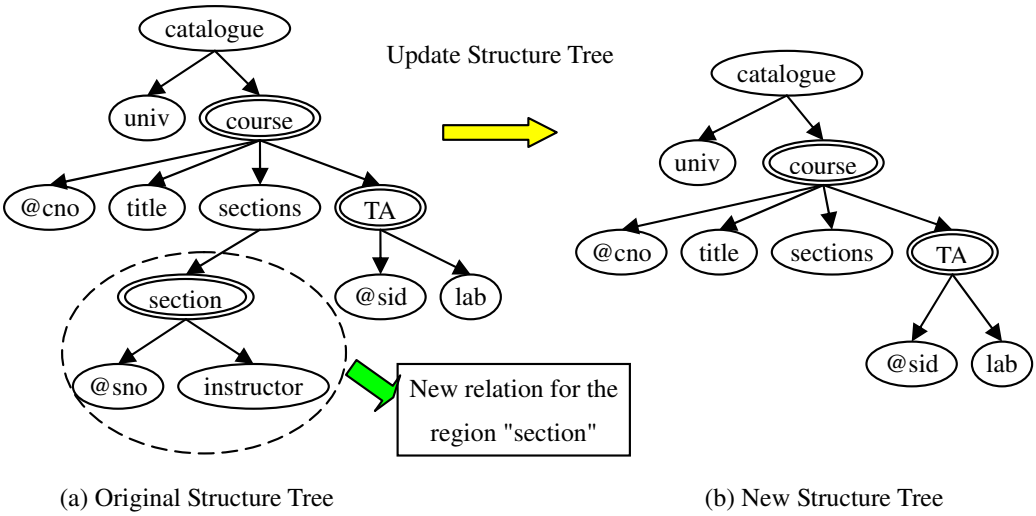


Figure 13: Generating a relation for the deepest set-valued node *section* and update the structure tree by cutting the *section* sub tree off.

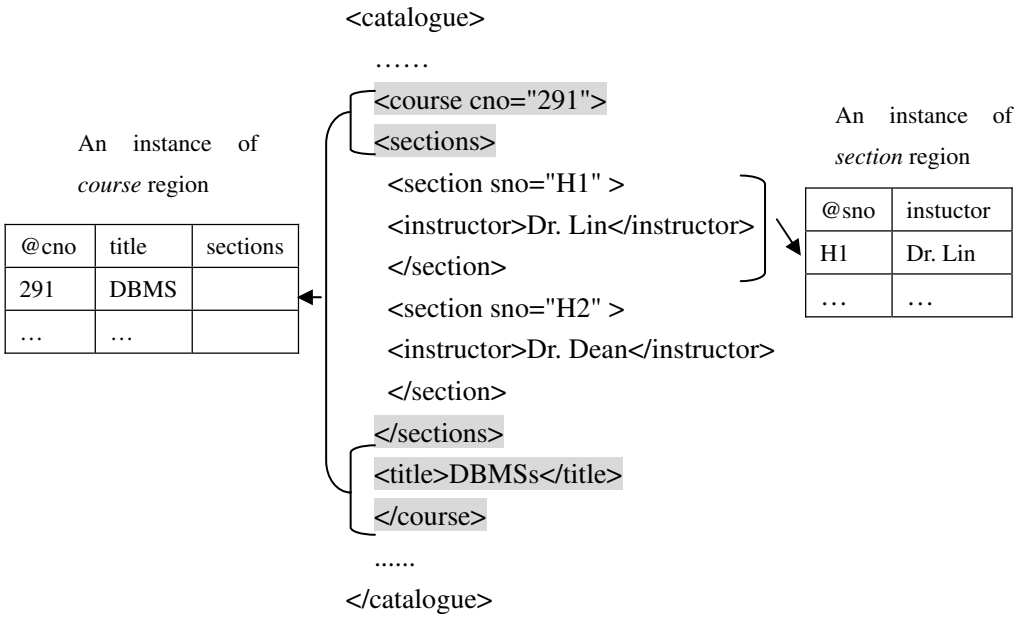


Figure 14: An instance of *course* region split by two *section* region instances

6 Experiments

To evaluate the effectiveness and scalability of the proposed XML generic mapping approach Xregion, extensive experiments have been conducted. In this section, we compare the performance of the Xregion with the Edge mapping, and XParent approach. The capability of storing and querying a large number of different XML documents in a single database has also been tested, and corresponding results will be discussed in this section.

6.1 Experimental Setups

For the purpose of performance comparison, we also implemented the Edge mapping and XParent mapping approaches using Java programming language and SAX parser API. All experiments were conducted on a

Name	Size	#paths
SHAKS	7.65MB	57
DBLP	200MB	156
SYN2G	2GB	156

Table 8: Data sets information

PIII/1GHz PC with 1G RAM running Red Hat Linux release 7.1. The relational database system used in the study was Oracle 9i Database Standard Edition release 2. We selected three different XML data collections, with size of 7.65M, 200MB and 2GB respectively, as our data sets, which contain XML documents with various depths and sizes. In order to cover different aspects of XML queries over XML data, queries were selected carefully for the corresponding data collections. Table 8 summaries the features of three XML collections in our experiments.

6.1.1 Data Sets

- SHAKS
  SHAKS consists of 37 Shakespeare plays in XML document format with the average size of 277kB and 30,000 words. The maximum depth of nested XML tags is 5 (Play/Act/Scene/Speech/Line). The whole collection, created by Jon Bosak, is available at

  `http://metalab.unc.edu/bosak/xml/eg/shaks200.zip`.

- DBLP (200MB)
  The DBLP data set is a large XML document downloaded from the DBLP server

  (http://dblp.uni-trier.de/xml/). The DBLP data set used in our experiment contained the data till Jan, 2004, which listed more than 470,000 articles. The size of this DBLP XML document is 200M.

- SYN2G (2GB)
  To test the scalability of these three XML relational mapping approaches, Xregion, Edge and XParent, we generated a synthetic XML document with the size of 2GB from the DBLP data set.

The SYN2G XML document used in this experiment is constructed by concatenating 9 modified DBLP with the original DBLP. The whole process is one sequential scan of the DBLP file using SAX for Java.

The rule used in modification is to keep numeric values unchanged, and only modify letters. In order to simulate the real distribution of authors and their publications, we also keep the values of "author" elements unchanged. A randomly generated 5-letter dictionary is used to translate each occurrence of any letter specified in the dictionary to its corresponding letter, at every time creating a new version of DBLP. For example, a title "An Object-Based Approach to the B Formal Method" is translated into "An Objezt-Based Ajjroazr to tre B Formal Metrod" based on the following 5-letter dictionary.

letter	new value
c	h
h	r
k	o
p	j
v	f

6.1.2 Query Set

For experiment on the DBLP and SYN2G XML documents, we used the queries from XParent and those presented by F. Tian et al [12] as query templates. The queries experimented in Xrel [14] was selected for testing the SHAKS data set. These queries test a variety aspect of query performance. In all, we test eighteen different queries in our benchmark.

All benchmark XML queries in the experiment were translated by us into a set of SQL statements, one for each XML query, and executed in ORACLE with session setting SQLTRACE enabled.

6.1.3 Performance Measurement

We compare the Xregion with Edge and XParent approaches with respect to query performance, such as query elapsed times and I/O blocks, as well as the size of resulting database for these mapping schemas.

In all our experiments, the size of the database buffer is set to 32 MB, which is much less than the size of DBLP and SYN2G XML documents, while four times larger than the size of SHAKS. Indexes are built properly on relational tables for all three mapping approaches. For Edge and XParent, we created indexes as proposed in [6] [7]. For Xregion, major indexes are composite indexes on table_i_j(doc_name, tuple_id), table_i_j(doc_name, p_id) and meta_table(doc_name, path).

All benchmark data, such as total elapsed time and I/O blocks of the translated SQL queries, are obtained from Oracle database trace file and formatted with the TKPROF utility provided by Oracle RDBMS. The sizes of database tables and indexes are calculated from the statistics generated by the Oracle database.

6.2 Experiment Results

In this paper we present experimental results of XML queries on three different XML collections with size of 7.65M, 200MB and 2GB respectively. In order to get reproducible experimental results, all the benchmark queries are executed for 5 times before timing. All the results reported are obtained after warming up the database buffer, and are based on the average elapsed times of 10 to 40 executions. The experiment results and discussion are given below for each data set.

6.2.1 Experiment on SHAKS

The SHAKS data set was experimented by many XML Relational mapping approaches in literature. We also experimented on SHAKS using the same queries used in Xrel[14] and XParent [7], in order to compare the query performance of our proposed approach Xregion with the other three mapping approaches, Edge, XParent and Xrel, on small XML documents, as well as check the correctness of our system by comparing the query results published in other papers[14].

The queries for the SHAKS XML collection are as follows.

- SQ1 /PLAY/ACT
- SQ2 /PLAY/ACT/SCENE/SPEECH/LINE/STAGEDIR
- SQ3 //SCENE/TITLE
- SQ4 //ACT//TITLE
- SQ5 /PLAY/ACT/SCENE/SPEECH [SPEAKER="CURIO"]
- SQ6 /PLAY/ACT/SCENE[//SPEAKER="Steward"]/ TITLE

The elapsed times of all queries for SHAKS are shown in the Figure 15 in logarithmic scale. All queries were executed 40 times to get a better precision. Because the size of SHAKS (7.65MB) is far less than the database buffer size (32MB), all mapping approaches do not require physical reads for evaluating all benchmark queries. Table 9 shows the number of logical I/Os, which are the database buffer cache reads, involved in each query for all three mapping approaches.

For all queries, Xregion outperforms other mapping approaches, and the elapsed time for each query is less than 0.01 sec. XParent performs similarly for SQ1, SQ2, SQ3 and SQ4, which queries only contain one path expression. However, for SQ5 and SQ6, which contain more than one simple path expressions, Xrel is much slower compared with other mapping approaches, because non-equijoins on element start and end positions are involved for evaluating these two queries. Edge approach consumes much time for SQ2 and SQ4, which either query on a long path expression or contains a "//" in the middle of a path expression, since it need a lot of joins to check the connection of all possible steps on the path expressions.

#of element nodes	179,689
#of attribute nodes	0
#of text nodes	147,442
#of simple paths	57

Table 10: Test data details for SHAKS XML collection(8MB)

Approach	Database size	#rows	#tables
Xrel	10.1MB	327131	3
xp	11.13MB	506820	4
edge	8.45MB	179689	1
xregion	8.37MB	177655	26

Table 11: Sizes of resulting database tables for Xregion, XParent and Edge schema of SHAKS XML collection(7.65MB)

Table 11 shows the size of the resulting relational database tables for each mapping schema.

6.2.2 Experiment on DBLP

For testing the DBLP, we adopted the queries from XParent and those presented by F. Tian et al [12] as query templates, which test a variety aspect of query performance. The followings are 6 query templates for the DBLP XML document.

- Q1 Select title of inproceedings by year and a keyword, such as "XML".
- Q2 Select articles written by author A.
- Q3 Select papers written by author A or author B.
- Q4 Select titles of papers published between year a and year b, with titles starting with a keyword, e.g. "Database".
- Q5 Select journal papers by a label of a cite entry.
- Q6 Select journal papers by author A quoted by papers published in a given year.
- Q7 Select journal papers by author M that are quoted by author N.

Query Retrieval

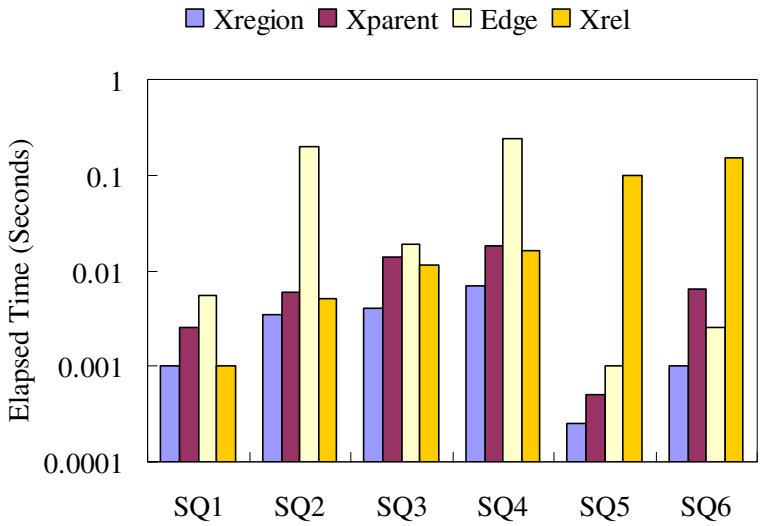


Figure 15: Query elapsed time for querying the SHAKS (size 7.65MB) using Xregion, XParent, Xrel and Edge

I/O Blocks

Query	Xegion	XParent	Edge
Q1	267	1228683	182288
Q2	253	1373	2455
Q3	380	1975	3132
Q4	1426	113910	9730
Q5	6	26	19
Q6	1063	96668014	38809339
Q7	919	289021	19728401

Elapsed Times(Seconds)

	Xregion	Xparent	Edge
Q1	0.03	17.18	4.44
Q2	0.003	0.01	0.02
Q3	0.005	0.02	0.03
Q4	0.11	1.82	0.16
Q5	0.002	0.003	0.003
Q6	0.01	1768.39	838.39
Q7	0.01	2.25	428.64

Table 12: I/O blocks and elapsed times for querying the DBLP (size 200MB) using Xregion, XParent and Edge

The elapsed times for all queries are shown in the Figure 16 in logarithmic scale and the number of I/O blocks involved together with elapsed times are shown in Table 12. These results show that Xregion dramatically improve the performance of query evaluation.

For simple queries that only contain simple path expressions and key search, such as Q2, Q3 and Q5, Edge and XParent performs comparably with Xregion,

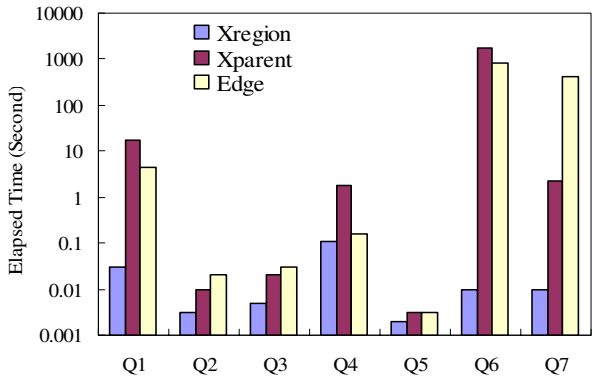


Figure 16: Query elapsed time for querying the DBLP (size 200MB) using Xregion, XParent and Edge

in that all re in the same magnitude.

For query Q1, which requires text matching, e.g. '%XML%', the performance of Edge and XParent are very inefficient, because they need to search the entire Data or Edge table for this matching operation. For some other complicated query, such as Q6 and Q7, Xregion outperforms the Edge and XParent significantly.

For Q6, XParent performs even worse than Edge. Although XParent or other path based mapping approaches can locate a node in the XML tree directly with the aid of path information stored in the relational schemas, they still need a lot of joins tracing nearest

Approach	DB size	#rows	#tables	index
XParent	323MB	16472978	4	416MB
Edge	237MB	5643462	1	296MB
Xregion	176MB	2777916	47	115MB

Table 13: Sizes of resulting database tables and indexes for Xregion, XParent and Edge schema of DBLP XML document.

common ancestors for processing queries with multiple paths and predicates specified on different branches. For example, query Q6 that contains four paths and three conditions. The following is Q6 using XQuery syntax.
Q6 Select journal papers by author Jim Gray quoted by papers published in 1995.

```
<result>
 {
 LET $cite:= document(dblp.xml)/dblp/article
          [year=‘‘1995"]/cite
 FOR $journal IN document(dblp.xml)/dblp/article
 WHERE $journal/author=‘‘Jim Gray" and
     $journal/@key=$cite
 RETURN
     $journal
 }
</result>
```

XParent uses 4 path selections and 10 joins to locate and check the connections among nodes involved in the query. Edge approach requires 7 selection on edge labels and 6 self-joins for checking edge connections to evaluate Q6. Because Xregion stores XML documents by regions, which groups nodes with one to one relationships to each other in one relation, e.g. the “year” and “cite” are stored in the same table with “article”, so Xregion use only 2 joins for connecting “author” relation with “article”.

6.2.3 Database Size

The resulting database sizes of mapping schemas are also a critical issue, when storing large XML documents into RDBMSs. Table 13 shows the size of the resulting relational database tables and indexes for three mapping schemas.

The size of the DBLP XML document is 200 MB. We see Xregion even use less spaces than the original DBLP file. It is because that all non-set-valued nodes of the XML document are stored in the same tuples as their parents. The total number of rows in the database of Edge schema shows that there are 5,643,462 nodes in the XML document, and that of Xregion schema, 2,777,916, shows that more than 50% of the nodes are inlined with their parent nodes.

Query	DBLP(200MB)	SYN2G(2GB)	Ratio
Q1	0.03	0.35	11.6
Q2	0.003	0.03	10
Q3	0.005	0.04	8
Q4	0.11	1.18	10.7
Q5	0.002	0.003	1.5

Table 14: Ratios of the elapsed times for querying the DBLP vs SYN2G for Xregion schemas

The sizes of database for Xparent schemas is more than 40% larger than the DBLP file, because it stores element nodes and their text values separately, and both tuples of an element nodes are bundled with position information. In addition, XParent also use another table DataPath table to record the parent-child relationships between element nodes, so the database size of XParent is the largest among all three mapping approaches.

Xregion also use less space for indexes, while XParent consumes more than 2 times of space for indexes.

6.2.4 Experiment on SYN2G

In order to inspect the scalability of our mapping approach, we generate a synthetic XML document SYN2G, by enlarging the size of original DBLP XML document to 2GB. In generating the new test XML document, we take care to keep the ratio of different elements and attributes in the original DBLP document.

We used the same query templates Q1 to Q5 of DBLP data set, and the same set of author names, year and paper types for experiment on the SYN2G XML document for Xregion, Xparent and Edge approaches. The sizes of the resulting databases of all these three mapping approaches scaled about 10 times the sizes of their corresponding database for DBLP data set.

Table 14 shows the query elapsed times ratio for Xregion on DBLP and SYN2G XML documents. The ratios for all queries except Q5 are around 10, which is the ratio of the size of DBLP and SYN2G.

The elapsed times of Q1 to Q5 for all three mapping approaches are shown in Figure 17 in logarithmic scale and the corresponding I/Os involved are displayed in Table 15.

These results show that the scalability of Xregion approach is superior to that of XParent an Edge. Most of the queries evaluated in Xregion schema were running within 1 second, whereas it took the other two methods several minutes to execute a single query.

Figure 18 shows the ratio of query elapsed time for DBLP and SYN2G using Xregion, XParent and Edge. The performances of XParent and Edge degrade dra-

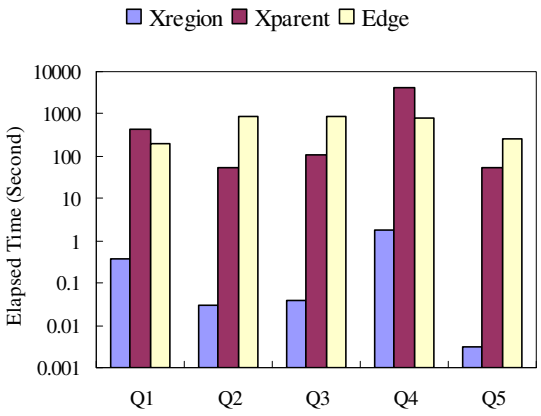


Figure 17: Query elapsed time for querying the DBLP (size 2GB) using Xregion, XParent and Edge

Query	Xregion	XParent	Edge
Q1	4464	1439115	2486350
Q2	3560	113920	16345182
Q3	5209	226412	17040573
Q4	20567	9338007	18676595
Q5	26	109664	7728207

Table 15: I/O blocks for querying SYN2G (size 2GB) using Xregion, XParent and Edge

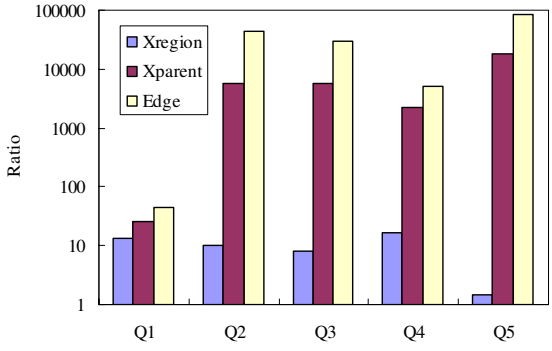


Figure 18: Query elapsed time ratios for DBLP and SYN2G using Xregion, XParent and Edge.

Data set	Size	Time
SHAKS	7.65MB	4.965 sec.
DBLP	200MB	66.868 sec.
SYN2G	2GB	412.569 sec.

Table 16: The elapsed time for schema generation

matically on large XML documents. It is because data are scattered with a high fragmentation degree in relations, a number of joins are needed to tracing ancestor information, and the data involved in the join operations are in very large volume.

6.2.5 Schema Generation Time

Different from other existing approaches, which use fixed schemas for storing XML documents, Xregion creates or assigns database schema for an XML document at the parsing time according to the structure of the underlying document. In our experiment, we also measured the schema generation times for Xregion ,which are shown in Table 16. The results show that the schema creation for XML documents using Xregion schema can be done within several minutes, even for large documents.

7 Conclusions and Future Work

In this paper, we have presented a new generic mapping approach, called Xregion, to storing XML data in relational database systems, based on reducing the fragmentation level of XML data in relations. Performance study showed promising results that Xregion outperforms existing generic mapping
techniques, such as Edge mapping and Xparent, especially for large XML documents. For example, every query on SYN2G in Xregion schema consumes less than 1.2 seconds, while it takes XParent or Edge several minutes to evaluate a single query. The new approach keeps the nested structure of XML documents and stores all non-set-valued nodes in the same tuples with their parents, which in turn reduces the number of join operations for complicated queries in query processing.

The proposed mapping method is a meta-data driven approach and no relational schema assignments are hard-coded. In addition, our method can store different XML documents in a limited number of tables. The mapping information of all component of an XML document is recorded as a meta-data identified by paths and document name. Since the schema is not hard-coded, the maintainability and flexibility are enhanced. Furthermore, this new mapping approach provides a standard interface for query processing and XML publishing. All changes of the relational schema assignments for an

XML document are transparent to the query processing module, since the interface of query processing is the meta-data stored in the meta_table.

We have implemented an XML importing system based on proposed approach. This system can create relational schema for any well-formed XML document, with or without DTD information, and load its data into the database automatically. The system can be easily built on top of off-the-shell relational database management systems.

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doc_name	Path	table_name	col_name	p_table
course.xml	/catalogue	table_1_1	col1	
course.xml	/catalogue/univ	table_1_1	col2	
course.xml	/catalogue/course	table_2_1	col1	table_1_1
course.xml	/catalogue/course/@cno	table_2_1	col2	table_1_1
course.xml	/catalogue/course/title	table_2_1	col3	table_1_1
course.xml	/catalogue/course/sections	table_2_1	col4	table_1_1
course.xml	/catalogue/course/sections/section	table_3_1	col1	table_2_1
course.xml	/catalogue/course/sections/section/@sno	table_3_1	col2	table_2_1
course.xml	/catalogue/course/sections/section/instructor	table_3_1	col3	table_2_1
course.xml	/catalogue/course/TA	table_3_2	col1	table_2_1
course.xml	/catalogue/course/TA/@sid	table_3_2	col2	table_2_1
course.xml	/catalogue/course/TA/lab	table_3_2	col3	table_2_1

Table 2: The meta_table.

doc_name	tuple_id	p_id	ord.	col1	col2	col3	col4
course.xml	2.0	1	1	*course1*	291	Database System	*sections1*
course.xml	5.0	1	2	*course2*	539	programming	*sections2*

Table 4: The table_2_1(*course*).

doc_name	tuple_id	p_id	ordinal	col1	col2	col3
course.xml	3.0	2.0	1	*section1*	H1	Dr. Lin
course.xml	4.0	2.0	2	*section2*	H2	Dr. Dean
course.xml	6.0	5.0	1	*section3*	H1	Dr. Hanks

Table 6: The table_3_1 (*section*)

doc_name	o_id	p_id	ord	col1	col2	col3
...	...	...	...	...	..	
course.xml	3	2	1	*section1*	H1	Dr. Lin
course.xml	4	2	2	*section2*	H2	Dr. Dean
course.xml	6	5	1	*section3*	H1	Dr. Hanks
test.xml	4	3	1	h1	j1	
test.xml	6	3	2	h2	j2	
...	...	...	...	...	..	

Table 7: Two different XML documents share the table_3_1.

Query	Xregion	Xparent	Edge	Xrel	#tupples returned
SQ1	20	202	598	18	185
SQ2	47	387	21685	49	618
SQ3	73	705	709	658	750
SQ4	96	930	29599	876	951
SQ5	10	33	64	116	4
SQ6	29	427	183	3952	6

Table 9: Logical I/O blocks for querying the SHAKS using Xregion, XParent, Xrel and Edge