Storing Linked XML Documents in Object-Relational DBMS

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Currently, several researchers have proposed mapping both structure and constraints of XML documents to an object-relational database (ORDB). However, these researches cannot be conducted because of the limited range of constraints in available object-relational DBMSs. We therefore propose mapping rules that are practicable in available technologies. Normally, an XML document is treated as a database, so much data redundancy occurs. To solve this problem, we keep non-redundant data in several separate XML documents, link the data dispersed in these documents together by a mechanism called ‘rlink’ and then map this mechanism to ORDB. Finally we perform a case study in Oracle9i to illustrate the mapping of XML to ORDB according to our rules. Our contribution is that we find that mapping linked XML documents to traditional databases such as (O)RDB makes it easier to join several documents and to update several documents in one update command.

Keywords: XML, semi-structured data, constraints, linked XML documents, ORDB

1. Introduction

When XML (Extensible Markup Language) became an effective standard for representation of structured and semi-structured data on the Web, researches were undertaken to store [10, 23], query [13, 10, 8, 6, 7] and publish [30, 4, 11] XML documents. A dominating approach for storing XML documents is applying traditional databases: relational database (RDB), object-oriented database (OODB) and object-relational database (ORDB) to manage XML documents. Mapping XML documents to RDB is a most popular research [39, 19]. However, the structure of XML documents is hierarchical whereas relational structure is flat; thus it is not a good fit. To fit the structure of XML documents to traditional databases, it seems that OODB [1] is suitable; nevertheless, some constraints such as not null and delete cascade are not supported by OODB [5]. In ORDB, constraints are inherited from RDB; nevertheless, not every feature in ORDB supports constraints. Our motivation comes from three reasons as follows.

- There is some research [26, 20] presented to map XML documents to ORDB, but it is not practicable though researchers [26] claim to use SQL4. One open problem is that available DBMSs have not supported all the features of SQL4.
- Usually, an XML document is treated as a database keeping all data in one document; thus data redundancy always occurs. The problem of data redundancy can lead to data inconsistency and low performance when updates are performed. Some work [9, 3] presented the technique of reducing data redundancy during mapping XML documents to RDB by using XML functional dependencies. However, with this method, data in the XML documents differ from the data in the database; thus it becomes difficult to maintain different data sets between the two storages.
- Updating several XML documents or performing joins between XML documents in one update command is not easy and thus, presently, no work proposes a methodology for this task. This will be discussed in Section 7.

In our approach, we will demonstrate how to map both structure and constraints of XML doc-

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documents to ORDB with awareness of practicability in available technologies whereby several object-relational features can be exploited. We store non-redundant data in separate XML documents and then propose a mechanism for linking these separate documents together and propose the rules for mapping these linked XML documents to ORDB. The result derived from a case study by mapping XML to ORDB is conducted through Oracle9i.

The rest of this paper is organized as follows. Related work is discussed in Section 2 and a mechanism for linking XML documents is proposed in Section 3. Section 4 describes the rules for mapping linked XML documents to ORDB and Section 5 describes the rules for mapping constraints to ORDB. We present the preserving of order of XML elements in Section 6. and a case study in Section 7. Finally, conclusion and further work are discussed in Section 8.

2. Related Work

There are a number of researches concentrating on mapping XML documents to traditional databases. These researches can be separated into two categories: automatic mapping and non-automatic mapping. The non-automatic mapping method [14] requires users to specify how to map the structure of XML to the schema of a database and this method is proposed by several commercial DBMSs such as IBM DB2 and Oracle database server [28]. Our work focuses on the automatic mapping of XML documents to traditional databases proposed by several previous workers as follows.

For RDB, [31] utilized a DTD graph to represent a DTD and to find a good mapping strategy. The researchers proposed three approaches: basic inlining, shared inlining and hybrid inlining techniques to map DTD to relational schema. They indicated that the hybrid inlining technique is superior to basic inlining and shared inlining techniques. [10] adapted a data mining algorithm to identify supported patterns for storage in relations and combined semistructured and relational techniques to process semi-structured data by using OEM model and RDB to store and manage semi-structured data. [12] evaluated several mapping techniques and indicated that the best overall approach is the attribute approach. However, another research presented by [35] identified that the attribute approach has a poorer performance than the DTD approach. [18] use both DTD and XML documents for mapping. They keep elements and path of elements in one table and keep attributes and path of attributes in another table. The reference between elements is represented by path-IDs kept in the tables. [39] presented their system called X-Database system which uses the XML-Schema file to generate a RDB schema and then decomposes valid XML documents according to the Schema to store their information in the database.

From the above researches, only [39] performed mapping constraints to database. However, mapping XML to RDB can produce many unnecessary tables leading to unnecessary joins in querying since usually XML documents contain multi-value attributes while mapping these data to RDB is performed by putting the data into separate tables.

For OODB, [1] proposed an approach to map semi-structured data (SGML) to an object model. In this approach, each SGML element definition in DTD is interpreted as a class, choice connector (|) is modeled by a union type, element components marked by “+” or “*” occurrence indicator are represented by lists, attributes are represented by private property of the class. Nonetheless, mapping semantics (constraints) of semistructured documents is not proposed because of the limited constraints of OODB.

In the case of ORDB, [32] proposed the method that decomposes XML documents into the nodes and stores them in four tables: element, attribute, text and path tables while [27] used XML data type to store a fragment of an XML document. However, these researchers did not use any object-relational feature. [20] and [23] exploited set/list and nested tables which are features of ORDB, but no DBMS supports both set/list and nested tables in one ORDB (Informix [17] supports list/set, Oracle [24] supports nested tables while PostgreSQL [25] supports array). In addition, [23] defined foreign keys in nested tables whereas [20] used several constraints such as domain and default constraints in collection type and [26] defined primary keys in collection type. Defining the full
range of constraints in nested tables or collection type is restricted in available object-relational DBMSs; thus none can be conducted. [36] mapped XML to ORDB by using UniSQL, but the researchers did not employ constraints and UniSQL/X itself is based on OODB having limited constraints [38].

To summarize, none of the previous work mapping both structure and constraints of XML to ORDB can be conducted in existing technologies; furthermore, none of the previous work mapped several types of linked XML documents to traditional databases; thus all XML update languages such as Extended XQL [42] and XML update extension [33] including update languages [43, 2, 29] for native XML database were designed to update an XML document without joins between documents.

3. A Mechanism for Linking XML Documents

In the case of (O)RDB, foreign keys and reference type are employed to represent inter-table references; thus to model linked XML documents, the mechanism for linking XML documents can be translated into foreign keys. For XML documents, XLinks (XML Linking Language) [41] and XInclude [40] are mechanisms for linking the documents together. However, XLink and XInclude are not designed from a database viewpoint; thus they do not provide enough information for linking XML documents from a database point of view. Moreover, XInclude [15] does not allow circular reference (recursion). The major purpose of XLink is to link XML documents in the Web while the main purpose of XInclude is to build a large XML document out of smaller XML documents. In our research, we propose a mechanism called rlink whose purpose is to associate the relationships between elements from different XML documents so that this provides more convenience for updating data across XML documents. The rlink provides information to identify the document and/or element to which a link is made. Although this may be extended to XLink, the main purposes of XLink and rlink are different from each other and currently only Mozilla and its derivatives such as Netscape support XLink, but the support is incomplete [16]; moreover, no XML query language supports XLink so we do not wish to make any extension to it.

To associate the relationships between elements from different documents, we propose two additional attributes, rlink:relationship and rlink:href. The rlink:relationship indicates which document and/or element are involved in the rlink mechanism whereas the rlink:href links to the document and the element specified by rlink:relationship. The ‘rlink’ is used as a namespace.

The rlink mechanism will only serve the function of linking XML documents; thus elements containing rlink mechanism must be EMPTY and have no other attributes except rlink:relationship and rlink:href. In DTDs, the format of

```
<ELEMENT Publications(Publication*)>
  <ELEMENT Publication(Title, Year, Author*)>
    <ATTLIST Publication PubID ID #REQUIRED>
    <ELEMENT Title(#PCDATA)>
    <ELEMENT Year(#PCDATA)>
    <ELEMENT Author EMPTY>
      <ATTLIST Author rlink:href CDATA #REQUIRED>
      rlink:relationship #FIXED "Authors.xml::Author"
    </ELEMENT>
  </ELEMENT>
</ELEMENT>
```

```
<ELEMENT Authors(Author*)>
  <ELEMENT Author(Name, Email?)>
    <ATTLIST Author AuthorID ID>
    <ELEMENT FName(#PCDATA)>
    <ELEMENT LName(#PCDATA)>
    <ELEMENT Email(#PCDATA)>
  </ELEMENT>
</ELEMENT>
```

Fig. 1. Publications.xml and Authors.xml.
value assigned to rlink:relationship is Linked-
Document::LinkedElement and its property is
FIXED while the value type of rlink:href is
CDATA. In XML documents, the format of the
value assigned to rlink:href is an XPath clause
linking to the document and the element speci-

To illustrate this, we will give an example of
using rlink:relationship and rlink:href in DTDs
and XML documents as follows:

Example 1: Suppose that there are two XML
documents: Publications.xml and Authors.xml
linked together by rlink as shown in Figure 1.
From the XML documents in Figure 1, the Au-
thor element in Publications.xml uses rlink:href
as an attribute to link information of Author
having AuthorID = A222 from Authors.xml
whereas rlink:relationship in part of DTD is
used to indicate which document and which el-

dament rlink:href will link to.

The recommendation for separating XML doc-

ument is as follows. C1 and C2 are complex

elements (elements consisting of sub-elements
or attributes) and value(E) is the value of ele-

ment where E is an element. If several C1 can
refer to the same value C2, the C2 should be

parated into another document.

For example, Publication and Author are com-
pelx elements where several publications can
have the same author. Therefore Author is sep-

ated into another document. Another exam-
p is that Author and Address (of author) are
complex elements as each author has a different
address; but here there is no need to separate
Address into another document. This principle
is only a recommendation. Users may or may
not separate a XML document into several doc-
uments. However, our mapping-rules support
both forms of documents.

Note: The attribute rlink:relationship used in
the DTD is applied to IDREF(s) to indicate the
involved elements.

4. Mapping Linked XML Documents
to ORDB

In this section, firstly we discuss the type of
recursion that can occur in DTD, secondly we
propose rules for mapping an XML document
to ORDB and finally we present additional rules
for mapping the rlink mechanism to ORDB. A
diagram for mapping XML structure and rlink
to ORDB is shown in Figure 2.

4.1. Forms of Recursion in DTD

In our research, mapping XML documents to
ORDB is based on DTD since DTD is more
compact than XML Schema; nonetheless, map-
ping XML documents based on XML Schema
will be our future work. Normally, there are two
forms of recursion in DTD. The first form of re-
cursion comes from a recursive structure: an
element contains its ancestor elements as child
elements. The second form of recursion stems
from IDREF(s). As we propose the rlink mech-

anism, the third form of recursion results in the

case that two elements in two XML documents
refer to each other.

4.2. Rules for Mapping Structure of an XML
document to ORDB

In our mapping rules, three features of object-
relational technology: abstract data type, ob-
ject table and nested tables, will be used. In
the rules, elements having type #PCDATA and
without attributes are called simple elements
whereas elements consisting of child-elements
or attributes are called complex elements.

1. Complex elements which do not correspond
to the rules 2-5 are converted to object ta-
bles.

2. Complex elements having only one com-
pelx child-element are converted to object
tables and their complex child-elements are
converted to abstract data type fields.

3. Complex elements which have occurrence?
or 1 (although there is no single symbol for
occurrence meaning one, from now on we
will use the symbol ‘1’ as canonical short
label), have sibling and all children as sim-
ple elements and are converted to abstract
data type fields.

4. Complex elements being the root element
and having only several complex child-ele-
ments with occurrence * or + are converted
to nothing in ORDB and their child elements
are converted to object tables.
5. Complex elements having occurrence * or +, having siblings and complying with the following conditions are converted to nested tables:
   - All children are simple elements and all attributes have no type IDREF(s).
   - There is reference to other elements and no reference from other elements to them.
   - There is recursive structure: they must not refer back to their ancestors.

This rule is to make sure that nested tables do not have any reference since the referential integrity constraint cannot be defined in nested tables; nevertheless, other constraints such as domain constraint and default constraint can be defined in nested tables.

6. Multi-valued simple elements are converted to nested tables having one field.

7. Simple elements, simple attributes, ID attribute, optional simple elements and choice of simple elements are converted to fields.
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8. Optional complex elements and choice of complex elements are converted to tables or fields according to the rules 1-5.

9. For the choice of groups of elements where some of elements in each group are the same, duplicate elements are eliminated and then rules 1-7 are applied.

10. For elements with type ANY, a separate table is created with three fields: referencing fields which refer to their position, name of elements and value.

11. For parent-child relationship and recursive structure with occurrence ? or 1, the primary key of the table of parent-element is copied to the table of the child-element.

12. For recursive structure with occurrence + or *, a separate table will be created to hold the relationship of recursive structure by storing the primary keys of tables of a parent-element and a child-element.

13. For an element referenced by IDREF, the primary key of the table of a referenced-element is copied to the table of a referencing element.

14. For an element referenced by IDREFs, a separate table will be created to keep the primary keys of tables of a referencing element and a referenced element.

4.3. Additional Rules for Mapping the Rlink Mechanism to ORDB

The relationship between XML documents is similar to the relationship specified by IDREF(s) in the same document; thus their mapping rules are similar too.

1. If the occurrence of elements containing rlink is 1 or ?, the primary key of the table of a referenced-element is added to the table of a referencing element.

2. If the occurrence of elements containing rlink is + or *, a separate table will be created to keep relationship between XML documents; thus the separate table consists of the primary keys of the table of a referencing-element and a referenced-element.

3. For recursive structure: rlink of elements in a referenced document refers to elements in a referencing document, it is considered in the same way as rules 1–2.

5. Mapping XML Constraints to ORDB Constraints

In this part, we firstly describe the types of constraints in (O)RDB. Secondly, we present the rules for mapping constraints in an XML document to constraints in ORDB. Thirdly, we propose supplementary rules for mapping constraints which stem from the rlink mechanism to constraints in ORDB. Finally, we determine how to preserve cardinality constraints when update operations are performed. A diagram for mapping XML constraints and rlink constraints to ORDB constraints is shown in Figure 3.

5.1. Type of Constraints in (O)RDB

The constraints in (O)RDB from a data-oriented viewpoint can be categorized into three types [37] as follows:

1. Row constraints: these constraints are related to exactly one table and can be evaluated independently for each row in that table. Constraints in this type include check (null value) constraint, domain constraint and default value constraint.

2. Table constraints: evaluating these constraints is associated with at least two rows in the same table. Examples of these constraints include primary key constraint, unique constraint and cardinality constraint.

3. Inter-table constraints: these constraints involve rows from at least two tables. An example of this constraint type is foreign key constraint (referential integrity constraint) including cascade rules.

Note: We have not found that the cardinality constraint is available in any (object-)relational products.

5.2. Rules for Mapping Constraints of an XML Document to ORDB

Since certain constraints in DTD are easily recognized, some of proposed rules are the same as some of the rules proposed in other work [22, 39, 21]. However, our work can extract more constraints in DTD than in previous work and some of our rules are different from the rules proposed in the previous work; in particular, no
### Row constraints:
1. #REQUIRED attributes and simple element with occurrence 1 or + are converted to the not null constraint.
2. #IMPLIED attributes and simple element with occurrence ? or * have default null constraint.
3. Default value is translated into default value constraint.
4. Choice of attribute values is converted to domain constraints.
5. For a choice of elements such as `<!ELEMENT e (s1 | s2)>`, meaning can have either

### Table constraints:
1. ID of an element in the case that the element is converted to table.
2. ID of an element in the case that the element is not converted to table.

### Inter table constraints
2. Referencing from descendants to ancestors by recursive structure with occurrence * or +.
3. Referencing from descendants to ancestors by IDREFs.
4. Referencing from ancestors to descendants by IDREFs.
5. Elements (siblings or relatives) refer to each other by IDREFs.
6. #REQUIRED attributes and simple element with occurrence 1 or +.
7. #IMPLIED attributes and simple element with occurrence ? or * have default null constraint.
8. Default value is translated into default value constraint.
9. Choice of attribute values is converted to domain constraints.

### Constraints derived from rlink
1. Occurrence of elements containing rlink is + or *.
2. Occurrence of elements containing rlink is 1 or ?.

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**Fig. 3.** Mapping XML constraints and rlink constraints to ORDB constraints.
s₁ or s₂ but not both simultaneously, then the constraint will be:
Check ((s₁ is not null AND s₂ is null) OR (s₁ is null AND s₂ is not null))
In translating <!ELEMENT e (s₁ |...| sₙ)>, the constraint will become:
Check((s₁ is not null AND s₂ is null AND ... AND sₙ is null) OR ... OR (s₁ is null AND s₂ is null AND ... AND sₙ is not null))

6. For a choice of groups of elements, that some of the elements in each group are the same but their constraints may be different, are converted with the following rules.
Firstly, every element+ or element in each group is converted to “AND element is not null”. Secondly, every element* or element? in each group is converted to nothing. Thirdly, the OR operation is performed on every group. Finally, if there are some elements in one group which do not appear in other groups, the “AND these elements are null” is added to the groups for which these elements do not appear. For example:
(name, telephone+)|(name, telephone*, email)
Constraints will be:
Check ((name is not null AND telephone is not null AND email is null) OR (name is not null AND email is not null))

Table constraints:
1. ID of an element is converted to primary key constraint in the case that the element is converted to an object table or a nested table; otherwise ID is defined with unique constraint.

2. Occurrence for complex elements converted to tables should be converted to the cardinality constraint; however no (object-)relational technology provides this constraint; hence this constraint will be checked with rules for preserving the cardinality constraint in Section 5.4.

Inter-table constraints:
1. Parent-child relationship (1 to many relationship)
2. Parent-child relationship (1 to 1 relationship)
3. Referencing from descendants to ancestors by recursive structure with occurrence ? or 1
4. Referencing from descendants to ancestors by recursive structure with occurrence * or +
5. Referencing from descendants to ancestors by IDREFs or IDREF (Recursive)
6. Referencing from ancestors to descendants by IDREFs or IDREF
7. Elements (siblings or relatives) refer to each other by IDREFs or IDREF

From parent-child relationship and recursive structure with occurrence ? or 1 (1-3), the primary key of parent-element table is copied to the child-element table as a foreign key constraint and a delete cascade is defined on this constraint.

From referencing by IDREFs and recursive structure with occurrence * or + (4-7), a new separate table will be created to hold relationships of references. This separate table consists of fields derived from the primary keys of tables of a referencing element and a referenced element. These fields are set as a combined key and foreign keys for this table. The foreign key derived from a referencing element is defined with the delete cascade. In the case of referencing by IDREFs (5-7), the foreign key derived from a referenced element is defined without a delete cascade whereas in the case of recursive structure (4), the foreign key derived from a referenced element is defined with a delete cascade.

From referencing by IDREF (5-7) by IDREF, a referencing field (same as primary key of the table of referenced element) is added to the table of a referencing element as a foreign key without a delete cascade to point to the primary key of a referenced element.

Not null is defined on a foreign key in the case that occurrence is 1 or IDREF is declared with #REQUIRED.

Note: For a table without a primary key, the RowID automatically created in an object table will be used as the primary key.
5.3. Additional Rules for Mapping Constraints Derived from Rlink Mechanism

The supplementary constraint rules for mapping rlink mechanism are similar to the constraint rules of IDREF. The rules are as follows.

1. In the case that the occurrence of elements containing rlink is 1 or ?, the primary key of the table of a referenced element will be held in the table of a referencing element as a foreign key without a delete cascade.

2. In the case that the occurrence of elements containing rlink is * or /+, a separate table is created consisting of two fields derived from keys of tables of referencing element and referenced elements. These two fields are set as a combined key and foreign keys but only the foreign key derived from the table of a referencing element is defined with a delete cascade whereas the foreign key derived from the table of a referenced element is defined without a delete cascade.

3. For a recursive structure, constraints are considered in the same way as rules 1, 2 and 4.

4. Not null is defined on a foreign key in the case that the occurrence of elements containing rlink is 1.

5.4. Rules for Preserving Cardinality Constraints when Updates are Performed

In this section, we will describe how the cardinality constraint is preserved when updates are performed since, nowadays, no (object-)relational DBMS can handle the cardinality constraint; hence a particular method is needed to manage it. Updating affects the relationship between elements; thus we preserve this constraint according to the type of relationship in the XML documents as follows:

1. Parent-child relationship (1 to many relationship)
   In the case that the child is a complex element converted to a nested table or the child is a complex element and has no sibling; then the child is converted to an abstract data type field and the parent element is converted to an object table containing only one abstract data type field.

   Delete child elements converted to abstract data type fields in case of occurrence +
   Cardinality constraint will be checked as follows:
   Select count(*) as count1
   From parent-element table;
   Select count(*) as count2
   From parent-element table
   Where delete-conditions;
   If (count2 - count1) >= 0 then
   Do not allow deletion
   End If

   Delete child elements converted to a nested tables in case of occurrence +
   Cardinality constraint will be checked as follows:
   Select count(*) as count1
   From child-element table
   Where PK(of parent-element table) = $PK;
   Select count(*) as count2
   From child-element table
   Where PK(of parent-element table) = $PK
   And delete-conditions;
   If (count2 - count1) >= 0 then
   Do not allow deletion
   End If

   Delete child elements in the case of occurrence *
   No need to be checked.

   Insert children in case of occurrence + or *
   Cardinality constraint is not needed to be checked since any number of children is allowed when inserting

2. Parent-child relationship (1 to 1 relationship)
   In the case that the child is a complex element and has no sibling; then the child is converted to an abstract data type field (and the parent element is converted to an object table containing only one abstract data type field).

   Delete child elements in the case of occurrence 1
   Do not allow deletion.

   Insert children in case of occurrence 1 or ?
   Cardinality constraint is checked as follows:
   Select count(*) as count1
   From parent-element table;
   IF count1 > 0 then
   Do not allow insertion
   End If
3. Parent-child relationship (1 to many relationship) including recursive structure with occurrence * or +

In the case that the parent and child are complex elements, the child is converted to an object table. In the case of recursive structure, a separate table is created to hold the relationship between the referencing (parent-element) and referenced elements (child-element).

*Delete child elements in case of parent-child relationship with occurrence +*

Cardinality constraint will be checked as follows:

1. Select count(*) as count1
2. From child-element table
3. Where FK (PK of parent-element table) = $FK;
4. Select count(*) as count2
5. From child-element table
6. Where FK = $FK
7. And delete-conditions;
8. If (count2 - count1) >= 0 then
9. Do not allow deletion
10. End If

*Delete child elements in case of recursive structure with occurrence +*

Cardinality constraint will be checked as follows:

1. Select count(*) as count1
2. From child-element table
3. Where FK (PK of parent-element table) = $FK;
4. Select count(*) as count2
5. From child-element table
6. Where FK = $FK
7. And delete-conditions;
8. If (count2 - count1) >= 0 then
9. Do not allow deletion
10. End If
11. Delete child elements in case of occurrence *

No need to be checked.

*Insert children in the case of occurrence 1 or ?*

Cardinality constraint is checked as follows:

1. Select count(*) as count1
2. From child-element table
3. Where FK (PK of parent-element table) = $FK;
4. IF count1 > 0 then
5. Do not allow insertion
6. End If

5. Referencing from descendants to ancestors by IDREFs (Recursive)

6. Referencing from ancestors to descendants by IDREFs

7. Elements (siblings or relatives) referring to each other by IDREFs

8. Referencing between XML documents by using rlink mechanism where the occurrence of an element containing rlink is + or *

For cases 5-8 above, in the case of referencing by IDREFs or by the rlink mechanism where the occurrence of an element containing rlink is + or *, a separate table is created to hold the relationship between the referencing and referenced elements.

*Delete values in #REQUIRED IDREFs or delete elements containing rlink where occurrence of the elements is +*

Cardinality constraint will be checked as follows:

1. Select count(*) as count1
2. From separate table
3. Where PK1 (PK of parent-element table) = $PK;
4. Select count(*) as count2
5. From separate table S, child-element table C
6. Where S.PK1 = $PK And S.PK2 = C.PK
7. And delete-conditions;
8. If (count2 - count1) >= 0 then
9. Do not allow deletion
10. End If

*Delete values in #IMPLIED IDREFs or delete elements containing rlink where occurrence of the elements is *

No need to be checked.

*Insert values to IDREFs or insert rlink*

No need to be checked.

4. Parent-child relationship (1 to 1 relationship)

In the case that the parent and child are complex elements, the child is converted to an object table.

*Delete child elements in case of occurrence 1*

Do not allow deletion

*Delete child elements in case of occurrence ?*

No need to be checked.

6. Preserving Order of XML Elements

When ordered XML documents are shredded into tables, ordering in tables has two dimen-
sions: column ordering and row ordering. For columns, they are automatically ordered when tables are created and this order will never be changed. For row ordering, at the first time of loading data into tables, data can be loaded in sequence but when delete or insert operation is performed, it is necessary to reorder the data.

There is a proposal [34] for reordering XML data held in relational database. The researchers of this proposal demonstrated that Local Order method performs best on updates since only siblings following the new node need to be renumbered as shown in Figure 4.

However, this method can yield low performance if the new node has numerous siblings as many siblings must be renumbered. For our method, rows are considered as a linked list. This means that each row will hold the RowID (automatically generated) of the next row in sequence; thus this method can guarantee that when the insert or delete operation is performed, no more than two rows are affected, as shown in Figure 5. From the figure, when we insert a new author ‘John’ after author ‘Peter’, this can be performed by copying RowOrder of ‘Peter’ to RowOrder of ‘John’ and copying RowID of ‘John’ to RowOrder of ‘Peter’.

7. A Case Study for Mapping Linked XML Documents

To elucidate, we will demonstrate how to map linked XML documents to ORDB. We suppose that three XML documents, Publications.xml, Authors.xml and References.xml, are linked together by two attributes: rlink:relationship and rlink:href, as shown in Figure 6. To gain more understanding, Schema Graph of DTDs in Figure 7 and the result tables in Figure 8 should be considered along with the description below.

Firstly, Publications has only one complex child element: Publication; thus Publications is converted to an object table and Publication is con-
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Fig. 6. Three linked XML documents.

Fig. 7. Schema Graph of DTDs.
verted to an abstract data type field (Structure mapping Rule 1). Publication has attributes: PubID, PubType and simple elements: Title, Year; these four are converted to simple fields (Structure mapping Rule 5). For the constraints, Title and Year have occurrence 1; thus not null is applied (row constraint mapping rule 1) and table constraint mapping rule 1 is applied to PubID as a primary key. PubType has a choice of attribute values and a default value; so domain and default value constraints are applied (row constraint mapping rules 3–4). For Publication*, rules for preserving cardinality constraint are applied when updates are performed.

Secondly, the complex child elements of Publication: Author and Reference whose attributes are rlink are handled as follow:

- Since the occurrence of Author is +, a separate table is created. This table consists of the primary keys of Publication and Author set as a combined key and foreign keys. PubID is defined with a delete cascade (structure mapping rule 2 and constraint mapping rule 2 of rlink are applied).

Thirdly, Authors has only one complex child element: Author; thus Authors is converted to an object table and Author is converted to an abstract data type field (Structure mapping Rule 1). Author consists of attribute: AuthorID and simple element: Email; so these two are converted to simple fields (Structure mapping Rule 5). Name has a sibling, occurrence 1, and all children are simple elements; thus Name is converted to an abstract data type field (Structure mapping Rule 3). Telephone has a sibling, occurrence *, and all children are simple elements and there is no reference; hence Telephone is converted to a nested table (Structure mapping Rule 2).

For the constraints, AuthorID is set as a primary key (table constraint mapping rule 1), Name, FName, LName, Location and TelNo have occurrence 1; thus not null is applied (row constraint mapping rule 1). For Author* and Telephone*, rules for preserving the cardinality constraints are applied.

Finally, References has only one complex child element: Reference; so References is converted to an object table and Reference is converted
to an abstract data type field (Structure mapping Rule 1). Reference has attributes: RefID, RefType and an element: Publication with occurrence + whose attribute is rlink referencing back to the Publication element in the document which cites it; thus RefID and RefType are converted to simple fields (Structure mapping Rule 5) and not null is applied (row constraint mapping rule 1). RefType has a default value and a choice of attribute values; so the row constraint mapping rules 3-4 are applied and RefID is set as a primary key (table constraint mapping rule 1). Publication contains a recursive rlink; hence a separate table is created and this separate table consists of the primary keys of Reference and Publication set as a combined key and foreign keys. The foreign key derived from Reference is defined with a delete cascade (structure mapping rule 3 and constraint mapping rule 3 of rlink are applied). For Reference#, rules for preserving cardinality constraint are applied.

We create a schema derived from our rules in Oracle9i [24] and assume that the length of fields which are primary keys and foreign keys is 15 characters whereas the length of other fields is 30 characters. The schema generated in Oracle9i by using our rules is shown in Figure 9.

Mapping linked XML documents makes it easier to perform joins between XML documents and to update several linked XML documents in an update command; for example, from Figure 6, if we want to update title and author’s email of publication having PubID = ‘P111’ and author having FName = ‘John’, an update command may be

```
Create Type TPublication as object
  ( PubID varchar2(15),
    PubType varchar2(30),
    Title varchar2(30),
    Year varchar2(30),
    RefID varchar2(15)
  );
Create Type TPUBLICATION as object
  ( Publication TPublication
  );
Create Table Publications of TPUBLICATION
(PubID varchar2(15) references Publications DEFAULT
Publication.PubID on delete cascade,
PubType varchar2(30),
Title varchar2(30),
Year varchar2(30),
RefID varchar2(15)
);
Create Type TName as object
  ( FName varchar2(30),
    MName varchar2(30),
    LName varchar2(30)
  );
Create Table TTelephone as object
  ( Location varchar2(30),
    TelNo varchar2(30)
  );
Create Type NTTelephone as table of TTelephone;
Create Type TAuthor as object
  ( AuthorID varchar2(15),
    Name TName,
    Email varchar2(30),
    Telephone NTTelephone
  )
Create Type TAuthors as object
  ( Author TAuthor
  );
Create Type TReference as object
  ( RefID varchar2(15),
    RefType varchar2(30)
  );
Create Table References of TReference
(RefID varchar2(15),
RefType varchar2(30)
);
Create Type TName as object
  ( FName varchar2(30),
    MName varchar2(30),
    LName varchar2(30)
  );
Create Table Authors of TAuthors
( AuthorID varchar2(15),
  Primary key (AuthorID),
  Check (Author.Name is not null),
  Check (Author.Name.FName is not null and
  Author.Name.LName is not null)
);
Create Table References of TReference
(RefID varchar2(15),
RefType varchar2(30)
);
Create Type TReferences as object
  ( Reference TReference
  );
Create Type TReferences as object
  ( Reference TReference
  );
Create Type TReferences as object
  ( Reference TReference
  );
Create Table References of TReference
(RefID varchar2(15),
RefType varchar2(30)
);
Create Table Publications of TPublications
(Publications.PubID,
Publication.PubType IN
('book', 'article', 'journal'),
CHECK (Publication.Title is not null and
Publication.Year is not null),
Foreign Key(Publication.PubID) references
References(Reference.RefID)
);
Create Type TAuthors as object
  ( AuthorID varchar2(15),
    Name TName,
    Email varchar2(30),
    Telephone NTTelephone
  );
Create Type TAuthor as object
  ( AuthorID varchar2(15),
    Name TName,
    Email varchar2(30),
    Telephone NTTelephone
  );
Create Type TAuthors as object
  ( Author TAuthor
  );
Create Table Authors of TAuthors
( AuthorID varchar2(15),
  Primary key (AuthorID),
  Check (Author.Name is not null),
  Check (Author.Name.FName is not null and
  Author.Name.LName is not null)
);
Create Table References of TReference
(RefID varchar2(15),
RefType varchar2(30)
);
Create Type TReferences as object
  ( Reference TReference
  );
Create Table References of TReference
(RefID varchar2(15),
RefType varchar2(30)
);
Create Table Publications of TPublications
(Publications.PubID,
Publication.PubType IN
('book', 'article', 'journal'),
CHECK (Publication.Title is not null and
Publication.Year is not null),
Foreign Key(Publication.PubID) references
References(Reference.RefID)
);
Create Table Authors of TAuthors
( AuthorID varchar2(15),
  Primary key (AuthorID),
  Check (Author.Name is not null),
  Check (Author.Name.FName is not null and
  Author.Name.LName is not null)
);
Create Table References of TReference
(RefID varchar2(15),
RefType varchar2(30)
);
Create Type TReferences as object
  ( Reference TReference
  );
Create Table Publications of TPublications
(Publications.PubID,
Publication.PubType IN
('book', 'article', 'journal'),
CHECK (Publication.Title is not null and
Publication.Year is not null),
Foreign Key(Publication.PubID) references
References(Reference.RefID)
);
Create Table Authors of TAuthors
( AuthorID varchar2(15),
  Primary key (AuthorID),
  Check (Author.Name is not null),
  Check (Author.Name.FName is not null and
  Author.Name.LName is not null)
);
```

Fig. 9. Schema generated in Oracle9i.
For $p$ in doc("Publications.xml")/Publication, $s$ in $p$/Author $a$ in doc("Authors.xml")/Author Where $s$/@PubID = "P111" Replace $s$/Title with <$Title>Java2</Title>. Replace $s$/Email with <$Email>au@Hill.com</Email>. Where $s$/Name/ FName = "John"

The above update language can be translated into SQL as follows:
Update Authors $A$
Set $A$.Author.Email = 'au@Hill.com'
Where $A$.Author.AuthorID in
(Select $A$.Author.AuthorID
From Authors $A$, PublicationAuthor $P A$
Where $P A$.Publication.PubID = 'P111'
And $P A$.AuthorID = $A$.Author.AuthorID
And $A$.Author.Name.FName = 'John');
Update Publications $P$
Set $P$.Publication.Title = 'Java2'
Where $P$.Publication.PubID = 'P111';

8. Conclusion and Further Work

For the time being, work converting both structure and constraints of XML to ORDB cannot be conducted readily because of limited constraints in available object-relational DBMSs. Oracle supports nested tables but the referential integrity constraint cannot be defined on them. Informix supports Set, List and Row types but some constraints such as default constraint and domain constraint cannot be defined on Set, List and fields of Row type while PostgreSQL only supports arrays and constraints cannot be defined on individual elements of an array.

In our work, we map both structure and constraints of XML to ORDB with awareness of practicability in available technologies. However we use nested tables instead of set/list since most constraints can be defined on nested-tables except the referential integrity constraint. Usually, data in XML documents are stored redundantly. We therefore propose an alternative way for keeping non-redundant data in several separate documents. This involves a mechanism called ‘rlink’ to link data in the separate documents together and additional rules for mapping the ‘rlink’ mechanism to ORDB. Finally, we create the object-relational schema with constraints derived from our mapping rules in Oracle9i. Our contribution is that we find that mapping linked XML documents makes it easier to perform joins between XML documents and to update several linked XML documents in one update command as discussed in Section 7.

In further work, we will make an extension to XQuery for updating (linked) XML documents and then we will translate it into SQL. The translation will include linear and non-linear recursive update commands and a mechanism will be proposed for propagating the change in ORDB to the XML documents. We will also conduct a performance comparison between updating one XML document containing redundant data and updating linked XML documents containing non-redundant data. This work is currently under development.

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