KEYS GRAPH - BASED RELATIONAL TO XML TRANSLATION ALGORITHM

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Abstract: The authors propose two algorithms for generating a DTD and an XML document respectively from the metadata and the content of a relational database without any intermediary language or user intervention. Such algorithms always generate semantically correct XML output by respecting database functional dependencies represented in a graph structure they take as input. Finally, different XML representations (or views) meeting expectations of different kind of users can be obtained from the same data according to the data entity chosen as translation pivot.

1 INTRODUCTION

In the last years, much have been said about XML and its applications. However, the majority of the business data are stored in relational databases and needs to be translated. In this paper, we present two separated algorithms for translating the structure and the content of a relational database respectively in a DTD and an XML document. The algorithms use a keys graph (Flory & Kouloumdjian, 1978) (automatic generation in (Manzi, Verdier & Flory, 2002)) to represent all functional dependencies in the database for ensuring that translation results reflect accurately semantic relationships between data entities. The algorithms can also generate XML output reflecting data from the point of view of a particular data entity (from a database containing professors and courses, we can create, for example, a *professor-centered* and a *course-centered* document for different purposes). Finally, no intermediary mapping languages nor user intervention are required.

2 EXAMPLE DATABASE

The example database we will use throughout this paper is the following:

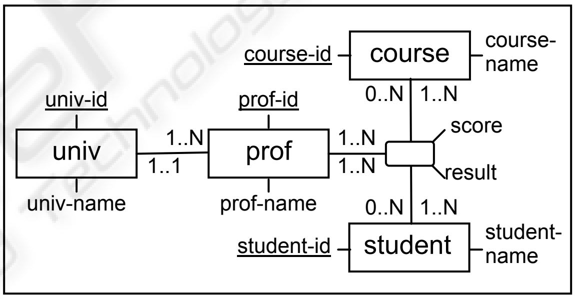

Figure 1: example database.

course table

course-id	course-name
C1	French
C2	sport

student table

student-id	student-name
S1	Mary
S2	Marc

prof table

prof-id	prof-name	univ-id
P1	John	U1
P2	Paul	U2
P3	Carl	U1
P4	Phil	U2

univ table

univ-id	univ-name
U1	INSA
U2	Lyon1

scores table

prof-id	course-id	student-id	score	result
P1	C1	S1	B	ok
P1	C1	S2	A	ok
P1	C2	S1	B	ok
P2	C1	S2	C	ok

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2.1 Table/entity-centered translations

Some algorithms transforms relational data in such a way that all tags and attributes in the resulting XML document represent database tables, rows, columns, data types, field lengths, default values and so on. We call this kind of transformation *table-centered*. In this paper, we follow an *entity-centered* approach in which the XML document we generate contains only high-level concepts present in the database Entity-Relationship model: data entities, associations (represented by element nestings) and attributes.

```
<database>
   <table1>
      <row>
         <att1>V1</att1>
         <att2>V2</att2>
      </row>
      …
   </table1>
   …
</database>
```

```
<database
   <entity1>
      <att1>V1</att1>
      <entity2>
         <att2>V2</att2>
         <att3>V3</att3>
      </entity2>
   </entity1>
   …
</database>
```

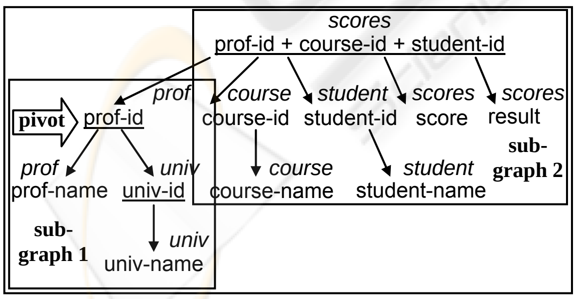
Figure 2: table and entity-centered translations.

3 DTD GENERATION

This algorithm is executed according to a data entity called *pivot node* which determines the meaning of the resulting XML representation since all database content is rearranged in order to present data from its point of view. The steps of the algorithm are:

3.1 Choosing the pivot node

As the translation *always* begins with a data entity, the pivot node *must* be intermediary. Suppose we have chosen *prof-id*:



3.2 Traversing the sub-graph below it

In this phase, the algorithm visits the *sub-graph 1*. The first node to be analyzed is the pivot node itself, which is an intermediary one. Then we:

(A) create a composite DTD element having the same name as the node table (*prof*) and whose children list is initially empty;
(B) create a new PCDATA element having the same name as the node attribute (*prof-id*);
(C) add the name of the DTD element created in *B* to the children list of the element created in *A*.

```
(A) <!ELEMENT prof ( )>
(B) <!ELEMENT prof-id (#PCD)>
(C) <!ELEMENT prof (prof-id)>
```

Next step consists in traversing all non-visited edges starting at the pivot node. Next node is *prof-name*, which is a leaf one. Then we:

(D) create a new PCDATA element having the same name as the attribute of the node (*prof-name*).

Now, we will represent in the DTD the edge linking *prof-id* and *prof-name* by creating a nesting between the DTD elements generated by these nodes. So, we:

(E) add the name of the DTD element created by the destination node in *D* to the children list of the DTD element created by the origin node in *A*/*C:*

```
(D) <!ELEMENT prof-name (#PC)>
(E) <!ELEMENT prof (prof-id, prof-name)>
```

Next two nodes we visit are *univ-id* and *univ-name*, which are treated according to the rules used in *A*, *B* and *C*. So we have three new elements:

```
<!ELEMENT univ (univ-id, univ-name)>
<!ELEMENT univ-id (#PCDATA)>
<!ELEMENT univ-name (#PCDATA>
```

Finally, we indicate there is an edge between *prof-id* and *univ-id* by creating a nesting between the DTD elements they created:

```
<!ELEMENT univ (univ-id, univ-name)>
<!ELEMENT prof (prof-id, prof-name, univ)>
```

3.3 Traversing the sub-graph above it

Now, we will traverse the *sub-graph 2*. Next node is the head of the graph which, differently from leaf and intermediary ones, does not create any DTD element. As the order in which branches starting at a head node are visited determines the meaning of the translation result, they are sorted so that branches starting with key attributes (e.g. *course-id*) appear before branches starting with relationship attributes (e.g. *score*).

Once graph branches are ordered, the algorithm traverses each *non-visited* one. Each time it finishes visiting a branch *b*, we indicate that *b* is linked to the graph head by creating a nesting between the DTD elements generated by the first node of *b* and by the first node of the branch visited immediately before *b*. For example, the first node of the branch starting with *course-id* create the following DTD element:

<!ELEMENT course (course-id, course-name)>

Then, for indicating the link between this branch and the graph head, we add the name of this element to the children list of the element created by the first node of the last visited branch (starting at *prof-id*):

<!ELEMENT course (course-id, course-name)>

<!ELEMENT prof (prof-id, prof-name, univ, course)>

The next branch we visit starts with *student-id* node and its relationship with the last visited one (starting with *course-id*) is indicated as follows:

<!ELEMENT student (student-id, student-name)>

<!ELEMENT course (course-id, course-name, student)>

Finally, we reach the nodes representing relationship attributes, and *all* remaining nestings will be made between the PCDATA elements they create and the composite element created by the first node of the last branch starting with a key attribute (*student-id*):

<!ELEMENT score (#PC)> <!ELEMENT result (#PC)>

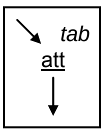
<!ELEMENT student (student-id, …, score, result)>

In the next section we present an algorithm for *predicting* the cardinalities of all nestings we have created so far.

3.4 Determination of cardinalities

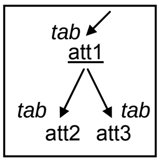
Each time we create a nesting between two elements E1 and E2, we *predict* the cardinality ω of E2 with relation to E1 (<!ELEMENT E1(E2ω)>) as follows:

(A) If we are analysing a key attribute contained in an intermediary node, the cardinality is 1..1 *for sure*.



for example, the cardinality of the key attribute *att* in the children list of *tab* element is 1..1 for sure.
<!ELEMENT tab (att, …)>

(B) If we are going down between two graph nodes, the cardinality is 1..1 *for sure* because upper attributes functionally determines lower ones.

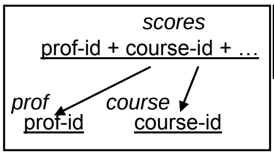


for example, *att2* and *att3* have cardinalities 1..1 for sure in the children list of *tab* element.
<!ELEMENT tab (att1, att2, att3, …)>

(C) If we are going up or at the same level in the graph, the destination node attribute is not functionally determined by the origin node one. Then, we query the database and the cardinality is *predicted* by composing the two rules below:
Rule 1: IF *at least one instance* of the origin node attribute is linked to *no instances* of the destination node attribute THEN the minimum cardinality is 0 *for sure*, ELSE it *can be* 1;
Rule 2: IF *at least one instance* of the origin node attribute is linked to *several instances* of the destination node attribute, THEN the maximum cardinality is N *for sure*, ELSE it *can be* 1. The composition table is:

Rule 1	Rule 2	Result	Likelihood
apply	apply	0..N (*)	sure
apply	not apply	0..1 (?)	not sure
not apply	apply	1..N (+)	not sure
not apply	not apply	1..1 ( )	not sure

For example, when going from *prof-id* to *course-id* nodes, we predict the cardinality of *course* element in the children list of *prof* element by applying these rules to the *scores* table. *Rule 1* applies as at least one value of the origin node is linked to no value of the destination node (P3 has no entries in the table). *Rule 2* applies as at least one value of the origin node is linked to several values of the destination node (P1 is linked to C1 and C2). So, the first line of the composition table states that the cardinality of *course* element is 0..N ("*" symbol) for sure.



<!ELEMENT prof (prof-id, prof-name, univ, course*)>

The final DTD the algorithm generates is (PCDATA elements are note included for space reasons):

<!ELEMENT prof (prof-id, prof-name, univ, course*****)>
<!ELEMENT univ (univ-id, univ-name)>
<!ELEMENT course (course-id, course-name, student**+**)>
<!ELEMENT student (student-id, student-name, score, result)>

The complete algorithm for generating a DTD from a relational database is presented in figure 3.

4 XML DOCUMENT GENERATION

Our second algorithm generates an XML document from a relational database. In this document, tags reflect database structure (as described by its DTD) and contents are retrieved from database tables. The algorithm starts at a pivot node and visits all nodes below and above it generating XML tags and SQL queries. In our example, suppose we chose *prof-id* attribute as pivot, which is intermediary. Then we:

(A) create an empty XML tag (element) having the same name as the node table (*prof*):

```
<prof></prof>
```

because it is the pivot node, we create an SQL query for retrieving *all* values of its attribute (*prof-id*) from its table (*prof*). The query and the result are:

SELECT *prof-id* FROM *prof*	P1, P2, P3, P4

(B) visit, *for each retrieved value*, all subsequent graph nodes. The first value is *P1*. Then, we create an XML tag having the same name as the node attribute (*prof-id*) and whose value is *P1*, and we add this new tag into the tag created in *A* (which is initially empty):

```
NBV = graph node being visited, PVN = prior visited graph node, ELEM = actual DTD element
function buildDTD ( GraphNode NBV , GraphNode PVN , DTDElement ELEM ) returns DTDElement
    if ( NBV is leaf ) then
        E1 ← new PCDATAElement ( NBV.attribute() )
        ELEM.addArgument ( E1 , " 1..1" )
        return ELEM
    else if ( NBV is head ) then
        sort NBV children so that branch with pivot node is at left and branches starting with relationship attributes at right
        EX ← ELEM
        for each N1 ← non-visited NBV child from left to right do
            E2 ← buildDTD ( N1 , PVN , EX )
            if ( N1 is not a leaf ) then
                PVN ← N1
                EX ← E2
        return ELEM
    else
        E3 ← new CompositeElement ( NBV.table() )
        E4 ← new PCDATAElement ( NBV.attribute() )
        E3.addArgument ( E4 , 1..1 )
        if ( ELEM is not null )  then
            C ← calculateCardinality ( PVN , NBV )
            ELEM.addArgument ( E3 , C )
        for each CN ← non-visited NBV child from left to right do
            buildDTD ( CN , NBV , E3 )
        FN ← non-visited father node of NBV below the graph head whose branches contain the pivot node
        if ( FN exists ) then buildDTD ( FN , NBV , E3 )
        return E3
function call : GraphNode PN = pivot node of translation
                CompositeElement rootElement  = buildDTD ( PN , null , null )
```

Figure 3: algorithm for generating a DTD from a relational database.

```
<prof-id> P1 </prof-id> ──►  <prof>
                                <prof-id> P1 </prof-id>
                             </prof>
```

(C) visit the sub-graph below the pivot node for the value *P1*. Next node, *prof-name*, is a leaf. Then, we create an SQL query for retrieving the value of this attribute *as functionally determined by the actual value of the father node attribute* (*prof-id = P1*). The query and the result are:

SELECT *prof-name* FROM *prof* WHERE *prof-id = P1*	John

now, we create an XML tag with the same name as the node attribute (*prof-name*), whose value is *John*, and we add it into the tag created in *A/B*

XML tag created by *prof-name* node

```
<prof>
   <prof-id> P1 </prof-id>
   <prof-name> John </prof-name>
</prof>
```

Next node, *univ-id*, is intermediary, so the process is the same as for *prof-id*. Then, we represent the edge linking *univ-id* to *prof-id* through a nesting between the XML tags representing them.

Now, the translation algorithm goes up in the graph and reaches its head. Again, it traverses all *non-visited* graph branches from left to right creating nestings linking the actual branch either to the last-visited or to the last one starting with a key attribute. All branches must be ordered as stated before.

Next branch starts with *course-id* node. Then, we retrieve all values of its attribute *as functionally determined by the combination of the values of the previous visited nodes starting with key attributes* (*prof-id* = *P1*). In other words, we want to know all courses taught by professor P1:

SELECT *course-id* FROM score WHERE *prof-id* = *P1* GROUP BY *course-id*	C1 C2

Once again, the algorithm must visit all subsequent graph nodes *for each retrieved value*. For *course-id* = *C1*, an XML tag is created and added into the tag representing the last visited graph branch, *prof-id*:

XML tag created by *course-id* node

```
<prof>
  ...
  <course>
    <course-id> C1 </course-id>
    <course-name>French</course-name>
  </course>
</prof>
```

For the next branches, we must combine the values of all already visited key attributes (*prof-id* = *P1* and *course-id* = *C1*). Next one starts with *student-id*:

SELECT *student-id* FROM score WHERE (*prof-id* = *P1*) AND (*course-id* = *C1*) GROUP BY *student-id*	S1 S2

```
NBV = graph node being visited , ELEM = actual XML element , TableName = name of a database table ,
CLAUSES = list of and clauses (like a=b) , IND = index of the child node the algorithm will visit
function buildXML (GraphNode NBV, XMLElement ELEM, ANDClauses CLAUSES, Str tableName, int IND) returns
XMLElement
    if ( NBV is leaf ) then
      DATASET1 ← select NBV.attribute() from tableName where CLAUSES group by NBV.attribute()
      LINE1 ← single line in DATASET1
      E1 ← new XMLElement ( NBV.attribute() , LINE1.value() )
      ELEM.addChild ( E1 )
      return ELEM
    else if ( NODE is head ) then
      sort NBV children so that branch with pivot node is at left and branches starting with relationship attributes at right
      DATASET2← select NBV.child(IND).attribute() from tableName where CLAUSES group by NBV.child(IND).attribute()
      IND2 ← IND + 1
      for each LINE2 ← line in DATASET2 do
        CLAUSES2 ← [ NBV.child(IND).attribute() = LINE2.value() ]
        E2 ← buildXML ( NBV.child(IND) , ELEM , CLAUSES2 , NBV.child(IND).table() , 0 )
        CLAUSES.addOrUpdateClause ( NBV.child(IND).attribute() = LINE2.value() )
        if  ( IND2 ≤ number of children of NBV ) then buildXML ( NBV , E2 , CLAUSES , NBV.table() , IND2 )
      return ELEM
    else
      if  ( CLAUSES is not null )
        then DATASET3 ← select NBV.attribute() from tableName where CLAUSES
        else DATASET3 ← select NBV.attribute() from NBV.table()
      for each LINE3 ← line in DATASET3 do
        E3 ← new XMLElement ( NBV.table() , “” )
        E4 ← new XMLElement ( NBV.attribute() , LINE3.value() )
        E3.addChild ( E4 )
        ELEM.addChild ( E3 )
        CLAUSES3 ← [ NBV.attribute() = LINE3. value() ]
        for each CN ← non visited NBV child from left to right do
          if ( CN is intermediary )
            then buildXML ( CN , E3 , CLAUSES3 , NBV.table() , 0 )
            else buildXML ( CN , E3 , CLAUSES3 , CN.table() , 0 )
        FN ← non-visited father node of NBV below the graph head whose branches contain the pivot node
        if ( FN exists ) then buildXML ( FN , E3 , CLAUSES3 , FN.table() , 2 )
      return E3
function call :   GraphNode PN = pivot node of translation
                  XMLElement rootElement = new XMLElement ( “database” , “” )
                  buildXML ( PN , rootElement , [ ] , “” , 0 )
```

Figure 4: algorithm for generating an XML from a relational database.

Then, *for each retrieved value*, we must traverse the branch starting with *student-id* and add the created tag into the tag created by *course-id* branch.

The last branches contain relationship attributes and must be linked to the last visited branch starting with a key attribute (*student-id*). Again, their values are *functionally determined by the combination of* *the values of the previous visited key nodes, prof-id = P1*, *course-id = C1* and *student-id = S1*:

SELECT *score* FROM *scores* WHERE (*prof-id = P1*) AND (*course-id = C1*) AND (*student-id = S1*)	B
SELECT *result* FROM *scores* WHERE (*prof-id = P1*) AND (*course-id = C1*) AND (*student-id = S1*)	ok

As *score* and *result* are leafs, their tags are added to the tag created by *student-id* node:

XML tags created by *score* and *result* nodes

```
<prof>
   …
      <student>
         …
         <score> B </score>
         <result> ok </result>
      </student>
</prof>
```

Although the graph traversal is finished at this point, the created XML document contains only data about professor *P1*, course *C1* and student *S1*. Then, for translating available data about the other elements, we must *revisit previous visited branches starting with key attributes from right to left* in order to take into account all possible combinations of values of these three attributes in the database. According to the *scores* table, such combinations are:

```
prof-id = P1, course-id = C1, student-id = S1
prof-id = P1, course-id = C1, student-id = S2
prof-id = P1, course-id = C2, student-id = S1
prof-id = P2, course-id = C1, student-id = S3
```

Now we come back to the last visited branch starting with a key attribute, *student-id*, whose next value is *S2* and we re-traverse all subsequent graph nodes. At this point, all values of *student-id* will be analyzed, then we come back to the prior branch, *course-id*. Its next value is C2. Again, all remaining branches are visited. The translation is complete when the graph is traversed for all of the combinations above.

The complete algorithm for generating an XML document from a relational database is presented in figure 4.

5 RELATED WORK

The translation of relational data into XML has been addressed by many researchers. Table-centered-only approaches are rare (Turau, 1999). On the other hand, entity-centered approaches are numerous. In XPERANTO (Carey et al. 2000) and SilkRoute (Fernandez, Suciu & Tan, 2000; Fernandez et al. 2001) users can specify entity-centered XML views over a relational database respectively through the mapping languages XQuery and RXL (proprietary). XML/SQL (Vittori, Dorneles & Heuser, 2001) is another proprietary language which allows users to define the structure of the final XML document, but they must also specify SQL queries for retrieving the data. In (Shanmugasundaram et al., 2000), SQL language is extended with XML translation and aggregation functions, but nestings in the final XML document are defined by users through complicated nested SQL queries. In (Lewis, 2002), users create a DTD or an XML-Schema which describes the XML document they need and the necessary SQL queries are generated by the system, but users must avoid demanding data from tables that can not be joined.

An hybrid table/entity-centered redundancy free approach is proposed in (Liu C., Liu J. & Guo, 2003), where a relational schema is translated into an XML-schema. NeT (Lee et al., 2001) and CoT (Lee et al., 2002) algorithms take database *create* statements as input. Then, the first creates a DTD by using an operator which deduces cardinalities, but it is only applicable to a single table at a time. The second handles several tables but outputs data in a proprietary language called XSchema. In (Kleiner & Lipeck, 2001), the authors also propose an algorithm for creating a DTD from an ER-Schema. However, while their DTD starts only with entities that are not functionally dependent on other ones, our DTD can start with any data entity. Mapping rules are also different: while we map data entities, attributes and relationships into DTD elements and nestings, they map them respectively into DTD elements, attributes and nestings *or* elements.

6 CONCLUSION

We have presented two algorithms for translating the structure and the content of a relational database respectively into a DTD and an XML document. They ensure the semantic correctness of the result by respecting database functional dependencies thanks to a directed graph indicating them. Additionally, these algorithms can create different entity-centered views of the same data. Finally, they require no user intervention, nor intermediary languages specifying mapping schemes. In the future, some improvements can be made in order to reduce the redundancy in the final XML document and the great number of SQL queries executed against the database.

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