XML-BASED EVALUATION OF SYNTHESIZED QUERIES

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Abstract: XML repositories are a common means for storing documents that are available through Web technologies. As the use of XML increases, there is a need to integrate XML repositories with other data sources to supply XML-oriented applications. In this paper, we examine documents that express business rules in XML format, and where the triggering and instantiation of rules requires execution of database queries. In this way, an inference process is governed by an XML document tree that controls the synthesis and evaluation of database queries.

1 INTRODUCTION

XML and related technologies are becoming a dominant standard for storing, managing, and exchanging information. In its basic application, XML is used to semantically enhance web pages through the use of user-defined tags. This enhancement allows one to understand the context in which data appears. For example, XML.org was formed in 1999 and its web pages (XML.org, 2005) provide a portal to XML technologies for data exchange purpose. At the time of writing, XML.org lists focus areas that include Human Resources and Printing & Publishing; other focus areas such as Defense, Insurance, and Retail are planned. XML is being adapted for use in many industries.

In this paper, we consider documents describing requirements or rules to be met to achieve some designation or status. As an example, consider a university setting where specific requirements are set out for students to receive a degree. Typically these documents are found in university calendars and are expressed in natural language as illustrated in Figure 1. This sample document presents the requirements for graduation for a 3-Year BSc in Geography from some university. It can be used by a student to guide the progress of his/her studies, a graduation officer to determine if a student can graduate, or by a university department to publish established requirements.

3-Year BSc (Geography)
- Graduation Requirement
  - 90 credit hours
- Residence Requirement
  - Degree: minimum 30 credit hours
  - Major: minimum 18 credit hours
- General Degree Requirement
  - Humanities: 12 credit hours
  - Science: 6 credit hours
- Major Requirement
  - Minimum 30 credit hours
  - Maximum 48 credit hours
  - Required Courses
    - 23.202 Intro Geography I
    - 23.203 Intro Geography II
    - 23.331 Advanced Geography
  - Choice
    - 23.205 Atmos Sci or 23.206 Earth Sci

Figure 1: Graduation Requirements

An observation shows that when applying such requirements to student histories, we can determine those students who can graduate. This is essentially a process deriving new information by making inference based on rules and facts (Business Rules Group 2000, Ross 1997). However, unlike a general rule-based system, the inferences here can be deduced only in the order implicit in a document structure. For instance, to know whether a student can graduate, we have to check whether the student has earned at least the required 90 credit hours, whether the residence requirement is satisfied, and so on. Furthermore, to determine whether the

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residence requirement is satisfied, we must check the number of degree credit hours and the number of major credit hours. Obviously, it is an ordered inference process.

In addition, during the process, a series of queries must be evaluated and each query corresponds to some inference step.

To handle the above problem, we introduce the concept of synthesized query tree, which is an XML document tree, to represent a set of queries that are evaluated along a tree structure.

The remainder of this paper is organized as follows. Next in section 2 we describe the system architecture. In section 3 we describe the requirements documents and in Section 4 we introduce the boolean and general synthesized query trees that are required to process the documents. Section 5 presents a short conclusion and directions for further work.

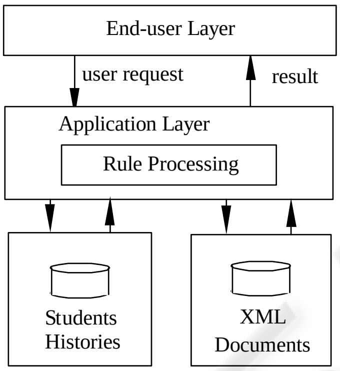


Figure 2: Rule Processing Architecture

2 SYSTEM ARCHITECTURE

In Figure 2, we present a layered architecture for processing student graduation requests.

In the architecture, the End-user Layer manages the interaction with the end-user and relays requests to the Application Layer which analyses a request and activates appropriate rules. Rule processing may require access to XML documents and to various other data stores. This architecture is designed for handling end-user requests and not for managing workflow as in the XRML architecture discussed in (Lee and Sohn, 2003).

The use case shown in Figure 3 illustrates how a user uses the system to determine a specific student's graduation status. From this, we can see that to handle the use case, the system needs to do the following:

1. retrieve relevant student identification information (see Figure 3, steps 3 and 4)
2. manage rule execution (see Figure 3, steps 5 and 6)
3. manage connections to other data sources such as XML and student history (see Figure 3, steps 3, 4, 5, and 6)

Use Case: Obtain Student Graduation Status

Main Success Scenario

1. Graduation officer selects the 3-Year BSc (Geography) graduation requirements page to view
2. System presents graduation requirements page
3. Graduation officer selects a student
4. System retrieves and presents student information
5. Graduation officer requests student graduation status
6. System evaluates document rules using student history data store and displays graduation status to user

Alternate Flows

5a) The student's status relative to a specific requirement in the document is requested
   1. Graduation officer selects a specific requirement and requests status relative to that requirement only
   2. System evaluates the specific rule and displays status

Figure 3: Student Status Use Case

All these are the main tasks of the application layer. In fact the Application Layer is basically an inference engine that derives knowledge using a rule set represented in an XML document and data from various data stores. The application layer implements all the operations that will be discussed in Sections 3 and 4.

From the above discussion, we can see that the sample document can be considered as a rule set that will be used to determine whether a student can graduate with a specific major. Our model assumes that querying some data store for ancillary information is required, but in this paper we are concerned only with query access and not updates to these data.

3 REQUIREMENTS DOCUMENTS

In this section, we describe the document category we are considering and specify how the document is coded as an XML document. To the best of our knowledge, this document category has not been studied elsewhere.

We consider documents that describe requirements to be met to achieve some designation or status, as exemplified in Figure 1. The sample document is typical of requirement specifications that a student must meet in order to graduate with a specific degree. As discussed previously, to determine if a student can graduate, an inference process is required that must adhere to the order implicit in the document structure.

The XML version of the sample document is shown in Figure 4. Next we describe how this document is established from the document shown in Figure 1.

As we know, XML documents comprise elements and attributes, which are marked up using tags. Therefore, when we translate a plain text like that in Figure 1 into an XML version, tags for elements, as well as attributes have to be defined. Especially, to model the inference process implied in a requirements document, the following principles should be followed.

1. Any requirement/sub-requirement relationship is handled as an element/sub-element relationship in XML.
2. For each element we define the attributes:

   title: each element has a title for display purposes.

   display: each element may have additional text for display purposes.

   query: the query attribute holds a database query that will be used to determine if the corresponding requirement is satisfied for a specific student. Only those elements that do not have sub-elements, have a query attribute.

   expected: the result expected from the query.

   comparison: the operator to use to verify the query result is the expected result.

   combining: the combining attribute is a logic operator "and" or "or" or a function call, which indicates how sub-requirements are combined. Only those elements that have sub-elements have a combining attribute.

```
<GeographyRule title= “Degree Requirement for 3-Year BSc
                                        (Geography)”,
                    combining = ”AND” >
<GraduationRule title=”Graduation Requirement”,
                    display=”90 credit hours”, query= “...”, ...>
</GraduationRule>
<ResidenceRule title = ”Residence Requirement”,
                   combining = ”AND” >
   <DegreeRule  title = ”Degree Requirement”,
                    display = ”minimum 30 credit hours”,
                    query = ”SELECT sum(creditHours)
                                   FROM studentHistory
                                   WHERE
                                   studentNumber=parameterValue”,
                    expected=”30”,
                    comparison= “>=” >
   </DegreeRule>
   <MajorRule   title=”Major”,  display=”minimum 18 credit hours”,
                   query=”... ”, ...>
   </MajorRule>
</ResidenceRule>
<GeneralRule     title=”General Degree Requirement,
                    combining = ”AND”>
  <HumanitiesRule   title=”Humanities”,
                       display=”12 credit hours”, query=”... ”, ...>
  </HumanitiesRule>
  <ScienceRule   title=”Science”, display=”6 credit hours”,
                    query=”... “, ...>
  </ScienceRule>
</GeneralRule>
<MajorRule>      title=”Major Requirement”
                    combining = ”AND”>
   <MinMaxRule
      display=”Minimum 30 credit hours, Maximum 48 credit hours”,
      query=”... “, ...>
   </MinMaxRule>
   <ReqCoursesRule    title=”Required Courses” ,
                         combining = ”AND”>
      <Course
          display=”23.02 Intro Geography I”, query=”...”, ...>
      </Course>
      <Course
         display=”23.203 Intro Geography II”, query=”...”, ...>
      </Course>
      <Course
         display=”23.331 Advanced Geography”, query=”...”, ...>
      </Course>
   </ReqCoursesRule>
   <ChoiceRule    title=”Choice”,
                     display=”23.205 Atmos Sci or 23.206 Earth Sci”
                     combining = ”OR”>
        <Course  query=”...” , ...> </Course>
        <Course  query=”...” , ...> </Course>
   </ChoiceRule>
</MajorRule>
</GeographyRule>
```

Figure 4: XML expression of graduation requirements

We give an example of the process to construct an XML document. Consider the Residence Requirement. This requirement has two sub-requirements as shown in Figure 1. So we need a Residence element and two sub-elements for Degree and Major in its XML version. Furthermore, the Residence element has a title with a value of "Residence Requirement", but does require any further text to be displayed and so there is no value for the display attribute. There is no query to execute to determine if the Residence Requirement is satisfied, rather it is necessary to determine if all sub-requirements are satisfied. Therefore, there is no value for the query attribute; queries will appear in its sub-requirements. Lastly, since the Residence Requirement has sub-requirements, the combining attribute must be “and” since both sub-requirements must be satisfied for the Residence Requirement to be satisfied.

We continue this example one step further by considering the Degree Sub-requirement. This requirement does not have sub-requirements itself and so we do not define any sub-elements of the Degree element. The Degree element has a title with a value of “Degree Requirement”, and requires a value for the display attribute for the additional text of “minimum 30 credit hours“. The Degree Requirement needs a value for the query attribute so that the minimum of 30 credits can be verified against a database of student history information. This query requires a parameter for the student number since the student would not be known until the query is executed. Note that the exact function or query expression required here depends on the database system being used. To pass the requirement, the result must be at least 30 and so the expected attribute is “30” and the comparison operator is “>=“. Finally, since the Degree Requirement has no sub-requirements, the combining attribute is not given any value. The above discussion leads to the following definitions which appear in the XML document shown in Figure 4.

```
<ResidenceRule title = ”Residence Requirement”,
              combining = ”AND” >
   <DegreeRule  title = ”Degree Requirement”,
               display = ”minimum 30 credit hours”,
               query = ”SELECT sum(creditHours)
                          FROM studentHistory
                          WHERE
                             studentNumber=parameterValue”,
                             expected=”30”,
                             comparison= “>=” >
  </DegreeRule>
   ...
</ResidenceRule>
```

Figure 4 can be viewed as a set of rules that require evaluation to know the graduation status of a student. Specifically, the rules will be evaluated in a bottom-up way. That is, to know the value of any rule, the value of its contained rules must be made available first. In the next section, we discuss how such a set of rules are evaluated.

4 SYNTHESIZED QUERY TREES

In this section, we describe the evaluation of the rules represented in an XML document. For this purpose, we introduce the concepts of *synthesized query trees*, which are implemented in our system to control the inference process. We distinguish two kinds of synthesized query trees. One is the so called boolean synthesized query tree, which will be discussed in 4.1. The other is its extended version for handling more complicated cases, and will be discussed in 4.2.

4.1 Boolean Synthesized Query Tree

The documents discussed in Section 3 form a single compound rule that comprises some other sub-rules. The evaluation of such a rule requires either for all of its sub-rules to be true, or, for at least one sub-rule to be true. To control the evaluation of such a rule, as well as the execution of the queries involved, we present the Boolean Synthesized Query Tree as follows.

Definition 1: a *boolean synthesized query tree (BSQT)* is a tree where each leaf node *v* is associated with a boolean query $Q(v)$, and each internal node *v* is labelled with a tag *T(v)*, and an operator $\theta = \vee \; or \; \wedge$; and each node *v* is assigned a boolean value, *V(v)*, determined as follows:

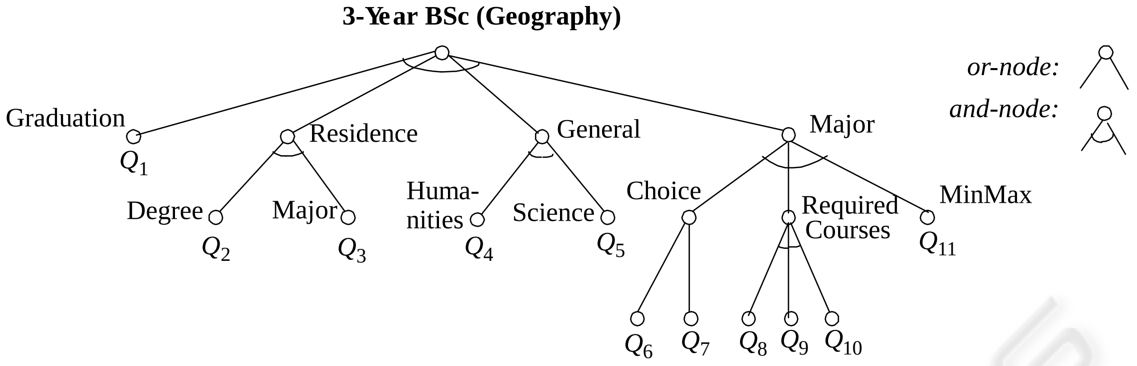
a) for a leaf node, *V*(*v*) is *true* if the return value of $Q(v)$ is not empty; otherwise, it is *false*, and

b) for an internal node, with children v_1, ... v_n, $V(v) = V(v_1)\theta V(v_2)\theta\ldots\theta V(v_n)$

In Figure 5, we show a tree which is a BSQT, derived from the XML document shown in Figure 4. From this, we can see that the whole process of evaluating the corresponding rule is explicitly specified.

We also notice that in the BSQT an internal node is either an *and*-node or an *or*-node according to the operator used at that node. In addition, the value of any node depends on the values of its descendants. To determine the value of a node *v*, *V*(*v*), the value of each descendant node must be determined first. Therefore, the function *V*(*v*) is evaluated bottom-up.

For instance, the 3-Year BSc (Geography) Requirement is satisfied if all of Graduation Requirement, Residence Requirement, General



```
Q1: select *
    from StudentHistory
    where studentNum = x and
        gradePoint >= 1
    group by studentNum
    having sum(crHours >=90)

Q2: select *
    from StudentHistory
    where studentNum = x and
        institution = 'UW'
    group by studentNum
    having sum(crHours >=90)

Q3: select *
    from StudentHistory
    where studentNum = x and
        property = 'major'
    group by studentNum
    having sum(crHours >=18)

Q4: select *
    from StudentHistory
    where studentNum = x and
        area = 'humanities'
    group by studentNum
    having sum(crHours >=12)

Q5: select *
    from StudentHistory
    where studentNum = x and
        area = 'science'
    group by studentNum
    having sum(crHours >=6)

Q6: select *
    from StudentHistory
    where studentNum = x and
        courseNum = 23.205

Q7: select *
    from StudentHistory
    where studentNum = x and
        courseNum = 23.206

Q8: select *
    from StudentHistory
    where studentNum = x and
        courseNum = 23.202

Q9: select *
    from StudentHistory
    where studentNum = x and
        courseNum = 23.203

Q10: select *
    from StudentHistory
    where studentNum = x and
        courseNum = 23.331

Q11: select *
    from StudentHistory
    where studentNum = x and
        property = 'major'
    group by studentNum
    having
    sum(30 <= crHours <= 48)
```

Figure 5: A BSQT for graduation requirements

Requirement, and Major Requirement are satisfied. Thus, the node labelled 3-Year BSc (Geography) is an internal *and*-node representing a compound rule where all sub-rules must be true for the requirement to be satisfied. However, the node labelled Choice is an internal *or*-node representing a choice a student must make: to take one of two courses 23.205 or 23.206 (see Q_6 and Q_7 in Figure 5).

Of course, some rules do not have sub-rules; for instance, the Degree Requirement specifies that the student must have completed at least 30 credit hours at the institution (see Q_2 in Figure 5). There is no sub-rule this rule depends on; this rule requires the evaluation of a query to determine if it is satisfied or not. Degree Requirement is a leaf node in the BSQT.

A leaf node represents a simple requirement that is not subdivided any further. In Figure 5, queries are indicated for each leaf node. For instance, the Graduation requirement is met if the student has at least 90 credit hours in courses that have been completed satisfactorily (a grade point of at least 1 in each course; see Q_1 in Figure 5). This can be determined by querying an appropriate data store, and the result is either true or false. For other leaf nodes, similar queries would be specified. For the purposes of this paper, we consider these queries are explicitly coded, as they are typically done for database applications.

Each node in the tree in Figure 5 expresses a business rule for graduation. The tree is organized in such a way that all data access is at leaf nodes and each internal node organizes and accumulates the results from its child nodes using logical *and* or *or* operators.

When the graduation officer requests a student's graduation status for a degree, the graduation rules must be evaluated bottom-up. This is accomplished by the application layer performing a post-order traversal of the tree. When leaf nodes are being evaluated, a data store of student history information must be accessed. Typically, this data store is a relational database and SQL would be used by an application layer to retrieve relevant information for the officer to assess.

4.2 General Synthesized Query Tree

We now generalize our model to distributed documents. In our exemplary requirements document, there is a list of required courses for the degree. Suppose the list of courses is not in this XML document; rather, suppose the list of required courses is stored in some data store and that the list can only be retrieved in a query. This situation is one where the list of required courses is maintained separately from this XML document.

As we will discuss, this type of document requires more expressive data manipulation, and so we propose a more general query tree where a leaf node may be single- or set-valued, and an internal node may have operators other than *and* or *or* associated with it. We define the general synthesized query tree as below.

Definition 2: a *general synthesized query tree (GSQT)* is a tree where each leaf node *v* is associated with a query *Q(v)*, which returns a value or a set of values, and each internal node *v* is labelled with a tag *T(v)*, a function *f*, and each node will be assigned a value *V(v)*, as follows:

a) for a leaf node, its value *V(v)* is equal to the return value of $Q(v)$, *i.e.*, $V(v) = Q(v)$, and
b) for an internal node, with children v_1, ... v_n, $V(v) = f(V(v_1), V(v_2), \ldots, V(v_n))$

In Figure 6, the same requirements as before are illustrated, but we imply that the set of required courses is obtained using a query submitted against some data store. Here, we assume that external data can be obtained from any available or required data store.

Now, given that the required courses for the 3-Year BSc (Geography) are kept elsewhere, to determine if a student has successfully passed all courses, the process of evaluating the requirement has to be carried out differently from before. To evaluate the requirement, the graduation officer must run two queries and combine their results as we explain next.

First, a list of courses successfully passed by the student is obtained. Let us name this result *SuccessResult* and assume this result is a relation with two attributes: student number and course number. Since we are considering a single student, the same student number will appear in each tuple. The other list obtained is a list of required courses. Let us name this result *RequiredList* and assume this result is a relation with one attribute: course number. Note these two relations have one common attribute: course number. The graduation officer needs to determine if the set of courses successfully passed includes the set of required courses. To do this, the relational algebra division operator (Elmasri and Navathe, 2003) should be conducted:

SuccessResult[studentNum, courseNum]
÷ *RequiredList[courseNum]*.

The result of this operation is a relation of one attribute: student number. In the result, a student number appears if the student number appears in *SuccessResult* with some course numbers which form a super-set of *RequiredList*. In our example, if the student has successfully taken each required course, then the result of division is a relation of one tuple having the student number of that student. If the student has not taken all of the required courses then our result is a relation of zero tuples - an empty relation. The division operator is difficult to explain. It is even more difficult to express in the standard relational language SQL and error-prone since it is not directly supported in that language. For this reason, the document designer may prefer a different approach where division is directly supported. We note that the division can be expressed simply, as shown in Figure 6.

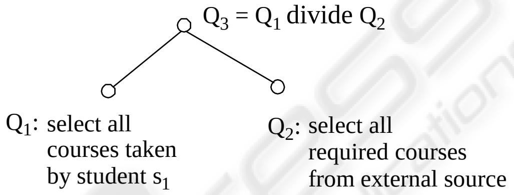

Q_3 = Q_1 divide Q_2
Q_1: select all courses taken by student s_1
Q_2: select all required courses from external source

Figure 6: Division operation

In Figure 7, we illustrate a subtree rooted at Major in the GSQT for our running example, for which various functions are required to manipulate the values obtained from descendant nodes in the GSQT. For instance, associated with v_8, we have a *division* operation while for v_6, the operation is the *projection*.

In the Figure, the functions *f*( ) and *g*( ) are defined as follows:

f(*x*, *y*): if $x \in y$, returns *true*; otherwise, *false*.

g(*x*): if $30 \le x \le 48$, returns *true*; otherwise, *false*.

As with the other operations, they take the values from the corresponding child nodes as the parameters. We also note that each leaf node in the tree is associated with a query, which provides the initial values for computation. Therefore, the evaluation of *V(v)* for any node is performed bottom-up. For instance, the value of v_8, $V(v_8)$, is calculated by dividing the result of $Q(v_{10})$ through the result of $Q(v_{11})$ (*i.e.*, $Q(v_{10}) \div Q(v_{11})$; both of them come from its children); $V(v_3)$ is obtained by computing $g(V(v_6))$, and so on.

The GSQT is similar to the concept of *query trees* used for constructing query execution plans in relational database systems (Elmasri and Navathe, 2003). We note that, however, our documents have a number of queries and for the purpose of evaluating sub-rules separately, it is necessary for each sub-rule to be self contained and for its query requirement to be expressed independently of other rules.

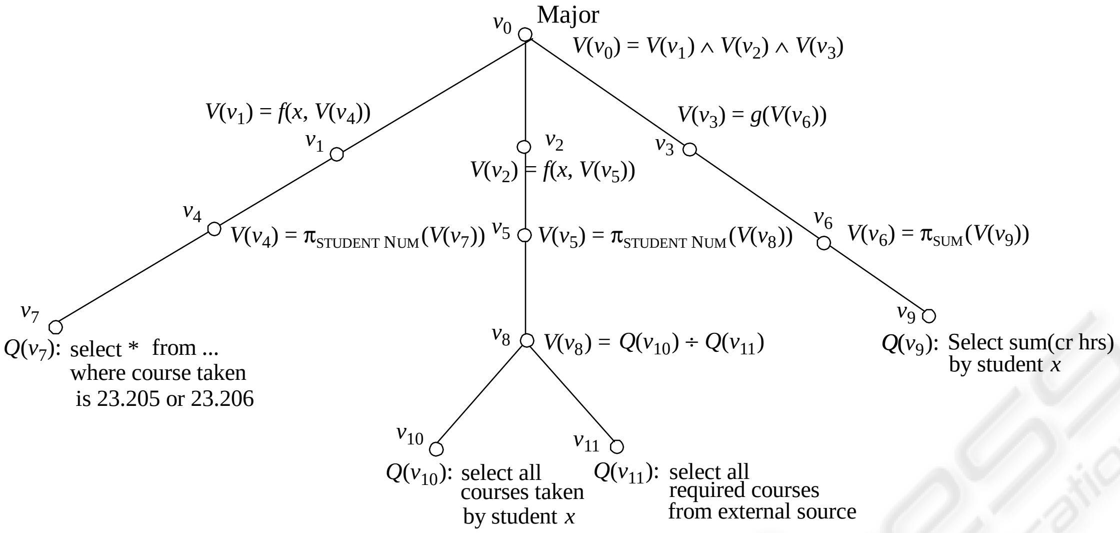

v_0 Major
$V(v_0) = V(v_1) \wedge V(v_2) \wedge V(v_3)$
$V(v_1) = f(x, V(v_4))$
v_1
v_2
$V(v_2) = f(x, V(v_5))$
$V(v_3) = g(V(v_6))$
v_3
v_4
$V(v_4) = \pi_{\text{STUDENT NUM}}(V(v_7))$
v_5
$V(v_5) = \pi_{\text{STUDENT NUM}}(V(v_8))$
v_6
$V(v_6) = \pi_{\text{SUM}}(V(v_9))$
v_7
$Q(v_7)$: select * from ... where course taken is 23.205 or 23.206
v_8
$V(v_8) = Q(v_{10}) \div Q(v_{11})$
v_9
$Q(v_9)$: Select sum(cr hrs) by student x
v_{10}
$Q(v_{10})$: select all courses taken by student x
v_{11}
$Q(v_{11})$: select all required courses from external source

Figure 7: Graduation requirements as a GSQT

Furthermore, for queries in our example, several queries access the same data and some query results can even be derived from other queries, which cannot be expressed in any kind of query trees. (Finally, if this knowledge is exploited during document/query processing, it is possible for us to realize efficient query processing.)

In (Bonifati, Ceri and Paraboschi 2001, Abiteboul, Benjelloun, Manolescu, Milo, and Weber 2002), distributed XML documents are considered. In these, document queries are used to retrieve distributed portions of an XML document. The queries and documents in (Bonifati et al 2001, Abiteboul et al 2002) are not the same as the situation here since in our model the queries we are considering are used to retrieve data from (for example) SQL database systems.

5 CONCLUSION AND FUTURE WORK

In this paper, we consider a kind of document, the so called requirements document. Each document can be considered as a single compound rule. When such a document (e.g. BSc Graduation Requirement) is evaluated in a certain context (e.g. for a specific student) there will be a value generated for it. In our example, the value generated for the document is the graduation status for a particular student. For this type of document, the BSQT and GSQT succinctly represent the document evaluation and query requirements; a simple tree traversal is required to evaluate a document.

The BSQT and the GSQT structures can be applied to any part of a document, and the BSQT and GSQT could appear in multiple places of a document. For example, the General Calendar published by a university would have many GSQTs, one for each degree program for each department.

We are currently developing a prototype system which requires a complete specification of rule processing, synthesized tree instantiation, and connection to a database system. Concurrently, we intend to examine other issues related to the processing of these types of query-based documents, such as rule markup, event-condition-action model, Document Object Model, query optimization, workflow, active XML documents, and composing/assembling documents from other documents. For example, the event-condition-action model for rule processing can be incorporated if we take into account the updates to the Student History Data Store. At the end of term, when marks for a student have been entered, the graduation requirements document/rule processing can be activated. As another example, a university may offer a double major program that can be represented as a composite requirements document defined and assembled from existing documents.

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