ON VIEW PROCESSING FOR A NATIVE XML DBMS

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Chapter 1

Introduction

Traditionally, view is an important aspect of data processing. View support is desirable because it provides automatic security for hidden data and allows the same data to be seen by different users in different ways at the same time. Compared with views in relational database, views for hierarchical data like XML not only allow basic operations like selection, projection and join, but also structural swapping of nodes in document trees. For example, a bibliography XML file (e.g DBLP[19]) contains a list of publications; "under" each publication there are the authors together with various other properties of the publication. A frequent view operation on XML data like DBLP is to find all authors together with their publications, which is indeed a swapping operation on nodes "Publication" and "Author".

The starting point of XML view transform is view definition. There are two general approaches to define views on source XML data:

1. One way is to define views or queries in script languages like XQuery[32] or XSLT[33].

2. The alternative approach is to define views by view schemas. Systems like Clio[24] , eXeclon[11] and the work in [7] fall into this category. Users only need define a view schema over source data to obtain desired the view result. This approach is declarative and alleviates user from writing complex scripts to perform view transformation.

There are problems with the above two approaches which hinder them to become ideal XML view definition formats.

The query languages (e.g. XSLT and XQuery) cited above in the first approach usually use regular expressions to express possible variations in the structure of the data. But the use of regular expression queries means the user is responsible to phrase their queries in a way that will cover the *variations* in the structure of the source data. As an example, suppose again we want to find the information of authors of each publication; however it is *possible* that the information we want may be presented in the source data in two ways: in some places *author* is nested under *publication* (e.g. in a bibliography record) whereas in some other places *publication* is nested under *author* (e.g. in a publication list of a researcher). Using regular expression means that we have to specify two patterns: *author//publication* and *publication//author* to obtain all relevant information. It would be clear that we can extend the example such that in the worst case an exponential number of regular expressions need to be written to cover all possible variation in source data.

To overcome the above problem, a solution is to utilize the *ontology* of source data, which consists of the list of tag names of elements and attributes in the data. Apparently, it is much easier to start from the ontology to define views than to require a user to comprehend the structural details of source data. As an example, we can extract two keywords *author* and *publication* from source schema. Next we let *author* be the parent node of *publication* in a view schema meaning that we want to find all matching pairs of *author* and *publication* elements which lie on the same path in source documents and construct the results by placing *publication* elements under *author* elements. Note that we do not restrict the hierarchical order of elements in a matching pair in source document. The approach discussed in this thesis greatly extends the above idea: it allows a user to extract element names from the ontology of source data and define the structure of view via a view schema. All the tedious work of finding structural variations of view schemas in the source document will be left to the view processing back-end system. Thus view definitions can be phrased succinctly based only on the *ontology*.

Meanwhile, simple tree/graph-structure schema languages like DTD and XML Schema used in the second approach for XML view (target) schema can not express many useful semantics and consequently causes ambiguity. To see this, let us take a look at a sample XML document in Figure 1.1. It contains information about researchers working under different projects and the publication list for each researcher.

Example 1.1 *Consider the source XML document and view schema in Figure 1.1. It has at least two possible meanings:*

1. *For each project, list all the papers published by project members; for each paper of the project, list all the authors of the paper.*

2. *For each project, list all the papers published by project members; for each paper of the project, list all the authors of the paper* working for the project.

The different interpretations result in quite different views. Current popular XML schema formats like DTD, XML Schema are unable to express these semantic differences.

It is one of the main focuses of our work to use a XML schema representation: Object-Relationship-Attribute model for Semi-Structured data (ORA-SS) [9], which overcomes the problems of the two current XML view definition approaches. ORA-SS can extract matches with structural variations from XML source and meanwhile clearly define the semantics of source data and views.

There are three main proposed ways to process XML view definitions: general document-based XML query processing engines (e.g. XQuery and XSLT query

```
< root >
  < Project J_Name = "j1" >
    < Researcher R_Name = "r1" >
      < Paper P_Name = "p1"/ >
    < /Researcher >
    < Researcher R_Name = "r2" >
      < Paper P_Name = "p1"/ >
      < Paper P_Name = "p2"/ >
    < /Researcher >
  < Project J_Name = "j2" >
    < Researcher R_Name = "r2" >
      < Paper P_Name = "p1"/ >
      < Paper P_Name = "p2"/ >
    < /Researcher >
    < Researcher R_Name = "r3" >
      < Paper P_Name = "p2"/ >
    < /Researcher >
  < /Project >
< /root >
```
(a) Source XML document

```
▷ Root
  ▷ Project
     ◇ J_Name
     ▷ Researcher
        ◇R_Name
        ▷ Paper
           ◇P_Name
```
(b) Source Schema

```
▷ Root
  ▷ Project
     ◇J_Name
     ▷ Paper
        ◇P_Name
        ▷Researcher
           ◇R_Name
```
(c) View Schema

Figure 1.1: **An sample XML document with DTD-like source and view schemas**

engines such as Xalan[30],XT[8],SAXON[26] and Quip[25]) traverse in-memory source data trees to output the result tree. Another possible solution is to load the XML data file into a relational or object-relational database and perform view transformation using available RDBMS facilities. This method requires conversion from hierarchical data and schema to relational data and schema. The third approach and also the one used in this paper is to use a *native* XML DBMS to support view transformation. A native XML DBMS is one which is designed and implemented from the ground up for storage and query processing of XML data.

Recently, great efforts have been put into the study of XML query optimization. Techniques[1][3][34] are developed mainly for processing of queries defined in the XPath[31] standard, which can express both path and branch patterns. However, as we demonstrated earlier, XML views defined based on the ontology of source data can not be mapped to a single XPath expression. To meet the new challenges, we investigate new XML query processing techniques for views defined via schema mapping. The new techniques are integrated with our native XML DBMS *XBase* to process XML views defined in ORA-SS format. Experiment results demonstrate the advantages of our method over current state-of-the-art approaches.

The main contributions of our work are:

1. We introduce a new view schema definition format based on ORA-SS which can
   (a) Extract matches with structural variants in tree-structured data like XML without issuing an excessive number of queries as XSLT and XQuery do.
   (b) Express a large variety of semantics which results in different view which is not possible under view schema format like DTD and XML Schema.
2. A native XML document storage and view transformation prototype *XBase* which implements novel XML document storage scheme and query processing techniques to obtain views defined in our view schema format.

This thesis is organized as follows:

- Chapter 2 introduces XML data model and the conceptual XML data model ORA-SS used in our work.
- Chapter 3 surveys recent work on graphical XML view definition, native XML DBMSs and the latest XML query/view processing techniques.
- Chapter 4 explains in details the advantages of using the ORA-SS data model for XML view schema definition.
- Chapter 5 explains storing XML documents in a new *Object Based Clustering* scheme in our prototype XML DBMS system: *XBase*.
- Chapter 6 shows a new XML query processing technique: *Associative Join* to efficiently process XML views defined in ORA-SS format.
- Chapter 7 shows a series of experiments to test the performances of view transformations in our XML DBMS: XBase.
- Chapter 8 concludes the thesis.

Chapter 2

Background

Recently there has been an increased interest in managing data that does not conform to traditional data models. The driving factors behind the shift are diverse: data coming from heterogeneous sources(especially the Web) may not conform to the traditional Relational or Object oriented model physically; meanwhile missing attributes and frequent updates to both data and schema render traditional data models inappropriate in the logical level. The term *semi-structured* data has been coined to refer to data with the afore-mentioned nature. In particular, XML is emerging as one of the leading formats for representing *semi-structured* data.

In this chapter, we first briefly describe the XML data model. Next we introduce a recently proposed conceptual model for XML data: Object Relationship Attribute Model for Semistructured Data or *ORA-SS*.

2.1 XML data model

An XML document is generally presented by a labelled directed graph $G = (V_G, E_G, root_G, \sum_G)$. Each node in the vertex set V_G is uniquely identified by its *oid*. A node can be of the following types: *Element*, *Attribute*, *Content*. Each node also has a string-literal *label* from the alphabet $\sum_G$. The root node is denoted by $root_G$. There are two types of edges in the edge set E_G. The *tree* edges represent parent-child relationships between two nodes in V_G. Note that any node except $root_G$ has one and only one incoming *tree* edge but any number of outgoing *tree* edges. The *reference* edges represent reference relationships defined using ID/IDREF features in XML. As an example, the following XML element *student* has an *id* attribute whose value is unique in the entire document:

$$< student\ id = \text{“}U888\text{”}\ name = \text{“}Tim\ Duncan\text{”}\ age = \text{“27”} >$$

Another element can refer to the above element using an ref attribute whose value is equal to the *id* value of referred element. E.g:

$$< student\ ref = \text{“}U0202888\text{”} >$$

The advantage to use ID/IDREF is that we can avoid replications of data in XML documents.

If we consider only *tree* edges, an XML document can be viewed as a tree. In the remaining of this paper, we focus on tree-structured XML data model which doesn't include ID/IDREF edges.

2.2 ORA-SS

DTD and XML Schema are *de facto* schema formats for XML documents, why do we need yet another model? There are multiple reasons. First of all, DTD and XML Schema are text-based; they are primarily designed for validation of XML documents. In the domain of view definition, it is troublesome to define views in DTD and XML Schema directly. On the other hand, graphical and conceptual data models are much more intuitive and easy to design. Next and more importantly DTD and XML Schema provide little features for expressing semantic constraints over data they represent as we have pointed out in the introduction section.

We introduce a semantically expressive data model ORA-SS[9]. ORA-SS has two important types of diagrams. An *ORA-SS instance diagram* represents a XML document while an *ORA-SS schema diagram* models the corresponding schema. Drawing from the success of Entity-Relationship model, an ORA-SS schema diagram has the following basic concepts:

1. Object Class

Object classes are similar to entity types in the *Entity-Relationship* model. Object classes are represented as *rectangles* in ORA-SS Schema diagram.

2. Relationship Type

   Two or more object classes are connected via a relationship type in schema diagram. Labels associated with edges between object classes denote the relationship type names and their degrees.

3. Attribute

   Attributes are properties of an object class or a relationship type. Attributes are represented as *circles* in ORA-SS Schema diagrams. An attribute can also be the identifier of an object instance and is represented as a *solid circle* in ORA-SS schema diagrams. Labels associated with edges between object classes and attributes indicate which relationship type the attribute belongs to. Edges between object classes and attributes without labels indicate the attributes are properties of the object classes.

In *ORA-SS instance diagrams*, objects are represented as rectangles labelled with class names. Labels under leaf nodes show attribute names followed by their values.

The most important difference between ORA-SS and DTD/XML Schema is that for each object class, an ORA-SS schema indicates which relationship types it participates in. Similarly for each attribute, an ORA-SS schema explicitly indicates its owner object class or relationship type. This information can be obtained from labels on edges in an ORA-SS schema diagram. In general, an edge with a relationship type label of degree n ($n \geq 2$) indicates that the two object classes (say A , B and A is B's parent) linked by the edge and the $n-2$ closest ancestors of A form a n-ary relationship type.

Example 2.1 *Fig. 2.1 shows an ORA-SS instance diagram and and Fig. 2.2 shows the corresponding schema diagram for the XML file in Fig. 1.1a (with a few additional attributes on Position and Date).*

Like DTD, XML Schema and Data-Guide[12], an ORA-SS schema diagram shows the tree structure of the XML file. What's more, the ORA-SS schema diagram explicitly indicates the following facts about XML documents conforming to the schema:

1. *There are two binary relationship types in the schema: Project−Researcher (JR) and Researcher − Paper (RP). A project can have several researchers and a researcher can work in different projects. Meanwhile, the set of papers under a researcher doesn't depend on the project he/she works in.*

2. *Position is an attribute of relationship type JR instead of Researcher. This means that a researcher may hold different positions across projects he works in.*

3. *Date is a* single-valued *attribute of object class Paper. Different occurrences of the same paper will always have the same Date value.*

4. *J_Name,R_Name and P_Name are identifiers of object classes Project, Researcher and Paper respectively as indicated by solid circles. Key values are used to tell if two object occurrences are identical.*

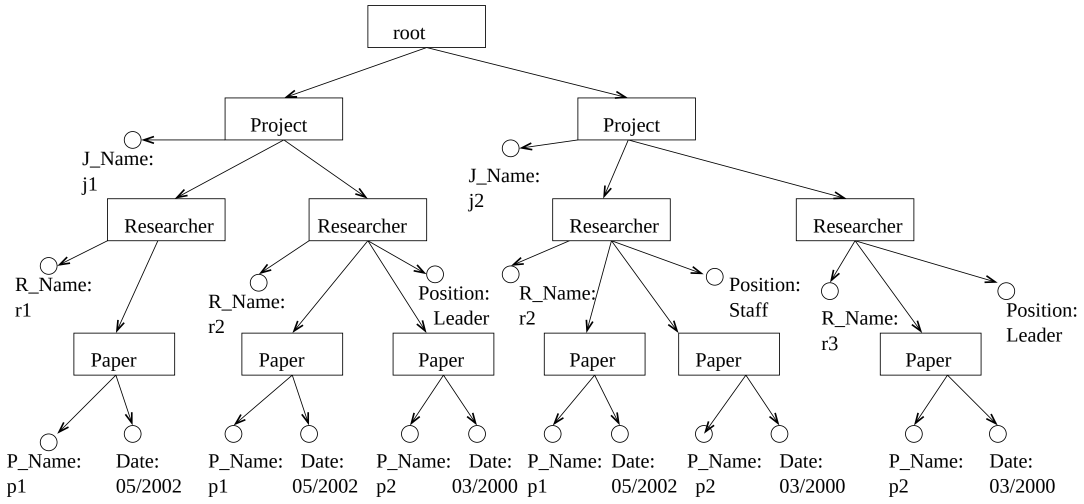


Figure 2.1: **ORA-SS instance diagram for the XML file in Fig. 1.1a**

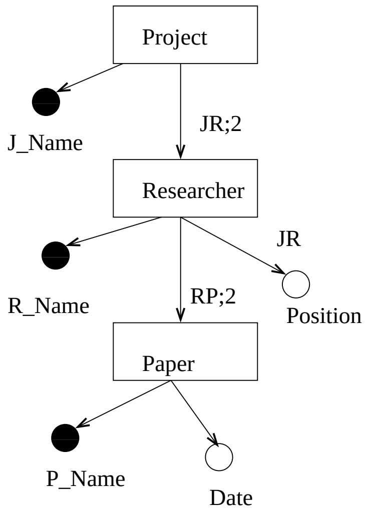


Figure 2.2: **ORA-SS schema diagram the XML file in Fig. 1.1a**

Information about relationship types in an ORA-SS schema can be obtained through several possible ways:

1. In the case that the XML document examined is exported from a relational source, then by knowing operations performed on the source tables to generate the XML data, we can deduce the ORA-SS schema. For example, in the above example, if we know that the XML file are generated by joining two relational tables $(Project, Researcher)$ and $(Researcher, Paper)$, then we can easily know there are two binary relationship types in the ORA-SS schema.

2. In the case that we only have XML documents, then we need to solve the classic schema discovery problem. This thesis does not focus on the problem of ORA-SS schema discovery; we use the example to illustrate the intuition. It should be noted that the relationship type information implies data dependencies. First we need to assign keys for each object class to tell if two objects are the same. Next if we find that all occurrences of the same *Researcher* object have the same set of papers as their children, then *Researcher* and *Paper* may probably form a binary relationship type. This fact has to be confirmed by users because the file may be too small to find an exception. Otherwise it means the set of papers under a researcher depends also on the project the researcher works in; then *Project*, *Researcher* and *Paper* forms a ternary relationship.

Chapter 3

Review of the State of the Art

In this chapter, we review topics related to XML views and view processing. First we survey popular XML schema formats and query languages and the relatively new field on graphical XML query language. Next we study XML document storage schemes which have direct impact on XML view processing. Finally we review state-of-the-art XML query processing techniques.

3.1 XML Schema Formats and Graphical view definitions

DTD[10] and XML Schema[27] are current dominant XML schema standards. DTD is essentially an extension of context-free grammar (CFG) which is able to specify graph structures of XML data as well as various constructs like

Element, *Attribute* and *ID/IDREF*. XML Schema has many more features compared with DTD. It allows the definition of complex data types in a schema which is not present in DTD. XML Schema also has features like inheritance. XML Schema is gradually replacing DTD as the standard XML schema format.

Under the W3C, there are two competing XML query language standards: XQuery[32] and XSLT[33]. While it is a matter of taste to say which is better, it seems that XQuery is gaining the upper-hand because strong endowment from the database research community. Both XQuery and XSLT provide rich features as query languages and thus become complex. Both of them follow the SQL tradition and use For-Let-Where-Return as the basic query skeleton. Aggregate functions are also supported by both languages. It should be noted that XPath[31] is used to extract information from XML documents in both standards.

One of the classical graphical query languages is *Query By Example* (QBE) from IBM. A graphical query language is often preferred over text-based query language because of its intuitiveness and ease of use. In the context of XML graphical query language, important recent developments include XML-GL[2] and GLASS[23]. XML-GL is built on the base of a graphical representation of XML documents and DTDs, which is called XML graphs. An XML graph represents the XML documents and DTDs by means of labelled graphs. An XML-GL query consists of two parts: left hand side (LHS) and right hand side (RHS). The LHS of an XML-GL query indicates the data source and conditions and the RHS constructs the output. Compared with XML-GL, GLASS is a more expressive XML visual query language. It employs ORA-SS as its XML data model. GLASS also supports *negation*, *quantifier* and *conditional output*, which are not present in XML-GL. A GLASS query consists of LHS and RHS parts just as XML-GL; however, it has an optional *Conditional Logic Window* (CLW) which allows specification of many useful logic conditions such as *negation*, *existential constraints* and *IF-THEN* conditions.

Example 3.1 *The GLASS query in Figure 3.1 displays the members with their names who have written a publication titled "Introduction to XML or "Introduction to Internet; and for those members who have written Introduction to XML, it also displays all information about the projects that they have participated in.*

The vertical line separates LHS and RHS of the GLASS query. $: A :$ *and* $: B :$ *are conditions which require the members should have a publication titled "Introduction to XML (or "Introduction to Internet) respectively.*

3.2 XML document storage schemes and Native XML DBMS

The storage scheme has a great impact on the performance of native XML DBMS systems. Several native storage schemes have been proposed to store

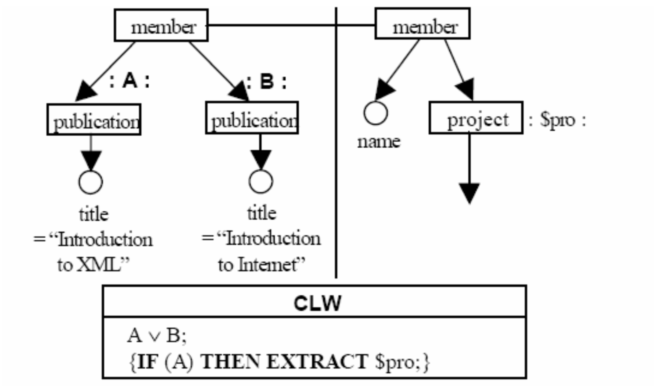


Figure 3.1: **An example of GLASS query**

XML documents:

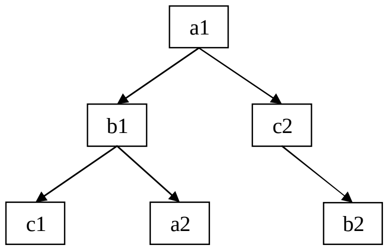
1. *Element-Based* scheme (EB). In EB scheme (Figure 3.2b), each element (and attribute which is also treated as an "element") is an atomic unit of storage and elements in an XML document are stored according to their document (i.e. pre-order) order. The Lore system[21] is a classical example which uses *EB* scheme.

2. *Element-Based Clustering* scheme (EBC). In EBC scheme (Figure 3.2c), elements with the same tag name are first clustered together and in each cluster elements are listed by their document order. TIMBER[14] is a native XML DBMS using EBC scheme.

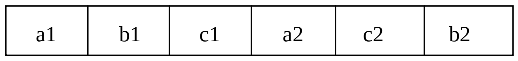
3. *Subtree-based* scheme (SB). In SB scheme (Figure 3.2d), a XML document tree is divided into subtrees according to the physical page size, following the rule that the size of a subtree should be as close as possible to the size of the physical page. A split matrix is defined to make certain

element nodes are clustered as a record. Similarly, records are stored in pre-order according to their roots. Natix[16] adopts SB strategy.

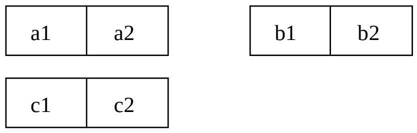
4. *Document-based* scheme (DB) . In DB scheme, the whole XML document is a single record. An example that adopts the DB strategy is the storage of Apache Xindice[18] system.



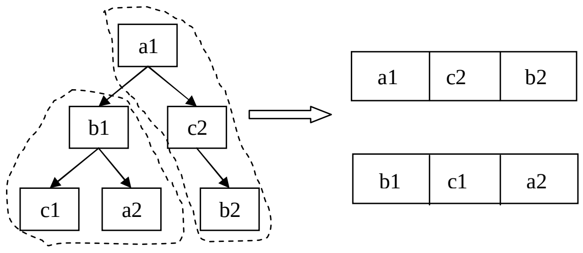
(a) A sample XML document: node *a1* and *a2* have tag name *A*; *b1* and *b2* have tag *B* and *c1* and *c2* have tag *C*.



(b) Storing the XML document in (a) using *EB* strategy



(c) Storing the XML document in (a) using *EBC* strategy



(d) Storing the XML document in (a) using *SB* strategy

Figure 3.2: **Illustration of various XML document storage schemes**

The advantage of the EB strategy is its simplicity and robustness. Its biggest disadvantage is tiny granularity of record because each element and attribute is treated as an atomic unit of storage. Tiny granularity results in too many pointers (physical pointer or logical pointer) among records, which leads to more storage space and increasing the cost of updating. Meanwhile, because elements with the same tag are not clustered together, the scheme incurs more I/O costs in processing queries involving only a small number of tags. The main disadvantage of the SB strategy is its relatively large granularity of record. In some cases, most data gained by a single page read from disk is useless for query processing. The DB strategy treats a whole document as a single record. It is fine with small files but not suitable for large ones. The whole XML document must be read and be memory-resident during query processing, which requires too much memory. EBC to some extents, avoids the problems of other storage schemes and thus is a more popular XML storage option currently.

Besides the choice of storage schemes, native XML DBMSs usually number node of an XML document for query processing purposes and store these numbers together with records in the database. One of these numbering schemes[3] is to use $(DocumentNo, StartPos : EndPos, LevelNum)$ to number each node in the XML file. $DocumentNo$ refers to the document identifier. $StartPos$ and $EndPos$ are calculated by counting the number of element start and end tags from the document root until the start and the end of the element. $LevelNum$ is the nesting depth of the element in the data tree.

Node numbering allows fast processing of XML documents because using the numbering scheme, the calculation to tell if two nodes are of ancestor/descendant or parent/child relationship is done in constant time. For example, in the numbering scheme we introduced previously, node A is a descendant of node B if and only if $StartPos(A) > StartPos(B)$ and $EndPos(A) < EndPos(B)$. Notice that using node numbering scheme, we do not need to travel the edges (note that in the number of travelling steps is dependant on document height) from A to B to do the ancestor/descendant testing. Similarly, node A is the parent of node B if and only if $StartPos(A) > StartPos(B)$, $EndPos(A) < EndPos(B)$ and $LevelNum(A) == LevelNum(B) - 1$.

3.3 XML View Processing techniques

Query processing and optimization of graph/tree structured data like XML poses many new problems. In the context of graph structured XML data, many techniques to build a structural summary on source XML data have been proposed. Summary structures of XML data, which play a similar role to indexes of traditional relational databases, are usually much smaller than the corresponding source data in size and thus they can be used to answer path and branch queries efficiently. $1 - index$[22],$A(k) - index$[17],$D(k) - index$[4] and $M(k) - index$[13] are recently proposed XML structural summaries to answer path queries.

We focus on tree-structured XML data in this thesis. In the context of tree (which is a special kind of graph) structured XML data, more optimization techniques are allowed. Join processing is central to query evaluation. *Structural join* is essential to XML query processing because most XML queries impose structural relationships (e.g. $Parent - Child$ and $Ancestor - Descendant$ relationships) to nodes in query results. For example, the XPath query $Researcher/Paper$ asks for all $Paper$ elements which are children of $Researcher$ elements. A binary structural join (which simply contains two query nodes linked by a $Parent - Child$ or $Ancestor - Descendant$ edge) is formally defined as follows:

Definition 3.1 *(Binary Structural Join[3]) Given two sorted input lists and a certain numbering scheme for each node in the lists where $AList$ is a list of potential ancestor (or parents) nodes and $DList$ is a list of potential descendant (resp. children) nodes, find the list $OutputList = [(a_i; d_j)]$ of join results, in which a_i is the parent/ancestor of d_j and a_i is from $AList$ and d_j is from $DList$.*

Zhang et al.[34] proposed a merge join ($MPMGJN$) algorithm based on ($DocId, LeftPos : RightPos, LevelNum$) labelling of XML elements. The later work by Al-Khalifa et al. [3] gives a stack-based binary structural join algorithm which is both I/O and CPU optimal based on the same XML labelling scheme. Wu et al. [29] studies the problem of (binary) join order selection for complex queries based on a cost model which takes into consideration factors such as selectivity and intermediate result size.

A more general form of XML query consists of more than binary relationships. Formally, a *twig pattern query* Q is a small tree whose nodes are predicates (e.g. node type test) and edges are either *Parent-Child* edges or *Ancestor-Descendant* edges. A *twig pattern match* in a XML database D is a mapping from nodes in Q to database nodes in D such that:

1. Node predicates in Q are satisfied by the corresponding database nodes; and
2. The Parent-Child or Ancestor-Descendant relationships between query nodes are also satisfied by the corresponding database nodes.

Usually, a match to a twig pattern query with n nodes is represented as a $n - ary$ tuple of databases nodes. For example, the following twig pattern query written using XPath format

$$section[/title]/paragraph//figure$$

selects distinct tuples each of which has 4 elements with types *section*, *title*, *paragraph* and $figure$ respectively. In addition, in each tuple, the $figure$ element should be a descendant of the *paragraph* element which in turn is the child of the *section* element which is the parent of the *title* element.

Formally, the problem of twig pattern matching is defined as:

Definition 3.2 *(Twig Pattern Matching [1])*

Given a query twig pattern Q, and an XML database D that has index structures to identify database nodes that satisfy each of Q's node predicates, compute ALL the answers to Q in D.

Prior work[29] on XML path pattern processing usually decomposes a twig pattern into a set of binary relationships which can be either parent-child or ancestor-descendant relationships. After that, each binary relationship is processed using binary structural join techniques and the final match results are obtained by joining individual binary join results together. For example, the afore-mentioned XPath expression can be processed by a series of structural joins and merges: (1) structurally join the list of $figure$ with the list of *paragraph* to get the paragraphs with at least one $figure$ descendant (2) structurally join the paragraphs resulted from step 1 with the list of *section* (3) structurally join the section *list* constructed in step 2 with the list of *title* (4) finally merge the list of *section* resulted in step 3 to get the final output. The intermediate output of each step except the final one is also represented as a list of tuples. The main problem with the above solution is that it may generate large and possibly unnecessary intermediate results. For example, if in the source document there are a lot of *paragraph* elements with $figure$ descendants but few of which have *section* parents, most of the intermediate output of step (1) becomes redundant once we join it with the list of *section* element.

Without resorting to the inefficient traditional decompose-then-join approach, *twig join* tries to evaluate branching queries as a whole. In their paper, Bruno et al. [1] propose a novel holistic method of XML path and twig pattern processing based on *Element-Based Clustering* which avoids storing intermediate results unless they contribute to the final results. Their algorithm is I/O and CPU optimal to twig pattern query consisting of only Ancestor-Descendant edges. Jiang et al.[15] studies the problem of holistic twig joins on all/partly indexed XML documents. Chen et al. [5] proposes a new XML element clustering approach which can process Ancestor-Descendant only, Parent-Child only and XML twig patterns with only one branch node optimally.

Chapter 4

ORA-SS as XML View Definition Format

ORA-SS schema diagrams can be used to define XML views with a great variety of semantics. In this chapter, we first explain the advantages of ORA-SS schema over popular tree/graph based XML schema formats likes DTD and XML Schema in defining XML views. Next, we explain in detail how to interpret XML view schemas defined in ORA-SS.

4.1 Why ORA-SS ?

The additional information in the ORA-SS schema diagram such as relationship type sets and attribute types allows to define XML views with a great variety of semantics.

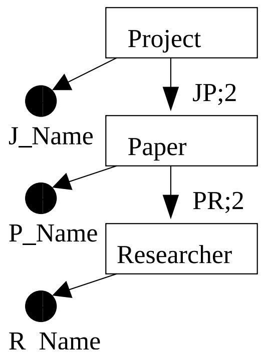
Figure 4.1 shows such an interesting example. Although the two view schemas over source schema in Figure 2.2 look nearly identical from a tree-structure point of view, they represent quite different semantics:

- Figure 4.1a has two binary relationship types. The intention of the view schema is to find all the papers published by researchers in a project; and for each paper to find all of its authors.

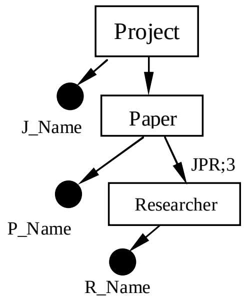
- Figure 4.1b has only one ternary relationship type. The view is defined to find all the papers published by researchers in a project just as Figure 4.1a; however, for each paper Figure 4.1b only finds those authors *working for the project*.

To illustrate the ideas, Figure 4.2 gives "correct" (which we will define formally in Section 4.2) views for view schemas in Figure 4.1a and b. To simplify the diagram, we use a variant of ORA-SS instance diagram which use identifiers to represent an object. Notice that both views are correct but view in Figure 4.1a has two more root-to-leaf paths (here we use XPath-like expressions to represent paths.) than Figure 4.1b: $root/j1/p2/r3$ and $root/j2/p1/r1$. They do NOT appear in view Figure 4.1b because researcher $r3$ is the author of paper $p2$ but not a member of project $j1$.

The above example clearly shows the expressive power of ORA-SS schema diagram. We are going to explain in detail how different semantics are derived from ORA-SS view schemas in the next section.

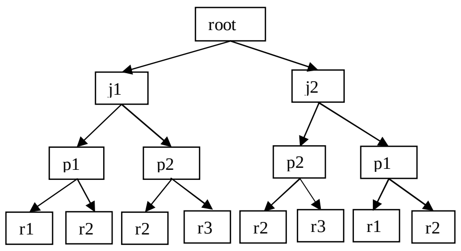


(a)

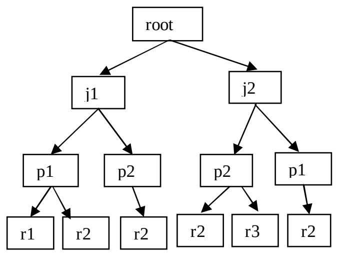


(b)

Figure 4.1: **Two view schemas for source schema in Fig. 2.2**



(a) Instance of view schema Fig. 4.1a



(b)Instance of view schema Fig. 4.1b

Figure 4.2: **Correct views for views schemas in Fig. 4.1**

User needs only the ontology of source data to define ORA-SS view schemas; by doing so we free the user from the trouble of looking into complicated details of the source schema. In terms of mapping from an ORA-SS source schema to a user-defined view schema, we extend the work by Chen[6] and define the following basic operations:

1. *Projection* Just like projection operations in relational model, projec-

tion in XML context drops object class and/or attributes in the source schema.

2. *Selection* The selection operator filters away object instances or attribute values by applying predicates to object classes or attributes in the source schema.

3. *Swapping* XML employs a tree data model; naturally, many views defined by swapping node positions in the source schema tree. This is an operator that finds no counter-part in the relational model.

4. *Join* Two relationship types can be joined on one or more common object classes.

5. *Union* Two identical relationship types or object classes can be unioned.

Remark: It should be pointed out that a user do not need to worry about these mapping operations; however back-end view transformation engines can utilize these mapping information for optimization.

Example 4.1 *Figure 4.3 defines a schema mapping for view transformation. The source ORA-SS schema has two branches with four binary relationship types. The relationship* $R_1 : Project - Researcher$ *lists researchers working under each project. The relationship* $R_2 : Researcher - Paper$ *shows the publication lists of each researcher. The relationship* $R_3 : Conference - Paper$

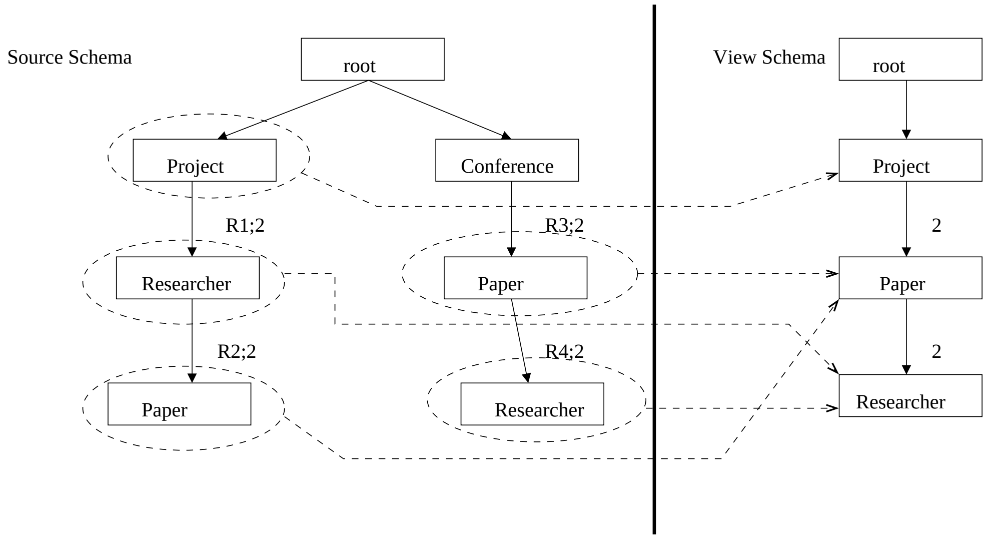


Figure 4.3: **Source Schema to View Schema Mapping with object class mapping**

lists papers published in each conference and the relationship $R_4 : Paper - Researcher$ *records the authors of each paper.*

The view schema has only two binary relationship types. The relationship $Project-Paper$ *shows all the papers published by project members of a project. It is formed by first join* R_1 *and* R_2 *on* $Researcher$ *and then taking projection on the join result. The relationship* $Paper - Researcher$ *shows the complete author list of each paper. It is constructed by first swapping* R_2 *and then unioning the resulting relationship with* R_4*.*

Figure 4.4 shows a sample XML document conforming to the source ORA-SS schema in Figure 4.3. The correct view transformation result is shown in Figure 4.5. The concept of object identifier in ORA-SS, which is missing in both DTD and XML Schema, is essential to correctly swap and merge objects in source XML documents to construct views. Due to its tree structure, an object with the same identifier may have several occurrences in the source document. A swap operation in XML view transformation may result in occurrences of the same object placed under the same parent and thus should be merged to reduce redundancy. Without the concept of object identifer, merging object occurrences is not possible. As an illustration, the relationship type $Paper-Researcher$ in the view schema of Figure 4.3 swaps the order of $R2$ in the source schema. Correspondingly, *Paper* objects now should be placed above *Researcher* objects in the view. Notice that in the sample XML document in Figure 4.4, there are three occurrences of object $p2$, using their object identifers, we can merge them and group their children together in the view. Certainly we can not obtain the desired view result if DTD or XML Schema is used as the schema definition format because they do not consider object identifiers.

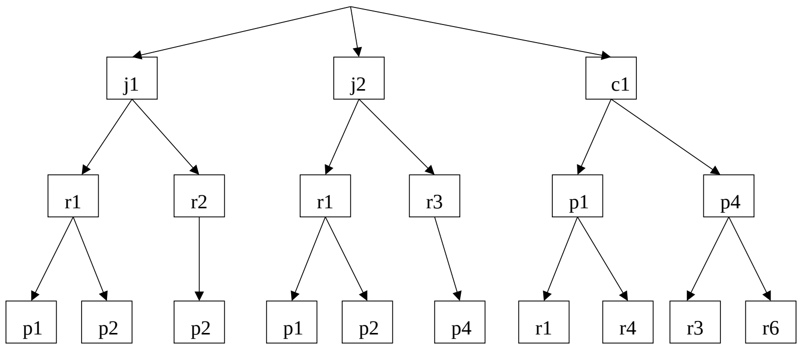


Figure 4.4: **Source XML Document of source schema in Fig. 4.3**

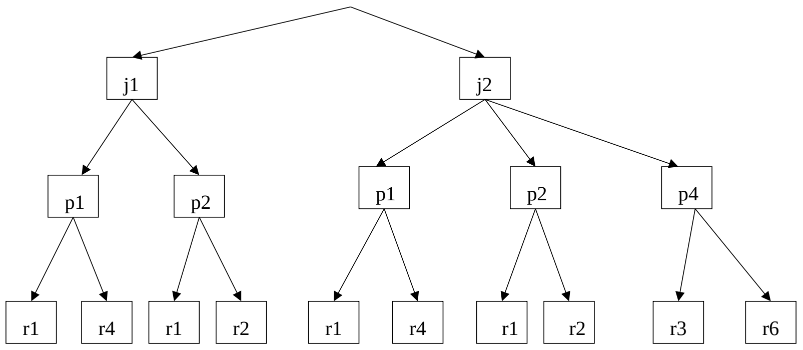


Figure 4.5: **View XML Document of view schema in Fig. 4.3 based on source XML document in Fig. 4.4**

4.2 Semantics of ORA-SS views

ORA-SS, used as the view schema format, introduces different semantics compared to XPath queries. Thus in this section, we define formally the semantics of ORA-SS view schema.

Our most important assumption is that several objects are *related* if they are located on the same path in a source document. Based on this assumption, given a relationship R: $O_1/O_2/\ldots/O_n$ in ORA-SS view schema, a match of R is a path $o_1/o_2/\ldots/o_n$ for which:

1. Object o_i is of class O_i.
2. $o_1, o_2, \ldots, o_n$ should be located on some path p in the source document but there is *no* restriction on their order on p.

A relationship type R: $O_1/O_2/\ldots/O_n$ in ORA-SS view schema allows much more possible matches than the XPath expression: $O_1//O_2//\ldots//O_n$. The reason is that the latter not only requires that the n nodes in a match are located on the same path but also impose the hierarchical ordering on the objects (i.e. objects from o_1 to o_n should have increasing depths). The semantics of ORA-SS view schema is useful in many practical scenarios and using it avoids an excessive number of XPath expressions needed to replace equivalent ORA-SS view schemas as we pointed out in the introduction chapter. We extend the idea to define ORA-SS view schema semantics.

In general, a view transformation based on schema mappings can be seen as an assignment from a source document to its view which satisfies various constraints imposed by a view schema which will be discussed shortly. Because view document trees consist of a collection of paths, naturally we should consider defining constraints over these paths. Formally, we define a *complete* path in an ORA-SS instance tree to be a path from the root to a leaf object. XPath-like expressions are used to represent paths. For example, path p: $o_1/o_2/\ldots/o_n$ denotes a path with object o_i as the parent of object o_{i+1}. An object in the path is denoted by its identifier. A complete path p is said to be of type P if p is an instance of a root-to-leaf path P in the ORA-SS schema diagram. Sub-path of a path p is a segment of p. We say a sub-path p' is a *relationship* sub-path if p' is an instance of relationship type R. A complete path is formed by the root and one or several relation sub-paths.

For example, in Figure 4.4, the complete path $root/j_1/r_1/p_1$ consists of relationship sub-path j_1/r_1 of type $Proj/Researcher$ and r_1/p_1 of type $Researcher/Paper$.

View schemas defined in ORA-SS impose the following constraints on views:

Definition 4.1 *(Relationship Constraint) A complete path p is in the view tree if p is of type P with P being a root-to-leaf path in the view schema and for each of p's relationship sub-paths $p_i : o_1/o_2/\dots/o_n$ of some relationship type R on P, o_1,o_2,...,o_n lie on some path in the source document, possibly in a different order than they are in p_i.*

Definition 4.2 *(Object Attribute Constraint) A sub-path p: o/a with object o as the owner object of object attribute a is in the view tree if o/a is also in the source document.*

Definition 4.3 *(Relationship Attribute Constraint) A relationship sub-path with its relationship attribute a (or p: $o_1/o_2/\dots/o_n/a$) is in the view tree if a lies on the same path with $o_1, o_2, \dots, o_n$ in the source document. The order of $o_1, o_2, \dots, o_n$ in the source document may be different from their order in p.*

A correct view is indeed the collection of *all* the complete paths together with attribute values which satisfies the above three constraints. To eliminate redundancy, we also require that *no* object (including the root) in views can have two child objects with the same identifier.

Intuitively, the *Relationship Constraint* requires objects in each relationship sub-path of the views be related in source document. Thus objects in a relationship sub-path of a view should also lie on some path in the source document. The *Object Attribute Constraint* can be understood as attributes of an object in a source document should still remain as the attributes of the same object in view. The *Relationship Attribute Constraint* essentially states that an attribute of a relational sub-path p in source document will be the attribute of a relationship sub-path p' in the view if p' contains all objects in p possibly in a different order.

Example 4.2 *The view in Figure 4.5 is the correct view source in Figure 4.4 under the schema mapping in Figure 4.3. The complete path* $p : j2/p4/r6$ *is in the view but none of the complete path in the source document contains all the three objects.* p *is in the view because its two relationship sub-paths* $j2/p4$ *and* $p4/r6$ *are present in the source document, which means the* relationship constraint *is satisfied.*

4.3 Comparison and Summary

In this chapter, we explain how to use ORA-SS schema diagram as XML view definition. Compared with other schema-based XML view transformation approaches like XML-GL[2] and GLASS[23], our approach is different because we do not require the user to have knowledge on the structure of source schema (which is often very complex) and perform tedious mapping from source to view schema. Instead the user only needs to know the ontology (i.e. the lists of object classes and attribute names) to define ORA-SS view schema and that is all users need to do to get view results.

Compared with DTD and XML Schema, the ORA-SS schema diagram provides a more flexible and expressive a new view schema definition format because:

1. it can succinctly extracts matches with structural variants in tree-structured data like XML because it considers a set of objects match a relationship type as long as they are located on some path in the source XML data and their structural order is not a concern. XSLT and XQuery can only achieve this by issuing an excessive number of XPath queries.

2. it can express a great variety of semantics which results in different views because the semantics of a path in ORA-SS view schema is defined not only by the sequence of its object classes in the path but also the set of relationship types in the path. This feature is not present in DTD and XML Schema.

In our discussion, we assume that all ORA-SS view schema defined by users are meaningful. This assumption may not always be true. We do not cover this case in this thesis and refer the reader to the work by Chen et.al. [6] which discusses how to define and validate meaningful views for XML document in ORA-SS formats.

Chapter 5

XML Document Storage in Native XML DBMSs

XML data can be stored in many ways. There has been a lot of work on storing XML documents in relational database. Under such schemes, XML queries have to be translated to SQL before relational DBMS can do query processing. Meanwhile because of the vast differences in XML queries and traditional relational queries many optimization techniques devised for relational DBMSs are shown to be inefficient[34].

An alternative is to store XML documents in specially designed native XML DBMSs. Recently there are quite a number of native XML DBMSs system designed and implemented[14][28]. These systems have already shows encouraging signs of efficient XML query processing capacities.

In this chapter, we focus on the aspect of XML storage strategy in native XML DBMS, which has great impact on XML query optimization.

5.1 Object Based Clustering

Object Based Clustering (*OBC*)[20] is a XML document storage strategy which facilitates efficient XML query processing. The starting point of *OBC* is the following observations:

1. When a query asks to retrieve an element node, it usually retrieves the text node and attribute node together with that element node. For example, the identifer of an object is often retrieved together with the object itself. So, to group attribute nodes and text node with their ownership element node as an object helps to reduce the cost of intermediate result join.

2. The majority of XML queries or views only involve elements whose tag names form just a subset of all possible tag names in source XML data. Certainly elements whose tag names do not appear in the query or view definition will not appear in query result. However, the previously discussed (Section 2 of Chapter 3) Element-based strategy (*EB*) and Subtree-based strategy (*SB*) store records (element or subtree) in preordered manner without considering their tag names. This will result in

great dispersal of elements with the same tag name, which subsequently leads to more redundant I/Os. Element Based Clustering, on the other hand, groups elements with the same tag name as a list. The advantage of this approach is obvious: in answering an XPath query such as $A//B$, all we need to do is to perform scans over the clusters A and B.

We can see that Element Based Clustering solves the second problem but not the first. Our Object Based Clustering approach groups objects of the same kind (instead of elements of the same tag) as a list and thus solves both problems. ORA-SS schema can help us to determine how to group several nodes as an object. More specifically,

1. Object identifier of an object will be stored in the same record as the object.
2. Object attributes of an object will be stored in the same record as the object.
3. Relationship attributes directly nested under an object will be stored in the same record as the object.
4. An object record will have a unique associated label whose use will be described in the next section.

Object Based Clustering usually have much fewer records (i.e. objects or elements) compared with Element Based Clustering. By having fewer records, we also reduce the total number of physical or logical pointers (e.g. node labels) associated with the records. On the other hand, unlike Subtree Based scheme, the contents bundled in a record (i.e. an object) in OBC are often semantically related and thus have much higher chance of being retrieved together in a single query. Therefore OBC can help to reduce unnecessary scanning which is a problem to SubTree Based XML storage schemes.

5.2 Object Labelling Scheme

One question about *OBC* is that if two objects with parent/child or ancestor/descendant relationship are stored in different clusters, how can we tell they have such relationship when processing path or branching queries. To solve the problem, *OBC* gives labels for objects in an XML document. This idea is borrowed from the well-known *region encoding*[3] for tree structured data.

An object label is a 3-tuple: $< startPos, endPos, level >$. *startPos* and *endPos* are calculated by performing a pre-order (document order) traversal of the document tree: *startPos* and *EndPos* of an element e are calculated by counting the number of start and end element tags from the document root until the start and the end of the element e. *level* is the nesting depth of the element in the data tree.

The labelling scheme allows us to tell if object o_1 is an ancestor of o_2 in *constant* time:

o_1 is ancestor of o_2 if $o_1.startPos < o_2.startPos$ and $o_1.endPos > o_2.endPos$.

Furthermore, if $o_1.level = o_2.level - 1$, we can see o_1 is the parent object of o_2. Another feature of such a scheme is that the determination of ancestor/descendant relationship is as easy as the determination of parent/child relationship: there is no need to traverse the path linking the two nodes.

Example 5.1 *Figure 5.1 shows how the document in Figure 2.1 is labelled and stored.*

5.3 Object Based Clustering vs. Element Based Clustering

Many native XML DBMSs (e.g. Timber[14]) use Element Based Clustering storage scheme. The scheme stores all XML elements with the same tag name or attribute values with the same type in a cluster. The advantage of this approach is that it does not need any schema information.

On the other hand, the Object Based Clustering (*OBC*) scheme groups attributes of an object together with the object itself. Such a scheme can result in greater efficiency in XML query processing because most real world

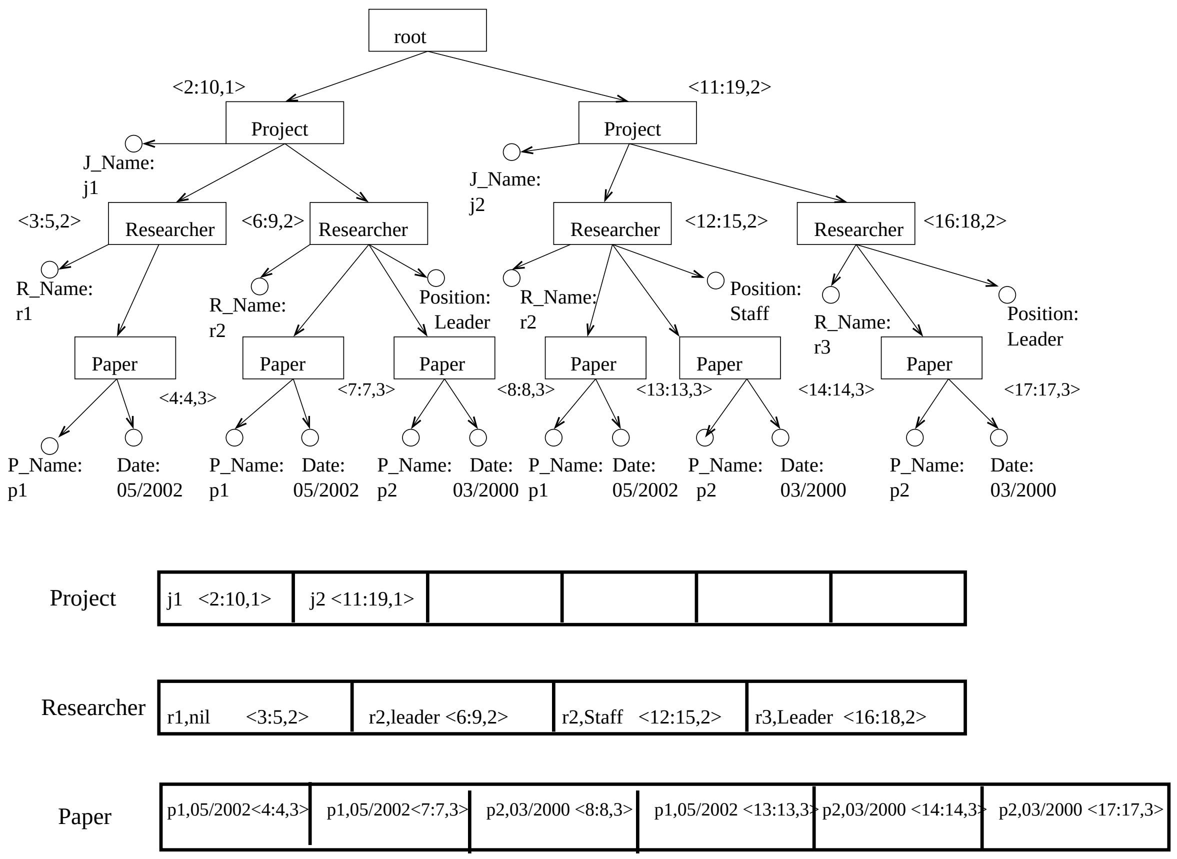


Figure 5.1: **The sample XML document in Fig.2.1 stored under Object Based Clustering. The numbers in parentheses are object labels**

queries on XML data retrieve not only matches to a certain pattern (e.g. $Project//Researcher$) in XML source documents but also associated attribute values of each object found. For example, instead of only specifying the pattern $Project//Researcher$, a real world XML query will often be in the form of

$$Project[J\_Name]//Researcher[R\_Name]$$

because users are not interested in a list of matches with nothing but tag names but the attribute values of each match.

Using the traditional Element Based Clustering (EBC) approach, attributes (e.g. J_Name) are stored in separate clusters from their owner objects(e.g. $Project$). This storage approach results in more structural (label-based) joins than the Object Based Clustering approach. As an example, in processing an XPath query which finds researchers with their names under some project

$$Project[J\_Name]//Researcher[R\_Name]$$

Object Based Clustering approach just needs one structural join between the clusters of $Project$ and $Researcher$. On the other hand, EBC needs:

1. Structural join the $Project$ and J_Name clusters and store the result in a temporary list L_1.

2. Structural join the *Researcher* cluster with the list L_1 and store the result in a temporary list L_2.

3. Finally structural join the *R_Name* cluster with the list L_2 to produce the final results to the query.

Note that although the above plan is just one alternative to process the query using *EBC*, other plans may change the order of joins but still need to go through three steps.

It can be seen that using *EBC* we have two more structural joins than using *OBC*: more I/O cost is incurred for storing and reading the two temporary result lists L_1 and L_2; we also pay more CPU cost because of the additional joins.

In summary, by bundling attribute values with their owner objects, *OBC* allows more efficient processing of XML queries.

Chapter 6

ORA-SS View Processing on a native XML DBMS

As the semantics of ORA-SS views show, the relationship type is essential to ORA-SS schema diagrams. Thus in this chapter, we first describe how to process view transformation for a single relationship type. Then we give an algorithm for processing view whose schemas is defined in ORA-SS format in general.

6.1 Associative Join: A Primitive XML Join Technique

6.1.1 Structural Query and Associative Query

Structural Join[34][3] and *Twig Join*[1], discussed in Section 3.3, are join techniques devised to process XML queries expressed in languages based on *Regular Expression.* These XML queries are structural, that is, they require nodes in returned results satisfy certain structural constraints (e.g. parent-child or ancestor-descendant constraints). For example, the XPath [31] query

$$course//student$$

is searching for *course* and *student* node pairs in which the *course* node is the ancestor of *student* node.

However, queries to traditional relational databases usually do not require elements in matching tuples to follow any order in the source data. Using the previous example, if we are interested in related *courses* and *students* but not their structural order, then we would have to issue two XPath queries: $course//student$ and $student//course$. In the worst case (although in the real world it seldom occurs), if we want to search for all occurrences of tuples of n related nodes located on the same path in an XML document, we need to issue $n!$ XPath queries to cover all possible structural variations and then union the results of individual queries.

Associative XML query is thus devised to provide great conveniences in composing XML queries without the excessive use of XPath expressions. Formally an associative XML query can be written in the following form:

Definition 6.1 (Associative XML Query) *An associative XML query Q is of the following form $< E_1, E_2, ..., E_n >$ in which each E_i is an element name. A tuple $t :< v_1, v_2, ..., v_n >$ is said to be a match of Q if (1) label$(v_i) = E_i$ and (2) there is a path p in the XML database which contains all nodes in M. The* associative XML query matching *problem is to find all distinct tuples in the database D which are matches of a given query Q.*

Example 6.1 *For the associative query $< A, B, C >$, it has five matchings in the XML document tree in Figure 6.1: $< a1, b1, c1 >$, $< a2, b1, c1 >$, $< a1, b2, c2 >$, $< a3, b2, c2 >$ and $< a1, b2, c3 >$. However, the XPath query $A//B//C$ has only two matches: $< a1, b2, c2 >$ and $< a1, b2, c3 >$.*

$< a1, b1, c1 >$ is a match to the associative query because there is a path $a1/c1/b1/a2$ containing the three elements although they do not follow the hierarchical order in the XPath query $A//B//C$.

6.1.2 Processing of Associative Query

Since an associative XML query with n nodes is equivalent to a set of $n!$ XPath expressions each having a different hierarchical order, one naive approach to process each of these $XPath$ queries and then union the results of all the queries. This approach suffers from the large number of XPath queries we need to process. Current techniques on multiple-XML-query processing also offer little help because although these techniques try to find common sub-expressions among multiple XML queries, the exponential number of XPath expressions is still too big to handle.

In this section, we describe an optimal technique called *Associative Join* to process associative XML query. Associative Join is based on XML data storage schemes which group elements with the same tag or objects of the same class together as a cluster. Therefore, either EBC or OBC XML storage scheme can be used. The reason to use such schemes is that they can avoid scanning of elements whose tag names (or objects whose classes) do not appear in the query. We also assume each element or object in the XML data tree has been labelled with a $(startPos : endPos, level)$ triple under region encoding scheme we have described earlier. Without loss of generality, in the following discussion of *Associative Join* algorithm we always use Element Based Clustering. The techniques can be easily extended to Object Based Clustering technique.

The following lemma is essential to the correctness of our algorithm:

Lemma 6.1 *Given an XML tree whose elements are labelled with* $(startPos : endPos, level)$ *under* region encoding *scheme and two of its elements* e_i *and* e_j*, if* $e_i.endPos < e_j.startPos$ *(i.e.* $e_i.startPos < e_j.startPos$ *and* e_i *is not an ancestor of* e_j*) , then* e_i *will not be an ancestor of any element* e_x *with* $e_x.startPos > e_j.startPos$*.*

The correctness of the above corollary is simple to prove once we see

$$e_x.startPos > e_i.endPos.$$

In our algorithm, for each tag N in an associative query Q, it is associated with:

- An element stream T_N, which consists of all the elements in the document with tag name N, ordered by their *startPos* increasingly. Each cluster T_N has a *cursor* interface. T_N.head refers to the element in the cluster currently under the *cursor* and T_N.advance() moves the cursor to the next element.

- A stack S_N, which stores elements of tag name N. *Set*(S_N) refers to the set of elements in the stack.

The use of stacks in processing XML query can also be found in the algorithms[1] for processing of XPath query.

Our algorithm performs a document-order (pre-order) traversal of element nodes whose tags appear in the associative query. When an element e_j of tag E_1 is visited, we store the element e_j in the stack S_{E_1} and discard all stored elements e_i in stacks such that e_i is not an ancestor of e_j (which means they can not appear in a match to the associative query together). Notice that according to Lemma 6.1, e_i will not be an ancestor of any unvisited element e_x with $e_x.startPos > e_j.startPos$. Therefore to throw away e_i will not affect the final matches. More importantly, we can see at any point of time during computation, we only keep in the stacks a set of elements which are located on a path p in the XML tree. Thus the space complexity of our algorithm is bounded by the longest path in the XML document. All currently known matches involving e_j on the path p can then be output. This can be done by taking one element from each stack to form the matching tuple.

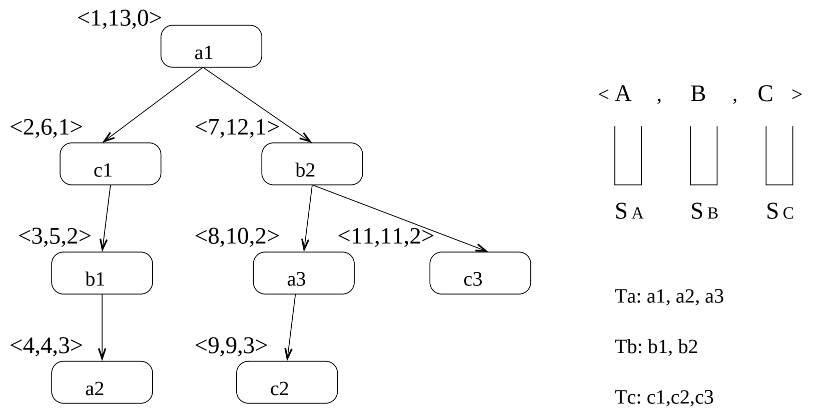


Figure 6.1: **Main data structures used in Associative Join**

Example 6.2 *Figure 6.1 shows the tree representation of a sample XML document and an associative query $Q :< A, B, C >$. The main data structures*

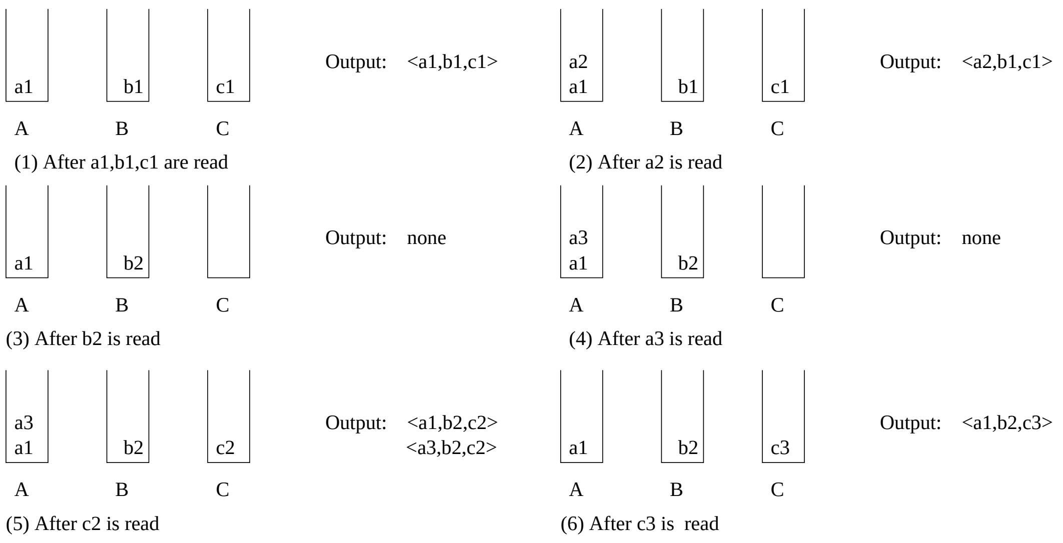


Figure 6.2: **Associative Join on the document and query in Fig. 6.1**

used in the algorithm are also shown in the diagram. Notice that we couple an element stream and a stack with each tag in the associative query. Figure 6.2 gives the details (by using step by step illustration) on how the algorithm (Figure 6.3) works.

Each iteration of the while *loop looks for the stream* $T_{Q_{min}}$ *whose current head element has the smallest startPos. In Figure 6.2 (1), the first matching tuple is found after elements* $a1$, $c1$, $b1$ *are read and pushed onto their respective stacks by order of their startPos. In Figure 6.2 (2), element* $a2$ *is read because now we compare the head elements of all streams and* $a2$ *has the smallest startPos among all remaining elements and pushed into stack* S_A*, we find another matching tuple* $< a2, b1, c1 >$ *because* $b1$ *and* $c1$ *are ancestors of* $a2$*. At this time, none of the elements* $a1$, $c1$, $b1$ *should be popped because they may have matches with elements after* $a2$*. As another example, in Figure 6.2*

```
Algorithm:  Associative Join

Input:
       Associative Query $Q$
       XML Document $D$ stored in $OBC$ clusters
Output:
       All matching tuples of $Q$ in $D$

01 while(not all stream end)
02     $Q_{min}$ = node $N$ such that $T_N$.head has the smallest $startPos$
       among all streams;
03     for each stack $S_I$ such that $I$ is a node in $Q$
04        pop elements in $S_I$ which are not ancestor of $T_{Q_{min}}$.head;
05     push $T_{Q_{min}}$.head into the stack $S_{Q_{min}}$;
06     if(none of the stacks is empty)
07        for each tuple $t$ in $Set(SI_1) \times \ldots \times Set(SI_k)$
           // $I_1, \ldots, I_k$ are the nodes in $Q$ except $Q_{min}$
08           order $T_{Q_{min}}$.head,$t.I_1$,...,$t.I_k$ according to the order of
          tags in $Q$ and output the corresponding tuple;
09     $T_{Q_{min}}$.advance();
```

Figure 6.3: **Algorithm: Associative Join**

(3), when $b2$ *is read, we are certain that* $b1$ *and* $c1$ *will not have anymore matches because no new element after* $b2$ *(in document order) will be on the same path with them and thus should be popped according to Lemma 6.1. No new matching tuple is found at this step. The algorithm halts after Figure 6.2 (6) when all elements in relevant streams have been read.*

Now we present the algorithm formally in detail.

The algorithm *Associative Join* takes in an input associative query Q and a XML document D stored in EBC or OBC streams. It outputs all matches of Q in the document D. Line 2 always returns the query node Q_{min} whose corresponding stream $T_{Q_{min}}$ has the smallest *startPos* among all streams of the query tags. Since the elements in a match to Q must be located on the same path in the document, in line $3-4$ we pop, from each stack, elements which are not ancestors of element $T_{Q_{min}}.head$. Now if none of the stacks is empty, we are sure that $T_{Q_{min}}.head$ must be in matches to Q. These matches involving $T_{Q_{min}}.head$ consist of $T_{Q_{min}}.head$ and one element from each stack except the stack $S_{Q_{min}}$. After outputting the matches in line $6-8$, we advance the cluster $T_{Q_{min}}$ in line 9. The process ends when all relevant streams end (line 1).

The algorithm *Associative Join* reads streams involved in an associative query only once. Its running time and I/O cost are both $O(|Input\_Streams| + |Output|)$. Notice that here *Input_Streams* refers to the streams whose corresponding tags appear in the associative query but not the source document itself. Meanwhile, the total space used by the stacks will never exceed the length of the longest root-to-leaf path in source XML document D. So the space complexity is $O(|L|)$ where L is the length of the longest path in D. The algorithm is thus both I/O and CPU optimal.

Theorem 6.1 *The algorithm* Associative Join *is both I/O and CPU optimal for processing an associative query Q. Its space complexity is bounded by the longest root-to-leaf path in the source XML document D.*

6.2 Processing XML views defined in ORA-SS formats

An ORA-SS view schema diagram usually consists of several relationships. To construct a relationship R in the view result, we need to build a list of paths each of which is of type R and contains objects located on some path in source XML data. Since we store source XML data using Object Based Clustering, the *associative join* technique can be used to build a relationship in ORA-SS schemas. Our view transformation technique works by processing each individual relationship type using associative join and then combine intermediate results together to get final view document. More specifically, we process views defined in ORA-SS through the following major steps:

1. Decompose a given ORA-SS view schema V into a set of relationship types.
2. Construct each relationship type R using *associative join* technique.
3. Join the intermediate results in Step 2 based on object identifers.
4. Merge the intermediate results in Step 3 based on object identifers to get the final view results.

Example 6.3 *Figure 6.4 shows the construction of views defined in Figure 4.3 over source data in Figure 4.4. The ORA-SS view schema has two relationship* *types:*$Project - Paper$ *and* $Paper - Researcher$*.*

1. *First we use associative join to build the two relationships* $Project - Paper$ *and* $Paper - Researcher$ *respectively (Figure 6.4 (1) and (2)). Note that associative join, just like structural join, depends solely on object labels. Although there exist tuples containing the same set of objects (e.g. two* $j1 - p2$ *tuples), they indeed represent different occurrences of objects (e.g. the two p2 objects have different labels). We remove identical sets of objects (judged by object keys) in the output of associative join operation.*

2. *Next, we join the two relations on their* overlapping *object class Paper based on identifers of Paper objects. (Figure 6.4(3))*

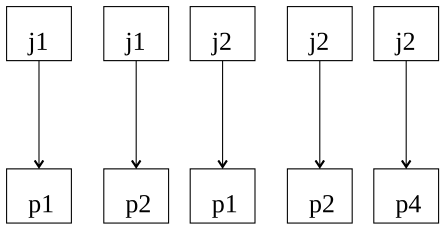
3. *Finally the view is produced by merging the paths. (Figure 6.4 (4))*

Notice that without the semantics in ORA-SS schema, we can not perform the above identifer based join.

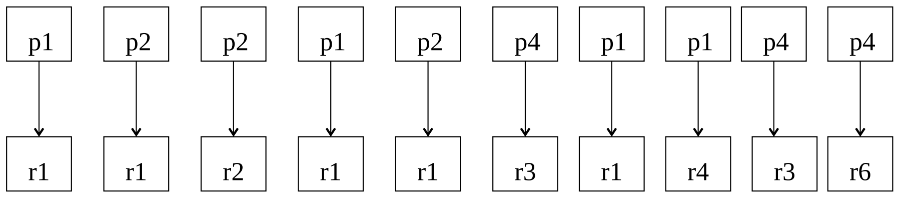
6.2.1 Value Join vs. Associative Join

In processing views defined in ORA-SS schema, there are two different kinds of join techniques used:

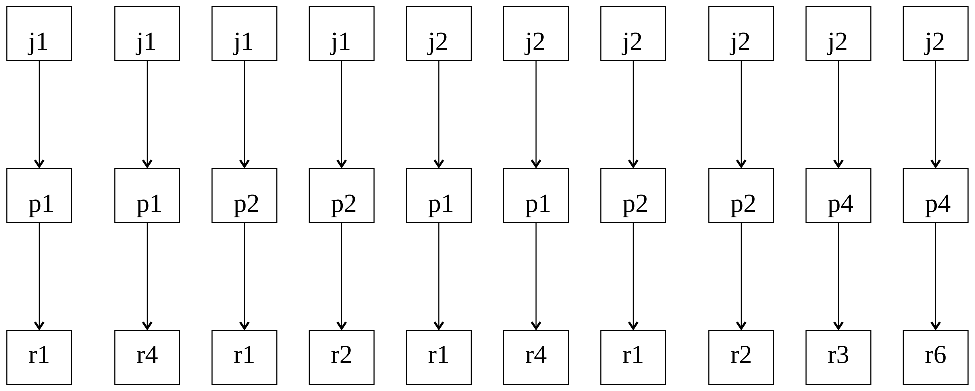
1. *Associative Join*, which joins objects based on their *object labels*.



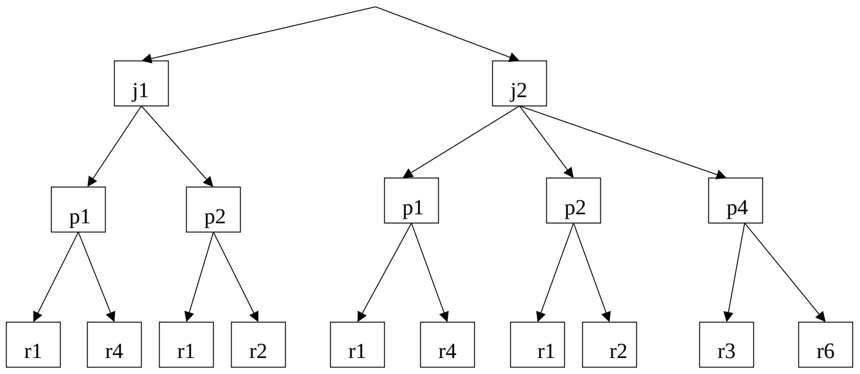
(1) Step 1: Construction of relationship $Project - Paper$



(2) Step 2: Construction of relationship $Paper - Researcher$



(3) Step 3: Value join the results in Step 1 and 2 on object $Paper$



(4) Step 4: Merge paths based object keys and the final output

Figure 6.4: **Major Steps in View Transformation for the source document in Fig.4.4 and the ORA-SS view schema in Fig.4.3**

2. *Value Join*, which is similar to traditional join in Relational model and join objects based on their *object identifers*.

Under *Object Based Clustering*, objects of a relationship instance are separated and stored in different streams. In addition, object label and object key are stored together with the object. *Associated Join* is used to find objects which locate on the same path in the original XML document. On the other hand, *Value Join* plays a similar role to equi-join in the relational model, which is based solely on object identifer values. To "value" join two lists of tuples which are results of an associative join or another value join, we first find the common object classes of the two tuple lists and then perform a sort-merge join. The details are described in the following algorithm.

```
Algorithm $ValueJoin$
Input:
       $L_A$:  a list of object tuples of the same type $A$
       $L_B$:  a list of object tuples of the same type $B$
Output:
       $L$:  the join result of $L_A$ and $L_B$

01   $C$ := the set of common object classes of $A$ and $B$
02   sort $L_A$ on the keys of objects whose classes are in $C$
03   sort $L_B$ on the keys of objects whose classes are in $C$
04   $L$ := join $L_A$ and $L_B$ on the keys of objects whose class are in $C$
05   return $L$
```

6.2.2 The importance of relationship set in ORASS view schema

Processing of XML view defined in ORA-SS schema is determined not only by the structure of the schema but also the relationship set of the schema because of the semantics of ORA-SS view. As an example, suppose we modify the view schema in Figure 4.3 by making *Project*, *Paper* and *Researcher* form a ternary relationship instead of two binary relationships. Now the transformation procedure will be greatly different:

1. First we construct the ternary relationship using one associative join on the three object classes.
2. Merge the tuples produced in step 1 to get the final view results.

Notice that there is no value join step required in this case because there is only one relationship type in the view schema. Obviously, the final view document (which is shown in Figure 6.5) will be different.

In the next section, we present the detailed view transformation algorithm formally.

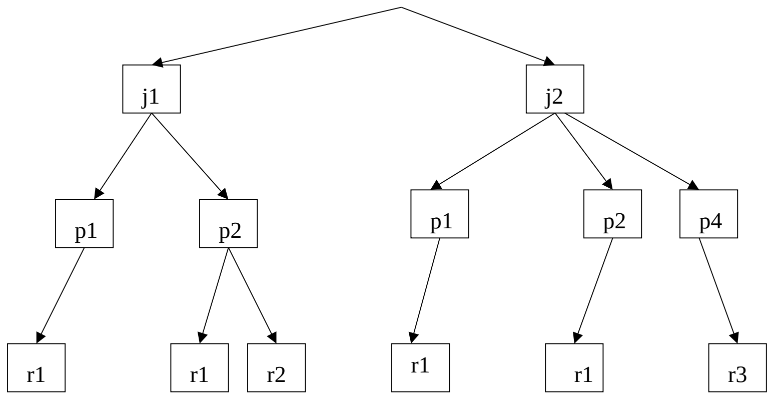


Figure 6.5: **The correct view result for the modified ORA-SS schema based on Fig. 4.3 with a ternary relationship**

6.2.3 ORA-SS View Transformation Algorithm

Because the relationship type set of an ORA-SS view schema is so important to view transformation, we first make a few definitions to classify different types of relationship type.

Definition 6.2 *(Independent Relationship Type) A relationship type is said to be* independent *if its set of participating object classes is not a subset of that of any other relationship type. Otherwise the relationship is* nested*.*

For example, in the source ORA-SS schema in Figure 4.3, the relationship types $Paper - Researcher$ and $Project - Paper$ are all independent relationship type.

In our transformation algorithm, when an independent relationship type is constructed, all relationship types nested within it will be constructed without additional cost.

Definition 6.3 *(Child Relationship Type) A relationship type R_1 is called child relationship type of another relationship type R_2 if the top-most object class (in term of schema tree depth) of R_1 participates in R_2 and is a descendant of the top-most object class of R_2.*

For example, in the view ORA-SS schema in Figure 4.3, the relationship type $Paper - Researcher$ is a child relationship type of $Project - Paper$ because the top-most object class $Paper$ of $Paper - Researcher$ participates in the relationship type $Project - Paper$ and is child of $Project$.

Definition 6.4 *(Top Level Relationship Type) A relationship type R in an ORA-SS schema is a top level relationship type if it is* not *child relationship type of* any *other relationship type in the schema.*

As an example, for the source ORA-SS schema in Figure 4.3 again, the only two top level relationships are $Project-Researcher$ and $Conference-Paper$.

The algorithm $ORA - SSViewTransformer$ follows the transformation procedure we discuss thus far. In line 1, it decomposes view schema into a set of independent relationships. In lines 2-4, it constructs the list of tuples whose fields correspond to portions of the view schema consisting of all the child relationship type of a top-level relationship. This is done by a recursive method

Build_SubTree. In the method, we first perform an associative join for the input relationship type R and store the resulting tuple list in L_R (line 1). If L_R is empty (line 2), since each tree and subtree must have root, we do *not* need to proceed to build the child relationships of R. Otherwise, if R has no child relationship type, the result of associative join will be returned directly (line 3-4). In the case when R has child relationship types, for each child relationship R_i of R, we recursively call the *Build_SubTree* method and then perform a value join on the returned list with the tuple list L_R (line 7-10). Notice that the number of fields in each tuple of L_R grows after each iteration.

The partial results of sub-trees of each top-level relationship type are then value joined to produce a list of tuples each of which consists of all the object classes with their attributes (line 4). When value joins are done, we merge the tuples and then output the view result in line 5.

```
Algorithm $ORA-SSViewTransformer$
Input:
       ORA-SS View Schema $V$
       XML Document stored in Element Clusters
Output:
       View Results $V$

01 $S$ := $\{R \mid R$ is an $\textit{independant}$ relationship in $V\}$
02 for each top-level relationship $R$ in $S$
03      $L_R$ := Build_SubTree($R$)
04      $L$ := Value_Join($L$,$L_R$)
05 Merge and Output $L$

Function Build_SubTree(Relationship $R$)
01 $L_R$ := Associative_Join($R$)
02 If($L_R$ is empty) return an empty list
03 If($R$ doesn't have child relationship in $S$)
04      return $L_R$
05 Else
07      for each child relationship $R_i$ of $R$ in $S$
08          $L_{R_i}$ := Build_SubTree($R_i$)
09          $L_R$ := Value_Join($L_R$,$L_{R_i}$)
10          return $L_R$
```

Algorithm Analysis

In building each individual relationship type, the Associative Join technique does not produce any intermediate results which do not appear in the results of associative queries. However, the algorithm *ORA-SS View Transformer* decomposes an ORA-SS view schema into several relationships and builds these relationship types separately. The approach thus may generate useless results which do not appear in the final view results. We comment that holistic join techniques like *TwigStack*[1] is not applicable here anymore because *TwigStack* is devised for extracting matches from source XML documents satisfying structural orders (e.g. *P*-*C* and *A*-*D* relationships) imposed by *twig pattern query*. However, the semantics of ORA-SS view schemas allows many more possible match patterns because the constraint (i.e. "co-path" property)for the database nodes in the matches is much more relaxed.

An object stream whose corresponding object class O appear in an ORA-SS view schema will be scanned C times to build independent relationships where C is the number of *independent* relationship types O participates in. It is easy to see that the complexity of our algorithm depends not only on the set of object classes of a view schema but also the set of independent relationships. Suppose there are n independent relationship types in an ORA-SS view schema, our algorithm will perform n associative join operations, $n-1$ value join operations to join the associative join and other value join results and 1 final merge to produce the view.

Chapter 7

Experiments

In this section, we present the performance study of various algorithms described in previous chapters. We first describe our prototype XML document storage and view transformation system: *XBase*. Next, we study in detail the impact of storage schemes on XML query processing. After that, the performance view transformation algorithm *ORA-SS View Transformer* will be presented.

7.1 XBase description

XBase, our XML document storage and view transformation prototype, consists of three main components(Figure 7.1):

1. *ORA-SS Schema Parser* This module parses ORA-SS source and view

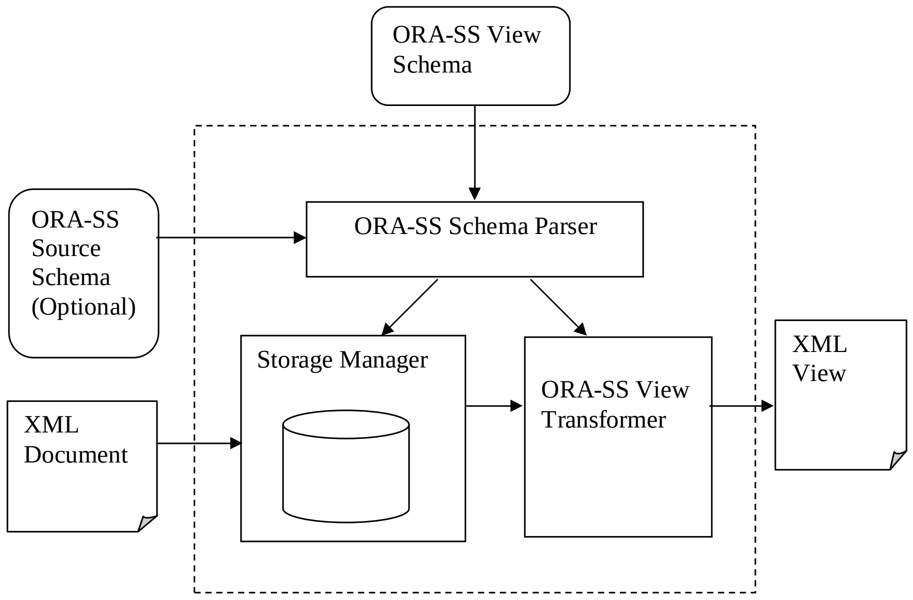


Figure 7.1: **Schematic view of our view transformer**

schema diagrams defined in XML formats.

2. *Storage Manager* For XML documents with associated ORA-SS schema diagram, our Data Storage Manager will store them using the Object Based Clustering approach.

3. *ORA-SS View Transformer* Given an ORA-SS view schema, this module, based on a source XML document, generates the view results.

All the above three modules are programmed in Java 1.4. Now we are going to describe the three main system components in detail.

7.1.1 ORA-SS Schema Parser

In XBase, an ORA-SS schema diagram is defined in XML format. XML documents defining ORA-SS schema are then parsed and turned into data structures accessible by other system modules. As an example, the XML document in Figure 7.2 is a valid XML document of the ORA-SS schema diagram in Figure 2.2. The XML document is easy to understand because we can find one-to-one mappings from the constructs used in the XML documents to the ORA-SS schema diagram definition. At the outermost level, the XML document consists of definitions of object classes. For each object class, we define its names, the relationships it participates in, the attributes nested in the object class and its child object classes. For each attribute, we use a field *Key* to indicate if it is a key; a field called *reln* indicates the attribute is a relationship attribute and its values tells the owner relationship of the attribute.

7.1.2 Storage Manager

Our XML document storage manager stores XML documents into a set of sequential files. Each sequential file consists of objects of the same class. We call each object in our system a *record*. The structure of each record is shown in Figure 7.3. A record in our storage system have varied length. Each record consists of a *header* and values of various fields which correspond to attributes of the object contained in the record. A record header has the following parts:

```
< schema >
  < Object name = “Project” >
    < Relationship name = “JR”/ >
    < Attribute Name = “J_Name” Key = “Y”/ >
    < ChildObject ref = “Researcher”/ >
  < /Object >
  < Object name = “Researcher” >
    < Relationship name = “JR”/ >
    < Relationship name = “RP”/ >
    < Attribute name = “R_Name” Key = “Y”/ >
    < Attribute name = “Position” Reln = “JR”/ >
    < ChildObject ref = “Paper”/ >
  < /Object >
  < Object name = “Paper” >
    < Relationship name = “RP”/ >
    < Attribute name = “P_Name” Key = “Y”/ >
    < Attribute name = “Date” Reln = “RP”/ >
  < /Object >
< /schema >
```

Figure 7.2: **A XML document representing the ORA-SS schema in Fig. 2.2**

1. *Label* which is the label of the object contained in this record. Each label has 10 bytes: 4 bytes each are used for *startPos* and *endPos* and 2 bytes for *level*.

2. *Number of Fields* which gives the number of attributes of the object. 2 bytes are assigned for this part.

3. *A list of <Field ID,Field length> pairs.* Each pair gives the type and length of each attribute value within the record. Each pair occupies 4 bytes with 2 for each component. Each unique attribute name is assigned a different Field ID.

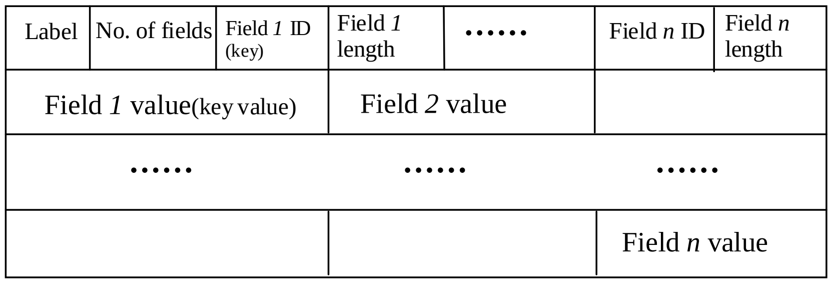


Figure 7.3: **The structure of a record in XBase**

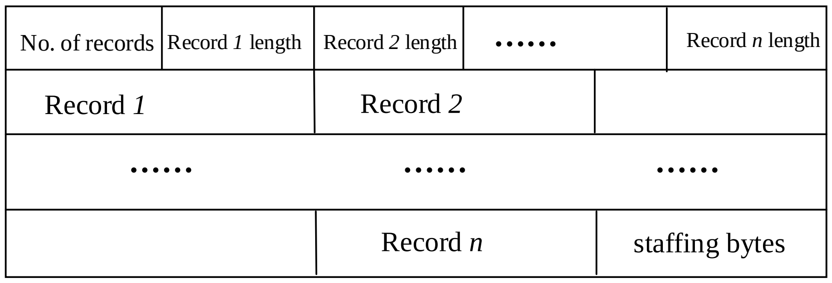


Figure 7.4: **The structure of a page in XBase**

The key of each record is always stored as the first field in the record for easy retrieval and comparison. We do not consider composite key in the implementation of XBase. The field lengths are used to calculate the offsets of corresponding field values in the record.

Records are placed within *pages*. The storage manager has a page size of 8KB. The structure of each page is shown in Figure 7.4. Each page has a page *header*. The page header gives the number of records in each page (2 bytes used for the number) and the length of each record (2 bytes used for each length). Staffing bytes are used to fill unused space in each page.

7.1.3 ORA-SS View Transformer

The ORA-SS view transformer of XBase implements various transformation techniques we discussed in the previous chapter. It takes in an ORA-SS view schema and accesses the data storage module and then performs view transformation. The resulting views are output as XML documents.

7.2 Datasets

We use both real-world and synthetic XML data in our experiments.

7.2.1 DBLP Bibliography Record (DBLP)

DBLP[19] dataset is a real-world XML data source frequently used as benchmark dataset. It is a bibliography file (100 Mbytes in total size) which contains about 380,000 computer science publications (journal articles, proceedings and so on) and over 80,000 authors. The ORA-SS schema of the dataset is shown in Figure 7.5.

7.2.2 Project-Researcher-Paper (JRP)

We synthesize the JRP dataset by our own XML data generator. In a JRP data instance, on average one project has 5 researchers and each researcher has

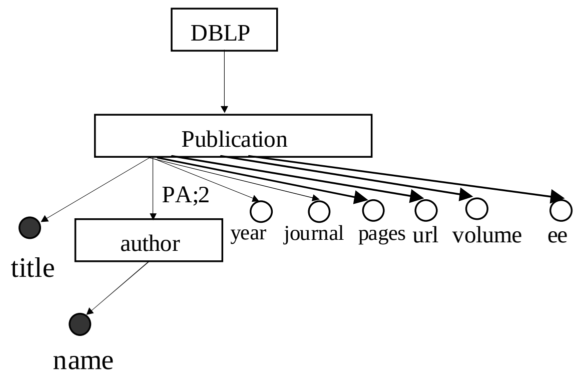


Figure 7.5: **The ORA-SS schema of DBLP Dataset**

10 publications. For example, in a 20MByte JRP file, there are in total 2400 (distinct) project elements and 12,000 researcher elements (6,000 distinct) and 120,000 (60,000 distinct) paper elements. These numbers increase proportionally with the size of JRP data file. The ORA-SS schema of the dataset is shown in Figure 7.6.

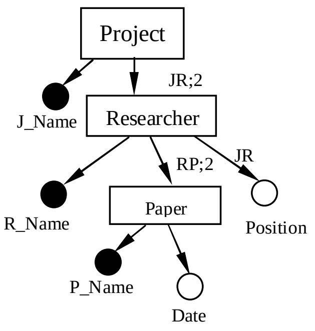


Figure 7.6: **The ORA-SS schema of JRP Dataset**

7.3 Performances and Analysis

All our experiments were run on a 2.4GHz Pentium 4 processor with 512MB memory. We primarily focus on two issues in our experiments. First we investigate the performance of Object Based Clustering in view processing. Next we want to compare the performance of our view transformation system with that of current popular XML query processing engines.

7.3.1 The advantages of OBC storage

Many native XML DBMSs use Element Based Clustering scheme. The scheme stores all XML element with the same tag name or attribute values with the same type in a cluster. On the other hand, the Object Based Clustering (*OBC*) scheme groups attributes of an object together with the object itself. By bundling attribute values with their owner objects, *OBC* allows more efficient processing of XML queries.

Our experiment results confirm the above observation. We implement both *EBC* and *OBC* storage schemes and use them to process queries on XML documents. We test the queries in Table. 7.1 for an JRP dataset of 20M bytes (135,000 elements) and the queries in Table. 7.2 for a DBLP dataset of 100M bytes. The set of queries consists of both simple ones which are mainly projections and complex ones. We choose queries with only Ancestor-Descendant relationships because we are ultimately interested in processing

Q1	$//Paper[P\_Name]$
Q2	$//Project[J\_Name]//Paper[P\_Name]$
Q3	$//Researcher[R\_Name]//Paper[P\_Name]$
Q4	$//Project[J\_Name]//Researcher[R\_Name]//Paper[P\_Name]$

Table 7.1: **XPath Queries on JRP dataset**

Q1	$//Author[text()]$
Q2	$//Publication[title]//Author[text()]$
Q3	$//Publication[title][year][journal][volume]//Paper[P\_Name]$

Table 7.2: **XPath Queries on DBLP dataset**

ORA-SS view schemas which do not concern with Parent-Child relationships.

The running times of processing the above queries using *OBC* AND *EBC* storage schemes can be seen from Figure 7.7 and Figure 7.8.

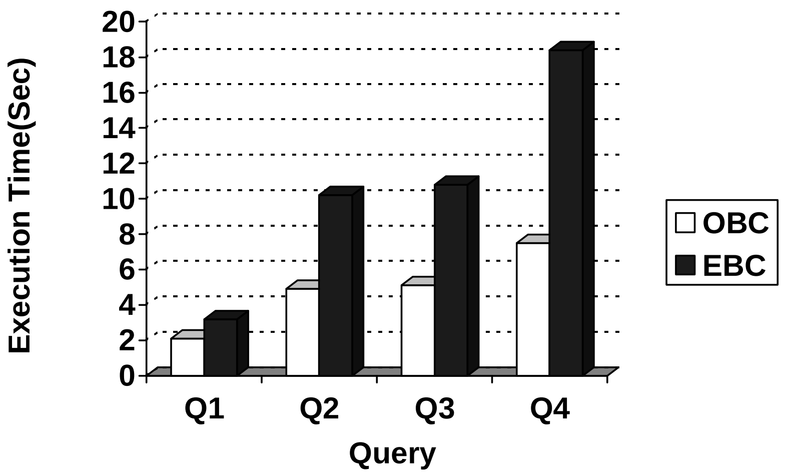


Figure 7.7: **Comparison of XPath Query Processing on EBC and OBC Storage schemes using a JRP dataset of 20MB**

From Figure 7.7 and 7.8, we can see that in most cases, OBC storage scheme

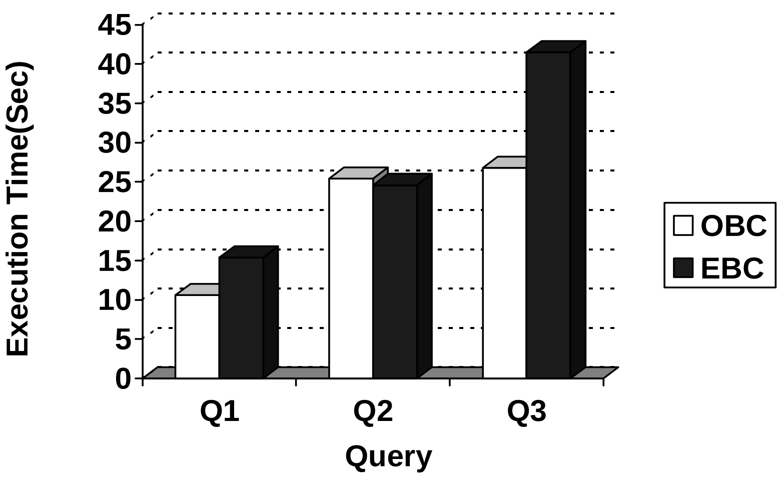


Figure 7.8: **Comparison of XPath Query Processing on EBC and OBC Storage schemes using a DBLP dataset of 100MB**

can provide more efficient processing of XPath Query compared with EBC. What is more, the more complex the query is, the more time saving that OBC results. The only exception is the query $Q2$ in Figure 7.8: in this case under the OBC scheme a *publication* object is bundled with many of its attributes but only one of them *title* is required in the final results. Thus OBC causes unnecessary I/O cost which is not a problem in *EBC* because *EBC* doesn't need to scan clusters whose elements or attribute values do not appear in the query. Consequently, the additional I/O costs overtake the benefit of less structural join. Interestingly, when we require more attributes of a *publication* to be output as in $Q3$ of Figure 7.8, OBC now performs much better than EBC because of less redundant I/O costs.

7.3.2 View Processing in XBase

We compare the view processing performance of XBase with state-of-art XML query processing engines. Among many available candidates, we choose SAXON[26] (version 7.5) XSLT processor and Quip[25] XQuery processor. SAXON is the only XSLT engine available now which supports XSLT2.0[33] standard. XSLT2.0 has features like grouping (i.e. $< xsl : for - each - group >$ directive) which is important to view transformation operation like value join but not present in the XSLT1.0. SAXON is implemented using Java and generally considered as one of the fastest XSLT processors available. Quip is a complete XQuery[32] processor freely available. XQuery has supports for grouping as well (i.e. $distinct - values()$ function in XQuery 1.0).

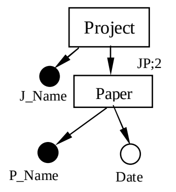
Project-Researcher-Paper(JRP)

We use the following four ORA-SS views (Figure 7.9) over the source schema which range from simple projections to more complex swapping.

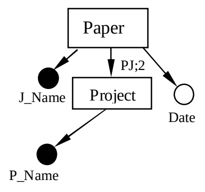
The performances of view transformation using XBase, SAXON and Quip are shown from Figure 7.10 to Figure 7.16. Note that the running times of SAXON and Quip include the time spent on loading source XML document.

DBLP

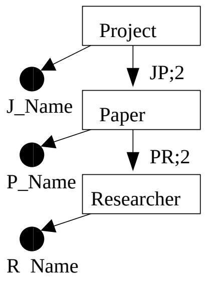
We use the following two ORA-SS views over the DBLP datasets:

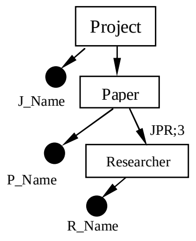


(a) view *Project − Paper*



(b) view *Paper − Researcher*





(c) view *Project − Paper − Researcher*1 (d) view *Project − Paper − Researcher*2

Figure 7.9: **Four views defined over JRP datasets**

The performances of view transformation using XBase, SAXON and Quip are shown in the following figures.

Analysis

XBase are much faster in all test cases than its competitors and we have the following observations:

1. Our algorithm performs transformation for view schemas having multiple relationship types on one path (e.g. view schema in Figure 7.9c) efficiently while the running time of SAXON and QuiP is unacceptable even for small files($<$ 1Mb).

   It would be interesting to compare transformation for view schemas in Figure 7.9c and Figure 7.9d. Our method requires about 50% more time

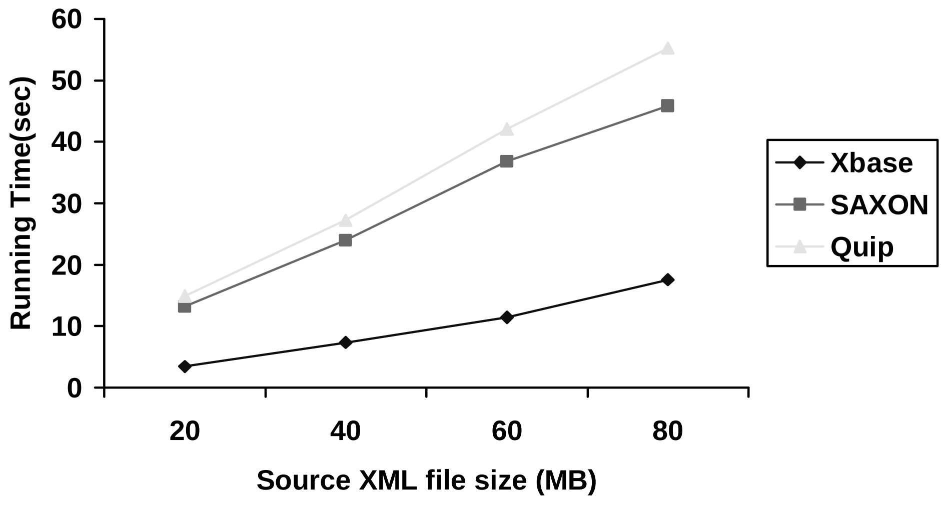


Figure 7.10: **Running time comparison of processing ORASS view schema in Fig. 7.9a for JRP dataset**

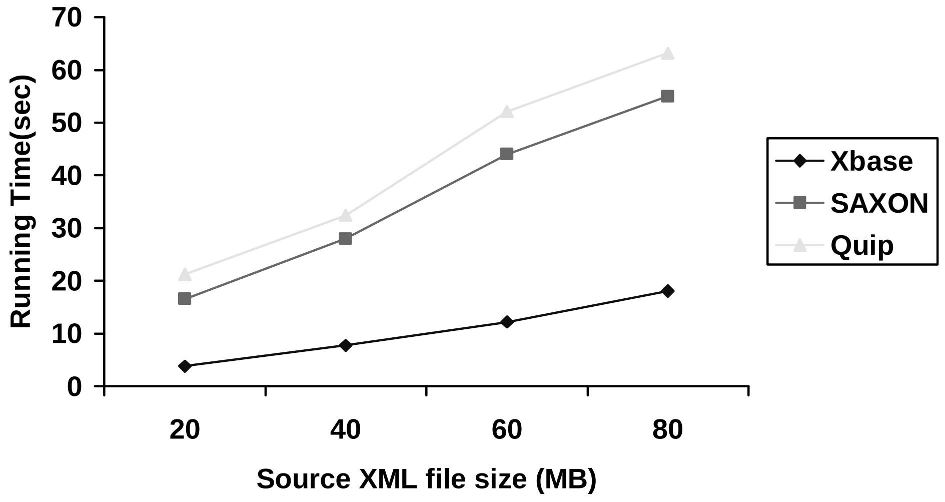


Figure 7.11: **Running time comparison of processing ORASS view schema in Fig. 7.9b for JRP dataset**

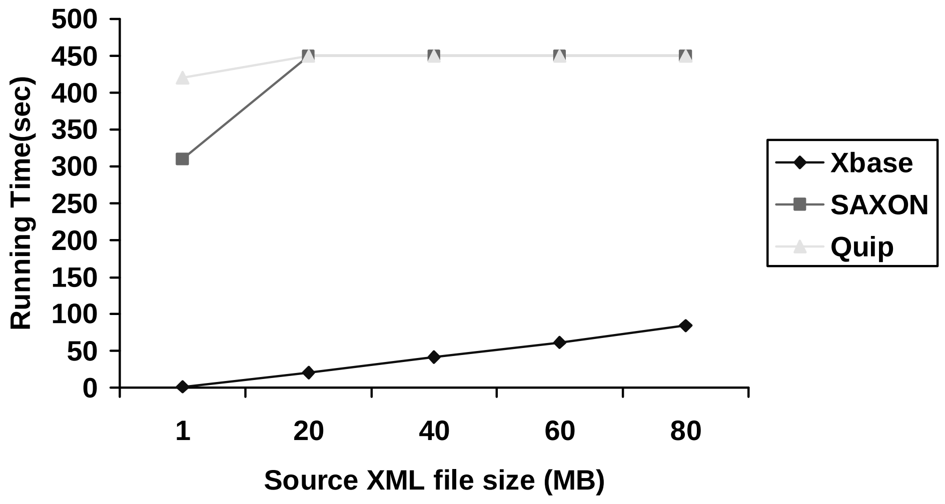


Figure 7.12: **Running time comparison of processing ORASS view schema in Fig. 7.9c for JRP dataset**

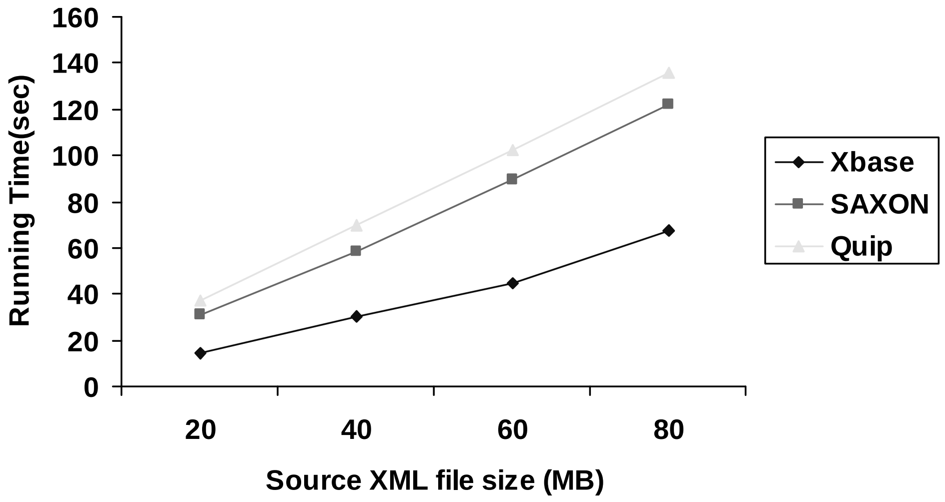


Figure 7.13: **Running time comparison of processing ORASS view schema in Fig. 7.9d for JRP dataset**

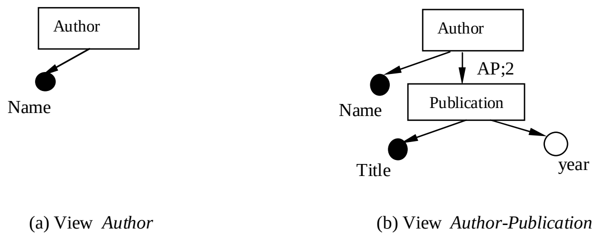


Figure 7.14: **Two views defined over DBLP datasets**

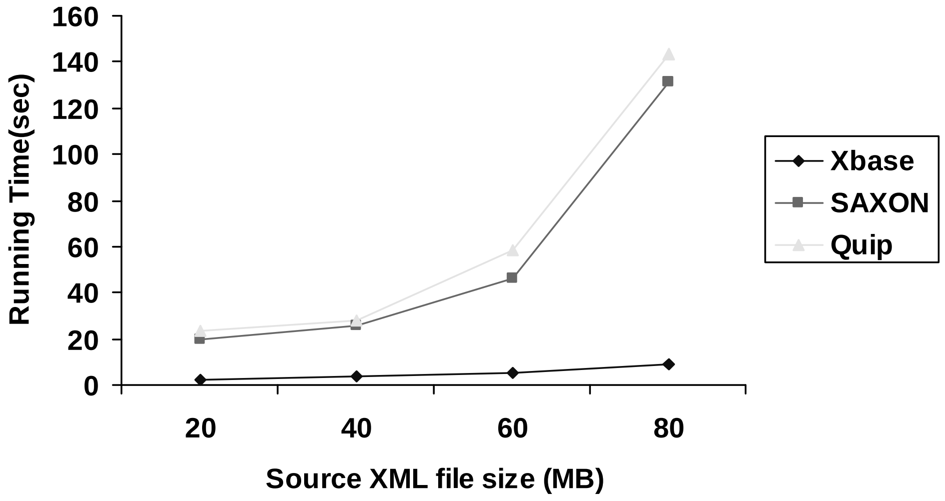


Figure 7.15: **Running time comparison of processing ORASS view schema in Fig.7.14a for DBLP dataset**

(Figure 7.10 and Figure 7.11)in view schema Figure7.9c because it has one more relationship type than Figure 7.9d and consequently needs one more round of associative join and value join. However, although SAXON 7.5 performs reasonably well in Figure7.9d, it simply takes too long to finish views for Figure7.9c. This happens to Quip too. We list the XSLT scripts used for both view schemas in Appendix I and II. The scripts explain why XSLT engines like SAXON is slow for the view schema with two binary relationship types but much quicker for the view schema with one ternary relationship type. We extract the most important sections

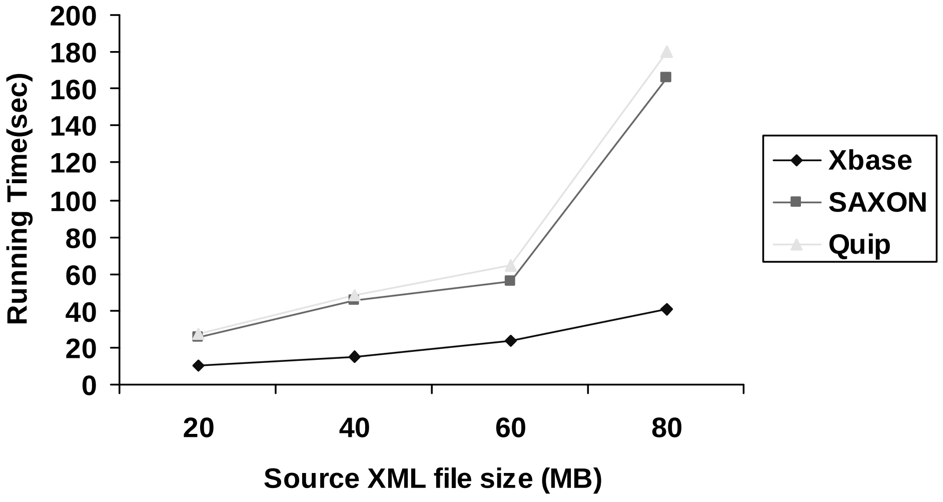


Figure 7.16: **Running time comparison of processing ORASS view schema in Fig.7.14b for DBLP dataset**

from the two scripts:

(a) Script for $Proj - Paper - Researcher1$

```
<xsl:for-each-group select="root/Project" group-by="@J_Name">
  <xsl:for-each-group select="current-group()/Researcher/Paper" group-by="@P_Name">
    <xsl:variable name="vPName" select="@P_Name"/>
    <xsl:for-each-group select="/root/Project/Researcher[Paper/@P_Name =$vPName]"
     group-by="@R_Name">
```

(b) Script for $Proj - Paper - Researcher2$

```
<xsl:for-each-group select="root/Project" group-by="@J_Name">
  <xsl:for-each-group select="current-group()/Researcher/Paper"   group-by="@P_Name">
    <xsl:for-each-group select="current-group/.."
     group-by="@R_Name">
```

The two scripts are identical in finding papers written by researchers in a project (i.e. the first two $xsl : for - each - group$ in the two scripts). Their main difference lies in the third $xsl : for - each - group$ directives for $Researcher$. The script for $Proj - Paper - Researcher1$ needs to search the whole document for each paper to find the complete paper author list because the authors may not work for the project. On the other hand, script for $Proj - Paper - Researcher2$ avoids the global search because it only intends to find authors of the paper working for the project. This example shows that today's general purpose view transformation engines still need more work on optimization.

2. Our algorithm is very efficient in views which project and swap over portion but not all of the source data(e.g. views $Project - Paper$, $Paper - Project$ of JRP datasets and $Author$,$Author - Publication$ of DBLP datasets).

   This is especially true with big files (e.g. 80MByte DBLP and JRP XML files) approaching the memory threshold because to load the whole document into the memory (which is what SAXON and QuiP do) degrades the performance significantly.

3. Our algorithm shows little differences in performances for views differing from each other only in their node structural order.

   To illustrate this, let us look at the running times of views $Project - Paper$ and $Paper - Project$ in Figure 7.10 and Figure 7.11. These two view schemas only differ on their node order. Our algorithm uses roughly the same amount of time (about -2 5% of difference) on both views for all file sizes; on the other hand, SAXON need about 20% more time to process view $Paper - Project$. The reason for the big difference in running times of SAXON and QuiP engines is due to their “tree-walk” transformation mechanism: different orders in views cause different tree traversal sequences. However, the running time of associative and value join and merge operation in the transformation algorithms of XBase are determined solely by the total list sizes.

Chapter 8

Conclusion

The starting point of our work is the observation of problems with two kinds of XML view transformation systems. High level systems like eXcelon[11] and Clio[24], which perform view transformations by defining target view schema, have problems with not being able to define views with complex semantics. On the other hand, general systems like XSLT and XQuery processors require the user to write transformation scripts themselves. The problem becomes worse with tree-structured XML data because many possible structural variants need to be considered in transformation scripts to cover all possible query results. As we have demonstrated in experiments, it is hard for the systems to optimize many simple and practical XSLT/XQuery scripts.

Our approach, like the other high-level systems, allows users to define view schema to get desired views. However, our method differs from other high-level XML view transformation system in the following aspects:

1. The use of ORA-SS as underlying schema representation allows us to

express view schemas with a great variety of semantic meanings.

2. Our ontology-based view definition approach saves users the trouble of looking into often complicated source schema. Users just need to know the set of element names (ontology) in the source schema to define views. Mapping from source schema to view schema is done by our system.

3. It performs view transformation directly on a native XML DBMS: XBase. Other systems usually convert schema mapping into XSLT/XQuery scripts and still rely on XSLT/XQuery engines to perform transformation.

At the same time, based on ORA-SS schemas, our system requires much less time than general XML processors in processing view transformations.

Our view transformation engine *XBase* has many novel features. Our storage method Object Based Clustering allows us to leverage on the new join processing techniques naturally. In most view transformations, only the relevant portions of source document are read. ORA-SS, as the conceptual model used in our transformation, differs from other traditional structure-based XML data models by taking into full consideration the semantic information such as keys, relationship and relationship attribute associated with XML data. In our transformation method, a relationship type in ORA-SS schema is the basic unit of transformation. We devise novel and efficient join technique called *associative join* to construct a single relationship type.

From a performance point of view, our transformation engine *XBase* is much more efficient compared with XQuery/XSLT engines. In particular, our method is very fast in projection and swapping over portion of source data because it only loads data which is required. In comparison, today's XSLT and XQuery processors are slow in processing view operations like projection and swapping. Our method is also much faster in processing ORA-SS view schema with multiple relationships on a single path.

Our work can be extended in several directions. View operations like value selection, negation and so on are not considered in our prototype. Meanwhile in our view transformation algorithms, we do not utilize source ORA-SS schema information, which can help to further optimize our view transformation engine.

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Appendix A

Appendix

A.1 XSLT Script for view schema in Figure 7.9c:

Remark: The differences of XSLT scripts in Appendix I and II are highlighted lines.

```
<xsl:transform>
  <xsl:template match="/">
  <root>
    <xsl:for-each-group select="root/Project" group-by="@J_Name"¿
    <Project>
      <J_Name><xsl:value-of select="@J_Name"/></J_Name>
        <xsl:for-each-group select="current-group()/Researcher/Paper" group-by="@P_Name">
        <Paper>
          <xsl:variable name="vPName" select="@P_Name"/>
          <P_Name><xsl:value-of select="@P_Name"/></P_Name>
            <xsl:for-each-group select="/root/Project/Researcher[Paper/@P_Name =$vPName]"
             group-by="@R_Name">
            <Researcher>
              <R_Name><xsl:value-of select="@R_Name"/></R_Name>
            </Researcher>
            </xsl:for-each-group>
        </Paper>
        </xsl:for-each-group>
    </Project>
    </xsl:for-each-group>
  </root>
  </xsl:template>
</xsl:transform>
```

A.2 XSLT Script for view schema in Figure 7.9d:

Remark: The differences of XSLT scripts in Appendix I and II are highlighted lines.

```
<xsl:transform>
  <xsl:template match=“/”>
  <root>
    <xsl:for-each-group select=“root/Project” group-by=“@J_Name”¿
    <Project>
      <J_Name><xsl:value-of select=“@J_Name”/></J_Name>
        <xsl:for-each-group select=“current-group()/Researcher/Paper” group-by=“@P_Name”>
        <Paper>
          <xsl:variable name=“vPName” select=“@P_Name”/>
          <P_Name><xsl:value-of select=“@P_Name”/></P_Name>
            <xsl:for-each-group select=“current-group()/..” group-by=“@R_Name”>
            <Researcher>
              <R_Name><xsl:value-of select=”@R_Name”/></R_Name>
            </Researcher>
            </xsl:for-each-group>
        </Paper>
        </xsl:for-each-group>
    </Project>
    </xsl:for-each-group>
  </root>
  </xsl:template>
</xsl:transform>
```