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XML and Relational Databases

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Two Approaches

- XML Publishing
  - treats existing relational data sets as if they were XML data
    - defines an XML view of the relational data
    - poses XML queries over this view
  - similar to schema integration
    - global as view (GAV) vs local as view (LAV)
  - materializing (parts of) the view
- XML Storage
  - uses an RDBMS to store and query existing XML data
    - need to choose a relational schema for storing XML data
    - translate XML queries to SQL

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Publishing without Views

- Constructs XML data in main memory on the fly
- Based on language extensions to SQL and modified query engine
- Requires user-defined functions for XML element construction
- Example:

```
define XML constructor ARTICLE ( artId:integer, title:varachar(20), authorList:xml ) AS {
   <article id=$artId>
         <title>$title</title>
         <authors>$authorList</authors>
   </article>
}
```

- Special function to concatenate input fragments
  - Problem: list vs set

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Publishing with Support for Views

- Provides XML views over relational data
  - a view is not necessarily materialized
- Queries are XML queries over these views
  - goal: retrieve only the required fragments of relational data by pushing the computation into the relational engine as much as possible
  - we don't want to reconstruct the entire XML document from all the relational data and then extract the answer from the document

Case Study: XPERANTO

- Automatically creates a default XML view from relational tables
  - top-level elements correspond to table names
  - row elements are nested under the table elements
  - for each row element, a column corresponds to an element whose tag name is the column name and text is the column value
- Example

Relational schema:

Department (deptno, dname, address)
Employee (ssn, dno,name, phone, salary)

DTD of the default view:

```
<!ELEMENT db (Department*,Employee*)>
<!ELEMENT Department (deptno,dname,address)>
<!ELEMENT Employee (ssn,dno,name,phone,salary)>
<!ELEMENT deptno (PCDATA)>
<!ELEMENT dname (PCDATA)>
...
```


XPERANTO (cont.)

- The default view may be refined by a user view
  - the view is defined using an XQuery

```
<info>{
  for $d in view("default")/db/Departments
  for $e in view("default")/db/Employees[dno=$d/deptno]
  return <employee ssn="{$e/ssn}">{$e/name,$d/dname}</employee>
}</info>
```

- Then the actual query can be on the user view

```
for $e in view("view")/info/employee[@ssn="123"]
return $e/name
```


XPERANTO (cont.)

- It uses the XML Query Graph Model (XQGM) as internal representation
  - enables the translation from XQuery to SQL
  - exploits an XML query algebra
- It removes all XML navigation operators
  - to avoid intermediate results
- It pushes joins and selections down to the relational query engine
  - query decorrelation

Relational Schemas for XML

- Various approaches
  - **generic mapping** regardless of any schema or data knowledge
    - same for all kinds of XML data
  - **user-defined mapping** from XML to relational tables
  - mapping is inferred from DTD or XML Schema
  - mapping is derived from conceptual model
  - mapping is deduced from ontologies or domain knowledge
  - mapping is derived from query workload

Generic Mapping

- XML data can be seen as a graph
- Three ways of storing graph edges:
  - edge approach: store all edges in a single table
  - binary approach: group all edges with the same label into a separate table
  - universal table: an outer join between all tables from the binary approach
- Two ways of mapping values:
  - using a separate value table
  - inlining the values into the edge table(s)
- Usually binary approach with inlining

A Single Table

```
create table element
  ( tagname   varchar(20),
    content   varchar(100),
    begin     int      not null,
    end       int      not null,
    level     int      not null
  )
<A><B>text1</B><B>text2</B></A>
0   1   2   3   4   5   6   7        <--  begin/end positions
```

tagname	content	begin	end	level
A	null	0	7	0
B	null	1	3	1
B	null	4	6	1
null	text1	2	2	2
null	text2	5	5	2

A Single Table (cont.)

For example, the XPath query:

//book/title

is translated into the following SQL query:

```
select e2
from element e1, element e2
where e1.tagname = 'book'
  and e2.begin > e1.begin
  and e2.end < e1.end
  and e2.level = e1.level+1
  and e2.tagname = 'title'
```


A Single Table (cont.)

The XPath query:

/books//book[author/name="Smith"]/title

is translated into:

```
select e6
from element e1, element e2, element e3,
     element e4, element e5, element e6
where e1.level = 0
  and e1.tagname = 'books'
  and e2.begin > e1.begin
  and e2.end < e1.end
  and e2.level > e1.level
  and e2.tagname = 'book'
  and e3.begin > e2.begin
  and e3.end < e2.end
  and e3.level = e2.level+1
  and e3.tagname = 'author'
  and e4.begin > e3.begin
  and e4.end < e3.end
  and e4.level = e3.level+1
  and e4.tagname = 'name'
  and e5.begin > e4.begin
  and e5.end < e4.end
  and e5.level = e4.level+1
  and e5.content = 'Smith'
  and e6.begin > e2.begin
  and e6.end < e2.end
  and e6.level = e2.level+1
  and e6.tagname = 'title'
```

Inferring the Relational Schema from DTD

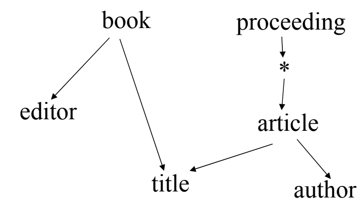
- A DTD graph is generated from the DTD
  - one node for each DTD <!ELEMENT ... >
  - a node '*' for repetition
  - an arrow connects a parent element to a child element in DTD
- Two approaches:
  - Shared inlining
    - an element node corresponds to one relation
    - … but element nodes with one parent are inlined
    - … but nodes below a '*' node correspond to a separate relations
    - mutual recursive elements are always mapped to separate relations
  - Hybrid inlining
    - may inline elements even with multiple parents, below '*', or recursive

Example

<!ELEMENT DB (proceeding | book)*>
<!ELEMENT proceeding (article*)>
<!ELEMENT article (title,author)>
<!ELEMENT book (editor,title)>

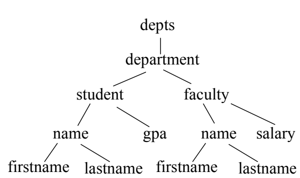
Shared inlining:
- proceeding(ID)
- article(ID,parent,author)
- title(ID,parent,title)
- book(ID,editor)

Hybrid inlining:
- proceeding(ID)
- article(ID,parent,author,title)
- book(ID,editor,title)



XML Indexing

- Many approaches
- Data guides
  - based on a *structural summary*
    - the structural summary is the minimum graph that captures all valid paths to data
    - deterministic: from each node you can go to only one node via a tagname
  - the leaves are sets of nodes (the indexed data)
  - designed for evaluating XPath efficiently
  - may take the form of a DFA or a tree



Inverted Index

- Inverted indexes are used in Information Retrieval (IR) in mapping words to sets of text documents that contain the word
  - typically implemented as a B+-tree having the word as a key
- Each XML element is assigned two numbers. Two choices:
  - (begin,end) which are the positions of the start/end tags of the element
  - (order,size) which are order=begin and size=end-begin
- We will use the following representation of an XML element:
  - (docnum,begin:end,level) where level is the depth level of the element
- Words in PCData are represented by:
  - (docnum,position,level)
- Two indexes:
  - E-index for indexing tagnames
  - T-index for indexing words

Example

<A><B>Computer Science</B><B>Science and Engineering</B></A>
0 1 2 3 4 5 6 7 8 9 <-- begin/end positions

E-index:
<A> { (1,0:9,0) }
<B> { (1,1:4,1), (1,5:8,1) }

E-index is implemented as a table with secondary index on tag

element table:

tagname	doc	begin	end	level
A	1	0	9	0
B	1	1	4	1
B	1	5	8	1

T-index:
Computer { (1,2,3) }
Science { (1,3,3), (1,6,3) }
Engineering { (1,7,3) }

Containment Join

XPath steps are evaluated using containment joins
- a join that indicates that the inner element should be 'contained' inside the outer element

For example, the XPath query `//book/title` is translated into the following SQL query:

```
select e2
from element e1, element e2
where e1.tagname = "book"
  and e2.doc = e1.doc
  and e2.begin > e1.begin
  and e2.end < e1.end
  and e2.level = e1.level+1
  and e2.tagname = "title"
```

It uses the E-index twice

Evaluating XPath Steps

From `path/A`, we generate the SQL query

```
select e2
from PATH e1, element e2
where e2.tagname = "A"
  and e2.doc = e1.doc
  and e2.begin > e1.begin
  and e2.end < e1.end
  and e2.level = e1.level+1
```

where PATH is the SQL query that evaluates path

From `path//A`, we get:

```
select e2
from PATH e1, element e2
where e2.tagname = "A"
  and e2.doc = e1.doc
  and e2.begin > e1.begin
  and e2.end < e1.end
```


Problems

Advantages:
- you can use an existing relational query evaluation engine
- the query optimizer will use the E-index

Disadvantages:
- many levels of query nesting
  - as many as the XPath steps
  - need query decorellation
- even after query unnesting, we get a join over a large number of tables
  - these are self joins because we are joining over the same table (element)
  - most commercial optimizers can handle up to 12 joins

Need a special evaluation algorithm for containment join
- based on sort-merge join
- requires that the indexes deliver the data sorted by major order of docnum and minor order of begin/position
- facilitates pipelining

Pipeline Processing of XPath Queries

A pipeline is a sequence of iterators

```
class Iterator {
    Tuple current();     // current tuple from stream
    void open ();        // open the stream iterator
    Tuple next ();       // get the next tuple from stream
    boolean eos ();      // is this the end of stream?
}
```

An iterator reads data from the input stream(s) and delivers data to the output stream

Connected through pipelines

- an iterator (the producer) delivers a stream element to the output only when requested by the next operator in pipeline (the consumer)
- to deliver one stream element to the output, the producer becomes a consumer by requesting from the previous iterator as many elements as necessary to produce *a single element*, etc, until the end of stream

Pipelines Pass one Tuple at a Time

For XPath evaluation, a Tuple is a Fragment

```
class Fragment {
    int document;     // document ID
    short begin;      // the start position in document
    short end;        // the end position in document
    short level;      // depth of term in document
}
```

E-index delivers Fragments sorted by major order of 'document' and minor order of 'begin'

XPath Steps are Iterators

```
class Child extends Iterator {
   String tag;
   Iterator input;
   IndexIterator ti;

void open () { ti = new IndexIterator(tag); }

Fragment next () {
   while (!ti.eos() && !input.eos()) {
      Fragment f = input.current();
      Fragment h = ti.current();
       if (!f.document < p.document) input.next();
       else if (!f.document > p.document) ti.next();
       else if  (f.begin < h.begin  &&  f.end > h.end  &&  h.level == f.level+1) {
             ti.next();
             return h;
       } else if (!f.begin < h.begin) input.next();
       else ti.next();
```


Example

```
1  <a>
2    <b>
3      X
4    </b>
5    <b>
6      Y
7    </b>
8  </a>
9  <a>
10   <c>
11     <b>
12       Z
13     </b>
14   </c>
15   <b>
16     W
17   </b>
18 </a>
```

<a>	<b>	<c>
(1,1:8,0)	(1,2:4,1)	(1,10:14,1)
(1,9:18,0)	(1,5:7,1)	
	(1,11:13,2)	
	(1,15:17,1)	

Query: //a/b

XPath Evaluation Based on Iterators

- Iterators implement containment joins using sort-merge joins
  - they maintain the invariant that all fragments are sorted by document (major) and begin/position (minor) order
- They can support two modes for path evaluation
  1) starting from a specific document, evaluate an XPath query
     - document(“book.xml”)//book/author
  1) evaluate an XPath query against all indexed documents
     - document(“*”)//book/author
- The sorted lists derived from E-index/T-index may be very long
  - improvement:
    - jump over the list elements that do not contribute to the result
    - can be accomplished if the index is a B+-tree

A Problem

- Pure sort-merge join may not work in some extreme cases
  - Example: //a/b

```
1  <a>
2     <a>
3        <b>
4           text1
5        </b>
6     </a>
7     <b>
8        text2
9     </b>
10 </a>
```

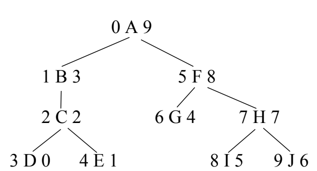
<a>	
(1,1:10,0)	(1,3:5,2)
(1,2:6,1)	(1,7:9,1)

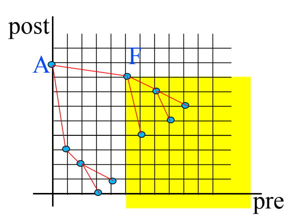
will miss text1

- This can be easily fixed by using a stack that holds the 'open' elements of the left input
  - when we advance from (1,1:10,0) to (1,2:6,1) we push (1,1:10,0)
  - very little space overhead: max size of stack = depth of the XML tree

Preorder/Postorder Encoding

- Each node is assigned a (pre,post) pair
  - replaces (begin,end)
  - Preorder is the document order of the opening tags
  - Postorder is the document order of the closing tags





We can now check for *all* XPath axes (steps) using pre, post, & level