Announcements (Mon., Oct. 21)

• Homework 3 due in two weeks
• Project milestone 2 due in 2½ weeks
  • Milestone #1 feedback available through Gradescope
• Weekly project progress updates starting this Wed.
  • Due on Piazza every Wednesday
Approaches to XML processing

• Text files/messages
• Specialized XML DBMS
  • Tamino (Software AG), BaseX, eXist, Sedna, ...
  • Not as mature as relational DBMS
• Relational (and object-relational) DBMS
  • Middleware and/or extensions
  • IBM DB2’s pureXML, Oracle XML DB, and XML type/functions from Microsoft SQL Server, PostgreSQL, MySQL...
Mapping XML to relational

• Store XML in a column
  • Simple, compact
  • CLOB (Character Large OBject) type + full-text indexing, or better, special XML type + functions
  • Poor integration with relational query processing
  • Updates are expensive

• Alternatives?
  • Schema-oblivious mapping: well-formed XML → generic relational schema
    • Node/edge-based mapping for graphs
    • Interval-based mapping for trees
    • Path-based mapping for trees
  • Schema-aware mapping: valid XML → special relational schema based on DTD

← Focus of this lecture
Node/edge-based: schema

- **Element**\((eid, \text{tag})\)
- **Attribute**\((eid, \text{attrName}, \text{attrValue})\)  Key:
  - Attribute order does not matter
- **ElementChild**\((eid, \text{pos}, \text{child})\)  Keys:
  - pos specifies the ordering of children
  - child references either **Element**\((eid)\) or **Text**\((tid)\)
- **Text**\((tid, \text{value})\)
  - tid cannot be the same as any eid

☞ Need to “invent” lots of id’s
☞ Need indexes for efficiency, e.g., **Element**\((\text{tag})\), **Text**\((\text{value})\)
Node/edge-based: example

```xml
<bibliography>
  <book ISBN="ISBN-10" price="80.00">
    <title>Foundations of Databases</title>
    <author>Abiteboul</author>
    <author>Hull</author>
    <author>Vianu</author>
    <publisher>Addison Wesley</publisher>
    <year>1995</year>
  </book>
</bibliography>
```

### Attribute

<table>
<thead>
<tr>
<th>eid</th>
<th>attrName</th>
<th>attrValue</th>
</tr>
</thead>
<tbody>
<tr>
<td>e1</td>
<td>price</td>
<td>80</td>
</tr>
</tbody>
</table>

### Text

<table>
<thead>
<tr>
<th>tid</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>t0</td>
<td>Foundations of Databases</td>
</tr>
<tr>
<td>t1</td>
<td>Abiteboul</td>
</tr>
<tr>
<td>t2</td>
<td>Hull</td>
</tr>
<tr>
<td>t3</td>
<td>Vianu</td>
</tr>
<tr>
<td>t4</td>
<td>Addison Wesley</td>
</tr>
<tr>
<td>t5</td>
<td>1995</td>
</tr>
</tbody>
</table>

### Element

<table>
<thead>
<tr>
<th>eid</th>
<th>tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>e0</td>
<td>bibliography</td>
</tr>
<tr>
<td>e1</td>
<td>book</td>
</tr>
<tr>
<td>e2</td>
<td>title</td>
</tr>
<tr>
<td>e3</td>
<td>author</td>
</tr>
<tr>
<td>e4</td>
<td>author</td>
</tr>
<tr>
<td>e5</td>
<td>author</td>
</tr>
<tr>
<td>e6</td>
<td>publisher</td>
</tr>
<tr>
<td>e7</td>
<td>year</td>
</tr>
</tbody>
</table>

### ElementChild

<table>
<thead>
<tr>
<th>eid</th>
<th>pos</th>
<th>child</th>
</tr>
</thead>
<tbody>
<tr>
<td>e0</td>
<td>1</td>
<td>e1</td>
</tr>
<tr>
<td>e1</td>
<td>1</td>
<td>e2</td>
</tr>
<tr>
<td>e1</td>
<td>2</td>
<td>e3</td>
</tr>
<tr>
<td>e1</td>
<td>3</td>
<td>e4</td>
</tr>
<tr>
<td>e1</td>
<td>4</td>
<td>e5</td>
</tr>
<tr>
<td>e1</td>
<td>5</td>
<td>e6</td>
</tr>
<tr>
<td>e1</td>
<td>6</td>
<td>e7</td>
</tr>
<tr>
<td>e2</td>
<td>1</td>
<td>t0</td>
</tr>
<tr>
<td>e3</td>
<td>1</td>
<td>t1</td>
</tr>
<tr>
<td>e4</td>
<td>1</td>
<td>t2</td>
</tr>
<tr>
<td>e5</td>
<td>1</td>
<td>t3</td>
</tr>
<tr>
<td>e6</td>
<td>1</td>
<td>t4</td>
</tr>
<tr>
<td>e7</td>
<td>1</td>
<td>t5</td>
</tr>
</tbody>
</table>
Node/edge-based: simple paths

• //title
  • SELECT eid FROM Element WHERE tag = 'title';

• //section/title
  • SELECT e2.eid
    FROM Element el, ElementChild c, Element e2
    WHERE el.tag = 'section'
    AND e2.tag = 'title'
    AND el.eid = c.eid
    AND c.child = e2.eid;

 thiệt Path expression becomes joins!
  • Number of joins is proportional to the length of the path expression
Node/edge-based: complex paths

- //bibliography/book[author="Abiteboul"]/@price
  - SELECT a.attrValue
    FROM Element e1, ElementChild c1,
    Element e2, Attribute a
    WHERE e1.tag = 'bibliography'
    AND e1.eid = c1.eid AND c1.child = e2.eid
    AND e2.tag = 'book'
    AND EXISTS (SELECT * FROM ElementChild c2,
                 Element e3, ElementChild c3, Text t
                 WHERE e2.eid = c2.eid AND c2.child = e3.eid
                 AND e3.tag = 'author'
                 AND e3.eid = c3.eid AND c3.child = t.tid
                 AND t.value = 'Abiteboul')
    AND e2.eid = a.eid
    AND a.attrName = 'price';
Node/edge-based: descendent-or-self

- //book//title
  - Requires SQL3 recursion
  - WITH RECURSIVE ` ReachableFromBook(id) AS
    ((SELECT eid FROM Element WHERE tag = 'book')
    UNION
    (SELECT c.child
     FROM ` ReachableFromBook` r, `ElementChild` c
     WHERE r.eid = c.eid))

    SELECT eid
    FROM Element
    WHERE eid IN (SELECT * FROM ` ReachableFromBook`) AND tag = 'title';
Interval-based: schema

- **Element**(left, right, level, tag)
  - *left* is the start position of the element
  - *right* is the end position of the element
  - *level* is the nesting depth of the element (strictly speaking, unnecessary)
  - Key is

- **Text**(left, right, level, value)
  - Key is

- **Attribute**(left, attrName, attrValue)
  - Key is
Where did ElementChild go?

- $e_1$ is the parent of $e_2$ iff:
  
  \[
  [e_1.left, e_1.right] \supseteq [e_2.left, e_2.right], \text{ and } \\
  e_1.level = e_2.level - 1
  \]
Interval-based: queries

• //section/title
  • SELECT e2.left
    FROM Element el, Element e2
    WHERE el.tag = 'section' AND e2.tag = 'title'
    AND el.left < e2.left AND e2.right < el.right
    AND el.level = e2.level-1;

  ⌨ Path expression becomes “containment” joins!
    • Number of joins is proportional to path expression length

• //book/title
  • SELECT e2.left
    FROM Element el, Element e2
    WHERE el.tag = 'book' AND e2.tag = 'title'
    AND el.left < e2.left AND e2.right < el.right;

  ⌨ No recursion!
Summary so far

Node/edge-based vs. interval-based mapping

• Path expression steps
  • Equality vs. containment join
• Descendent-or-self
  • Recursion required vs. not required
Path-based mapping: approach 1

Label-path encoding: paths as strings of labels

- **Element(pathid, left, right, …), Path(pathid, path), …**
  - *path* is a string containing the sequence of labels on a path starting from the root
  - Why are *left* and *right* still needed?

<table>
<thead>
<tr>
<th>Element</th>
<th>Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>pathid</td>
<td>path</td>
</tr>
<tr>
<td>1</td>
<td>/bibliography</td>
</tr>
<tr>
<td>2</td>
<td>/bibliography/book</td>
</tr>
<tr>
<td>3</td>
<td>/bibliography/book/title</td>
</tr>
<tr>
<td>4</td>
<td>/bibliography/book/author</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Label-path encoding: queries

• Simple path expressions with no conditions
  //book/title
  • Perform string matching on Path
  • Join qualified pathid’s with Element

• //book[publisher='Prentice Hall']/title
  • Evaluate //book/title
  • Evaluate //book/publisher[text()='Prentice Hall']
  • Must then ensure title and publisher belong to the same book (how?)

ียน Path expression with attached conditions needs to be broken down, processed separately, and joined back
Path-based mapping: approach 2

Dewey-order encoding

• Each component of the id represents the order of the child within its parent
  • Unlike label-path, this encoding is “lossless”

Element(dewey_pid, tag)
Text(dewey_pid, value)
Attribute(dewey_pid, attrName, attrValue)
Dewey-order encoding: queries

• Examples:
  //title
  //section/title
  //book/title
  //book[publisher='Prentice Hall']/title

• Works similarly as interval-based mapping
  • Except parent/child and ancestor/descendant relationship are checked by prefix matching

• Serves a different purpose from label-path encoding

• Any advantage over interval-based mapping?
Summary

• XML data can be “shredded” into rows in a relational database
• XQueries can be translated into SQL queries
  • Queries can then benefit from smart relational indexing, optimization, and execution
• With schema-oblivious approaches, comprehensive XQuery-SQL translation can be easily automated
  • Different data mapping techniques lead to different styles of queries
• Schema-aware translation is also possible and potentially more efficient, but automation is more complex