XML-Relational Mapping

CompSci 316
Introduction to Database Systems

Announcements (Tue. Nov. 1)

- Homework #3 due next Tuesday
- Project milestone #2 due in 2 weeks

Approaches to XML processing

- Text files (!)
- Specialized XML DBMS
  - Lore (Stanford), Strudel (AT&T), Timber (Michigan), MonetDB/XQuery (CWI, Netherlands), Tamino (Software AG), BaseX, eXist, Sedna, …
  - Still some way to go
- Object-oriented DBMS
  - ObjectStore, ozone, …
  - Not as mature as relational DBMS
- Relational (and object-relational) DBMS
  - Middleware and/or extensions
  - IBM DB2's pureXML, PostgreSQL's XML type/functions…

Mapping XML to relational

- Store XML in a CLOB (Character Large OBject) column
  - Simple, compact
  - Full-text indexing can help (often provided by DBMS vendors as object-relational "extensions")
  - 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

Node/edge-based: schema

- *Element*(<u>*eid*</u>, *tag*)
- *Attribute*(*eid*, *attrName*, *attrValue*) Key: (*eid*, *attrName*)
  - Attribute order does not matter
- *ElementChild*(*eid*, *pos*, *child*) Keys: (*eid*, *pos*), (*child*)
  - *pos* specifies the ordering of children
  - *child* references either *Element*(*eid*) or *Text*(*tid*)
- *Text*(<u>*tid*</u>, *value*)
  - *tid* cannot be the same as any *eid*
- ☞ Need to "invent" lots of *id*'s
- ☞ Need indexes for efficiency, e.g., *Element*(*tag*), *Text*(*value*)

Node/edge-based: example

```
<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

eid	attrName	attrValue
e1	ISBN	ISBN-10
e1	price	80

Text

tid	value
t0	Foundations of Databases
t1	Abiteboul
t2	Hull
t3	Vianu
t4	Addison Wesley
t5	1995

Element

eid	tag
e0	bibliography
e1	book
e2	title
e3	author
e4	author
e5	author
e6	publisher
e7	year

ElementChild

eid	pos	child
e0	1	e1
e1	1	e2
e1	2	e3
e1	3	e4
e1	4	e5
e1	5	e6
e1	6	e7
e2	1	t0
e3	1	t1
e4	1	t2
e5	1	t3
e6	1	t4
e7	1	t5

Node/edge-based: simple paths

- `//title`
  - `SELECT eid FROM Element WHERE tag = 'title';`
- `//section/title`
  - ```
    SELECT e2.eid
    FROM Element e1, ElementChild c, Element e2
    WHERE e1.tag = 'section'
    AND e2.tag = 'title'
    AND e1.eid = c.eid
    AND c.child = e2.eid;
    ```
- ☞ Path expression becomes joins!
  - Number of joins is proportional to the length of the path expression

Node/edge-based: more 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

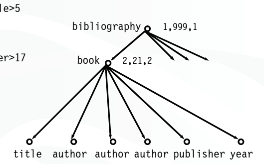
- `//book//title`
  - Requires SQL3 recursion
  - ```
    WITH RECURSIVE ReachableFromBook(id) AS
    ((SELECT eid FROM Element WHERE tag = 'book')
     UNION ALL
     (SELECT c.child
      FROM ReachableFromBook r, ElementChild c
      WHERE r.eid = c.eid))
    SELECT eid
    FROM Element
    WHERE 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 *left*
- *Text*(*left*, *right*, *level*, *value*)
  - Key is *left*
- *Attribute*(*left*, *attrName*, *attrValue*)
  - Key is (*left*, *attrName*)

Interval-based: example

```
1<bibliography>
   2<book ISBN="ISBN-10" price="80.00">
      3<title>4Foundations of Databases</title>5
      6<author>7Abiteboul</author>8
      9<author>10Hull</author>11
      12<author>13Vianu</author>14
      15<publisher>16Addison Wesley</publisher>17
      18<year>191995</year>20
    </book>21…
  </bibliography>999
```



- ☞ Where did *ElementChild* go?
  - $E1$ is the parent of $E2$ iff:

    $[E1.\mathit{left}, E1.\mathit{right}] \supset [E2.\mathit{left}, E2.\mathit{right}]$, and
    $E1.\mathit{level} = E2.\mathit{level} - 1$

Interval-based: queries

- `//section/title`
  - ```
    SELECT e2.left
    FROM Element e1, Element e2
    WHERE e1.tag = 'section' AND e2.tag = 'title'
    AND e1.left < e2.left AND e2.right < e1.right
    AND e1.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 e1, Element e2
    WHERE e1.tag = 'book' AND e2.tag = 'title'
    AND e1.left < e2.left AND e2.right < e1.right;
    ```
  - ☞No recursion!
    ```

Summary of interval-based mapping

- ❖ Path expression steps become containment joins
- ❖ No recursion needed for descendent-or-self
- ❖ Comprehensive XQuery-SQL translation is possible

A path-based mapping

Label-path encoding

- ❖ *Element*(*pathid*, *left*, *right*, …), *Path*(*pathid*, *path*), …
  - *path* is a label path starting from the root
  - Why are *left* and *right* still needed? To preserve structure

Element

pathid	left	right	…
1	1	999	…
2	2	21	…
3	3	5	…
4	6	8	…
4	9	11	…
4	12	14	…
…	…	…	…

Path

pathid	path
1	/bibliography
2	/bibliography/book
3	/bibliography/book/title
4	/bibliography/book/author
…	…

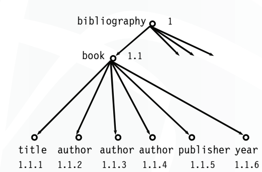
Label-path encoding: queries

- ❖ 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']`
  - How to ensure `title` and `publisher` belong to the same `book`?
  - ☞Path expression with attached conditions needs to be broken down, processed separately, and joined back

Another path-based mapping

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?

Schema-aware mapping

- ❖ Idea: use DTD to design a better schema
- ❖ Basic approach: elements of the same type go into one table
  - Tag name → table name
  - Attributes → columns
    - If one exists, `ID` attribute → key column; otherwise, need to "invent" a key
    - `IDREF` attribute → foreign key column
  - Children of the element → foreign key columns
    - Ordering of columns encodes ordering of children

```
<!DOCTYPE bibliography […
  <!ELEMENT book (title, …)>
  <!ATTLIST book ISBN ID #REQUIRED>
  <!ATTLIST book price CDATA #IMPLIED>
  <!ELEMENT title (#PCDATA)>…
]>
```

book(*ISBN*, *price*, *title_id*, …)
title(*id*, *PCDATA_id*)
PCDATA(*id*, *value*)

Handling * and + in DTD

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- What if an element can have any number of children?
- Example: Book can have multiple authors
  - *book*(*ISBN*, *price*, *title_id*, *author_id*, *publisher_id*, *year_id*)?
  - ☞BCNF?
- Idea: create another table to track such relationships
  - *book*(<u>*ISBN*</u>, *price*, *title_id*, *publisher_id*, *year_id*)
  - *book_author*(ISBN, <u>*author_id*</u>)
  - ☞BCNF decomposition in action!
  - ☞A further optimization: merge *book_author* into *author*
- Need to add position information if ordering is important
  - *book_author*(<u>*ISBN*</u>, <u>*author_pos*</u>, *author_id*)

Inlining

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- An `author` element just has a `PCDATA` child
- Instead of using foreign keys
  - *book_author*(*ISBN*, *author_pos*, *author_id*)
  - *author*(*id*, *PCDATA_id*)
  - *PCDATA*(*id*, *value*)
- Why not just "inline" the string value inside *book*?
  - *book_author*(*ISBN*, *author_pos*, *author_PCDATA_value*)
  - *PCDATA* table no longer stores `author` values

More general inlining

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- As long as we know the structure of an element and its number of children (and recursively for all children), we can inline this element where it appears

```
<book ISBN="…">…
  <publisher>
    <name>…</name><address>…</address>
  </publisher>…
</book>
```

- With no inlining at all
  - *book*(*ISBN*, *publisher_id*)
  - *publisher*(*id*, *name_id*, *address_id*)
  - *name*(*id*, *PCDATA_id*)
  - *address*(*id*, *PCDATA_id*)
- With inlining
  - *book*(*ISBN*, *publisher_name_PCDATA_value*, *publisher_address_PCDATA_value*)

Queries

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- *book*(<u>*ISBN*</u>, *price*, *title*, *publisher*, *year*), *book_author*(<u>*ISBN*</u>, <u>*author_pos*</u>, *author*), *book_section*(*ISBN*, *section_pos*, <u>*section_id*</u>), *section*(<u>*id*</u>, *title*, *text*), *section_section*(*id*, *section_pos*, <u>*section_id*</u>)
- `//title`
  - `(SELECT title FROM book) UNION ALL (SELECT title FROM section);`
- `//section/title`
  - `SELECT title FROM section;`
- `//bibliography/book[author="Abiteboul"]/@price`
  - `SELECT price FROM book, book_author WHERE book.ISBN = book_author.ISBN AND author = 'Abiteboul';`
- `//book//title`
  - `(SELECT title FROM book) UNION ALL (SELECT title FROM section)`

These queries only work for the given DTD

Pros and cons of inlining

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- Not always applicable
  - `*` and `+`, recursive schema (e.g., `section`)
- Fewer joins
- More "scattering" (e.g., there is no longer any table containing all titles; author information is scattered across *book*, *section*, etc.)
  - ☞Heuristic: do not inline elements that can be shared

Result restructuring

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- Simple results are fine
  - Each tuple returned by SQL gets converted to an element
- Simple grouping is fine (e.g., books with multiple authors)
  - Tuples can be returned by SQL in sorted order; adjacent tuples are grouped into an element
- Complex results are problematic (e.g., books with multiple authors and multiple references)
  - One SQL query returns one table, whose columns cannot store sets
  - Option 1: return one table with all combinations of authors and references → bad
  - Option 2: return two tables, one with authors and the other with references → join is done as post processing
  - Option 3: return one table with all author and reference columns; pad with `NULL`'s; order determines grouping → messy

Comparison of approaches

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- Schema-oblivious
  - Flexible and adaptable; no DTD needed
  - Queries are easy to formulate
    - Translation can be easily automated
  - Queries involve lots of join and are expensive
- Schema-aware
  - Less flexible and adaptable
  - Need to know DTD to design the relational schema
  - Query formulation requires knowing DTD and schema
  - Queries are more efficient
  - XQuery is tougher to formulate because of result restructuring