XML-Relational Mapping

CPS 216

Advanced Database Systems

Announcements (March 29)

- Homework #3 assigned today
  - Due in two weeks (April 12)
- Reading assignment due this Wednesday
  - Two *VLDB* papers on native XML databases
- Course project milestone 2 due this Thursday

Approaches to XML processing

- Text files (!)
- Specialized XML DBMS
  - Lore (Stanford), Strudel (AT&T), Tamino/QuiP (Software AG), X-Hive, Timber (Michigan), etc.
  - Still a long way to go
- Object-oriented DBMS
  - eXcelon (ObjectStore), ozone, etc.
  - Not as mature as relational DBMS
- Relational (and object-relational) DBMS
  - Middleware and/or object-relational extensions

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>
```

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

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

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 e2.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 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

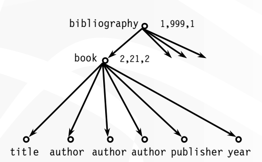
- *Element*(*left*, *right*, *level*, *tag*)
  - *left* is the start position of the element
  - *right* is the end position of the element
  - *level* is the nesting depth of the element (strictly speaking, unnecessary)
  - Key is *left*
- *Attribute*(*left*, *attrName*, *attrValue*)
- *Text*(*left*,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

☞ Where did *ElementChild* go?

  - $E1$ is the parent of $E2$ iff:
    $[E1.left, E1.right] \supset [E2.left, E2.right]$, and
    $E1.level = E2.level - 1$

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
```



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 = 'section'
    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 with "dynamic interval encoding"
  - DeHaan et al. *SIGMOD* 2003
  - Looks hairy, but with some special tweaks to the relational engine, it actually performs better than many of the currently available native XQuery products!

  ☞Set-oriented processing helps!

A path-based mapping

Label-path encoding

- ❖ *Element*(*pathid*, *left*, *right*, *value*), *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
…	…

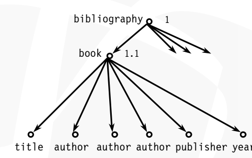
Label-path encoding: queries

- ❖ Simple path expressions with no conditions
  `//book//title`
  - Perform string matching on *Path*
  - Join qualified *pathid*'s with *Element*
- ❖ Path expression with attached conditions needs to be broken down, processed separately, and joined back
  `//book[publisher='Prentice Hall']/title`
  - Evaluate `//book/title`
  - Evaluate `//book/publisher[text()='Prentice Hall']`
  - Join to ensure `title` and `publisher` belong to the same `book`
    - How?

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"



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

- 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*(*ISBN*, *price*, *title_id*, *publisher_id*, *year_id*)
  - *book_author*(*ISBN*, *author_id*)
  - ☞BCNF decomposition in action!
  - ☞A further optimization: merge *book_author* into *author*
- Need to add position information if ordering is important
  - *book_author*(*ISBN*, *author_pos*, *author_id*)

Inlining

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

More general inlining

- 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

- *book*(*ISBN*, *price*, *title*, *publisher*, *year*), *book_author*(*ISBN*, *author*), *book_section*(*ISBN*, *section_id*), *section*(*id*, *title*, *text*), *section_section*(*id*, *section_pos*, *section_id*)
- `//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

- 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

- 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: one SQL query only returns a single table; columns cannot contains sets or structures
  - E.g., books with multiple authors and multiple references
    - Option 1: one table with all combo of authors/references → bad
    - Option 2: two tables, one w/ authors and the other w/ references → join is done as post processing
    - Option 3: sorted "union" of `NULL`-padded authors and references

Comparison of approaches

- Schema-oblivious
  - Flexible and adaptable; no DTD needed
  - Queries are easy to formulate
    - Translation from Xpath/XQuery 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