Bridging Relational Technology and XML

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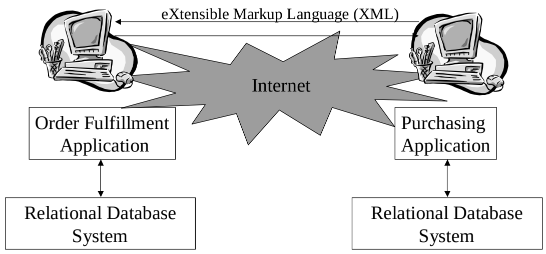
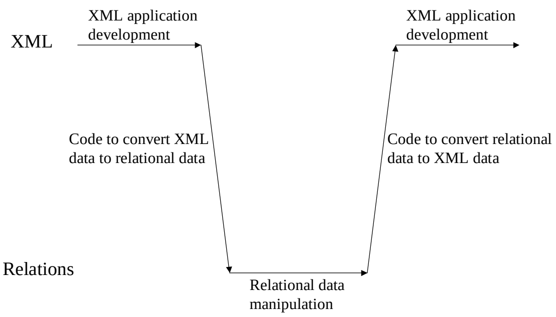
Business to Business Interactions

Tires R Us

Cars R Us



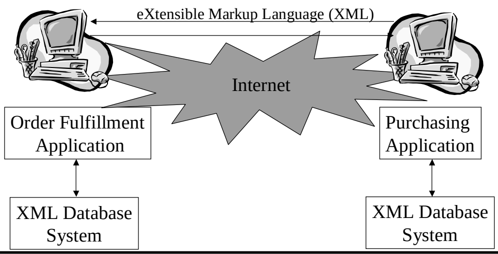
Shift in Application Developers' Conceptual Data Model



Are XML Database Systems the Answer?

Tires R Us

Cars R Us



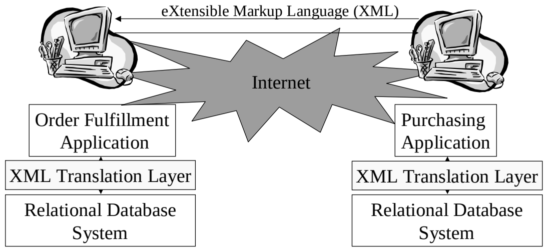
Why use Relational Database Systems?

- Highly reliable, scalable, optimized for performance, advanced functionality
  - Result of 30+ years of Research & Development
  - XML database systems are not "industrial strength" … and not expected to be in the foreseeable future
- Existing data and applications
  - XML applications have to inter-operate with existing relational data and applications
  - Not enough incentive to move all existing business applications to XML database systems
    - Remember object-oriented database systems?

A Solution

Tires R Us

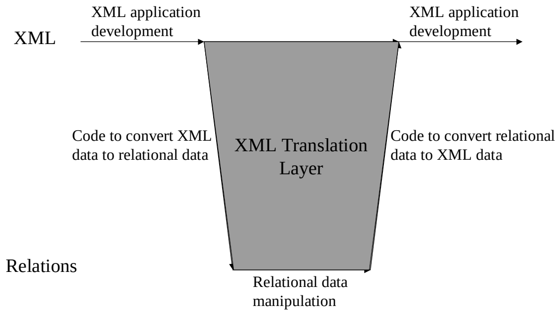
Cars R Us



XML Translation Layer (Contributions)

- Store and query XML documents
  - Harnesses relational database technology for this purpose [VLDB'99]
- Publish existing relational data as XML documents
  - Allows relational data to be viewed in XML terms [VLDB'00]

Bridging Relational Technology and XML



Outline

- Motivation & High-level Solution
- Background (Relations, XML)
- Storing and Querying XML Documents
- Publishing Relational Data as XML Documents
- Conclusion

Relational Data

PurchaseOrder

Id	Customer	Day	Month	Year
200I	Cars R Us	10	June	1999
300I	Bikes R Us	null	July	1999

Item

Pid	Name	Quantity	Cost
200I	Firestone Tire	50	2000.00
300I	Schwinn Tire	100	2500.00
300I	Trek Tire	20	400.00
200I	Goodyear Tire	200	8000.00

Payment

Pid	Installment	Percentage
200I	1	40%
200I	2	60%
300I	1	100%

SQL Query

Find all the items bought by "Cars R Us" in the year 1999

```
Select  it.name
From    PurchaseOrder po, Item it
Where po.customer = "Cars R Us" and   } Predicates
          po.year = 1999 and
          po.id = it.pid                  } Join
```

XML Document

Self-describing tags

```
<PurchaseOrder id="200I" customer="Cars R Us">
    <Date>
        <Day> 10 </Day>
        <Month> June </Month>
        <Year> 1999 </Year>
    </Date>
    <Item name="Firestone Tire" cost="2000.00">
        <Quantity> 50 </Quantity>
    </Item>
    <Item name="Goodyear Tire" cost="8000.00">
        <Quantity> 200 </Quantity>
    </Item>
    <Payment> 40% </Payment>
    <Payment> 60% </Payment>
</PurchaseOrder>
```

XML Document

Self-describing tags

Nested structure

```
<PurchaseOrder id="200I" customer="Cars R Us">
    <Date>
        <Day> 10 </Day>
        <Month> June </Month>
        <Year> 1999 </Year>
    </Date>
    <Item name="Firestone Tire" cost="2000.00">
        <Quantity> 50 </Quantity>
    </Item>
    <Item name="Goodyear Tire" cost="8000.00">
        <Quantity> 200 </Quantity>
    </Item>
    <Payment> 40% </Payment>
    <Payment> 60% </Payment>
</PurchaseOrder>
```

XML Document

Self-describing tags

Nested structure

Nested sets

```
<PurchaseOrder id="200I" customer="Cars R Us">
    <Date>
        <Day> 10 </Day>
        <Month> June </Month>
        <Year> 1999 </Year>
    </Date>
    <Item name="Firestone Tire" cost="2000.00">
        <Quantity> 50 </Quantity>
    </Item>
    <Item name="Goodyear Tire" cost="8000.00">
        <Quantity> 200 </Quantity>
    </Item>
    <Payment> 40% </Payment>
    <Payment> 60% </Payment>
</PurchaseOrder>
```

XML Document

Self-describing tags

Nested structure

Nested sets

Order

```
<PurchaseOrder id="200I" customer="Cars R Us">
    <Date>
        <Day> 10 </Day>
        <Month> June </Month>
        <Year> 1999 </Year>
    </Date>
    <Item name="Firestone Tire" cost="2000.00">
        <Quantity> 50 </Quantity>
    </Item>
    <Item name="Goodyear Tire" cost="8000.00">
        <Quantity> 200 </Quantity>
    </Item>
    <Payment> 40% </Payment>
    <Payment> 60% </Payment>
</PurchaseOrder>
```

XML Schema

```
PurchaseOrder  →  <PurchaseOrder id={integer} customer={string}>
                      Date (Item)* (Payment)*
                  </PurchaseOrder>

Date           →  <Date>
                      Day? Month Year
                  </Date>

Day            →  <Day> {integer} </Day>

Month          →  <Month> {string} </Month>

Year           →  <Year> {integer} </Year>

Item           →  <Item name={string} cost={float}>
                      Quantity
                  </Item>
… and so on
```

XML Schema (contd.)

```
PurchaseOrder  →  <PurchaseOrder id={integer} customer={string}>
                      Date? (Item | Payment)*
                  </PurchaseOrder>

PurchaseOrder  →  <PurchaseOrder id={integer} customer={string}>
                      (Date | Payment*) (Item (Item Item)* Payment)*
                  </PurchaseOrder>

PurchaseOrder  →  <PurchaseOrder id={integer} customer={string}>
                      Date Item (PurchaseOrder)* Payment
                  </PurchaseOrder>
```

XML Query

Find all the items bought by “Cars R Us” in 1999

```
For     $po in /PurchaseOrder
Where $po/@customer = "Cars R Us" and $po/date/year = 1999
Return $po/Item
```

XML Query (contd.)

//Item

//Item[5]

//Item Before //Payment

/(Item/(Item/Payment)*/(Payment | Item))*/Date

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- Motivation & High-level Solution
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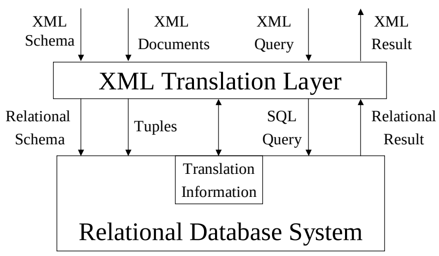
Storing and Querying XML Documents

[Shanmugasundaram et. al., VLDB'99]



Outline

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  - Relational Schema Design and XML Storage
  - Query Mapping and Result Construction
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XML Schema

PurchaseOrder → <PurchaseOrder id={integer} customer={string}>
(Date | (Payment)*) (Item (Item Item)* Payment)*
</PurchaseOrder>

Desired Properties of Generated Relational Schema *R*

- All XML documents conforming to XML schema should be "mappable" to tuples in *R*
- All queries over XML documents should be "mappable" to SQL queries over *R*
- Not Required: Ability to re-generate XML schema from *R*

Simplifying XML Schemas

- XML schemas can be “simplified” for translation purposes

PurchaseOrder ⟶ <PurchaseOrder id={integer} customer={string}>
(Date | (Payment)*) (Item (Item Item)* Payment)*
</PurchaseOrder>

PurchaseOrder ⟶ <PurchaseOrder id={integer} customer={string}>
Date? (Item)* (Payment)*
</PurchaseOrder>

- All without undermining storage and query functionality!

Why is Simplification Possible?

- Structure in XML schemas can be captured:
  - Partly in relational schema
  - Partly as *data values*

PurchaseOrder ⟶ <PurchaseOrder id={integer} customer={string}>
Date? (Item)* (Payment)*
</PurchaseOrder>

- Order field to capture order among siblings
- Sufficient to answer ordered XML queries
  - PurchaseOrder/Item[5]
  - PurchaseOrder/Item AFTER PurchaseOrder/Payment
- Sufficient to reconstruct XML document

Simplification Desiderata

- Simplify structure, but preserve differences that matter in relational model
  - Single occurrence (attribute)
  - Zero or one occurrences (nullable attribute)
  - Zero or more occurrences (relation)

PurchaseOrder ⟶ <PurchaseOrder id={integer} customer={string}>
(Date | (Payment)*) (Item (Item Item)* Payment)*
</PurchaseOrder>

PurchaseOrder ⟶ <PurchaseOrder id={integer} customer={string}>
Date? (Item)* (Payment)*
</PurchaseOrder>

Translation Normal Form

- An XML schema production is either of the form:

P ⟶ <P $attr_1$={$type_1$} … $attr_m$={$type_m$}>
$a_1 \ldots a_p\ a_{p+1}? \ldots a_q?\ a_{q+1}* \ldots a_r*$
</P>

where $a_i \neq a_j$

- … or of the form:

P ⟶ <P $attr_1$={$type_1$} … $attr_m$={$type_m$}>
{type}
</P>

Example Simplification Rules

$(e_1 \mid e_2)$ ⟶ $e_1?\ e_2?$

(Date | (Payment)*) (Item (Item Item)* Payment)*

Date? (Item)*? (Item (Item Item)* Payment)*

e*? ⟶ e*

Date? (Payment)*? (Item (Item Item)* Payment)*

Date? (Item)* (Item (Item Item)* Payment)*

Simplified XML Schema

PurchaseOrder ⟶ <PurchaseOrder id={integer} customer={string}>
Date (Item)* (Payment)*
</PurchaseOrder>

Date ⟶ <Date>
Day? Month Year
</Date>

Day ⟶ <Day> {integer} </Day>

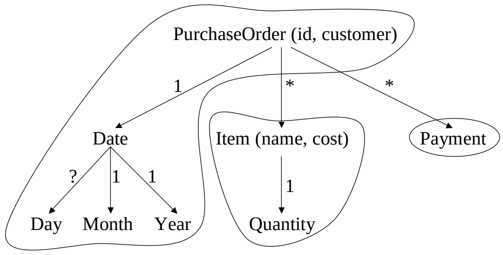
Month ⟶ <Month> {string} </Month>

Year ⟶ <Year> {integer} </Year>

Item ⟶ <Item name={string} cost={float}>
Quantity
</Item>

… and so on

Relational Schema Generation



Satisfy: Fourth normal form
Minimize: Number of joins for path expressions

Generated Relational Schema and Shredded XML Document

PurchaseOrder

Id	Customer	Day	Month	Year
200I	Cars R Us	10	June	1999

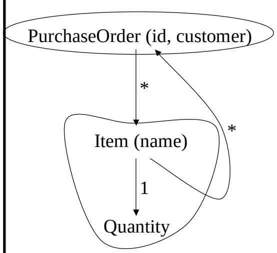
Item

Pid	Order	Name	Cost	Quantity
200I	1	Firestone Tire	2000.00	50
200I	3	Goodyear Tire	8000.00	200

Payment

Pid	Order	Value
200I	2	40%
200I	4	60%

Recursive XML Schema



PurchaseOrder

Id	Customer	Order	*Pid*
200I	Cars R Us	null	null
900I	Us Again	1	5

Item

Pid	Order	Name	Quantity	Id
200I	1	Firestone Tire	50	5
200I	2	Goodyear Tire	200	6

Relational Schema Generation and XML Document Shredding (Completeness and Optimality)

- Any XML Schema *X* can be mapped to a relational schema *R*, and …
- Any XML document *XD* conforming to *X* can be converted to tuples in *R*
- Further, *XD* can be recovered from the tuples in *R*
- Also minimizes the number of joins for path expressions (given fourth normal form)

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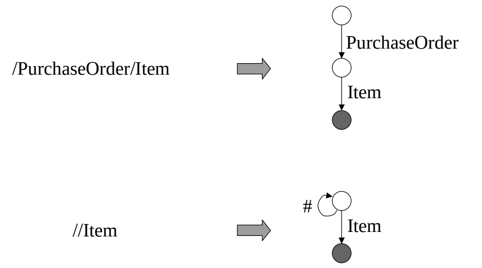
XML Query

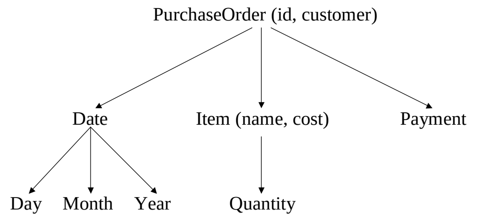
Find all the items bought by “Cars R Us” in 1999

For $po in /PurchaseOrder
Where $po/@customer = “Cars R Us” and $po/date/year = 1999
Return $po/Item

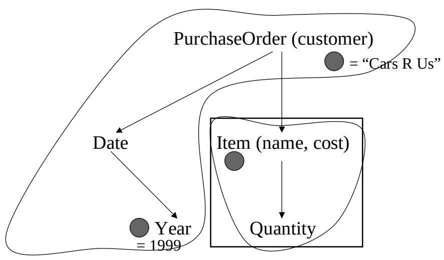
Path Expression Automata (Moore Machines)



XML Schema Automaton (Mealy Machine)



Intersected Automaton

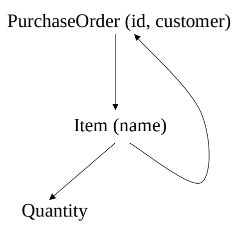


Generated SQL Query

Select i.name, i.cost, i.quantity
From PurchaseOrder p, Item i
Where p.customer = “Cars R Us” and
p.year = 1999 and
p.id = i.pid

Predicates
Join condition

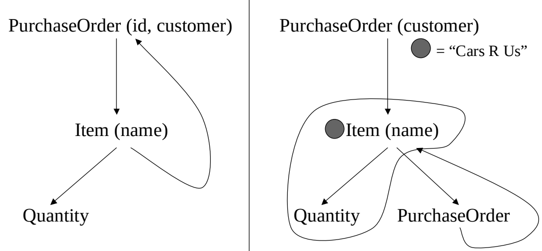
Recursive XML Query



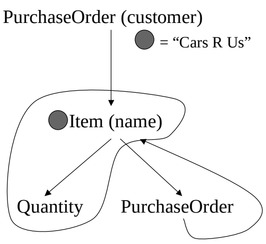
Find all items (directly or indirectly) under a “Cars R Us” purchase order

For $po in /PurchaseOrder
Where $po/@customer = “Cars R Us”
Return $po//Item

Recursive Automata Intersection



Recursive SQL Generation



ResultItems (id, name, quantity) as (
  Select it.id, it.name, it.quantity
  From PurchaseOrder po, Item it
  Where po.customer = “Cars R Us”
      and po.id = it.pid

  Union all

  Select it.id, it.name, it.quantity
  From ResultItems rit,
      PurchaseOrder po, Item it
  Where rit.id = po.pid and
      po.id = it.pid
)

SQL Generation for Path Expressions (Completeness)

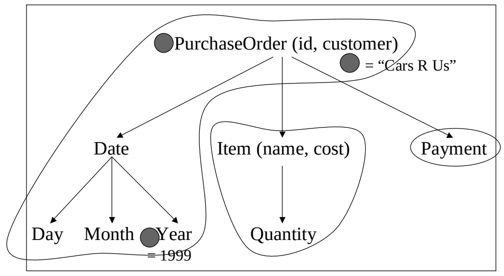
- (Almost) all path expressions can be translated to SQL
- SQL does not support
  - Nested recursion
  - Meta-data querying
- Meta-data query capability provided in the XML translation layer

Constructing XML Results

<item name = “Firestone Tire” cost=“2000.00”>
  <quantity> 50 </quantity>
</item>
<item name=“Goodyear Tire” cost=“8000.00”>
  <quantity> 200 </quantity>
</item>

(“Firestone Tire”, 2000.00, 50)
(“Goodyear Tire”, 8000.00, 200)

Complex XML Construction



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Relational Schema and Data

PurchaseOrder

Id	Customer	Day	Month	Year
200I	Cars R Us	10	June	1999

Item

Pid	Name	Quantity	Cost
200I	Firestone Tire	50	2000.00
200I	Goodyear Tire	200	8000.00

Payment

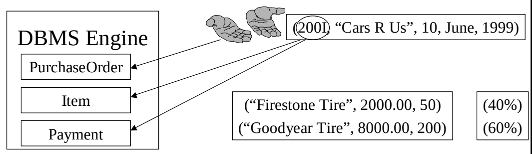
Pid	Installment	Percentage
200I	1	40%
200I	2	60%

XML Document

```
<PurchaseOrder id="200I" customer="Cars R Us">
   <Date>
      <Day> 10 </Day>
      <Month> June </Month>
      <Year> 1999 </Year>
   </Date>
   <Item name="Firestone Tire" cost="2000.00">
      <Quantity> 50 </Quantity>
   </Item>
   <Item name="Goodyear Tire" cost="8000.00">
      <Quantity> 200 </Quantity>
   </Item>
   <Payment> 40% </Payment>
   <Payment> 60% </Payment>
</PurchaseOrder>
```

Naïve Approach

- Issue many SQL queries that mirror the structure of the XML document to be constructed
- Tag nested structures as they are produced



Problem 1: Too many SQL queries
Problem 2: Fixed (nested loop) join strategy

Relations to XML: Issues

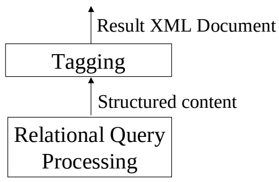
[Shanmugasundaram et. al., VLDB'00]

- Two main differences:
  - Ordered nested structures
  - Self-describing tags
- Space of alternatives:

	Early Tagging	Late Tagging
Early Structuring		✓
Late Structuring		

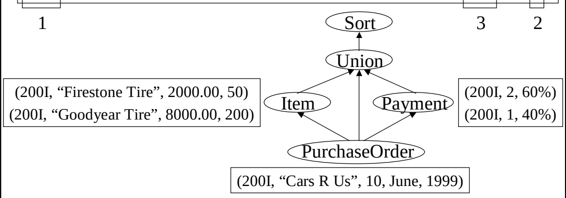
Late Tagging, Early Structuring

- *Structured* XML document content produced
  - In document order
  - "Sorted Outer Union" approach
- Tagger just adds tags
  - In constant space



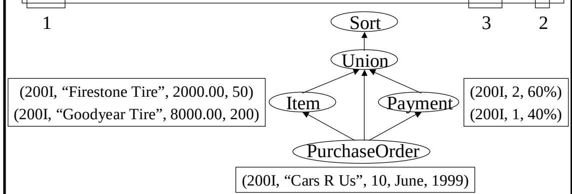
Sorted Outer Union Approach

(200I, null , null, null , null , null , null , null, 1 , 40%, 2)
(200I, "Cars R Us", 10 , June, 1999, null , null , null, null, null, 0)
(200I, null , null, null , null , null , null , null, 2 , 60%, 2)
(200I, null , null, null , null , "Firestone Tire" , 2000.00, 50 , null, null, 1)
(200I, null , null, null , null , "Goodyear Tire", 8000.00, 200, null, null, 1)



Sorted Outer Union Approach

(200I, "Cars R Us", 10 , June, 1999, null , null , null, null, null, 0)
(200I, null , null, null , null , "Firestone Tire" , 2000.00, 50 , null, null, 1)
(200I, null , null, null , null , "Goodyear Tire", 8000.00, 200, null, null, 1)
(200I, null , null, null , null , null , null , null, 1 , 40%, 2)
(200I, null , null, null , null , null , null , null, 2 , 60%, 2)



XML Document Construction (Completeness and Performance)

- Any nested XML document can be constructed using “sorted outer union” approach
- 9x faster than previous approaches [VLDB’00]
  - 10 MB of data
  - 17 seconds for sorted outer union approach
  - 160 seconds for “naïve XML application developer” approach

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Conclusion

- XML has emerged as the Internet data format
- But relational database systems will continue to be used for data management tasks
- Internet application developers currently have to explicitly bridge this “data model gap”
- Can we design a system that automatically bridges this gap for application developers?

```
For $cust in /Customer
Where $cust/name = “Jack”
Return $cust
```

```
// First prepare all the SQL statements to be executed and create cursors for them
Exec SQL Prepare CustStmt From “select cust.id, cust.name from Customer cust where cust.name = ‘Jack’“
Exec SQL Declare CustCursor Cursor For CustStmt
Exec SQL Prepare AcctStmt From “select acct.id, acct.acctnum from Account acct where acct.custId = ?“
Exec SQL Declare AcctCursor Cursor For AcctStmt
Exec SQL Prepare PorderStmt From “select porder.id, porder.acct, porder.date from PurchOrder porder
                                   where porder.custId = ?“
Exec SQL Declare PorderCursor Cursor For PorderStmt
Exec SQL Prepare ItemStmt From “select item.id, item.desc from Item item where item.poId = ?“
Exec SQL Declare ItemCursor Cursor For ItemStmt
Exec SQL Prepare PayStmt From “select pay.id, pay.desc from Payment pay where item.poId = ?“
Exec SQL Declare PayCursor Cursor For PayStmt
// Now execute SQL statements in nested order of XML document result. Start with customer
XMLresult = ““
Exec SQL Open CustCursor
while (CustCursor has more rows) {
   Exec SQL Fetch CustCursor Into :custId, :custName
   XMLResult += “<customer id=“ + custId + “><name>“ + custName + “</name><accounts>“
   // For each customer, issue sub-query to get account information and add to custAccts
   Exec SQL Open AcctCursor Using :custId
   while (AcctCursor has more rows) {
      Exec SQL Fetch AcctCursor Into :acctId, :acctNum
      XMLResult += “<account id=“ + acctId + “> “ + acctNum + “</account>“
   }
   XMLResult += “</accounts><porders>“
   // For each customer, issue sub-query to get purchase order information and add to custPorders
   Exec SQL Open PorderCursor Using :custId
   while (PorderCursor has more rows) {
      Exec SQL Fetch PorderCursor Into :poId, :poAcct, :poDate
      XMLResult += “<porder id=“+ poId + “ acct=“+poAcct +“><date>“+poDate +“</date><items>“
      // For each purchase order, issue a sub-query to get item information and add to porderItems
      Exec SQL Open ItemCursor Using :poId
      while (ItemCursor has more rows) {
         Exec SQL Fetch ItemCursor Into :itemId, :itemDesc
         XMLResult += “<item id=“ + itemId + “>“ + itemDesc + “</item>“
      }
      XMLResult += “</items><payments>“
      // For each purchase order, issue a sub-query to get payment information and add to porderPays
      Exec SQL Open PayCursor Using :poId
      while (PayCursor has more rows) {
         Exec SQL Fetch PayCursor Into :payId, :payDesc
         XMLResult += “<payment id=“ + payId + “>“ + payDesc + “</payment>“
      }
      XMLResult += “</payments></porder>“
   } // End of looping over all purchase orders associated with a customer
   XMLResult += “</customer>“
   Return XMLResult as one result row; reset XMLResult = ““
} // loop until all customers are tagged and output
```

Conclusion (Contd.)

- Yes! XPERANTO is the first such system
- Allows users to …
  - Store and query XML documents using a relational database system
  - Publish existing relational data as XML documents

  … using a high-level XML query language
- Also provides a dramatic improvement in performance

Industry Impact

- Sorted outer union approach is used in the DB2 XML Extender product (beta version)
- XPERANTO is now an IBM initiative

Relational Database System Vendors

- IBM, Microsoft, Oracle, Informix, …
  - SQL extensions for XML
- XML Translation Layer
  - "Pure XML" philosophy … provides high-level XML query interface
    - SQL extensions for XML, while better than writing applications, is still low-level
  - More powerful than XML-extended SQL
    - SQL just not designed with nifty XML features in mind