

# Storage and Retrieval of XML Data Using Relational Databases

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## About this Tutorial

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- Tutorial presented based solely on publicly available information
- Information is incomplete and could be inaccurate
- Our presentation reflects our understanding which may be erroneous
- Does not reflect views of our employers



## What's the big deal about XML?



## Disconnected Empires

- Before XML
  - No “universal” programming language
  - Various wire interoperation protocols based on RPC
    - Based on CORBA, DCOM
  - Corporate firewalls block DCOM, CORBA traffic
    - But allows HTTP in



## XML: A Wire Protocol

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- XML = A minimal wire representation for data and storage exchange
  - A low-level wire transfer format – like IP in networking
- Minimal level of standardization for distributed components to interoperate
  - Platform, language and vendor agnostic
  - Easy to understand and is extensible
- Data exchange enabled via XML transformations



## SOAP

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- Facilitate Platform independent distributed computing
- Protocol that defines a uniform way to perform RPC with
  - HTTP as wire protocol
  - Data encoded as XML

## Example (SOAP)

```
POST /cgi-bin/purchase-book.cgi HTTP/1.1
Methodname: Purchasebook
InterfaceName:
  soap:cdl:com.develop.demos.purchase_book
MessgeType: Call
Content-Type: text-xml-SOAP
<Purchasebook>
<ISBN>0201379369</ISBN>
</Purchasebook>
```

## Core XML Technologies

- Validation of XML
  - Schema and namespaces
- XML API: Programmatic Access to XML
  - DOM, SAX
- Transformation Technology: For Data Exchange and Display
  - XSL, XSLT, XQuery

## Implications of XML for Databases

- Data stored in SQL databases need to be published in XML for data exchange
  - Core requirement
  - Specification schemes for publishing needed
- Storage and retrieval of native XML for “document-centric” applications
  - Need to support XML API-s

## Architectural Alternatives for Storing Native XML

- Relational Approach – exploit traditional benefits of databases
- Other Architectures (not discussed)
  - File Systems
  - Native semistructured store
    - e.g. eXcelon, LORE, NATIX



## Rationale for Relational Representation for Native XML

- Relational and native XML data can co-exist
- RDBMS are scalable and offers many services
  - Transaction Management, Query optimization
- XML Schema/DTD can help guide relational representation
  - Incremental update and partial retrieval enabled
- LOB storage and indexing complements structured XML ("shredded") representation
  - Fast for storing and retrieving whole documents
  - Incremental update is difficult



## Outline of Tutorial

- XML and Related Technologies
- Examples of XML Support in Commercial Systems
- Publication of Relational Data in XML
- Storage of Native XML in Relational Databases
- Final Thoughts



# XML and Related Technologies



## XML

- Tagged elements describe the semantics of the data
- An element may have attributes to provide additional information
- An element can contain a sequence of nested sub-elements
  - Sub-elements may themselves be tagged elements or character data

## An XML Document

```
<?xml version="1.0"?>
<!DOCTYPE sigmodRecord SYSTEM "sigmodRecord.dtd">
<sigmodRecord>
<issue>
  <volume>1</volume>
  <number>1</number>
<articles>
  <article>
    <title> XML Research Issues</title>
    <initPage>1</initPage>
    <endPage>5</endPage>
    <authors>
      <author AuthorPosition="00">Tom Hanks</author>
    </authors>
  </article>
  <article>
    ..
  </article>
</articles>
</issue>
</sigmodRecord>
```

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## Document Type Definition (DTD)

- An XML document may have a DTD
- Grammar for describing the structure of XML document
- Terminology
  - well-formed: if tags are correctly closed
  - valid: if it has a DTD and conforms to it
  - For exchanges of data, validation is useful

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## A DTD Example (SIGMOD Record)

```
<?xml version="1.0"?>
<!-- SIGMOD Record DTD -->
<!ELEMENT SigmodRecord (issue)* >
<!ELEMENT issue (volume,number,articles) >
<!ELEMENT volume (#PCDATA)>
<!ELEMENT number (#PCDATA)>
<!ELEMENT articles (article)* >
<!ELEMENT article (title, initPage, endPage, authors) >
<!ELEMENT title (#PCDATA)>
<!ELEMENT initPage (#PCDATA)>
<!ELEMENT endPage (#PCDATA)>
<!ELEMENT authors (author)* >
<!ELEMENT author (#PCDATA)>
<!ATTLIST author AuthorPosition CDATA #IMPLIED>
```

## DTD Specification

- comma: sequence
- |: or
- (): grouping
- ?, \*, +: zero or one, zero or more, one or more occurrences
- ANY: allows an arbitrary XML fragment to be nested within the element
- PCDATA: parsed character data.
- CDATA: character data.

## XML Schema

- Schema
  - <http://www.w3c.org/TR/xmlschema-i> (i=0..2)
  - Specifies structure of XML documents
  - Datatypes for elements/attributes
    - string, int, float
    - Unordered set is also allowed
    - Derivation of types are allowed
  - Constraints/Keys
- Replaces DTDs
  - Removes syntactic distinctions between DTD and XML
  - Richer types compared to DTD

## XML Schema Example

```
<xsd:element name="article" minOccurs="0" maxOccurs="unbounded">  
  <xsd:complexType>  
    <xsd:sequence>  
      <xsd:element name="title" type="xsd:string"/>  
      <xsd:element name="initPage" type="xsd:string"/>  
      <xsd:element name="endPage" type="xsd:string"/>  
      <xsd:element name="author" type="xsd:string"/>  
    </xsd:sequence>  
  </xsd:complexType>  
</xsd:element>
```

### DTD

```
<!ELEMENT article (title, initPage, endPage, author) >  
<!ELEMENT title (#PCDATA)>  
<!ELEMENT initPage (#PCDATA)>  
<!ELEMENT endPage (#PCDATA)>  
<!ELEMENT author (#PCDATA)>
```



## XML API: DOM

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- Characteristics
  - Hierarchical (tree) object model for XML documents
  - Associate a list of children with every node (or text value)
  - Preserves the sequence of the elements in the XML document
- May be expensive to materialize for a large XML collection



## XML API: SAX

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- Characteristics
  - Event-driven: fire an event for every open tag/end tag
  - Does not require full parsing
  - Enables custom object model building
- Could be significantly faster for a simple object model



## XSL

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- Styling is rendering information for consumption
- XSL = A language to express styling ("Stylesheet language")
- Two components of a stylesheet
  - Transform: Source to a target tree using template rules expressed in XSLT
  - Format: Controls appearance



## XSLT

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- XPATH acts as the pattern language (more later)
- Primary goal is to transform XML vocabularies to XSL formatting vocabularies
  - But, often adequate for many transformation needs



## XQuery: An XML Query Language

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- Focused on expressing transformation
  - XPATH is a starting point
  - Unlike XSLT, no need to write stylesheet
- Make “database queries” easy to express (and hopefully to optimize)
- Strong Typing



## XPATH

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- [[www.w3.org/TR/xpath](http://www.w3.org/TR/xpath)]
- Used as a building block for
  - XSL Transformations (XSLT)
  - XQuery
- Syntax for tree navigation and node selection
  - Navigation is described using location paths

## XPATH

- . : current node
- .. : parent of the current node
- / : root node, or a separator between steps in a path
- // : descendants of the current node
- @ : attributes of the current node
- \* : "any" (node with unrestricted name)
- [ ] : a predicate for a given step
- [n] : the element with the given ordinal number from a list of elements

## XPATH Example

- List the titles of articles in which the author has "Tom Hanks"  
`//article[//author="Tom Hanks"]/title`
- Find the titles of articles authored by "Tom Hanks" in volume 1.  
`//issue[/volume="1"]/articles/article[//author="Tom Hanks"]/title`



## XQuery

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- Origin: Quilt [Chamberlin, Jobie, Florescu: WebDB 00]
- A functional language
  - query is an expression
  - expressions are recursively constructed
- Features
  - Includes XPATH as a sub-language
  - SQL-like FLWR expression
- Borrows features from many other languages: XQL, XML-QL, ML,..

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## XQuery

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- FLWR expression
  - FOR/LET Clauses
    - Ordered list of tuples of bound variables
  - WHERE Clause
    - Pruned list of tuples of bound variables
  - RETURN Clause
    - Instance of XML Query data model

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## Example: XQuery

- List the titles of the articles authored by "Tom Hanks"

### Query Expression

```
for $b IN document("sigmodRecord.xml")//article
where $b//author = "Tom Hanks"
return <title> $b/title.text() </title>
```



### Query Result

```
<title>XML Research Issues</title>
```

## Example: XQuery

- List the articles authored by "Tom Hanks".

### Query Expression

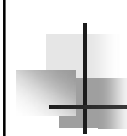
```
<articles>
{
  for $b IN document("sigmodRecord.xml")//article
  where $b//author = "Tom Hanks"
  return $b
}
</articles>
```



### Query Result

```
<articles>
<article>
<title>XML: Where are we heading for?</title>
<initPage>6</initPage>
<endPage>10</endPage>
<authors>
<author AuthorPosition="00">Tom Hanks</author>
</authors>
</article>
</articles>
```





## Examples of XML Support in Commercial Systems



## Microsoft SQL Server: Publishing

- Provide extensions on SQL to return results as XML document (FOR XML clause)
  - RAW mode: Converts each row in the SQL result into an XML without subelements
  - AUTO mode: Produce query result as nested XML document
  - EXPLICIT mode: the most general
    - Can control the shape of XML document
    - Expected nesting is explicitly specified as part of the query
- Generation of XML view using XDR
- Templates

## RAW Mode

- Returns Flat XML documents
  - Each row in the query result becomes an XML element with the name row
  - Each non-NULL column value is mapped to an attribute (column name becomes the attribute name)
- Q: 

```
select Customers.CustomerID, Orders.OrderID, Orders.OrderDate
from Customers, Orders
where Customers.CustomerID = Orders.CustomerID
order by Customers.CustomerID
for XML RAW
```
- A: 

```
<row CustomerID="ALFKI" OrderID="10643" OrderDate="1997-08-25"/>
<row CustomerID="ANATR" OrderID="10308" OrderDate="1996-09-18"/>
```

## AUTO Mode

- Returns nested XML elements.
  - Each table in the FROM clause is represented as an XML element
  - Table-list determines element nesting
  - The columns listed in the SELECT clause are mapped to the attributes
  - When the ELEMENTS option is specified, the table columns are mapped to sub-elements

## Example: AUTO Mode

```
select Customers.CustomerID, Orders.OrderID,  
       Customers.ContactName  
from Customers, Orders  
where Customers.CustomerID = Orders.CustomerID  
for XML AUTO
```

```
<Customers CustomerID="ALFKI" ContactName="Maria Ansers">  
  <Orders OrderID="10643"/>  
  <Orders OrderID="10692"/>  
  <Orders OrderID="10702"/>  
  <Orders OrderID="10835"/>  
  <Orders OrderID="10952"/>  
  <Orders OrderID="11011"/>  
</Customers>
```

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## Example: AUTO Mode (2)

```
select Customers.CustomerID, Orders.OrderID,  
       Customers.ContactName  
from Customers, Orders  
where Customers.CustomerID = Orders.CustomerID  
for XML AUTO, ELEMENTS
```

```
<Customers>  
  <CustomerID>ALFKI</CustomerID>  
  <ContactName>Maria Ansers</ContactName>  
  <Orders><OrderID>10643</OrderID></Orders>  
  <Orders><OrderID>10835</OrderID></Orders>  
  <Orders><OrderID>10952</OrderID></Orders>  
  <Orders><OrderID>11011</OrderID></Orders>  
</Customers>
```

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## EXPLICIT Mode

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- Motivation: Flexible publishing of relational data
  - Unlike RAW, AUTO modes
- Steps
  - Define a SQL view to assemble relevant rows
  - The rowset (universal table) must have certain format
    - Special Columns: Tag and Parent
    - Column names
    - Row ordering

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## Explicit Mode: Universal Relation Format

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- 1st column
  - Column name: Tag
  - Tag number of the current element
- 2nd column:
  - Column name: Parent
  - Tag number of the parent element
  - If the value is 0 or NULL, the row is placed on the top level
- Ordering of Rows: Parent must be followed immediately by its children

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## Example1: EXPLICIT Mode

```
select 1                as Tag,  
       NULL             as Parent,  
       Customers.CustomerID as [Customer!1!CustomerID]  
       NULL             as [Order!2!OrderID]  
from Customers  
  
UNION ALL  
  
select 2,  
       1,  
       Customers, Orders  
where Customers.CustomerID = Orders.CustomerID  
order by [Customer!1!CustomerID], [Order!2!OrderID]  
for XML EXPLICIT
```

## Example1: EXPLICIT Mode (2)

Tag	Parent	Customer!1!CustomerID	Order!2!OrderID
1	NULL	ALFKI	NULL
2	1	ALFKI	10643
2	1	ALFKI	10692
2	1	ALFKI	10702
2	1	ALFKI	11011
2	1	ALFKI	...
1	NULL	ANATR	NULL
2	1	ANATR	10308
2	1	ANATR	10625
2	1	ANATR	...

## Example1: EXPLICIT Mode (3)

```
<Customer CustomerID="ALFKI">
  <Order OrderID="10643" />
  <Order OrderID="10692" />
  <Order OrderID="10702" />
  <Order OrderID="11011" />
</Customer>
<Customer CustomerID="ANATR">
  <Order OrderID="10308" />
  <Order OrderID="10625" />
</Customer>
```

## Example2: EXPLICIT Mode (1)

```
select 1
      NULL
      Customers.CustomerID
      NULL
from Customers

      as Tag,
      as Parent,
      as [Customer!1!CustomerID]
      as [Order!2!OrderID!element]

UNION ALL

select 2,
      1,
      Customers, Orders
where Customers.CustomerID = Orders.CustomerID
order by [Customer!1!CustomerID], [Order!2!OrderID!element]
for XML EXPLICIT
```

## Example2: EXPLICIT Mode (2)

```
<Customer CustomerID="ALFKI">
  <Order> <OrderID>10643 </OrderID </Order>
  <Order> <OrderID>10692</OrderID>
  <Order> <OrderID>10702</OrderID>
</Customer>
<Customer CustomerID="ANATR">
  .....
</Customer>
```

## Defining XML Views

- Annotated schema using XDR (XML-Data Reduced Data)
  - Description similar to DTD
  - Also includes mapping to SQL
- Views may be consumed by XML tools
  - Queried by XQuery
  - Processed by XSLT

## Example: XML Views using XDR

```
<schema xmlns = ..  
  xmlns:sql = ..>  
  <ElementType name = "Customer"  
    sql:relation = "Customers">  
    <AttributeType name = "ID" />  
    <attribute type = "ID" Sql:field  
      = "CustomerID" />  
  </ElementType  
</schema>
```

## MS SQL Server: Support for Native XML

- Alternatives using OpenXML rowset provider
  - Edge Table: A graph representation of the XML (parent-child hierarchy)
    - Select \* from OpenXML(@doc, '/ROOT/Customer')
  - Shredded Rowset: Derive custom rowset from XML
    - A Flag determines alternatives:
      - Columns = Attributes or Columns = Elements



## Example: Shredded Rowset

### Attribute-Centric Mapping

```
Select * from  
OpenXML(@doc, '/ROOT/Customer', 1)  
WITH (CustomerID varchar(10)  
      Contactname varchar(20))
```

### Retrieval from Different levels

```
Select * from  
OpenXML(@doc, '/ROOT/Customer/Order/OrderDetail', 2)  
WITH (OrderDate datetime `./@OrderDate`,  
      ProdID int `@ProductID`)
```

## IBM DB2

- Publishing
  - Mapping from SQL to XML specified in Data Access Definition (DAD) files
- Storage of Native XML
  - Provides two primary storage and access methods for native XML
    - XML column and XML collection
  - Mapping specified using DAD files as well

## Using DAD File for Publishing

- Defines the mapping to XML view
  - An XML document itself
  - Used also for native storage of XML (discussed later)
- Two ways to specify mapping
  - SQL Mapping
  - RDB\_node Mapping
- Use dxxGenXML() Stored Procedure to generate XML
  - Input: DAD
  - Output: Output\_Table (single-column)
  - Additional customization parameters

## Example: DAD-SQL Mapping

```
<?xml version="1.0"?>
<!DOCTYPE DAD SYSTEM "dxx_install/dtd/dad.dtd">
<dad>
  <dtdid>dxx_install/dtd/getstart.dtd</dtdid>
  <validation>YES</validation>
  <Xcollection>
    <SQL_stmt>
      select o.order_key, customer_name, customer_email, p.part_key, color,
             quantity, price, tax, ship_id, date, mode
      from order_tab o, part_tab p,
           (select db2xml.generate_unique() as ship_id, date, mode, part_key
            from ship_tab) as s
      where o.order_key = 1 and p.price > 20000 and p.order_key =
             o.order_key and s.part_key = p.part_key
      order by order_key, part_key, ship_id
    </SQL_stmt>
  </Xcollection>
</dad>
```

## Example: DAD-SQL Mapping (Contd.)

```
<prolog?xml version="1.0"?></prolog>
<root_node>
  <element_node name="Order">
    <attribute_node name="key">
      <column name="order_key"/>
    </attribute_node>
    <element_node name="Customer">
      <element_node name="Name">
        <text node>
          <column name="customer_name"/>
        </text node>
      </element_node>
    </element_node>
  </element_node>
</root_node>
</Xcollection>
</dad>
```

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## Example: DAD-RDB\_node Mapping

```
<DAD> <Xcollection> <root_node>
  <element_node name = "Order">
    <RDB_node>
      <table_name = "order_tab"/>
      <table_name = "part_tab"/>
      <table_name = "ship_tab"/>
      <condition>
        Order_tab.order_key = part_tab_order_key AND
        Part_tab.part_key = ship_tab.part_key
      </condition>
    </RDB_node>
    <attribute_node name ="key">
      <RDB_node>
        <table_name= "order_tab"/>
        <column name = "order_key" />
      </RDB_node>
    </attribute_node>
```

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## Example: DAD-RDB\_NODE Mapping (2)

```
....
<element_node name = "ShipDate"
  <text_node>
    <RDB_node>
      <table_name= "ship_tab"/>
      <column name= "date" />
      <condition>
        Date > "1966-01-01"
      </condition>
    </RDB_node>
  </text_node>
</element_node>
...
</root_name>
</Xcollection>
</DAD>
```

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## IBM DB2: Storing Native XML in a Column

- Store DTD in DTD repository
- Register a XML column with type:
  - *XMLCLOB*: for large XML documents; *XMLVARCHAR*: for small XML documents, *XMLFile*: for XML documents stored outside DB2
- Create a DAD file
  - To specify any "side tables" for indexing
- Enable the XML column
  - Creates side tables as per DAD
  - Add necessary triggers and other meta information
- Insert XML document
  - Side tables get automatically updated

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## DAD for Side Table Specification

```
.. <dad>
  <dtdid>dxx_install/dtd/getstart.dtd</dtdid>
  <validation>YES</validation>
  <Xcolumn>
    <table name="order_side_tab"> </table>
    <table name="part_side_tab">
      <column name="price" type="decimal(10,2)"
        path="/Order/Part/ExtendedPrice" multi_occurrence="YES"/>
    </table>
    <table name="ship_side_tab">
      <column name="date" type="DATE"
        path="/Order/Part/Shipment/ShipDate"
        multi_occurrence="YES"/>
    </table>
  </Xcolumn>
</dad>
```

## Stored Procedures for Handling XML Columns

- Storage: Type conversion
  - XMLVarCharFromFile(),...
- Retrieval: Cast Functions
  - Varchar(XMLVarChar)
- Update
  - Cast functions or storage UDFs
  - Update(xmlobj, path,value)
- Selection using XPATH
  - WHERE Extractvarchar(order, '/order/Customer') LIKE '%IBM%'
  - Or, use side tables

## Native XML Storage: XML Collection Option

- Allows to decompose an XML document into a set of DB2 tables
  - A subset of data requires frequent update
  - Strongly related to other relational data
  - Retrieve only a subset of data
- DAD is used to define the mapping of DTD to relational tables and columns
  - Using RDB\_Node mapping in DAD
    - Need primary key for each table and column types
  - To decompose an incoming XML document, use `dxxShredXML` (uses DAD)
  - To compose a shredded XML, use `dxxGenXML()` as in publishing phase

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## Oracle

- XML SQL Utility (XSU) supports publishing and native storage/retrieval
- Publishing Relational Data
  - The desired hierarchy in XML output can be specified by object views
    - Exploits the object-relational support in Oracle
  - Mapping is *implicit* for the object table/view
    - Result can be in text or a DOM tree
- Native storage of XML
  - System Provided XMLTYPE with supporting methods
  - Shredding by mapping to an object table or view

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## Publishing Relational Data

- Mapping Rules
  - Columns map to top level elements
  - Scalar values map to a elements with text only content
  - Object types are mapped to elements with its attributes appearing as sub-elements. Collections map to lists of elements
  - Object references and referential constraints can be mapped to IDREFs in the XML document
- Steps (From [Bannerjee et al.] )
  - Initialize
    - OracleXMLQuery qry = new OracleXMLQuery(conn, query)
  - Set document and row element names
    - qry.setRowsetTag("str"), qry.setRowTag("str")
  - Get XML
    - qry.getXMLString()

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## Example: Object of Publishing

```
CREATE TYPE EmployeeType AS OBJECT (  
    EMPNO NUMBER,  
    ENAME VARCHAR2(20),  
    SALARY NUMBER );
```

```
CREATE TYPE EmployeeListType AS TABLE OF EmployeeType;
```

```
CREATE TABLE Dept (  
    DEPTNO NUMBER,  
    DEPTNAME VARCHAR2(20),  
    EMPLIST EmployeeListType );
```

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## Example: Corresponding XML

```
<?xml version='1.0'?>
<ROWSET>
  <ROW num="1">
    <DEPTNO>100</DEPTNO>
    <DEPTNAME>Sports</DEPTNAME>
    <EMPLIST>
      <EMPLOYEE_TYPE num="1">
        <EMPNO>7369</EMPNO>
        <ENAME>John</ENAME>
        <SALARY>10000</SALARY>
      </EMPLOYEE_TYPE>
      <!-- additional employee types within the employee list -->
    </EMPLIST>
  </ROW>
</ROWSET>
```

## Native Storage of XML using XMLType

- Oracle9i introduces XMLType as a new server datatype
  - Currently allows only CLOB storage natively
  - Enables Strong Typing and XPATH functionality
  - Unsuitable for piecwise updates
- Create an XMLType instance
  - Sys.XMLType.createXML('xml\_as\_string')
  - Use techniques for XML Publishing from database rows



## Selecting/Extracting XMLType Instance

- Extract()
  - Obtains the node/nodes from the document identified by the XPath (subset of) expression
  - Use getStringVal() or getNumberVal() to get scalar content  
Select p.poDoc.extract('/PO/PONO/text()').getnumberval()  
From po\_xml\_tab p;
- ExistsNode()
  - Checks if the given XPath evaluates in at least a single XML element or text node
  - Useful for filtering as well as for functional indexes  
Select e.poDoc.extract('/PO/PONO/text()').getNumberVal() as pono  
From po\_xml\_tab e  
Where **e.poDoc.existsnode('/Po/PONO') = 1** and poid > 1
- Functions to convert from XMLType to other types

## Indexing XMLType

- Functional Indexes using ExistsNode or Extract
  - Create Index city\_index ON po\_xml\_tab  
(poDoc.extract('/PO/PONO/text()').getNumberVal())
- Text Indexes
  - Supports CONTAINS
  - CONTAINS has been extended using INPATH
    - <text query> INPATH(<path expression>)

## Storage of Native XML in Structured Fashion

- Shredded storage
  - Can be mapped to an object table if "mapping rules" (discussed earlier) are satisfied

```
String xmldoc = ".."
OracleXMLSave sav = new OracleXMLSave(conn, tablename)
Sav.insertXML(xmldoc)
```
  - Decompose using custom XSLT

## Commercial Systems: Other Aspects of XML Support

- Enabling specification for custom publishing
  - XSLT support for rendering
- Updates, Bulkloading
- HTTP Access , Security
- Use of File systems
- ...



## Publication of Relational Data in XML



## Approaches to Publication

- Publishing without full support for views
  - Published XML cannot be composed with XQuery without materialization
    - [Shanmugasundaram et al. VLDB 00]
- Publishing with support for views
  - SilkRoute
    - [Fernandez, Tan, Suci: WWW 00]
    - [Fernandez, Morishima, Suci: SIGMOD 01]
  - XPERANTO
    - [Shanmugasundaram et. al.: VLDB 01]

## Publishing without support for Views

- [Shanmugasundaram et al.: VLDB 00]
  - Explores different execution plans for generating the contents of XML documents
- Conclusion
  - Constructing XML document inside the relational engine best for performance
    - When the result fits in main memory, Unsorted outer union approach
    - Otherwise, Sorted outer union approach
  - Need extensions to SQL

## Example: Desired XML

```
<article id = "a1">
  <title> XML Research Issues</title>
  <authors>
    <author>Tom Hanks</author>
  </authors>
</article>
<article id = "a2">
  <title>Storage and Retrieval of XML Data Using Relational DBMS</title>
  <authors>
    <author>Surajit Chaudhuri</author>
    <author>Kyuseok Shim</author>
  </authors>
</article>
```

## Example: Query Syntax

```
select art.name, ARTICLE(art.id, art.title,  
      (select XMLAGG(AUTH(auth.ID, auth.name))  
      from authors auth  
      where art.ID=auth.IDfrom))  
from articles art
```

- XML element is created by calling ARTICLE() constructor
- XMLAGG() concatenates the XML fragments
- XMLAGG aggregate function needs to work on ordered inputs.

## Example: Defining User Defined Function

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



## Implementation Alternatives

- Early Tagging and Early Structuring
  - Stored Procedure Approach
    - Process queries for each nested structure
    - A fixed join ordering and join technique
  - CLOB Approach
    - Need to support XML constructors and XML aggregation functions
    - Represents the XML fragments generated by constructors as Character Large Objects (CLOBs)
    - Correlated or De-correlated



## Implementation Alternatives

- Late Tagging and Late Structuring
  - Redundant Relation Approach
    - Represents a hierarchical structure as a single table
    - Number of tuples grows as product of relations – inefficient!
  - Unsorted Outer Union Approach
    - Computes each path from root level table to a leaf level table and outer union them
    - A separate tuple describing an ancestor is needed if ancestor has no children
    - NULL is used to fill the columns of other children
  - Hash-based tagging is used



## Implementation Alternatives

- Late Tagging and Early Structuring
  - Sorted Outer Union Approach
    - Sort on its id fields
    - The children of a parent nodes are grouped together after the parent
    - Tuples having NULL values in sort field are placed before tuples having non-NULL values
    - **Scales well for large data sets**
  - Tagging requires only memory to keep the parent ids of the last tuple seen



## Publishing with support for Views

- Provide XML views over relational data
- Allow queries on these views using an XML query language
- Steps
  - **Query composition with view definition**
  - Query optimization
  - Various structuring and tagging techniques
  - Generation of XML



## Query Composition

---

- XML view is not necessarily materialized
  - Materializing the entire XML view incurs unnecessary computations
- Retrieve only the required fragment of relational data
  - Push computation into relational engine as much as possible



## SilkRoute

---

- XML view is defined using a declarative RXL query language
  - Allows complex structure and arbitrary levels of nesting
  - Do not address the ordering issue in XML document
- Accept XML-QL queries over the defined view
- XML-QL queries are composed with the view
  - Generates another RXL query



## XML-QL

- [Deutch, Fernandez, Florescu, Suciu: WWW 99]
- Similar structure to SQL: "WHERE-IN-CONSTRUCT"
  - WHERE – specify XML pattern to search
  - IN – specify data sources to search
  - CONSTRUCT – specify the format of XML result
- Support nested query
- Can express selection, projection, join, grouping
- Can construct deeply nested XML elements

## Example: Sample Relational Schema

Issues(ID, volume, number, articleID)  
Articles(ID, title, initPage, endPage, authorID)  
Authors(ID, name, authorPosition)

## Example: Desired XML Output

```
<articles>
  <article id = "a1">
    <title> XML Research Issues</title>
    <authors>
      <author>Tom Hanks</author>
    </authors>
  </article>
  <article id = "a2">
    <title>Storage and Retrieval of XML Data Using Relational DBMS</title>
    <authors>
      <author>Surajit Chaudhuri</author>
      <author>Kyuseok Shim</author>
    </authors>
  </article>
</articles>
```

## Example: View Definition using RXL

- Allow nested and block structures
- A left-outer join
- Skolem function is used to group elements

```
construct
<articles ID=Articles()>
  from articles $a
  construct
  { <article ID=Article($a.ID)>
    <title>$a.title</title>
    <authors>
      { from authors $b
        where $a.authorID = $b.ID
        construct
        <author>$b.name</author>
      }
    </authors>
  }
</articles>
```

## XML-QL Query on the View

```
construct
  <result> {
    where <articles>
      <article>
        <title> $t </title>
        <authors>
          <author>
            <name $n</name>
          </author>
        </authors>
      </article>
    <articles> in "sigmodRecord.xml",
    $n = "Tom Hanks"
  }
  construct
    <title> $t </title>
  } </result>
```

## Composed RXL query

```
construct
  <result>
  {
    from articles $a, authors $b
    where $a.authorID = $b.ID,
          $b.name ="Tom Hanks"
    construct
      <title> $t </title>
    } </result>
```

## Query Composition

- Construct the view tree consisting of a global template and a set of Datalog rules
  - Obtain the global template by merging templates from all construct clause
  - Two template are merged if and only if they share the same Skolem function
  - Construct one Datalog rule for each Skolem function
  - Datalog rules are non-recursive

## Query Composition

- The composed query is the union of all possible matches
  - Construct one block for each match
  - Perform minimization to eliminate redundancies for each block (could be expensive)



## Query Processing

---

- **Sorted outer-union approach**
  - Construct one large SQL query from XML query and XML view
  - The SQL query consists of several left-outer joins, which are combined in outer unions
- **Fully partitioned strategy**
  - Construct multiple SQL queries without outer joins and unions
  - Each result is sorted to permit merging and tagging



## Query Processing

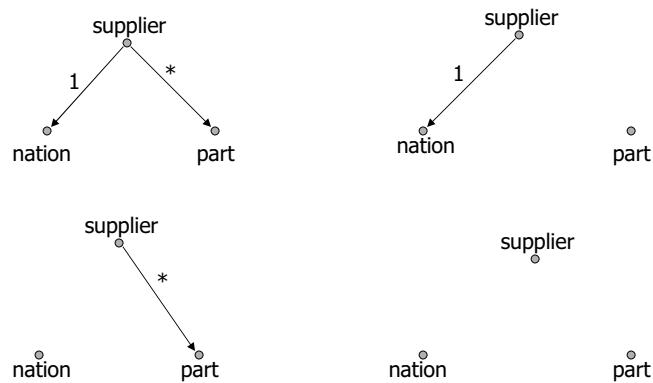
---

- The optimal plan lies between two extreme strategies
  - Need to optimize!
  - The number of possible translations of an RXL query into SQL is  $2^E$  where E is the number of edges in the view tree
  - SilkRoute uses heuristic to choose a good plan

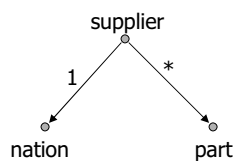
## Example

```
From supplier $s
Construct
<supplier>
  <name>${s.name}</name>
  { from nation $n
    where ${s.nationkey} = $n.nationkey
    construct
      <nation>${n.name}</nation> }
  { from PartSupp $ps, Part $p
    where ${s.supkey} = $ps.supkey,
          $ps.partkey = $p.partkey
    construct
      <part><name>${p.name}</name></part> }
</supplier>
```

## Execution Plans

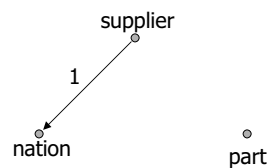


## Transformed SQLs



```

select s.superkey, n.name, Q.partkey, Q.name
from supplier s, nation n
where s.nationkey = n.nationkey
left outer join
  (select ps.supkey as supkey, p.name as pname
   from PartSupp ps, Part p
   where ps.partkey = p.partkey
  ) as Q
on s.supkey = Q.supkey
order by s.supkey
  
```



```

select s.superkey, n.name
from supplier s, nation n
where s.nationkey = n.nationkey
order by s.supkey
  
```

```

select s.supkey, p.name
from supplier s, Part p, PartSupp ps
where s.supkey = ps.supkey and
      ps.partkey = p.partkey
order by s.supkey
  
```

## XPERANTO

- Automatically creates a default XML view
  - Top-level elements correspond to table names
  - Row elements are nested under the table elements
  - Within a row element, column names appear as tags and column values appears as text
- Then, transform the default view into desired XML format
  - XQuery language is used to express the desired XML view

## XPERANTO

- XML Query Graph Model (XQGM) is used as an internal representation
  - XQGM is a generalization of QGM model used for DB2
  - Enables translation of XQuery queries to SQL
  - Exploits XML query algebra
- Removes all XML navigation operators
  - Thus avoids construction of unnecessary intermediate XML fragments
  - Composition rules are used for elimination
- Pushes down join and selections into relational engine
  - Query Decorrelation
  - Tagger Pull-up

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## Example: Desired XML

```
<article id = "a1">
  <title> XML Research Issues</title>
  <authors>
    <author>Tom Hanks</author>
  </authors>
</article>
<article id = "a2">
  <title>Storage and Retrieval of XML Data Using Relational DBMS</title>
  <authors>
    <author>Surajit Chaudhuri</author>
    <author>Kyuseok Shim</author>
  </authors>
</article>
```

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## Example: Default XML View

```
<db>
  <Issues>
    <row>
      <ID>1</ID><volume>1</volume><number>1</number><articleID>a1</articleID>
    </row>
  </Issues>
  <Articles>
    <row>
      <ID>a1</ID><title>XML Research Issues</title>
      <initPage>1</initPage><endPage>5</endPage><authorID>1</authorID>
    </row>
    .....
  </Articles>
  <Authors>
    <row>
      <ID>1</ID><name>Tom Hanks</name><authorPosition>1</authorPosition>
    </row>
    .....
  </Authors>
</db>
```

## Example: XML View Definition and Query

```
Create view articles as (
  for $article in view("default")/Articles/row
  return
    <article id = $article/ID>
      <title>$article/title</title>
      <authors>
        for $auth in view("default")/Authors/row
        where $article/authorID = $auth/ID
        return
          <author>$auth/name</author>
      </authors>
    </article>
```

### Query

```
for $articles in view("articles")
where $articles/article/authors/author/text() = "Tom Hanks"
return $articles/article/title
```



## Storage of Native XML in Relational Databases



## How to store Native XML Data?

- Generic Mapping
  - No user-defined mapping, no DTD, no use of data
- User provides mapping to relational tables (discussed for commercial products)
- Infer mapping from DTD or XML Schema
- Analyze XML data and query workload



## Generic Mapping

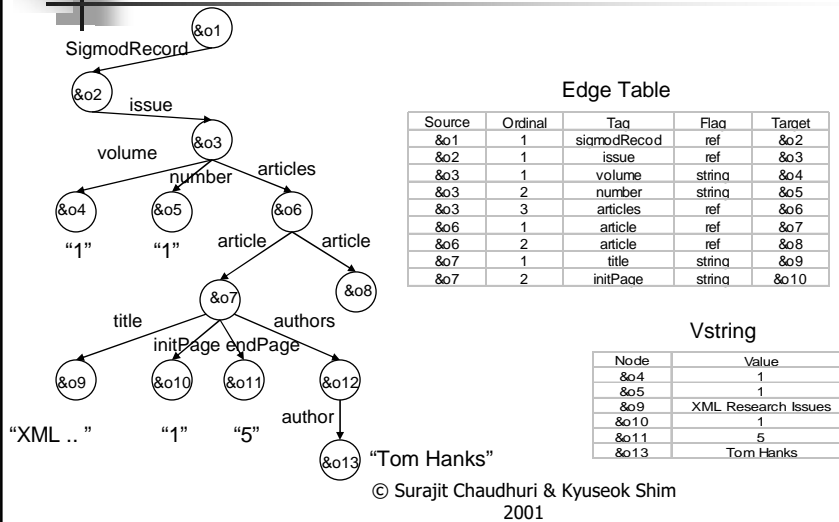
- [Florescu, Kossmann: IEEE Data Eng. Bulletin 99]
- Alternative ways to store edges for graphs
  - Edge Approach
    - Stores all edges in a single table
  - Binary Approach
    - Group all edges with the same label into one table
  - Universal Table
    - Result of a full outer join of all binary tables
    - Many fields with null
    - A lot of redundancy



## Generic Mapping (2)

- Alternative ways to map values
  - Separate Value Table
  - Inlining
    - Keep columns for all types together
    - Thus, there could be many null values
- Binary approach + inlining shows the best overall
  - Most of data in a single edge table is irrelevant for a query
  - Universal table approach performs poorly for query with large results
  - Binary approach processes only relevant data
  - Inlining saves the cost of the joins with the Value tables

# A Edge Table with Separate Value Tables



Edge Table

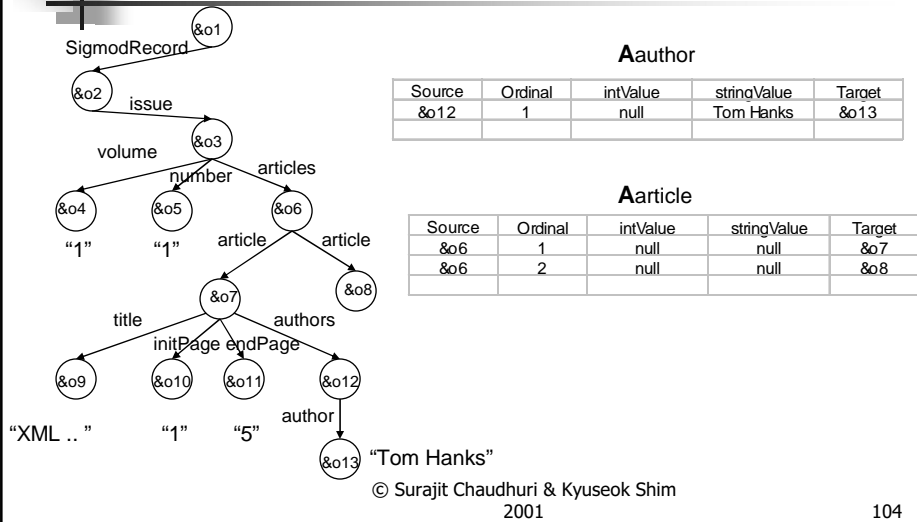
Source	Ordinal	Tag	Flag	Target
&o1	1	sigmodRecord	ref	&o2
&o2	1	issue	ref	&o3
&o3	1	volume	string	&o4
&o3	2	number	string	&o5
&o3	3	articles	ref	&o6
&o6	1	article	ref	&o7
&o6	2	article	ref	&o8
&o7	1	title	string	&o9
&o7	2	initPage	string	&o10

Vstring

Node	Value
&o4	1
&o5	1
&o9	XML Research Issues
&o10	1
&o11	5
&o13	Tom Hanks

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# Binary Approach and Inlining Values



Aauthor

Source	Ordinal	intValue	stringValue	Target
&o12	1	null	Tom Hanks	&o13

Aarticle

Source	Ordinal	intValue	stringValue	Target
&o6	1	null	null	&o7
&o6	2	null	null	&o8

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## XML Query Translation to SQL

- A single edge table
  - For every projection and selection attributes, perform self joins
  - Simple path expressions: self-joins
  - Kleene closures (\*): recursive SQL
- Normalized Tables
  - Use SilkRoute or XPERANTO
  - Limited for certain class of XML queries

## A Single Edge Table

- [Tian, DeWitt, Chen, Zhang: Wisconsin TR 00]

SourceID	Ordinal	Tag	TargetID	Data
1	1	sigmodRecord	2	""
2	1	issue	3	""
3	1	volume	4	"1"
3	2	number	5	"1"
3	3	articles	6	""
6	1	article	7	""
6	2	article	8	""
7	1	title	9	XML Research Issues
7	2	initPage	10	"1"
7	3	endPage	11	"5"
7	4	authors	12	""
12	1	author	13	"Tom Hanks"

## Query Transformation

```
XQuery: for $b IN document("sigmodRecord.xml")/sigmodRecord/issue
       where $b/volume = "1"
       return $b/articles/article/title
```

```
SQL: select t6.value
     from edges t1, edges t2, edges t3, edges t4, edges t5, edges t6
     where t1.TargetID = t2.SourceID and t2.TargetID = t3.sourceID
           and t2.TargetID = t4.sourceID and t4.TargetID = t5.sourceID
           and t5.TargetID = t6.sourceID
           and t1.tag = "sigmodRecord" and t2.tag = "issue"
           and t3.tag = "volume" and t3.value = "1"
           and t4.tag = "articles" and t5.tag = "article" and t6.tag = "title"
```

## Infers Mapping from DTD

- [Shanmugasundaram et al. 99]
- Use DTD to generate a relational schema
  - DTD graph is generated from DTD
  - Element graph is generated by depth first traversal of the DTD graph for each element
- Viable Approaches
  - Shared
  - Hybrid

## Shared and Hybrid Inlining Technique

### ■ Shared Inlining

- An element node is represented in exactly one relation
- Relations are created for all elements having in-degree greater than one in DTD graph
  - Nodes with an in-degree of one are inlined
  - Nodes with an in-degree of zero are made into separate relations
- Nodes below a \* node are made into separate relations
- Of mutually recursive elements all having in-degree one, one of them is made a separate relation

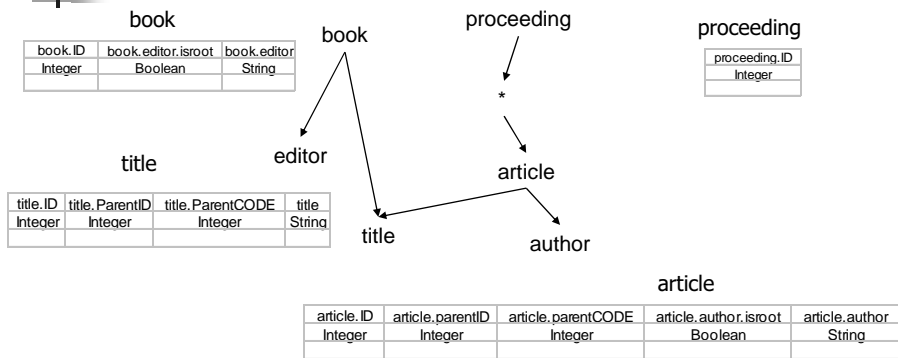
### ■ Hybrid Inlining

- Additionally inlines elements with in-degree greater than one that are not recursive or reached through a "\*" node

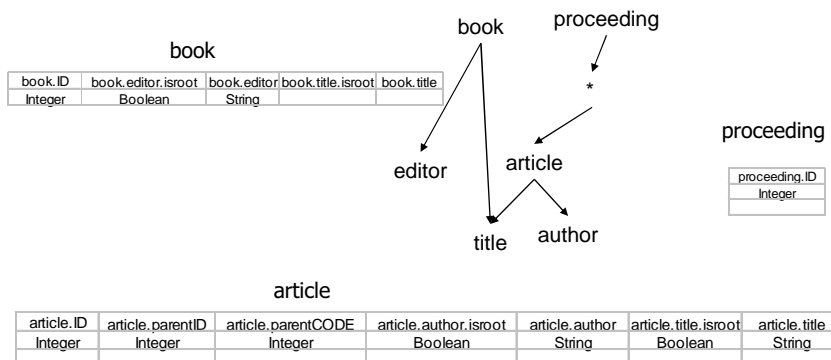
## Example: DTD (SIGMOD Record)

```
<?xml version="1.0"?>
<!-- DTD -->
<!ELEMENT proceeding (article)* >
<!ELEMENT article (title, author) >
<!ELEMENT title (#PCDATA)>
<!ELEMENT author (#PCDATA)>
<!ELEMENT book (editor, title) >
<!ELEMENT editor (#PCDATA)>
```

# Example: Shared Inlining Technique



# Example: Hybrid Inlining Technique







## STORED: Analyze XML Data

- [Deutsch, Fernandez, Suciu: SIGMOD'99]
- Semistructured data into relational data
- Integrate both relational and overflow systems
- Use data mining algorithm to find out frequent subtrees
  - There is no notion of DTD in semistructured data
- Overflow mapping is used to insure no loss of information
  - Overflow objects or object parts are stored in a separate semistructured data object repository



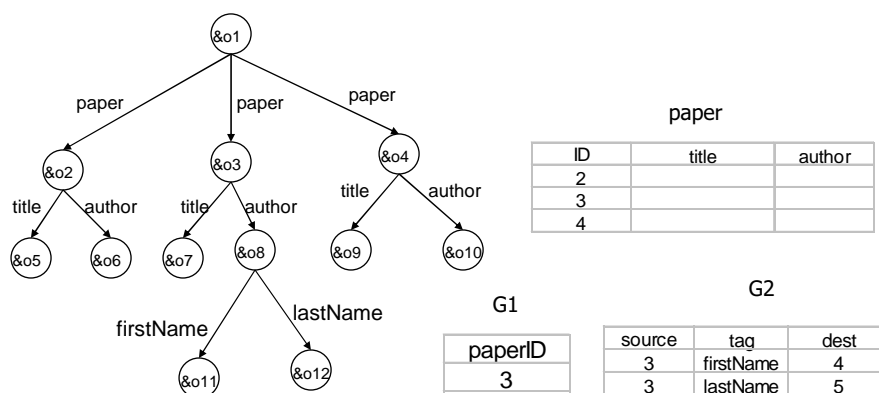
## STORED: Overview of Technique

- Compute minimal path prefixes
  - Generates all prefixes  $l_1 \dots l_k$  with min support
- Discover frequent subtrees (patterns)
  - Use WL's algorithm
- Select  $K_0$  patterns
  - Greedily choose a subset of  $K_0$  patterns
- Select required attributes
- Generate mapping of  $K_0$  patterns using STORED query languages
- Generate overflow mapping

## Example

- Assume
  - The semistructured data has either
    - One author with string type
    - Or author having first name and last name
  - One author type appears frequently
- One relation for frequent structure and overflow relations G1 and G2 are generated

## Example: Relational Schema





# Structural Summary and Indexing for XML



# Structural Summary and Index

- Structural summary only
  - DTD
  - XML Schema
  - Representative Objects
- Structural summary and Index
  - Strong Dataguide
  - T-index: 1-index, 2-index
- Index only
  - Extensions of Inverted index
  - Access Support Relations
  - ToXin
  - Index Fabric



## Why Structural Summary?

- Can help users to formulate meaningful queries
- Allows query processor to restrict the search space to only relevant portions of XML data
- Can be used to design an efficient relational representations for XML data
  - XML document may not always have an accompanying DTD or XML Schema
- Can be stored as a single edge table representation



## Representative Objects

- [Nestorov, Ullman, Wiener, Chawathe: ICDE'97]
- Provides a concise representation of the inherent schema of semistructured data
- Full Representative Objects (FRO)
  - Describe the global structure of the data
  - Similar to Dataguide
- Degree-K Representative Objects
  - Describe the local aspects of the data by considering only paths of length K
  - Take less space than FRO
  - Construction time may be less than that of FRO



## XTRACT

- [Garofalakis, Gionis, Rastogi, Seshadri, Shim: SIGMOD 00]
- Infers concise and semantically meaningful DTDs for XML documents
- Generalization
  - Generate zero or more candidate DTDs by replacing patterns in the data with meta-characters like \*
  - e.g. abab => (ab)\*, bbbe => b\*e
- Factorization
  - Factors common subexpressions from the candidate DTDs
  - e.g. b\*d | b\*e => b\* (d | e)
- Minimum Description Length (MDL) Principle
  - MDL choose the minimum cost candidate DTD



## Strong Dataguide

- [Goldman, Widom: VLDB 97]
- Summary of path structure from the root
  - Concise: describes every label path in the data once
  - Accurate: every label path in the data appears in the data guide
- Representation of the equivalent classes based on a deterministic automata (DFA)

## Strong Dataguide

- All label paths reaching the same node in dataguide belong to the same equivalence class
- Construction is equivalent to the conversion of non-deterministic automata (NFA) into deterministic automata (DFA)
- Linear time for tree structured data
- Exponential time for graph structured data
- The size may be exponential in database size

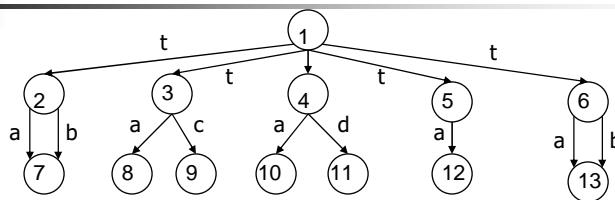
## T-index

- [Milo and Suciu: ICDT 99]
- 1-index
  - To support queries of  $s_0 P v_1$ 
    - $s_0$  : root
    - $P$ : a regular expression
    - E.g.  $s_0//title$
  - Summary of path structure from the root
  - Representation of the equivalent classes based on a non-deterministic automata using bisimulation
  - Extents are disjoint
  - More compact size than dataguides
    - The size is at most linear in database size

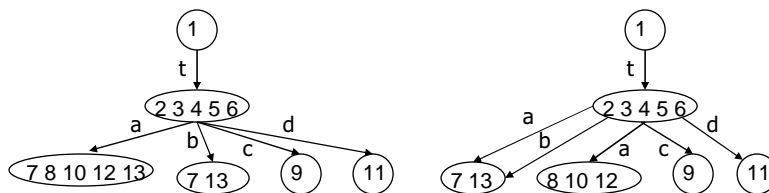
# T-index

- 2-index
  - To support queries of  $s_0 v_1 P v_2$ 
    - E.g.  $s_0//articles//title$
  - Summary of path structure between two arbitrary nodes in database
  - Intended to find pairs of nodes matching some arbitrary path expression
- T-index
  - To support queries of  $s_0 v_1 P_1 v_2 P_2 v_3 P_3 \dots P_n v_n$

# Exmample



A Data Graph



Strong Dataguide

1-index

## Access Support Relations

- [Kemper, Moerkotte: IS 92]
- To support join along arbitrary reference chains between two object instances
- Not straight-forward to use with XML document without schema information
  - They are based on the paths in the schema
- Materialize access paths of arbitrary length

## ToXin

- [Rizzolo: MS Thesis 01]
- Supports navigation of forward and backward traversals
  - Strong dataguide and 1-index support only forward traversal from the root
- Supports not only regular path expressions but also predicates over values
  - Access support relations and T-index store only predefined subsets of paths
- The index size is linear w.r.t. the size of database
  - Strong dataguide has exponential growth



## Extension to Inverted Index

- Can be implemented as an edge table in RDBMS
- Assign a range to each element
- Containment is used to decide ancestor-descendant relationship
- [Chun Zhang et al. :SIGMOD'01]
  - Text words: T-index - (docno, wordno, level)
  - Elements: E-index - (docno, begin:end, level)
- [Quanzhong Li and Bongki Moon: VLDB'01]
  - Each element in XML has a pair of numbers <order, size>
  - If x is a parent of y,
    - $order(x) < order(y)$
    - $order(y) + size(y) \leq order(x) + size(x)$

## Example: T-index and E-index

<pre>&lt;articles&gt; &lt;article&gt;   &lt;title&gt; XML Research   Issues&lt;/title&gt;   &lt;authors&gt;     &lt;author&gt;Tom     Hanks&lt;/author&gt;   &lt;/authors&gt; &lt;/article&gt; &lt;/articles&gt;</pre>	<p><b>E-index</b></p> <pre>&lt;articles&gt; (1, 1:15,0) &lt;article&gt; (1, 2:14, 1) &lt;title&gt; (1, 3:7, 2) &lt;authors&gt; (1, 8: 13, 2) &lt;author&gt; (1, 9:12, 3)</pre> <p><b>T-index</b></p> <pre>XML (1, 4, 3) Research (1, 5, 3) Tom (1, 10, 4) Hanks (1, 11, 4)</pre>
--	--

## Example

- XPath Expression: `articles//author`
  - The inverted list of articles and author are retrieved
  - The containment is checked for both lists

```
select *
from ELEMENTS e1, ELEMENTS e2
where e1.term = 'articles' and e2.term = 'author' and
      e1.docno = e2.docno and
      e1.begin < 2.begin and e2.end < e1.end
```

## Index Fabric

- [Cooper et al.: VLDB'01]
- Encodes paths in XML data as strings
- Insert these strings into an efficient index for strings
- The index block and XML data are both stored in relational database system
- Evaluation of queries encode the desired path traversal as a search key string and perform a lookup
- Use Patricia trie to index a large number of strings



## Final Thoughts

- XML enables data exchange and interoperability
- Efficient and flexible publishing of relational information will continue to be important
  - More work on query processing infrastructure as application needs evolve
  - Middleware v.s. server
- Native XML storage in the crossroads
  - Document Storage, LOB and structured search all play roles
  - Current support in RDBMS not yet sophisticated
  - Applications need to frame performance criteria
- Eventually performance yardsticks and benchmarks will be necessary



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