# XML
# (Extensible Markup Language)
# 扩展标记语言

# XML

- Structure of XML Data
- XML Document Schema
- Querying and Transformation
- Application Program Interfaces to XML
- Storage of XML Data
- XML Applications

# Introduction

- XML:  Extensible Markup Language
- Defined by the WWW Consortium (W3C)
- Derived from SGML (Standard Generalized Markup Language), but simpler to use than SGML
- Documents have tags giving extra information about sections of the document
  - E.g.  <title> XML </title>  <slide> Introduction …</slide>
- **Extensible**, unlike HTML
  - Users can add new tags, and *separately* specify how the tag should be handled for display

# XML Introduction (Cont.)

- The ability to specify new tags, and to create nested tag structures make XML a great way to exchange **data**, not just documents.
  - Much of the use of XML has been in data exchange applications, not as a replacement for HTML
- Tags make data (relatively) self-documenting （自描述）
  - E.g.

```
<bank>
    <account>
        <account_number> A-101     </account_number>
        <branch_name>     Downtown </branch_name>
        <balance>             500        </balance>
    </account>
    <depositor>
        <account_number> A-101    </account_number>
        <customer_name> Johnson </customer_name>
    </depositor>
</bank>
```

# XML: Motivation

- Data interchange is critical in today’s networked world
  - Examples:
    - Banking:  funds transfer
    - Order processing (especially inter-company orders)
    - Scientific data
      - Chemistry:  ChemML, …
      - Genetics:   BSML (Bio-Sequence Markup Language), …
  - Paper flow of information between organizations is being replaced by electronic flow of information
- Each application area has its own set of standards for representing information
- XML has become the basis for all new generation data interchange formats

# XML Motivation (Cont.)

- Earlier generation formats were based on plain text with line headers indicating the meaning of fields
  - Similar in concept to email headers
  - Does not allow for nested structures, no standard “type” language
  - Tied too closely to low level document structure (lines, spaces, etc)
- Each XML based standard defines what are valid elements, using
  - XML type specification languages to specify the syntax
    - DTD (Document Type Descriptors)
    - XML Schema
  - Plus textual descriptions of the semantics
- XML allows new tags to be defined as required
  - However, this may be constrained by DTDs
- A wide variety of tools is available for parsing, browsing and querying XML documents/data

# Comparison with Relational Data

- Inefficient: tags, which in effect represent schema information, are repeated
- Better than relational tuples as a data-exchange format
  - Unlike relational tuples, XML data is self-documenting due to presence of tags
  - Non-rigid format: tags can be added
  - Allows nested structures
  - Wide acceptance, not only in database systems, but also in browsers, tools, and applications

# Structure of XML Data

- **Tag**（标签） label for a section of data
- **Element**（元素） section of data beginning with <*tagname*> and ending with matching </*tagname*>
- Elements must be properly nested
  - Proper nesting
    - <account> … <balance> …. </balance> </account>
  - Improper nesting
    - <account> … <balance> …. </account> </balance>
  - Formally: every start tag must have a unique matching end tag, that is in the context of the same parent element.
- Every document must have a single top-level element

# Example of Nested Elements

```
<bank-1>
    <customer>
       <customer_name> Hayes </customer_name>
      <customer_street> Main </customer_street>
      <customer_city>     Harrison </customer_city>
      <account>
        <account_number> A-102 </account_number>
        <branch_name>      Perryridge </branch_name>
        <balance>              400 </balance>
      </account>
      <account>
         …
      </account>
     </customer>
       .
       .
  </bank-1>
```

# Motivation for Nesting

- Nesting of data is useful in data transfer
    - Example:  elements representing *customer_id*, *customer_name*, and address nested within an *order* element
- Nesting is not supported, or discouraged, in relational databases
    - With multiple orders, customer name and address are stored redundantly
    - normalization replaces nested structures in each order by foreign key into table storing customer name and address information
    - Nesting is supported in object-relational databases
- But nesting is appropriate when transferring data
    - External application does not have direct access to data referenced by a foreign key

# Structure of XML Data (Cont.)

- Mixture of text with sub-elements is legal in XML.
  - Example:

```
  <account>
      This account is seldom used any more.
       <account_number> A-102</account_number>
       <branch_name> Perryridge</branch_name>
       <balance>400 </balance>
</account>
```

  - Useful for document markup, but discouraged for data representation

# Attributes（属性）

- Elements can have **attributes**

```
<account acct-type = “checking” >
    <account_number> A-102 </account_number>
    <branch_name> Perryridge </branch_name>
    <balance> 400 </balance>
  </account>
```

- Attributes are specified by *name=value* pairs inside the starting tag of an element
- An element may have several attributes, but each attribute name can only occur once

```
<account  acct-type = “checking”  monthly-fee=“5”>
```

# Attributes vs. Subelements

- Distinction between subelement and attribute
  - In the context of documents, attributes are part of markup, while subelement contents are part of the basic document contents
  - In the context of data representation, the difference is unclear and may be confusing
    - Same information can be represented in two ways
      - <account  account_number = "A-101">  …. </account>
      - <account>
          <account_number>A-101</account_number> …
        </account>
  - Suggestion: use attributes for identifiers of elements, and use subelements for contents

# Namespaces（名字空间）

- XML data has to be exchanged between organizations
- Same tag name may have different meaning in different organizations, causing confusion on exchanged documents
- Specifying a unique string as an element name avoids confusion
- Better solution: use unique-name:element-name
- Avoid using long unique names all over document by using XML Namespaces

```
<bank xmlns:FB=‘http://www.FirstBank.com’>
      …
     <FB:branch>
             <FB:branchname>Downtown</FB:branchname>
         <FB:branchcity>   Brooklyn   </FB:branchcity>
     </FB:branch>
    …
</bank>
```

# More on XML Syntax

- Elements without subelements or text content can be abbreviated by ending the start tag with a /> and deleting the end tag
  - <account number=“A-101” branch=“Perryridge” balance=“200”/>
- To store string data that may contain tags, without the tags being interpreted as subelements, use CDATA as below
  - <![CDATA[<account> … </account>]]>

  Here, <account> and </account> are treated as just strings

  CDATA stands for “character data”

# XML Document Schema

- Database schemas constrain what information can be stored, and the data types of stored values
- XML documents are not required to have an associated schema
- However, schemas are very important for XML data exchange
  - Otherwise, a site cannot automatically interpret data received from another site
- Two mechanisms for specifying XML schema
  - **Document Type Definition (DTD)**
    - Widely used
  - **XML Schema**
    - Newer, increasing use

# Document Type Definition (DTD)

- The type of an XML document can be specified using a DTD
- DTD constraints structure of XML data
  - What elements can occur
  - What attributes can/must an element have
  - What subelements can/must occur inside each element, and how many times.
- DTD does not constrain data types
  - All values represented as strings in XML
- DTD syntax
  - <!DOCTYPE document […]>
  - <!ELEMENT element (subelements-specification) >
  - <!ATTLIST   element (attributes)  >

# Element Specification in DTD

- Subelements can be specified as
  - names of elements, or
  - #PCDATA (parsed character data), i.e., character strings
  - EMPTY (no subelements) or ANY (anything can be a subelement)
- Example

  <! ELEMENT depositor (customer_name  account_number)>
  <! ELEMENT customer_name (#PCDATA)>
  <! ELEMENT account_number (#PCDATA)>
- Subelement specification may have regular expressions

  <!ELEMENT bank ( ( account | customer | depositor)+)>
  - Notation:
    - "|"  -  alternatives
    - "+"  -  1 or more occurrences
    - "*"  -  0 or more occurrences
    - "?" – 0 or 1

# Bank DTD

```
<!DOCTYPE bank [
   <!ELEMENT bank ( ( account | customer | depositor)+)>
   <!ELEMENT account (account_number branch_name
   balance)>
   <! ELEMENT customer(customer_name customer_street

   customer_city)>
   <! ELEMENT depositor (customer_name
   account_number)>
   <! ELEMENT account_number (#PCDATA)>
   <! ELEMENT branch_name (#PCDATA)>
   <! ELEMENT balance(#PCDATA)>
   <! ELEMENT customer_name(#PCDATA)>
   <! ELEMENT customer_street(#PCDATA)>
   <! ELEMENT customer_city(#PCDATA)>
]>
```

# Attribute Specification in DTD

- Attribute specification : for each attribute
  - Name
  - Type of attribute
    - CDATA
    - ID (identifier) or IDREF (ID reference) or IDREFS (multiple IDREFs)
      - more on this later
  - Whether
    - mandatory (#REQUIRED)
    - has a default value (value),
    - or neither (#IMPLIED)
- Examples
  - <!ATTLIST account  acct-type CDATA “checking”>
  - <!ATTLIST customer

    ```
    customer_id   ID          # REQUIRED
    accounts      IDREFS # REQUIRED   >
    ```

# IDs and IDREFs

- An element can have at most one attribute of type ID
- The ID attribute value of each element in an XML document must be distinct
  - Thus the ID attribute value is an object identifier
- An attribute of type IDREF must contain the ID value of an element in the same document
- An attribute of type IDREFS contains a set of (0 or more) ID values.  Each ID value must contain the ID value of an element in the same document

# Bank DTD with Attributes

- Bank DTD with ID and IDREF attribute types.

```
      <!DOCTYPE bank-2[
        <!ELEMENT account (branch, balance)>
        <!ATTLIST account
                account_number ID         # REQUIRED
                owners                IDREFS # REQUIRED>
         <!ELEMENT customer(customer_name,
  customer_street, customer_city)>
         <!ATTLIST customer
                customer_id       ID          # REQUIRED
                accounts             IDREFS # REQUIRED>
          … declarations for branch, balance, customer_name,
                                     customer_street and customer_city
  ]>
```

# XML data with ID and IDREF attributes

```
<bank-2>
        <account account_number=“A-401” owners=“C100 C102”>
                <branch_name> Downtown </branch_name>
               <balance>         500 </balance>
        </account>
        <customer customer_id=“C100” accounts=“A-401”>
                <customer_name>Joe         </customer_name>
               <customer_street> Monroe  </customer_street>
               <customer_city>     Madison</customer_city>
        </customer>
        <customer customer_id=“C102” accounts=“A-401 A-402”>
                <customer_name> Mary     </customer_name>
               <customer_street> Erin       </customer_street>
               <customer_city>     Newark </customer_city>
        </customer>
</bank-2>
```

# Limitations of DTDs

- No typing of text elements and attributes
  - All values are strings, no integers, reals, etc.
- Difficult to specify unordered sets of subelements
  - Order is usually irrelevant in databases (unlike in the document-layout environment from which XML evolved)
  - (A | B)* allows specification of an unordered set, but
    - Cannot ensure that each of A and B occurs only once
- IDs and IDREFs are untyped
  - The *owners* attribute of an account may contain a reference to another account, which is meaningless
    - *owners* attribute should ideally be constrained to refer to customer elements

# XML Schema

- XML Schema is a more sophisticated schema language which addresses the drawbacks of DTDs.  Supports
  - Typing of values
    - E.g. integer, string, decimal, boolean, date, etc
    - Also, constraints on min/max values
  - User-defined, complex types
  - Many more features, including
    - uniqueness and foreign key constraints, inheritance
- XML Schema is itself specified in XML syntax, unlike DTDs
  - More-standard representation, but verbose
- XML Scheme is integrated with namespaces
- BUT:  XML Schema is significantly more complicated than DTDs.

# XML Schema Version of Bank DTD

```
<xs:schema xmlns:xs=http://www.w3.org/2001/XMLSchema>
<xs:element name=“bank” type=“BankType”/>
<xs:element name=“account”>
    <xs:complexType>
        <xs:sequence>
            <xs:element name=“account_number” type=“xs:string”/>
            <xs:element name=“branch_name”     type=“xs:string”/>
            <xs:element name=“balance”            type=“xs:decimal”/>
        </xs:squence>
    </xs:complexType>
</xs:element>
….. definitions of customer and depositor ….
<xs:complexType name=“BankType”>
    <xs:squence>
        <xs:element ref=“account”   minOccurs=“0” maxOccurs=“unbounded”/>
        <xs:element ref=“customer” minOccurs=“0” maxOccurs=“unbounded”/>
        <xs:element ref=“depositor” minOccurs=“0” maxOccurs=“unbounded”/>
    </xs:sequence>
</xs:complexType>
</xs:schema>
```

# XML Schema Version of Bank DTD

- Choice of “xs:” was ours -- any other namespace prefix could be chosen
- Element “bank” has type “BankType”, which is defined separately
  - xs:complexType is used later to create the named complex type “BankType”
- Element “account” has its type defined in-line

# More features of XML Schema

- Attributes specified by xs:attribute tag:
  - <xs:attribute name = “account_number”/>
  - adding the attribute use = “required” means value must be specified
- Key constraint: “account numbers form a key for account elements under the root bank element:

```
        <xs:key name = “accountKey”>
                <xs:selector xpath = “]bank/account”/>
                <xs:field xpath = “account_number”/>
        <\xs:key>
```

- Foreign key constraint from depositor to account:

```
        <xs:keyref name = “depositorAccountKey” refer=“accountKey”>
                <xs:selector xpath = “]bank/account”/>
                <xs:field xpath = “account_number”/>
        <\xs:keyref>
```

# Querying and Transforming XML Data

- Translation of information from one XML schema to another
- Querying on XML data
- Above two are closely related, and handled by the same tools
- Standard XML querying/translation languages
  - XPath
    - Simple language consisting of path expressions
  - XSLT
    - Simple language designed for translation from XML to XML and XML to HTML
  - XQuery
    - An XML query language with a rich set of features

# Tree Model of XML Data

- Query and transformation languages are based on a **tree model** of XML data
- An XML document is modeled as a tree, with **nodes** corresponding to elements and attributes
  - Element nodes have child nodes, which can be attributes or subelements
  - Text in an element is modeled as a text node child of the element
  - Children of a node are ordered according to their order in the XML document
  - Element and attribute nodes (except for the root node) have a single parent, which is an element node
  - The root node has a single child, which is the root element of the document

# XPath

- XPath is used to address (select) parts of documents using **path expressions**
- A path expression is a sequence of steps separated by “/”
  - Think of file names in a directory hierarchy
- Result of path expression: set of values that along with their containing elements/attributes match the specified path
- E.g. /bank-2/customer/customer_name evaluated on the bank-2 data we saw earlier returns

  <customer_name>Joe</customer_name>
  <customer_name>Mary</customer_name>
- E.g. /bank-2/customer/customer_name/text( )

  returns the same names, but without the enclosing tags

# XPath (Cont.)

- The initial "/" denotes root of the document (above the top-level tag)
- Path expressions are evaluated left to right
  - Each step operates on the set of instances produced by the previous step
- Selection predicates may follow any step in a path, in [ ]
  - E.g. /bank-2/account[balance > 400]
    - returns account elements with a balance value greater than 400
    - /bank-2/account[balance] returns account elements containing a balance subelement
- Attributes are accessed using "@"
  - E.g. /bank-2/account[balance > 400]/@account_number
    - returns the account numbers of accounts with balance > 400
  - IDREF attributes are not dereferenced automatically (more on this later)

# Functions in XPath

- XPath provides several functions
  - The function count() at the end of a path counts the number of elements in the set generated by the path
    - E.g. /bank-2/account[count(./customer) > 2]
      - Returns accounts with > 2 customers
  - Also function for testing position (1, 2, ..) of node w.r.t. siblings
- Boolean connectives and and or and function not() can be used in predicates
- IDREFs can be referenced using function id()
  - id() can also be applied to sets of references such as IDREFS and even to strings containing multiple references separated by blanks
  - E.g. /bank-2/account/id(@owner)
    - returns all id numbers of customers referred to from the owners attribute of account elements.

# More XPath Features

- Operator “|” used to implement union
  - E.g. /bank-2/account/id(@owner) | /bank-2/loan/id(@borrower)
    - Gives customers with either accounts or loans
    - However, “|” cannot be nested inside other operators.
- “//” can be used to skip multiple levels of nodes
  - E.g. /bank-2//customer_name
    - finds any customer_name element *anywhere* under the /bank-2 element, regardless of the element in which it is contained.
- A step in the path can go to parents, siblings, ancestors and descendants of the nodes generated by the previous step, not just to the children
  - “//”, described above, is a short from for specifying “all descendants”
  - “..” specifies the parent.
- doc(name) returns the root of a named document

# XQuery

- XQuery is a general purpose query language for XML data
- Currently being standardized by the World Wide Web Consortium (W3C)
  - The textbook description is based on a January 2005 draft of the standard. The final version may differ, but major features likely to stay unchanged.
- XQuery is derived from the Quilt query language, which itself borrows from SQL, XQL and XML-QL
- XQuery uses a
  **for … let … where … order by …result …**
  (FLWOR) syntax
  **for** ⇔ SQL **from**
  **where** ⇔ SQL **where**
  **order by** ⇔ SQL **order by**

  **result** ⇔ SQL **select**
  **let** allows temporary variables, and has no equivalent in SQL

# FLWOR Syntax in XQuery

- For clause uses XPath expressions, and variable in for clause ranges over values in the set returned by XPath
- Simple FLWOR expression in XQuery
  - find all accounts with balance > 400, with each result enclosed in an <account_number> .. </account_number> tag

```
for     $x in /bank-2/account
let     $acctno := $x/@account_number
where $x/balance > 400
return <account_number> { $acctno } </account_number>
```

  - Items in the **return** clause are XML text unless enclosed in {}, in which case they are evaluated
- Let clause not really needed in this query, and selection can be done In XPath.  Query can be written as:

```
for $x in /bank-2/account[balance>400]
return <account_number> { $x/@account_number }
          </account_number>
```

# Joins（连接）

- Joins are specified in a manner very similar to SQL

```
for $a  in  /bank/account,
     $c  in /bank/customer,
     $d  in  /bank/depositor
 where   $a/account_number = $d/account_number
     and $c/customer_name = $d/customer_name
 return <cust_acct> { $c $a } </cust_acct>
```

- The same query can be expressed with the selections specified as XPath selections:

```
for $a in /bank/account
     $c in /bank/customer
     $d in /bank/depositor[
                account_number = $a/account_number and
                customer_name  = $c/customer_name]
return <cust_acct> { $c $a } </cust_acct>
```

# Nested Queries（嵌套查询）

- The following query converts data from the flat structure for bank information into the nested structure used in bank-1

```
  <bank-1> {
    for $c in /bank/customer
    return
      <customer>
         { $c/* }
         { for $d in /bank/depositor[customer_name = $c/customer_name],
               $a in /bank/account[account_number=$d/account_number]
         return $a }
        </customer>
 } </bank-1>
```

- $c/* denotes all the children of the node to which $c is bound, without the enclosing top-level tag
- $c/text() gives text content of an element without any subelements / tags

# Sorting（排序） in XQuery

- The **order by** clause can be used at the end of any expression. E.g. to return customers sorted by name

```
          for $c in /bank/customer
          order by $c/customer_name
          return <customer> { $c/* } </customer>
```

- Use **order by** $c/customer_name to sort in descending order
- Can sort at multiple levels of nesting (sort by customer_name, and by account_number within each customer)

```
  <bank-1> {
          for $c in /bank/customer
          order by $c/customer_name
          return
                <customer>
                         { $c/* }
                        { for $d in /bank/depositor[customer_name=$c/customer_name],
                                     $a in /bank/account[account_number=$d/account_number] }
                        order by $a/account_number
                        return <account> $a/* </account>
                </customer>
 } </bank-1>
```

# Functions, Types and Other XQuery Features

- User defined functions with the type system of XMLSchema

```
function balances(xs:string $c) returns list(xs:decimal*) {
    for $d in /bank/depositor[customer_name = $c],
          $a in /bank/account[account_number = $d/account_number]
    return $a/balance
  }
```

- Types are optional for function parameters and return values
- The * (as in decimal*) indicates a sequence of values of that type
- Universal and existential quantification in where clause predicates
  - **some** $e **in** *path* **satisfies** *P*
  - **every** $e **in** *path* **satisfies** *P*
- XQuery also supports If-then-else clauses

# XSLT

- A **stylesheet** stores formatting options for a document, usually separately from document
  - E.g. an HTML style sheet may specify font colors and sizes for headings, etc.
- The **XML Stylesheet Language (XSL)** was originally designed for generating HTML from XML
- XSLT is a general-purpose transformation language
  - Can translate XML to XML, and XML to HTML
- XSLT transformations are expressed using rules called **templates(模板）**
  - Templates combine selection using XPath with construction of results

# XSLT Templates

- Example of XSLT template with **match** and **select** part

```
<xsl:template match=“/bank-2/customer”>
  <xsl:value-of select=“customer_name”/>
</xsl:template>
<xsl:template match=“*”/>
```

- The match attribute of xsl:template specifies a pattern in XPath
- Elements in the XML document matching the pattern are processed by the actions within the xsl:template element
  - xsl:value-of selects (outputs) specified values (here, customer_name)
- For elements that do not match any template
  - Attributes and text contents are output as is
  - Templates are recursively applied on subelements
- The <xsl:template match=“*”/> template matches all elements that do not match any other template
  - Used to ensure that their contents do not get output.
- If an element matches several templates, only one is used based on a complex priority scheme/user-defined priorities

# Creating XML Output

- Any text or tag in the XSL stylesheet that is not in the xsl namespace is output as is
- E.g. to wrap results in new XML elements.

```
<xsl:template match=“/bank-2/customer”>
   <customer>
  <xsl:value-of select=“customer_name”/>
  </customer>
</xsl;template>
<xsl:template match=“*”/>
```

- Example output:

```
<customer> Joe   </customer>
<customer> Mary </customer>
```

# Creating XML Output (Cont.)

- Note: Cannot directly insert a xsl:value-of tag inside another tag
  - E.g. cannot create an attribute for <customer> in the previous example by directly using xsl:value-of
  - XSLT provides a construct  xsl:attribute to handle this situation
    - xsl:attribute adds attribute to the preceding element
    - E.g.  <customer>

```
        <xsl:attribute name="customer_id">
            <xsl:value-of select = "customer_id"/>
        </xsl:attribute>
            </customer>
```

results in output of the form

```
        <customer  customer_id="….”> ….
```

- xsl:element is used to create output elements with computed names

# Structural Recursion（结构递归）

- Template action can apply templates recursively to the contents of a matched element

```
<xsl:template match=“/bank”>
      <customers>
      <xsl:template apply-templates/>
      </customers >
 </xsl:template>
 <xsl:template match=“/customer”>
     <customer>
    <xsl:value-of select=“customer_name”/>
     </customer>
</xsl:template>
<xsl:template match=“*”/>
```

- Example output:

```
<customers>
   <customer> John </customer>
   <customer> Mary </customer>
</customers>
```

# Joins in XSLT

- XSLT keys allow elements to be looked up (indexed) by values of subelements or attributes
  - Keys must be declared (with a name) and, the key() function can then be used for lookup. E.g.

```
<xsl:key name=“acctno” match=“account”
                                                  use=“account_number”/>
<xsl:value-of select=key(“acctno”, “A-101”)
```

- Keys permit (some) joins to be expressed in XSLT

```
        <xsl:key name=“acctno” match=“account” use=“account_number”/>
        <xsl:key name=“custno” match=“customer” use=“customer_name”/>
        <xsl:template match=“depositor”>
                    <cust_acct>
                    <xsl:value-of select=key(“custno”, “customer_name”)/>
                    <xsl:value-of select=key(“acctno”, “account_number”)/>
                    </cust_acct>
</xsl:template>
<xsl:template match=“*”/>
```

# Sorting in XSLT

- Using an xsl:sort directive inside a template causes all elements matching the template to be sorted
  - Sorting is done before applying other templates

```
<xsl:template match=“/bank”>
        <xsl:apply-templates select=“customer”>
        <xsl:sort select=“customer_name”/>
        </xsl:apply-templates>
</xsl:template>
<xsl:template match=“customer”>
        <customer>
                <xsl:value-of select=“customer_name”/>
                <xsl:value-of select=“customer_street”/>
                <xsl:value-of select=“customer_city”/>
        </customer>
<xsl:template>
<xsl:template match=“*”/>
```

# Application Program Interface

- There are two standard application program interfaces to XML data:
  - **SAX** (Simple API for XML)
    - Based on parser model, user provides event handlers for parsing events
      - E.g. start of element, end of element
      - Not suitable for database applications
  - **DOM** (Document Object Model)
    - **XML** data is parsed into a tree representation
    - Variety of functions provided for traversing the DOM tree
    - E.g.: Java DOM API provides Node class with methods
      getParentNode( ), getFirstChild( ), getNextSibling( )
      getAttribute( ), getData( ) (for text node)
      getElementsByTagName( ), …
    - Also provides functions for updating DOM tree

# Storage of XML Data

- XML data can be stored in
  - Non-relational data stores
    - Flat files
      - Natural for storing XML
      - But has all problems discussed in Chapter 1 (no concurrency, no recovery, …)
    - XML database
      - Database built specifically for storing XML data, supporting DOM model and declarative querying
      - Currently no commercial-grade systems
  - Relational databases
    - Data must be translated into relational form
    - Advantage:  mature database systems
    - Disadvantages: overhead of translating data and queries

# Storage of XML in Relational Databases

- Alternatives:
  - String Representation
  - Tree Representation
  - Map to relations

# String Representation（字符表示法）

- Store each top level element as a string field of a tuple in a relational database
  - Use a single relation to store all elements, or
  - Use a separate relation for each top-level element type
    - E.g.  account, customer, depositor relations
      - Each with a string-valued attribute to store the element
- Indexing:
  - Store values of subelements/attributes to be indexed as extra fields of the relation, and build indices on these fields
    - E.g. customer_name or account_number
  - Some database systems support **function indices,** which use the result of a function as the key value.
    - The function should return the value of the required subelement/attribute

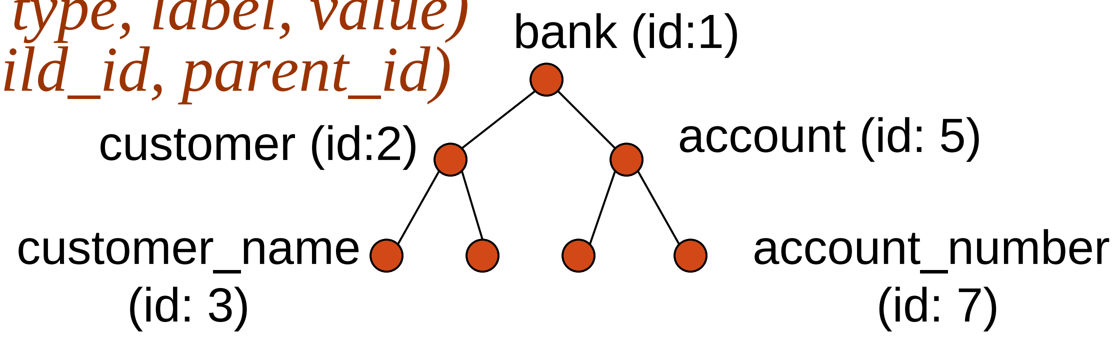
# String Representation (Cont.)

- Benefits:
  - Can store any XML data even without DTD
  - As long as there are many top-level elements in a document, strings are small compared to full document
    - Allows fast access to individual elements.
- Drawback: Need to parse strings to access values inside the elements
  - Parsing is slow.

# Tree Representation（树表示法）

- **Tree representation:** model XML data as tree and store using relations

  *nodes(id, type, label, value)*
  *child (child_id, parent_id)*



- Each element/attribute is given a unique identifier
- Type indicates element/attribute
- Label specifies the tag name of the element/name of attribute
- Value is the text value of the element/attribute
- The relation *child* notes the parent-child relationships in the tree
  - Can add an extra attribute to *child* to record ordering of children

# Tree Representation (Cont.)

- Benefit: Can store any XML data, even without DTD
- Drawbacks:
  - Data is broken up into too many pieces, increasing space overheads
  - Even simple queries require a large number of joins, which can be slow

# Mapping XML Data to Relations（映射到关系）

- Relation created for each element type whose schema is known:
  - An id attribute to store a unique id for each element
  - A relation attribute corresponding to each element attribute
  - A parent_id attribute to keep track of parent element
    - As in the tree representation
    - Position information ($i^{th}$ child) can be store too
- All subelements that occur only once can become relation attributes
  - For text-valued subelements, store the text as attribute value
  - For complex subelements, can store the id of the subelement
- Subelements that can occur multiple times represented in a separate table
  - Similar to handling of multivalued attributes when converting ER diagrams to tables

# Storing XML Data in Relational Systems

- *Publishing* （发布） : process of converting relational data to an XML format
- *Shredding* （分解） : process of converting an XML document into a set of tuples to be inserted into one or more relations
- XML-enabled database systems support automated publishing and shredding
- Some systems offer *native storage* of XML data using the **xml** data type. Special internal data structures and indices are used for efficiency

# SQL/XML

- New standard SQL extension that allows creation of nested XML output
  - Each output tuple is mapped to an XML element *row*

```
<bank>
   <account>
       <row>
                <account_number> A-101 </account_number>
                <branch_name> Downtown </branch_name>
                <balance> 500 </balance>
       </row>
   …. more rows if there are more output tuples …
   </account>
</bank>
```

# SQL Extensions

- **xmlelement** creates XML elements
- **xmlattributes** creates attributes

```
select xmlelement (name “account,
        xmlattributes (account_number as
account_number),
        xmlelement (name “branch_name”,
branch_name),
        xmlelement (name “balance”, balance))
from account
```

# Web Services

- The Simple Object Access Protocol (SOAP) standard （简单对象访问协议）
  - Invocation of procedures across applications with distinct databases
  - XML used to represent procedure input and output
- A *Web service* is a site providing a collection of SOAP procedures
  - Described using the Web Services Description Language (WSDL)
  - Directories of Web services are described using the Universal Description, Discovery, and Integration (UDDI) standard（通用描述、发现和集成标准）