Chapter 10: XML

Introduction

- XML: Extensible Markup Language
- Defined by the WWW Consortium (W3C)
- Originally intended as a document markup language not a database language
  - Documents have tags giving extra information about sections of the document
    - E.g. <title> XML </title> <slide> Introduction …</slide>
  - Derived from SGML (Standard Generalized Markup Language), but simpler to use than SGML
  - **Extensible**, unlike HTML
    - Users can add new tags, and *separately* specify how the tag should be handled for display
  - Goal was (is?) to replace HTML as the language for publishing documents on the Web

XML Introduction (Cont.)

- The ability to specify new tags, and to create nested tag structures made 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
  - 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

Structure of XML Data

- **Tag**: label for a section of data
- **Element**: 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

- 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

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

Namespaces

- 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>
```

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
  - <!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

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
  - (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, etc
    - Also, constraints on min/max values
  - User defined types
  - Is itself specified in XML syntax, unlike DTDs
    - More standard representation, but verbose
  - Is integrated with namespaces
  - Many more features
    - List types, uniqueness and foreign key constraints, inheritance ..
- BUT: significantly more complicated than DTDs, not yet widely used.

XML Schema Version of Bank DTD

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

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
- Wide variety of other languages have been proposed, and some served as basis for the Xquery standard
  - XML-QL, Quilt, XQL, …

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 children 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
- We use the terminology of nodes, children, parent, siblings, ancestor, descendant, etc., which should be interpreted in the above tree model of XML data.

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 those 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[customer/count() > 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 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.
  - We omit further details,

XSLT

- A **stylesheet** stores formatting options for a document, usually separately from document
  - E.g. 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**
  - 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.

XSLT Templates (Cont.)

- If an element matches several templates, only one is used
  - Which one depends on a complex priority scheme/user-defined priorities
  - We assume only one template matches any element

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

- Action of a template can be to recursively apply templates to the contents of a matched element
- E.g.

```
<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
- E.g.

```
<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="*"/>
```

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 March 2001 draft of the standard. The final version may differ, but major features likely to stay unchanged.
- Alpha version of XQuery engine available free from Microsoft
- XQuery is derived from the Quilt query language, which itself borrows from SQL, XQL and XML-QL
- XQuery uses a

  for … let … where .. result …

  syntax

  for ⇔ SQL from

  where ⇔ SQL where

  result ⇔ SQL select

  let allows temporary variables, and has no equivalent in SQL

FLWR Syntax in XQuery

- For clause uses XPath expressions, and variable in for clause ranges over values in the set returned by XPath
- Simple FLWR 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>
```

- 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>
```

Path Expressions and Functions

- Path expressions are used to bind variables in the for clause, but can also be used in other places
  - E.g. path expressions can be used in **let** clause, to bind variables to results of path expressions
- The function distinct( ) can be used to removed duplicates in path expression results
- The function **document(name)** returns root of named document
  - E.g. document("bank-2.xml")/bank-2/account
- Aggregate functions such as sum( ) and count( ) can be applied to path expression results
- XQuery does not support group by, but the same effect can be got by nested queries, with nested FLWR expressions within a **result** clause
  - More on nested queries later

Joins

- 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>
```

Changing Nesting Structure

- 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
- Exercise for reader: write a nested query to find sum of account balances, grouped by branch.

XQuery Path Expressions

- $c/text() gives text content of an element without any subelements/tags
- XQuery path expressions support the “–>” operator for dereferencing IDREFs
  - Equivalent to the id( ) function of XPath, but simpler to use
  - Can be applied to a set of IDREFs to get a set of results
  - June 2001 version of standard has changed “–>” to “=>”

Sorting in XQuery

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

```
for $c in /bank/customer
return <customer> $c/* </customer> sortby(name)
```

- 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
return
    <customer>
        $c/*
        for $d in /bank/depositor[customer-name=$c/customer-name],
             $a in /bank/account[account-number=$d/account-number]
        return <account> $a/* </account> sortby(account-number)
    </customer> sortby(customer-name)
</bank-1>
```

Functions and Other XQuery Features

- User defined functions with the type system of XMLSchema

```
function balances(xsd:string $c) returns list(xsd:numeric) {
  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
- 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

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

- 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
  - Oracle 9 supports **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.)

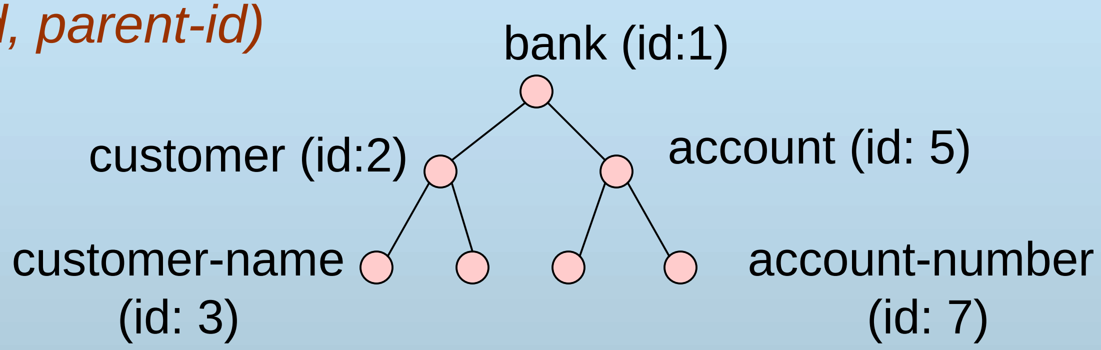
- Benefits:
  - Can store any XML data even without DTD
  - As long as there are many top-level elements in a document, strings are small compared to full document
    - Allows fast access to individual elements.
- Drawback**:** Need to parse strings to access values inside the elements
  - Parsing is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

Tree Representation

- **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

- **Map to relations**
  - If DTD of document is known, can map data to relations
  - A relation is created for each element type
    - Elements (of type #PCDATA), and attributes are mapped to attributes of relations
    - More details on next slide …
- Benefits:
  - Efficient storage
  - Can translate XML queries into SQL, execute efficiently, and then translate SQL results back to XML
- Drawbacks: need to know DTD, translation overheads still present

Mapping XML Data to Relations (Cont.)

- Relation created for each element type contains
  - 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

Mapping XML Data to Relations (Cont.)

- E.g. For bank-1 DTD with account elements nested within customer elements, create relations
  - customer(id, parent-id, customer-name, customer-stret, customer-city)
    - parent-id can be dropped here since parent is the sole root element
    - All other attributes were subelements of type #PCDATA, and occur only once
  - account (id, parent-id, account-number, branch-name, balance)
    - parent-id keeps track of which customer an account occurs under
    - Same account may be represented many times with different parents