Chapter 30: XML
Outline

- 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
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

- E.g.

```
<university>
  <department>
    <dept_name> Comp. Sci. </dept_name>
    <building> Taylor </building>
    <budget> 100000 </budget>
  </department>
  <course>
    <course_id> CS-101 </course_id>
    <title> Intro. to Computer Science </title>
    <dept_name> Comp. Sci </dept_name>
    <credits> 4 </credits>
  </course>
</university>
```
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**: 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
    - `<course> ... <title> .... </title> </course>`
  - Improper nesting
    - `<course> ... <title> .... </course> </title>`
  - 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

<purchase_order>
  <identifier> P-101 </identifier>
  <purchaser> .... </purchaser>
  <itemlist>
    <item>
      <identifier> RS1 </identifier>
      <description> Atom powered rocket sled </description>
      <quantity> 2 </quantity>
      <price> 199.95 </price>
    </item>
    <item>
      <identifier> SG2 </identifier>
      <description> Superb glue </description>
      <quantity> 1 </quantity>
      <unit-of-measure> liter </unit-of-measure>
      <price> 29.95 </price>
    </item>
  </itemlist>
</purchase_order>
Motivation for Nesting

- Nesting of data is useful in data transfer
  - Example: elements representing *item* nested within an *itemlist* 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
Mixture of text with sub-elements is legal in XML.

Example:

```xml
<course>
    This course is being offered for the first time in 2009.
    <course id> BIO-399 </course id>
    <title> Computational Biology </title>
    <dept name> Biology </dept name>
    <credits> 3 </credits>
</course>
```

Useful for document markup, but discouraged for data representation.
Attributes

- Elements can have attributes
  
  ```xml
  <course course_id=“CS-101”>
    <title> Intro. to Computer Science</title>
    <dept name> Comp. Sci. </dept name>
    <credits> 4 </credits>
  </course>
  ```

- 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
  
  ```xml
  <course course_id=“CS-101” credits=“4”>
  ```
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
      - `<course course_id=“CS-101”> … </course>`
      - `<course>
          <course_id>CS-101</course_id> …
        </course>`
  - Suggestion: use attributes for identifiers of elements, and use subelements for contents
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

```xml
<university xmlns:yale="http://www.yale.edu">
  ...

  <yale:course>
    <yale:course_id> CS-101 </yale:course_id>
    <yale:title> Intro. to Computer Science </yale:title>
    <yale:dept_name> Comp. Sci. </yale:dept_name>
    <yale:credits> 4 </yale:credits>
  </yale:course>

  ...

</university>
```
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
  - `<course course_id="CS-101" Title="Intro. To Computer Science"
    dept_name = "Comp. Sci." credits="4" />`

- To store string data that may contain tags, without the tags being interpreted as subelements, use CDATA as below
  - `<![CDATA[<course> ... </course>]]>

Here, `<course>` and `</course>` 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
  - `<!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
  ```xml
  <! ELEMENT department (dept_name building, budget)>
  <! ELEMENT dept_name (#PCDATA)>
  <! ELEMENT budget (#PCDATA)>
  ```

- Subelement specification may have regular expressions
  ```xml
  <!ELEMENT university ( ( department | course | instructor | teaches )+)>
  ```
  - Notation:
    - “|” - alternatives
    - “+” - 1 or more occurrences
    - “*” - 0 or more occurrences
<!DOCTYPE university [ 
  <!ELEMENT university ( (department|course|instructor|teaches)+)> 
  <!ELEMENT department ( dept name, building, budget)> 
  <!ELEMENT course ( course id, title, dept name, credits)> 
  <!ELEMENT instructor (IID, name, dept name, salary)> 
  <!ELEMENT teaches (IID, course id)> 
  <!ELEMENT dept name( #PCDATA )> 
  <!ELEMENT building( #PCDATA )> 
  <!ELEMENT budget( #PCDATA )> 
  <!ELEMENT course id ( #PCDATA )> 
  <!ELEMENT title ( #PCDATA )> 
  <!ELEMENT credits( #PCDATA )> 
  <!ELEMENT IID( #PCDATA )> 
  <!ELEMENT name( #PCDATA )> 
  <!ELEMENT salary( #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 course course_id CDATA #REQUIRED>`, or
- `<!ATTLIST course
  course_id   ID       #REQUIRED
  dept_name   IDREF    #REQUIRED
  instructors IDREFS  #IMPLIED>`
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.
University DTD with Attributes

- University DTD with ID and IDREF attribute types.

```xml
<!DOCTYPE university-3 [
    <!ELEMENT university ( (department|course|instructor)+)>
    <!ELEMENT department ( building, budget )>
    <!ATTLIST department
department
    dept_name ID #REQUIRED >
    <!ELEMENT course (title, credits )>
    <!ATTLIST course
course
course_id ID #REQUIRED
department IDREF #REQUIRED
    instructors IDREFS #IMPLIED >
    <!ELEMENT instructor ( name, salary )>
    <!ATTLIST instructor
    IID ID #REQUIRED
department IDREF #REQUIRED >
    · · · declarations for title, credits, building,
budget, name and salary · · ·
]>```

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XML data with ID and IDREF attributes

```
<university-3>
  <department dept name="Comp. Sci.">
    <building> Taylor </building>
    <budget> 100000 </budget>
  </department>
  <department dept name="Biology">
    <building> Watson </building>
    <budget> 90000 </budget>
  </department>
  <course course id="CS-101" dept name="Comp. Sci"
    instructors="10101 83821">
    <title> Intro. to Computer Science </title>
    <credits> 4 </credits>
  </course>
  ....
  <instructor IID="10101" dept name="Comp. Sci.">
    <name> Srinivasan </name>
    <salary> 65000 </salary>
  </instructor>
  ....
</university-3>
```
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)
  - \((A \mid B)^*\) allows specification of an unordered set, but
    - Cannot ensure that each of A and B occurs only once

- IDs and IDREFs are untyped
  - The *instructors* attribute of an course may contain a reference to another course, which is meaningless
    - *instructors* attribute should ideally be constrained to refer to instructor 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, 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 Schema is integrated with namespaces
- BUT: XML Schema is significantly more complicated than DTDs.
XML Schema Version of Univ. DTD

```xml
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <xs:element name="university" type="universityType" />
  <xs:element name="department">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="dept name" type="xs:string"/>
        <xs:element name="building" type="xs:string"/>
        <xs:element name="budget" type="xs:decimal"/>
      </xs:sequence>
    </xs:complexType>
  </xs:element>
  ....
  <xs:element name="instructor">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="IID" type="xs:string"/>
        <xs:element name="name" type="xs:string"/>
        <xs:element name="dept name" type="xs:string"/>
        <xs:element name="salary" type="xs:decimal"/>
      </xs:sequence>
    </xs:complexType>
  </xs:element>
</xs:schema>
```

... Contd.
Choice of “xs:” was ours -- any other namespace prefix could be chosen.

Element “university” has type “universityType”, which is defined separately.

- \texttt{xs:complexType} is used later to create the named complex type “UniversityType”
More features of XML Schema

- Attributes specified by `xs:attribute` tag:
  - `<xs:attribute name = “dept_name”/>`
  - adding the attribute `use = “required”` means value must be specified

- Key constraint: “department names form a key for department elements under the root university element:
  `<xs:key name = “deptKey”>`
  `<xs:selector xpath = “/university/department”/>`
  `<xs:field xpath = “dept_name”/>`

- Foreign key constraint from course to department:
  `<xs:keyref name = “courseDeptFKey” refer=“deptKey”>`
  `<xs:selector xpath = “/university/course”/>`
  `<xs:field xpath = “dept_name”/>`

```xml
<x:key name = “deptKey”>
  <xs:selector xpath = “/university/department”/>
  <xs:field xpath = “dept_name”/>
</xs:key>

<x:keyref name = “courseDeptFKey” refer=“deptKey”>
  <xs:selector xpath = “/university/course”/>
  <xs:field xpath = “dept_name”/>
</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. `/university-3/instructor/name` evaluated on the university-3 data we saw earlier returns
  ```
  <name>Srinivasan</name>
  <name>Brandt</name>
  ```
- E.g. `/university-3/instructor/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. \( /\text{university-3}/\text{course}[\text{credits} \geq 4] \)
    - returns account elements with a balance value greater than 400
    - \( /\text{university-3}/\text{course}[\text{credits}] \) returns account elements containing a credits subelement
- Attributes are accessed using “@”
  - E.g. \( /\text{university-3}/\text{course}[\text{credits} \geq 4]/@\text{course}_\text{id} \)
    - returns the course identifiers of courses with credits \( \geq 4 \)
  - 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. `/university-2/instructor[count(./teaches/course)> 2]`  
      - Returns instructors teaching more than 2 courses (on university-2 schema)
    - 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. `/university-3/course/id(@dept_name)`
      - returns all department elements referred to from the dept_name attribute of course elements.
More XPath Features

- Operator "|" used to implement union
  - E.g. /university-3/course[@dept name="Comp. Sci"]  |  
    /university-3/course[@dept name="Biology"]
  - Gives union of Comp. Sci. and Biology courses
  - However, "|" cannot be nested inside other operators.

- "//" can be used to skip multiple levels of nodes
  - E.g. /university-3//name
    - finds any name element anywhere under the /university-3 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 ...

  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:
  1. find all courses with credits > 3, with each result enclosed in an <course_id> .. </course_id> tag
  ```xquery
  for $x in /university-3/course
  let $courseId := $x/@course_id
  where $x/credits > 3
  return <course_id> { $courseId } </course_id>
  ```
  2. 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:
  ```xquery
  for $x in /university-3/course[credits > 3]
  return <course_id> { $x/@course_id } </course_id>
  ```

- Alternative notation for constructing elements:
  ```xquery
  return element course_id { element $x/@course_id }
  ```
Joins

- Joins are specified in a manner very similar to SQL

  ```
  for $c \text{ in } /\text{university/course},
  \quad $i \text{ in } /\text{university/instructor},
  \quad $t \text{ in } /\text{university/teaches}
  
  \text{where } $c/\text{course_id} = $t/\text{course_id} \text{ and } $t/\text{IID} = $i/\text{IID}
  
  \text{return } <\text{course_instructor}> \text{ { } } $c $i \text{ } </\text{course_instructor}>
  ```

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

  ```
  for $c \text{ in } /\text{university/course},
  \quad $i \text{ in } /\text{university/instructor},
  \quad $t \text{ in } /\text{university/teaches}[ \quad $c/\text{course_id} = $t/\text{course_id}
  \quad \text{ and } $t/\text{IID} = $i/\text{IID}] 

  \text{return } <\text{course_instructor}> \text{ { } } $c $i \text{ } </\text{course_instructor}>
  ```
Nested Queries

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

```xml
<university-1>
    { for $d in /university/department
        return <department>
            { $d/* }
            { for $c in /university/course[dept name = $d/dept name]
                return $c }
        </department> }
    { for $i in /university/instructor
        return <instructor>
            { $i/* }
            { for $c in /university/teaches[IID = $i/IID]
                return $c/course id }
        </instructor> }
</university-1>
```

$c/* denotes all the children of the node to which $c is bound, without the enclosing top-level tag
Grouping and Aggregation

- Nested queries are used for grouping

```xml
for $d in /university/department
return

<department-total-salary>
  <dept_name> { $d/dept name } </dept_name>
  <total_salary> { fn:sum(
    for $i in /university/instructor[dept_name = $d/dept_name]
    return $i/salary
  )
  }
</total_salary>
</department-total-salary>
```
The \textbf{order by} clause can be used at the end of any expression. E.g. to return instructors sorted by name

\begin{verbatim}
fors $i$ in /university/instructor
  order by $i$/name
  return <instructor> { $i/* } </instructor>
\end{verbatim}

- Use \textbf{order by} $i$/name \textbf{descending} to sort in descending order
- Can sort at multiple levels of nesting (sort departments by dept\_name, and by courses sorted to course\_id within each department)

\begin{verbatim}
<university-1> {
  for $d$ in /university/department
    order by $d$/dept\_name
    return
      <department>
        { $d/* }
        { for $c$ in /university/course[dept\_name = $d$/dept\_name]
          order by $c$/course\_id
          return <course> { $c/* } </course> }
      </department>
  } </university-1>
\end{verbatim}
Functions and Other XQuery Features

- User defined functions with the type system of XMLSchema
  
  ```xquery
  declare function local:dept_courses($iid as xs:string) as element(course)*
  {
    for $i in /university/instructor[IID = $iid],
    $c in /university/courses[dept_name = $i/dept_name]
    return $c
  }
  ```

- 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 $e in path satisfies P`
  - Add `and fn:exists($e)` to prevent empty $e from satisfying `every` clause

- XQuery also supports If-then-else clauses
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**
- Templates combine selection using XPath with construction of results
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

- **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
    ```java
    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
  - 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

- **Tree representation:** model XML data as tree and store using relations
  \[\text{nodes}(id, \text{parent}_id, \text{type}, \text{label}, \text{value})\]

  - 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
  - Can add an extra attribute *position* 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

- 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 (ith child) can be stored too

- All subelements that occur only once can become relation attributes
  - For text-valued subelements, store the text as an attribute value
  - For complex subelements, 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

- Applying above ideas to department elements in university-1 schema, with nested course elements, we get:
  
  \[
  \text{department}(id, \text{dept\_name}, \text{building}, \text{budget})
  \]
  
  \[
  \text{course}(\text{parent\_id}, \text{course\_id}, \text{dept\_name}, \text{title}, \text{credits})
  \]

- **Publishing**: process of converting relational data to an XML format

- **Shredding**: 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

- Many 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`
    ```xml
    <university>
      <department>
        <row>
          <dept name> Comp. Sci. </dept name>
          <building> Taylor </building>
          <budget> 100000 </budget>
        </row>
      </department>
      … other relations ..
    </university>
    ```
    … more rows if there are more output tuples …
SQL Extensions

- `xmlelement` creates XML elements
- `xmlattributes` creates attributes

```sql
select xmlelement (name "course",
    xmlattributes (course id as course id, dept name as dept name),
    xmlelement (name "title", title),
    xmlelement (name "credits", credits))
from course
```

- Xmlagg creates a forest of XML elements

```sql
select xmlelement (name "department",
    dept_name,
    xmlagg (xmlforest(course_id)
        order by course_id))
from course
    group by dept_name
```
XML Applications

- Storing and exchanging data with complex structures
  - E.g. Open Document Format (ODF) format standard for storing
    Open Office and Office Open XML (OOXML) format standard for
    storing Microsoft Office documents
  - Numerous other standards for a variety of applications
    - ChemML, MathML

- Standard for data exchange for Web services
  - remote method invocation over HTTP protocol
  - More in next slide

- Data mediation
  - Common data representation format to bridge different systems
Web Services

- The Simple Object Access Protocol (SOAP) standard:
  - 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
End of Chapter 30