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Chapter 23: XML

Database System Concepts, 6th Ed.

CMSC424: Database Design
XML

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Slides adapted from the slides developed by:
Silberschatz, Korth, Sudarshan (http://www.db-book.com)

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
  - 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.)

- 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

Structure of XML Data (Cont.)

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

```
<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**

```
<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

```
<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

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

```
<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

```
<! ELEMENT department (dept_name  building, budget)>
<! ELEMENT dept_name (#PCDATA)>
<! ELEMENT budget (#PCDATA)>
```

- Subelement specification may have regular expressions

```
<!ELEMENT university ( ( department | course | instructor | teaches )+)>
```

  - Notation:
    - “|” - alternatives
    - “+” - 1 or more occurrences
    - “*” - 0 or more occurrences

University DTD

```
<!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 )>

]>
```

More details…

See the book for more details on:

- DTDs, including how to specify attributes
- Limitations of DTDs
- XMLSchema

Corresponding slides at the end

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. /university-3/course[credits >= 4]
    - returns account elements with a balance value greater than 400
    - /university-3/course[credits] returns account elements containing a credits subelement
- Attributes are accessed using “@”
  - E.g. /university-3/course[credits >= 4]/@course_id
    - returns the course identifiers of courses with credits >= 4
  - IDREF attributes are not dereferenced automatically (more on this later)

More XPath

- XPath provides several functions like count(), sum()
- IDREFs can be referenced using function id()
- "//" 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
- See book/reference manuals for more examples of XPath queries

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

Xquery: Some Examples

- Joins are specified in a manner very similar to SQL

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

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

```
 for $c in /university/course,
      $i in /university/instructor,
      $t in /university/teaches[ $c/course_id= $t/course_id
                                                  and $t/IID = $i/IID]
return <course_instructor> { $c $i } </course_instructor>
```

XQuery: Some Examples

- Nested queries are used for grouping

```
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>
```

XQuery is very powerful – this is a really small portion of what it can do
See book/reference manuals for more details

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**
  - Templates combine selection using XPath with construction of results

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
  - **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 problems like 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
      - **Shredding**: converting XML to relations
    - Advantage: mature database systems
    - Disadvantages: overhead of translating data and queries

SQL/XML

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

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

SQL Extensions

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

```
 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

```
   select xmlelement (name “department”,
                dept_name,
                xmlagg (xmlforest(course_id)
                               order by course_id))
  from course
  group by dept_name
```

Extra Slides Follow…

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

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.

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

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 I 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, comlex 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 Univ. DTD

```
<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>
… Contd.
```

XML Schema Version of Univ. DTD (Cont.)

```
….
<xs:complexType name=“UniversityType”>
   <xs:sequence>
      <xs:element ref=“department” minOccurs=“0” maxOccurs=“unbounded”/>
      <xs:element ref=“course” minOccurs=“0” maxOccurs=“unbounded”/>
      <xs:element ref=“instructor” minOccurs=“0” maxOccurs=“unbounded”/>
      <xs:element ref=“teaches” minOccurs=“0” maxOccurs=“unbounded”/>
   </xs:sequence>
</xs:complexType>
</xs:schema>
```

- Choice of “xs:” was ours -- any other namespace prefix could be chosen
- Element “university” has type “universityType”, which is defined separately
  - 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”/>
<\xs:key>
```

- Foreign key constraint from course to department:

```
<xs:keyref name = “courseDeptFKey” refer=“deptKey”>
        <xs:selector xpath = “/university/course”/>
        <xs:field xpath = “dept_name”/>
<\xs:keyref>
```

XQuery

- XQuery is a general purpose query language for XML data
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  - 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
  - find all courses with credits > 3, with each result enclosed in an <course_id> .. </course_id> tag

```
for  $x in /university-3/course
let   $courseId := $x/@course_id
where $x/credits > 3
return <course_id> { $courseId } </course id>
```

  - 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 /university-3/course[credits > 3]
 return <course_id> { $x/@course_id } </course_id>
```

- Alternative notation for constructing elements:

```
return element course_id { element  $x/@course_id }
```

Joins

- Joins are specified in a manner very similar to SQL

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

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

```
 for $c in /university/course,
      $i in /university/instructor,
      $t in /university/teaches[ $c/course_id= $t/course_id
                                              and $t/IID = $i/IID]
return <course_instructor> { $c $i } </course_instructor>
```

Nested Queries

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

```
 <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

```
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>
```

Sorting in XQuery

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

```
for $i in /university/instructor
order by $i/name
return <instructor> { $i/* } </instructor>
```

- Use **order by** $i/name **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)

```
<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>
```

Functions and Other XQuery Features

- User defined functions with the type system of XMLSchema

```
 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

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

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

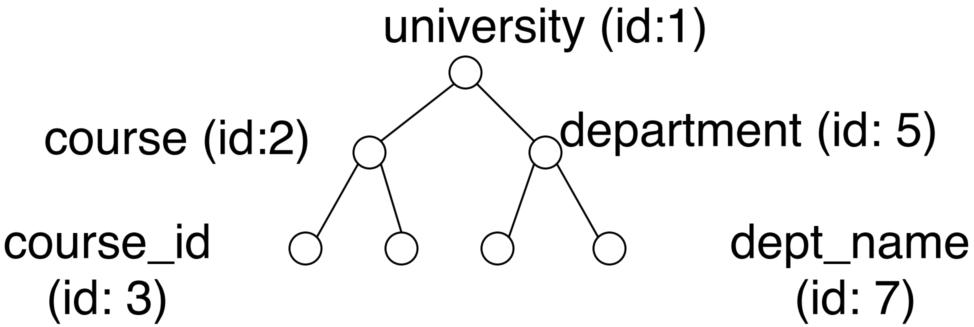
String Representation (Cont.)

- 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

  nodes(id, parent_id, type, label, 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 (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

- Applying above ideas to department elements in university-1 schema, with nested course elements, we get

  department(*id*, *dept_name*, *building*, *budget*)
  course(*parent id*, *course_id*, *dept_name*, *title*, *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