XML and Databases

Chapter 17

What's in This Module?

- Semistructured data
- XML & DTD – introduction
- XML Schema – user-defined data types, integrity constraints
- XPath & XPointer – core query language for XML
- XSLT – document transformation language
- XQuery – full-featured query language for XML

In class

At home

Why XML?

- XML is a standard for data exchange that is taking over the World
- All major database products have been retrofitted with facilities to store and construct XML documents
- There are already database products that are specifically designed to work with XML documents rather than relational or object-oriented data
- XML is closely related to object-oriented and so-called *semistructured* data

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Semistructured Data

- A typical piece of data on the Web:

Mark up

```
<dt>Name: John Doe
     <dd>Id: 111111111
     <dd>Address:   <ul>
                         <li>Number:  123
                         <li>Street:     Main
                    </ul>
</dt>
<dt>Name: Joe Public
      <dd>Id:  222222222
      … … … …
</dt>
```

Semistructured Data (contd.)

- To make the previous student list suitable for machine consumption on the Web, it should have these characteristics:
  - Be *object-like*
  - Be *schemaless* (doesn't guarantee to conform exactly to any schema, but different objects have some commonality among themselves)
  - Be *self-describing* (some schema-like information, like attribute names, is part of data itself)

What is Self-describing Data?

- Non-self-describing (relational, object-oriented):

Data part:

(#123, ["Students", {["John", 111111111, [123,"Main St"]],
["Joe", 222222222, [321, "Pine St"]] }
])

Schema part:

PersonList[*ListName*: String,
Contents: [*Name*: String,
Id: String,
Address: [*Number*: Integer, *Street*: String]]
]

What is Self-Describing Data? (contd.)

- *Self-describing*:
  - Attribute names embedded in the data itself
  - Doesn't need schema to figure out what is what (but schema might be useful nonetheless)

(#12345,
[*ListName*: "Students",
Contents: { [*Name*: "John Doe",
Id: "111111111",
Address: [*Number*: 123, *Street*: "Main St."]] ,
[*Name*: "Joe Public",
Id: "222222222",
Address: [*Number*: 321, *Street*: "Pine St."]] }
])

XML – The De Facto Standard for Semistructured Data

- XML: eXtensible Markup Language
  - Suitable for semistructured data and has become a standard:
    - Easy to describe object-like data
    - Selfdescribing
    - Doesn't require a schema (but can be provided optionally)
- We will study:
  - DTDs – an older way to specify schema
  - XML Schema – a newer, more powerful (and much more complex!) way of specifying schema
  - Query and transformation languages:
    - XPath
    - XSLT
    - XQuery

Overview of XML

- Like HTML, but any number of different tags can be used (up to the document author)
- Unlike HTML, no semantics behind the tags
  - For instance, HTML's <table>…</table> means: render contents as a table; in XML: doesn't mean anything
  - Some semantics can be specified using XML Schema (structure), some using stylesheets (rendering)
- Unlike HTML, is intolerant to bugs
  - Browsers will render buggy HTML pages
  - *XML processors* are not supposed to process buggy XML documents

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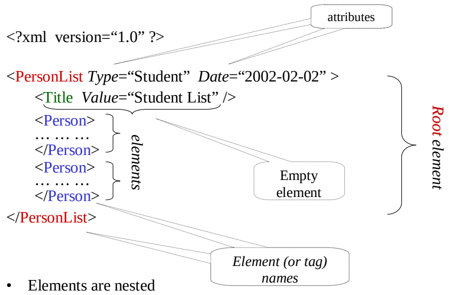
Example

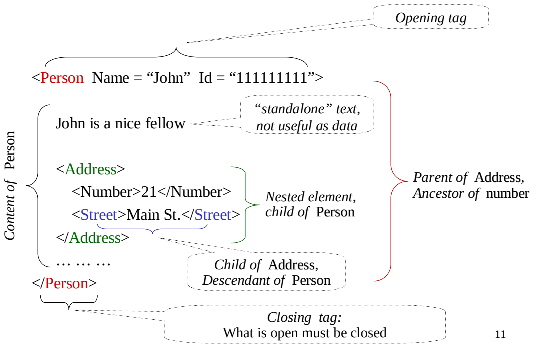


<?xml version="1.0" ?>

<PersonList *Type*="Student" *Date*="2002-02-02" >
<Title *Value*="Student List" />
<Person>
… … …
</Person>
<Person>
… … …
</Person>
</PersonList>

- Elements are nested
- Root element contains all others

More Terminology



<Person Name = "John" Id = "111111111">
John is a nice fellow
<Address>
<Number>21</Number>
<Street>Main St.</Street>
</Address>
… … …
</Person>

Conversion from XML to Objects

- Straightforward:

<Person Name="Joe">
<Age>44</Age>
<Address><Number>22</Number><Street>Main</Street>
</Person>

Becomes:

(#345, [*Name*: "Joe",
Age: 44,
Address: [*Number*: 22, *Street*: "Main"]
])

Conversion from Objects to XML

- Also straightforward
- Non-unique:
  - Always a question if a particular piece (such as Name) should be an element in its own right or an attribute of an element
  - *Example*: A reverse translation could give

```
<Person>                              <Person  Name="Joe">
    <Name>Joe</Name>                   … … …
    <Age>44</Age>
    <Address>
       <Number>22</Number>
       <Street>Main</Street>
    </Address>
</Person>
```

This or this

Differences between XML Documents and Objects

- XML's origin is document processing, not databases
  - Allows things like standalone text (useless for databases)

    `<foo> Hello <moo>123</moo> Bye </foo>`
  - Attributes aren't needed – just bloat the number of ways to represent the same thing
  - XML data is ordered, while database data is not:

    `<something><foo>1</foo><bar>2</bar></something>`

    is different from

    `<something><bar>2</bar><foo>1</foo></something>`

    but these two complex values are same:

    [*something*: [*bar*:1, *foo*:2]]

    [*something*: [*foo*:2, *bar*:1]]

Well-formed XML Documents

- Must have a *root element*
- Every *opening tag* must have matching *closing tag*
- Elements must be *properly nested*
  - `<foo><bar></foo></bar>` is a no-no
- An *attribute* name can occur *at most once* in an opening tag. It it occurs,
  - It *must have a value* (boolean attrs, like in HTML, are not allowed)
  - The value *must be quoted* (with " or ')
- *XML processors are not supposed to try and fix ill-formed documents (unlike HTML browsers)*

Identifying and Referencing with Attributes

- An attribute can be declared to have type
  - *ID* – unique identifier of an element
    - If attr1 & attr2 are both of type ID, then it is illegal to have `<something attr1="abc"> … <somethingelse attr2="abc">` within the same document
  - *IDREF* – references to unique element identifiers (in particular, an XML document with IDREFs is not a tree)
    - If attr1 has type ID and attr2 has type IDREF then we can have: `<something attr1="abc"> … <somethingelse attr2="abc">`
  - *IDREFS* – a list of references, if attr1 is ID and attr2 is IDREFS, then we can have
    - `<something attr1="abc">…<somethingelse attr1="cde">…`
      `<someotherthing attr2="abc cde">`

Example: Report Document with Cross-References

```
<?xml version="1.0"  ?>
<Report  Date="2002-12-12">
  <Students>
     <Student  StudId="111111111">
        <Name><First>John</First><Last>Doe</Last></Name>   <Status>U2</Status>
        <CrsTaken  CrsCode="CS308"  Semester="F1997" />
        <CrsTaken  CrsCode="MAT123"  Semester="F1997" />
     </Student>
     <Student  StudId="666666666">
        <Name><First>Joe</First><Last>Public</Last></Name>   <Status>U3</Status>
        <CrsTaken  CrsCode="CS308"  Semester="F1994" />
        <CrsTaken  CrsCode="MAT123"  Semester="F1997" />
     </Student>
     <Student  StudId="987654321">
        <Name><First>Bart</First><Last>Simpson</Last></Name>  <Status>U4</Status>
        <CrsTaken  CrsCode="CS308"  Semester="F1994" />
     </Student>
  </Students>
```

ID

IDREF

…… *continued … …*

Report Document (contd.)

```
  <Classes>
    <Class>
       <CrsCode>CS308</CrsCode> <Semester>F1994</Semester>
       <ClassRoster  Members="666666666  987654321" />
    </Class>
    <Class>
       <CrsCode>CS308</CrsCode> <Semester>F1997</Semester>
       <ClassRoster  Members="111111111" />
    </Class>
    <Class>
       <CrsCode>MAT123</CrsCode> <Semester>F1997</Semester>
       <ClassRoster  Members="111111111  666666666" />
    </Class>
  </Classes>
```

IDREFS

…… *continued … …*

Report Document (contd.)

ID

```
<Courses>
   <Course CrsCode = “CS308” >
      <CrsName>Market Analysis</CrsName>
   </Course>
   <Course CrsCode = “MAT123” >
      <CrsName>Market Analysis</CrsName>
   </Course>
 </Courses>
</Report>
```

XML Namespaces

- A mechanism to prevent name clashes between components of same or different documents
- Namespace declaration
    - *Namespace* – a symbol, typically a URL
    - *Prefix* – an abbreviation of the namespace, a convenience; works as an alias
    - Actual name (element or attribute) – *prefix*:*name*
    - Declarations/prefixes have *scope* similarly to begin/end
- Example:

```
<item xmlns = “http://www.acmeinc.com/jp#supplies”
       xmlns:toy = “http://www.acmeinc.com/jp#toys”>
    <name>backpack</name>
    <feature>
        <toy:item><toy:name>cyberpet</toy:name></toy:item>
    </feature>
 </item>
```

Default namespace

toy namespace

reserved keyword

Namespaces (contd.)

- Scopes of declarations are color-coded:

```
<item xmlns=“http://www.foo.org/abc”
      xmlns:cde=“http://www.bar.com/cde”>
    <name>…</name>
    <feature>
        <cde:item><cde:name>…</cde:name><cde:item>
    </feature>
    <item  xmlns=“http://www.foobar.org/”
           xmlns:cde=“http://www.foobar.org/cde” >
        <name>…</name>
        <cde:name>…</cde:name>
    </item>
</item>
```

New default; overshadows old default

Redeclaration of cde; *overshadows old declaration*

Namespaces (contd.)

- xmlns=“http://foo.com/bar” *doesn’t* mean there is a document at this URL: using URLs is just a convenient convention; and a namespace is just an identifier
- Namespaces aren’t part of XML 1.0, but all XML processors understand this feature now
- A number of prefixes have become “standard” and some XML processors might understand them without any declaration. E.g.,
    - **xsd** for http://www.w3.org/2001/XMLSchema
    - **xsl** for http://www.w3.org/1999/XSL/Transform
    - Etc.

Document Type Definition (DTD)

- A *DTD* is a grammar specification for an XML document
- DTDs are optional – don’t need to be specified
    - If specified, DTD can be part of the document(at the top; or it can be given as a URL
- A document that conforms (i.e., parses) w.r.t. its DTD is said to be *valid*
    - XML processors are not required to check validity, even if DTD is specified
    - But they are required to test well-formedness

DTDs (cont’d)

- DTD specified as part of a document:

```
<?xml  version=“1.0” ?>
<!DOCTYPE  Report [
    … … …
]>
<Report> … … … </Report>
```

- DTD specified as a standalone thing

```
<?xml  version=“1.0” ?>
<!DOCTYPE  Report  “http://foo.org/Report.dtd”>
<Report> … … … </Report>
```

DTD Components

- **<!**ELEMENT *elt-name* (*…contents…*) >
- **<!**ATTLIST *elt-name attr-name*

  ID/IDREF/IDREFS

  EMPTY/#IMPLIED/#REQUIRED

  \>

optional

Other declarations

- Can define other things, like macros (called *entities*)

DTD Example

```
<!DOCTYPE   Report  [
     <!ELEMENT  Report  (Students, Classes, Courses)>
     <!ELEMENT  Students  (Student*)>
     <!ELEMENT  Classes  (Class*)>
     <!ELEMENT  Courses  (Course*)>
     <!ELEMENT  Student  (Name, Status, CrsTaken*)>
     <!ELEMENT  Name  (First,Last)>
     <!ELEMENT  First  (#PCDATA)>
     … … …
     <!ELEMENT  CrsTaken  EMPTY>
     <!ELEMENT  Class (CrsCode,Semester,ClassRoster)>
     <!ELEMENT  Course  (CrsName)>
     … … …
     <!ATTLIST  Report  Date  #IMPLIED>
     <!ATTLIST  Student  StudId  ID  #REQUIRED>
     <!ATTLIST  Course  CrsCode  ID  #REQUIRED>
     <!ATTLIST  CrsTaken  CrsCode  IDREF  #REQUIRED>
     <!ATTLIST  ClassRoster  Members  IDREFS  #IMPLIED>
]>
```

Zero or more

text

Empty element

Same attribute in different elements

Limitations of DTDs

- Doesn't understand namespaces
- Very limited assortment of data types (just strings)
- Very weak w.r.t. consistency constraints (ID/IDREF/IDREFS only)
- Can't express unordered contents conveniently
- All element names are global: can't have one Name type for people and another for companies:

  ```
  <!ELEMENT   Name   (Last, First)>
  <!ELEMENT   Name   (#PCDATA)>
  ```

  both can't be in the same DTD

XML Schema

- Came to rectify some of the problems with DTDs
- Advantages:
  - – Integrated with namespaces
  - – Many built-in types
  - – User-defined types
  - – Has local element names
  - – Powerful key and referential constraints
- Disadvantages:
  - – Unwieldy – much more complex than DTDs

Schema and Namespaces

```
<schema  xmlns="http://www.w3.org/2001/XMLSchema"
            targetNamespace="http://xyz.edu/Admin">
   … … …
</schema>
```

- http://www.w3.org/2001/XMLSchema – namespace for keywords used in the official XML Schema specifications, e.g., "*schema*", *targetNamespace*, etc.
- targetNamespace – defines the namespace for the schema being defined by the above <schema>…</schema> document

Instance Document

- Report document whose structure is being defined by the earlier schema document

  ```
  <?xml  version = "1.0" ?>
  <Report  xmlns="http://xyz.edu/Admin">
            xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
            xsi:schemaLocation="http://xyz.edu/Admin
                                   http://xyz.edu/Admin.xsd" >
     …  same contents as in the earlier Report document …
  </Report>
  ```

Namespace for XML Schema names that occur in instance documents rather than their schemas

- xsi:schemaLocation says: the schema for the namespace http://xyz.edu/Admin is found in http://xyz.edu/Admin.xsd
- Document schema & its location are not binding on the XML processor; it can decide to use another schema, or none at all

Building Schemas from Components

```
<schema  xmlns=“http://www.w3.org/2001/XMLSchema”
         targetNamespace=“http://xyz.edu/Admin”  >
   <include  schemaLocation=“http://xyz.edu/StudentTypes.xsd”>
   <include  schemaLocation=“http://xyz.edu/ClassTypes.xsd”>
   <include  schemaLocation=“http://xyz.edu/CourseTypes.xsd”>
  … … …
</schema>
```

- <include…> works like #include in C language
  - Included schemas must have the same targetNamespace as the including schema
- schemaLocation – tells where to find the piece to be included
  - Note: this schemaLocation is defined in the XMLSchema namespace – different from the earlier xsi:schemaLocation

Simple Types

- *Primitive types*: *decimal*, *integer*, *boolean*, *string*, ID, IDREF, etc.
- *Type constructors*: *list* and *union*
  - A simple way to derive types from primitive types:

```
<simpleType  name=“myIntList”>
   <list  itemType=“integer” />
</simpleType>

<simpleType  name=“phoneNumber” >
   <union  memberTypes=“phone7digits  phone10digits” />
</simpleType>
```

Deriving Simple Types by Restriction

```
<simpleType  name=“phone7digits” >
   <restriction  base=“integer” >
        <minInclusive  value=“1000000” />
        <maxInclusive  value=“9999999” />
     </restriction>
</simpleType>
<simpleType  name=“emergencyNumbers” >
   <restriction  base=“integer” >
        <enumeration  value=“911” />
        <enumeration  value=“333” />
   </restriction>
</simpleType>
```

- Has more type-building primitives (see textbook and specs)

Some Simple Types Used in the Report Document

```
<simpleType  name=“studentId” >
        <restriction  base=“ID” >
                <pattern  value=“[0-9]{9}” />
        </restriction>
</simpleType>
<simpleType  name=“studentIds” >
        <list  itemType=“studentRef” />
</simpleType>

<simpleType  name=“studentRef” >
        <restriction  base=“IDREF” >
                <pattern  value=“[0-9]{9}” />
        </restriction>
</simpleType>
```

Simple Types for Report Document (contd.)

```
<simpleType  name=“courseCode” >
        <restriction  base=“ID” >
                <pattern  value=“[A-Z]{3}[0-9]{3}” />
        </restriction>
</simpleType>
<simpleType  name=“courseRef” >
        <restriction  base=“IDREF” >
                <pattern  value=“[A-Z]{3}[0-9]{3}” />
        </restriction>
</simpleType>
<simpleType  name=“studentStatus” >
        <restriction  base=“string” >
                <enumeration value=“U1” />
                … … …
                <enumeration value=“G5” />
        </restriction>
</simpleType>
```

Instance Document That Uses Simple Types

```
<schema  xmlns=“http://www.w3.org/2001/XMLSchema”
         xmlns:adm=“http://xyz.edu/Admin”
         targetNamespace=“http://xyz.edu/Admin”>
  … … …
  <element  name=“CrsName”  type=“string”/>
  <element  name=“Status”  type=“adm:studentStatus” />

  … … …
  <simpleType  name=“studentStatus” >
     … … …
  </simpleType>
</schema>
```

element declaration using derived type

Why is a namespace prefix needed here? (think)

Complex Types

- Allows to define element types that have complex internal structure
- Similar to class definitions in object-oriented databases
  - Very verbose syntax
  - Can define both child elements and attributes
  - Supports ordered and unordered collections of elements

Example: studentType

```
<element  name="Student"  type="adm:studentType" />
<complexType  name="studentType" >
    <sequence>
          <element  name="Name"  type="adm:personNameType" />
           <element  name="Status"  type="adm:studentStatus" />
           <element  name="CrsTaken"  type="adm:courseTakenType"
                    minOccurs="0"  maxOccurs="unbounded" />
    </sequence>
    <attribute  name="StudId"  type="adm:studentId" />
</complexType>

<complexType  name="personNameType" >
    <sequence>
          <element  name="First"  type="string" />
          <element  name="Last"  type="string" />
    </sequence>
</complexType>
```

Compositors: Sequences, Bags, Alternatives

- *Compositors*:
  - *sequence*, *all*, *choice* are required when element has at least 1 child element (= *complex content*)
- sequence -- have already seen
- all – can express unordered sequences (bags)
- choice – can express alternative types

Bags

- Suppose the order of components in addresses is unimprotant:

```
<complexType  name="addressType" >
          <all>
                    <element  name="StreetName"  type="string" />
                    <element  name="StreetNumber"  type="string" />
                    <element  name="City"  type="string" />
          </all>
</complexType>
```

- *Problem*: all comes with a host of awkward restrictions. For instance, cannot occur inside a sequence

Alternative Types

- Assume addresses can have P.O.Box or street name/number:

```
<complexType  name="addressType" >
      <sequence>
         <choice>
               <element  name="POBox"  type="string" />
               <sequence>
                         <element  name="Name"  type="string" />
                         <element  name="Number"  type="string" />
               </sequence>
         </choice>
         <element  name="City"  type="string" />
      </sequence>
</complexType>
```

This or that

Local Element Names

- A DTD can define only global element name:
  - Can have oat most one <!ELEMENT foo …> statement per DTD
- In XML Schema, names have scope like in programming languages – the nearest containing complexType definition
  - Thus, can have the same element name, say *Name*, within different types and with different internal structures

Local Element Names: Example

```
<complexType  name=“studentType” >
    <sequence>
          <element  name=“Name”  type=“adm:personNameType” />
          <element  name=“Status”  type=“adm:studentStatus” />
          <element  name=“CrsTaken”  type=“adm:courseTakenType”
                                minOccurs=“0”  maxOccurs=“unbounded” />
    </sequence>
    <attribute  name=“StudId”  type=“adm:studentId” />
</complexType>
<complexType  name=“courseType” >
    <sequence>
          <element  name=“Name”  type=“string” />
    </sequence>
    <attribute  name=“CrsCode”  type=“adm:courseCode” />
</complexType>
```

Same element name, different types, inside different complex types

---

Importing XML Schemas

- Import is used to share schemas developed by different groups at different sites
- Include vs. import:
  - *Include*:
    - Included schemas are usually under the control of the same development group as the including schema
    - Included and including schemas must have the same target namespace (because the text is physically included)
  - *Import*:
    - Schemas are under the control of different groups
    - Target namespaces are different
    - The import statement must tell the including schema what that target namespace is

---

Import of Schemas (cont’d)

```
<schema  xmlns=“http://www.w3.org/2001/XMLSchema”
            targetNamespace=“http://xyz.edu/Admin”
            xmlns:reg=“http://xyz.edu/Registrar”
            xmlns:crs=“http://xyz.edu/Courses” >
    <import  namespace=“http://xyz.edu/Registrar”
               schemaLocation=“http://xyz.edu/Registrar/StudentType.xsd” />
    <import  namespace=“http://xyz.edu/Courses”  />
          … … …
          … … …
</schema>
```

Prefix declarations for imported namespaces

required

optional

Extension and Resriction of Base Types

- Mechanism for modifying the types in imported schemas
- Similar to subclassing in object-oriented languages
- *Extending* an XML Schema type means adding elements or adding attributes to existing elements
- *Restricting* types means tightening the types of the existing elements and attributes (ie, replacing existing types with subtypes)

Type Extension: Example

```
<schema  xmlns=“http://www.w3.org/2001/XMLSchema”
            xmlns:xyzCrs=“http://xyz.edu/Courses”
            xmlns:fooAdm=“http://foo.edu/Admin”
            targetNamespace=“http://foo.edu/Admin” >
    <import  namespace=“http://xyz.edu/Courses” />

    <complexType  name=“courseType” >
        <complexContent>
                <extension  base=“xyzCrs:CourseType”>
                      <element  name=“syllabus”  type=“string” />
                </extension>
        </complexContent>
    </complexType>
    <element  name=“Course”  type=“fooAdm:courseType” />
    … … …
</schema>
```

Extends by adding

Type Restriction: Example

```
<schema  xmlns=“http://www.w3.org/2001/XMLSchema”
            xmlns:xyzCrs=“http://xyz.edu/Courses”
            xmlns:fooAdm=“http://foo.edu/Admin”
            targetNamespace=“http://foo.edu/Admin” >
    <import  namespace=“http://xyz.edu/Courses” />

    <complexType  name=“courseType” >
          <complexContent>
              <restriction  base=“xyzCrs:studentType” >
                  <sequence>
                      <element  name=“Name”  type=“xyzCrs:personNameType” />
                      <element  name=“Status”  type=“xyzCrs:studentStatus” />
                      <element  name=“CrsTaken”  type=“xyzCrs:courseTakenType”
                                 minOccurs=“0”  maxOccurs=“60” />
                  </sequence>
                  <attribute  name=“StudId”  type=“xyzCrs:studentId” />
              </restriction>
          </complexContent>
          <element  name=“Student”  type=“fooAdm:studentType” />
    </complexType>
```

Must repeat the original definition

Tightened type: the original was “unbounded”

Structure of an XML Schema Document

```
<schema  xmlns=“http://www.w3.org/2001/XMLSchema”
              xmlns:adm=“http://xyz.edu/Admin”
              targetNamespace=“http://xyz.edu/Admin”>
     <element  name=“Report”  type=“adm:reportType” />

     <complexType  name=“reportType” >
         … … …
     </complexType>
      <complexType  name=… >
         … … …
      </complexType>
       … … …
</schema>
```

Root type

Root element

Definition of root type

Definition of types mentioned in the root type; Types can also be included via <include …> statement

Anonymous Types

- So far all types were *named*
  - Useful when the same type is used in more than one place
- When a type definition is used exactly once, *anonymous* types can save space

```
<element  name=“Report” >
   <complexType>
          <sequence>
               <element  name=“Students”  type=“adm:studentList” />
               <element  name=“Classes”  type=“adm:classOfferings” />
               <element  name=“Courses”  type=“adm:courseCatalog” />
          </sequence>
   </complexType>
</element>
```

“element” used to be empty element – now isn’t

No type name

Integrity Constraints in XML Schema

- A DTD can specify only very simple kinds of key and referential constraint; only using attributes
- XML Schema also has ID, IDREF as primitive data types, but these can also be used to type elements, not just attributes
- In addition, XML Schema can express complex key and foreign key constraints

Schema Keys

- A *key* in an XML document is a sequence of components, which might include elements and attributes, which uniquely identifies document components in a *source collection* of objects in the document
- *Issues*:
  - Need to be able to identify that source collection
  - Need to be able to tell which sequences form the key
- For this, XML Schema uses *XPath* – a simple XML query language. (Much) more on XPath later

(Very) Basic XPath – for Key Specification

- Objects selected by the various XPath expressions are color coded

```
<Offerings>        – –  current reference point
    <Offering>
           <CrsCode  Section=“1”>CS532</CrsCode>
           <Semester><Term>Spring</Term><Year>2002</Year></Semester>
    </Offering>
    <Offering>
           <CrsCode  Section=“2”>CS305</CrsCode>
           <Semester><Term>Fall</Term><Year>2002</Year></Semester>
    </Offering>
</Offerings>
```

Offering/CrsCode/@Section – *selects occurrences of attribute* Section + *value within* Offerings *within* CrsCode

Offering/CrsCode – *selects all* CrsCode *element occurrences within* Offerings

Offering/Semester/Term –*all* Term *elements within* Offerings *within* Semester

Offering/Semester/Year –*all* Year *elements within* Offerings *within* Semester

Keys: Example

```
<complexType  name=“reportType”>
   <sequence>
     <element  name=“Students”  … />
     <element  name=“Classes” >
         <complexType>
            <sequence>
                <element  name=“Class”  minOccurs=“0”  maxOccurs=“unbounded” >
                     <sequence>
                          <element  name=“CrsCode”  … />
                          <element  name=“Semester” … />
                          <element  name=“ClassRoster”  … />
                     </sequence>
                </element>
            </sequence>
         </complexType>
     </element>
     <element  name=“Courses”  … />
   <sequence>
 … … key specification goes here – next slide … …
</complexType>
```

Example (cont'd)

- A key specification for the previous document:

```
<key  name="PrimaryKeyForClass" >
      <selector  xpath="Classes/Class" />

      <field  xpath="CrsCode" />
      <field  xpath="Semester" />

</key>
```

*Defines **source collection** of objects to which the key applies. The XPath expression is relative to* Report *element*

Fields that form the key.
The XPath expression is relative to the source collection of objects in select.
So, CrsCode *is like* Classes/Class/CrsCode

Foreign Keys

- Like the REFERENCES clause in SQL, but more involved
- Need to specify:
  - *Foreign key*:
    - *Source collection* of objects
    - Fields that form the foreign key
  - *Target key*:
    - A previously defined *key* (or *unique*) specification, which is comprised of:
      - *Target collection* of objects
      - Sequence of fields that comprise the key

Foreign Key: Example

- Every class must have at least one student

```
<keyref  name="NoEmptyClasses"  refer="adm:PrimaryKeyForClass" >
      <selector  xpath="Students/Student/CrsTaken" />

      <field  name="@CrsCode" />
      <field  name="@Semester" />

</keyref>
```

Source collection

Fields of the foreign key.
The XPath expressions are relative to the source collection

Target key

XML Query Languages

- XPath – core query language. Very limited, a glorified selection operator. Very useful, though: used in XML Schema, XSLT, XQuery, many other XML standards
- XSLT – a functional style document transformation language. Very powerful, <u>very</u> complicated
- XQuery – upcoming standard. Very powerful, fairly intuitive, SQL-style

---

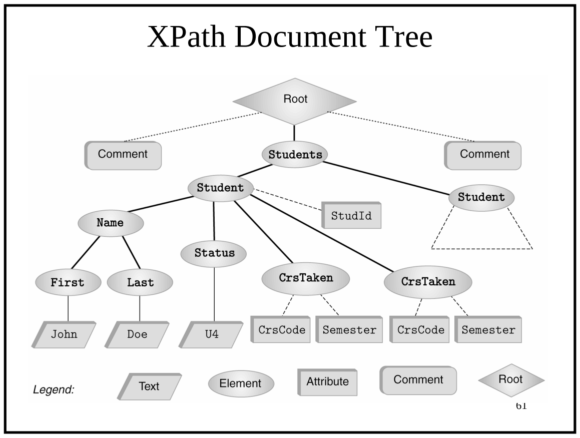
Why Query XML?

- Need to extract parts of XML documents
- Need to transform documents into different forms
- Need to relate – join – parts of the same or different documents

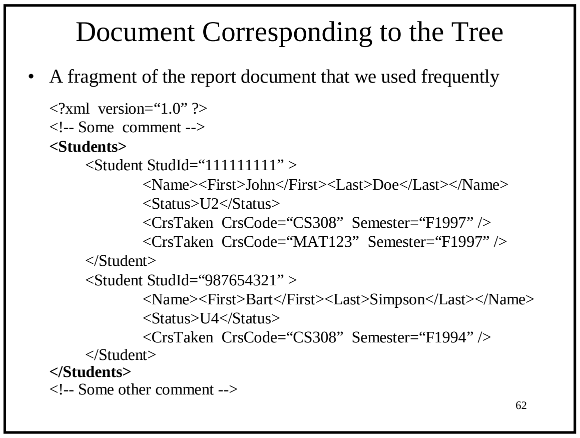
---

XPath

- Analogous to path expressions in object-oriented languages (e.g., OQL)
- Extends path expressions with query facility
- XPath views an XML document as a tree
  - Root of the tree is a <u>*new*</u> node, which doesn't correspond to anything in the document
  - Internal nodes are elements
  - Leaves are either
    - Elements that have no subelements or attributes
    - Attributes
    - Text nodes
    - Comments
    - Other things that we didn't discuss (processing instructions, …)



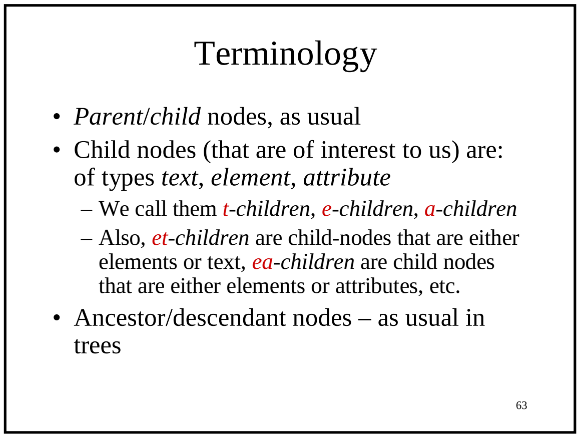
XPath Document Tree



Document Corresponding to the Tree

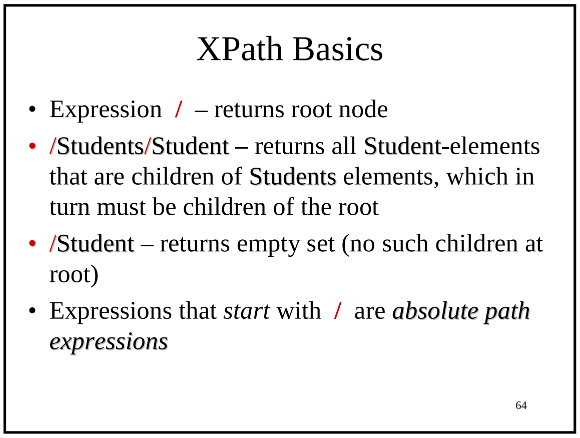
- A fragment of the report document that we used frequently

```
<?xml  version=“1.0” ?>
<!-- Some  comment -->
<Students>
      <Student StudId=“111111111” >
                  <Name><First>John</First><Last>Doe</Last></Name>
                  <Status>U2</Status>
                  <CrsTaken  CrsCode=“CS308”  Semester=“F1997” />
                  <CrsTaken  CrsCode=“MAT123”  Semester=“F1997” />
      </Student>
      <Student StudId=“987654321” >
                  <Name><First>Bart</First><Last>Simpson</Last></Name>
                  <Status>U4</Status>
                  <CrsTaken  CrsCode=“CS308”  Semester=“F1994” />
      </Student>
</Students>
<!-- Some other comment -->
```



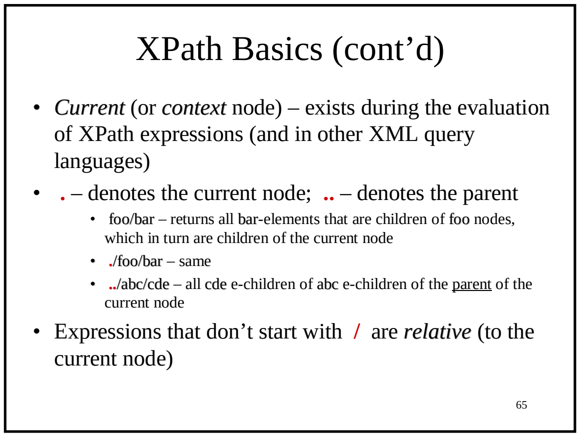
Terminology

- *Parent*/*child* nodes, as usual
- Child nodes (that are of interest to us) are: of types *text*, *element*, *attribute*
  - We call them *t-children*, *e-children*, *a-children*
  - Also, *et-children* are child-nodes that are either elements or text, *ea-children* are child nodes that are either elements or attributes, etc.
- Ancestor/descendant nodes – as usual in trees



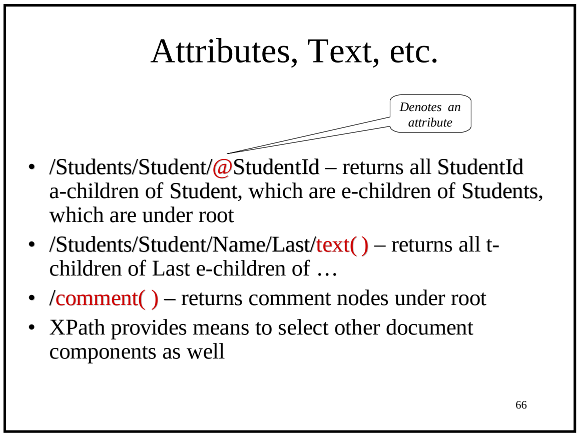
XPath Basics

- Expression / – returns root node
- /Students/Student – returns all Student-elements that are children of Students elements, which in turn must be children of the root
- /Student – returns empty set (no such children at root)
- Expressions that *start* with / are *absolute path expressions*



XPath Basics (cont’d)

- *Current* (or *context* node) – exists during the evaluation of XPath expressions (and in other XML query languages)
- . – denotes the current node; .. – denotes the parent
  - foo/bar – returns all bar-elements that are children of foo nodes, which in turn are children of the current node
  - ./foo/bar – same
  - ../abc/cde – all cde e-children of abc e-children of the parent of the current node
- Expressions that don’t start with / are *relative* (to the current node)



Attributes, Text, etc.

Denotes an attribute

- /Students/Student/@StudentId – returns all StudentId a-children of Student, which are e-children of Students, which are under root
- /Students/Student/Name/Last/text( ) – returns all t-children of Last e-children of …
- /comment( ) – returns comment nodes under root
- XPath provides means to select other document components as well

Overall Idea and Semantics

This is called *full* syntax.
We used *abbreviated* syntax before.
Full syntax is better for describing meaning. Abbreviated syntax is better for programming.

- An XPath expression is:
  locationStep1/locationStep2/…
- *Location step*:
  Axis::nodeSelector[predicate]
- Navigation *axis*:
  - *child, parent* – have seen
  - *ancestor, descendant, ancestor-or-self, descendant-or-self* – will see later
  - some other
- *Node selector*: node name or wildcard; e.g.,
  - ./child::Student (we used ./Student, which is an abbreviation)
  - ./child::* – any e-child (abbreviation: ./*)
- *Predicate*: a selection condition; e.g.,
  Students/Student[CourseTaken/@CrsCode = “CS532”]

XPath Semantics

- The meaning of the expression locationStep1/locationStep2/… is the set of all document nodes obtained as follows:
  - Find all nodes reachable by locationStep1 from the current node
  - For each node *N* in the result, find all nodes reachable from *N* by locationStep2; take the union of all these nodes
  - For each node in the result, find all nodes reachable by locationStep3, etc.
  - The value of the path expression on a document is the set of all document nodes found after processing the last location step in the expression

Overall Idea of the Semantics (Cont’d)

- locationStep1/locationStep2/… means:
  - Find all nodes specified by locationStep1
  - For each such node N:
    - Find all nodes specified by locationStep2 using N as the current node
    - Take union
  - For each node returned by locationStep2 do the same
- locationStep = axis::node[predicate]
  - Find all nodes specified by axis::node
  - Select only those that satisfy predicate

More on Navigation Primitives

- 2nd course taken by the first student in the list:
  /Students/Student[1]/CrsTaken[2]
- All last CourseTaken elements within each Student element:
  /Students/Student/CrsTaken[last( )]

Wildcards

- Wildcards are useful when the exact structure of document is not known
- *Descendant-or-self* axis, // : allows to descend down any number of levels (including 0)
  - //CrsTaken – all CrsTaken nodes under the root
  - Students//@Name – all Name attribute nodes under the elements Students, who are children of the current node
  - *Note*:
    - ./Last and Last are same
    - .//Last and //Last are different
- The * wildcard:
  - * – any element: Student/*/text()
  - @* – any attribute: Students//@*

XPath Queries (selection predicates)

- Recall: Location step = Axis::nodeSelector[predicate]
- Predicate:
  - XPath expression = const | built-in function | XPath expression
  - XPath expression
  - built-in predicate
  - a Boolean combination thereof
- Axis::nodeSelector[predicate] ⊆ Axis::nodeSelector but contains only the nodes that satisfy predicate
- Built-in predicate: special predicates for string matching, set manipuation, etc.
- Built-in function: large assortment of functions for string manipulation, aggregation, etc.

XPath Queries – Examples

- Students who have taken CS532:

  //Student[CrsTaken/@CrsCode="CS532"]

  True if : "CS532" ∈ //Student/CrsTaken/@CrsCode
- Complex example:

  //Student[Status="U3" and starts-with(.//Last, "A")
  and contains(concat(.//@CrsCode), "ESE")
  and not(.//Last = .//First)]
- Aggregation: sum( ), count( )

  //Student[sum(.//@Grade) div count(.//@Grade) > 3.5]

Xpath Queries (cont'd)

- Testing whether a subnode exists:
  - //Student[CrsTaken/@Grade] – students who have a grade (for some course)
  - //Student[Name/First or CrsTaken/@Semester

    or Status/text() = "U4"] – students who have either a first name or have taken a course in some semester or have status U4
- Union operator, | :

  //CrsTaken[@Semester="F2001"] | //Class[Semester="F1990"]

  – union lets us define *heterogeneous* collections of nodes

---

XPointer

- XPointer = URL + XPath
  - A URL on steroids
- Syntax:

  url # xpointer (XPathExpr1) # xpointer (XPathExpr2) …
  - Follow *url*
  - Compute XPathExpr1
    - Result non-empty? – return result
    - Else: compute XPathExpr2; and so on
- Example: you might click on a link and run a query against your Registrar's database

  http://yours.edu/Report.xml#xpointer(
  //Student[CrsTaken/@CrsCode="CS532"
  and CrsTaken/@Semester="S2002"])

XSLT: XML Transformation Language

- Powerful programming language, uses *functional programming paradigm*
- Originally designed as a stylesheet language: this is what "S", "L", and "T" stand for
  - The idea was to use it to display XML documents by transforming them into HTML
  - For this reason, XSLT programs are often called *stylesheets*
  - Their use is not limited to stylesheets – can be used to query XML documents, transform documents, etc.
- In wide use, but semantics is very complicated

XSLT Basics

- One way to apply an XSLT program to an XML document is to specify the program as a stylesheet in the document *preamble* using a *processing instruction*:

```
<?xml version="1.0"  ?>
… … …
<?xml-stylesheet  type="text/xsl"
                  href="http://xyz.edu/Report/report.xsl" ?>
… … …
<Report  Date="2002-11-11">
… … …
</Report>
```

Processing instruction

Preamble

Simple Example

- *Extract the list of all students* from this (hyperlinked) document

```
<?xml version="1.0"  ?>
<StudentList  xmlns:xsl="http://www.w3.org/1999/XSL/Transform"
                  xsl:version="1.0" >

    <xsl:copy-of  select="//Student/Name"  />
</StudentList>
```

Standard XSLT namespace

Result document skeleton

XSLT instruction – copies the result of path expression to stdout

- Result:

```
<StudentList>
   <Name><First>John</First><Last>Doe</Last></Name>
   <Name><First>Bart</First><Last>Simpson</Last></Name>
</StudentList>
```

- Quiz: *Can we use the XSLT namespace as the default namespace in a stylesheet*? What problem might arise?

More Complex (Still Simple) Stylesheet

```
<StudentList  xmlns:xsl=“http://www.w3.org/1999/XSL/Transform”
              xsl:version=“1.0”>
    <xsl:for-each  select=“//Student”>
      <xsl:if  test=“count(CrsTaken) &gt; 1”  >
           <FullName>
               <xsl:value-of  select=“*/Last” /> ,
               <xsl:value-of  select=“*/First” />
           </FullName>
      </xsl:if>
    </xsl:for-each>
</StudentList>
```

Extracts ***contents*** *of element, not the element itself (unlike copy-of)*

Result:

```
<StudentList>
   <FullName>
           Doe, John
   </FullName>
</StudentList>
```

XSLT Pattern-based Templates

- Where the real power lies
  … and also where the peril lurks
- *Issue*: how to process XML documents by descending into their structure
- Previous syntax was just a shorthand for template syntax – next slide

Full Syntax vs. Simplified Syntax

- Simplified syntax:

```
<StudentList xmlns:xsl=“http://www.w3.org/1999/XSL/Transform”
             xsl:version=“1.0”>
    <xsl:for-each  select=“//Student”>
      … … …
    </xsl:for-each>
</StudentList>
```

- Full syntax:

```
<xsl:stylesheet  xmlns:xsl=“http://www.w3.org/1999/XSL/Transform”
                 xsl:version=“1.0”>
    <xsl:template  match=“/” >
       <StudentList>
          <xsl:for-each  select=“//Student”>
             … … …
          </xsl:for-each>
       </StudentList>
    </xsl:template>
</xsl:stylesheet>
```

Recursive Stylesheets

- A bunch of templates of the form:

```
<xsl:template  match=“XPath-expression” >
     … tags, XSLT instructions …
</xsl:template>
```

- Template is applied to the node that is *current* in the evaluation process (will describe this process later)
- Template is used if its XPath expression is *matched*:
  - “Matched” means: *current node* ∈ *result set of XPath expression*
  - If several templates match: use the *best matching template* – template with the smallest (by inclusion) XPath expression result set
  - If several of those: other rules apply (see XSLT specs)
  - If *no* template matches, use the matching *default* template
    - There is one default template for *et*-children and one for *a*-children – later

Resursive Traversal of Document

- <xsl:apply-templates/> – XSLT instruction that drives the recursive process of descending into the document tree
- Constructs the list of *et*-children of the current node
- For each node in the list, applies the best matching template
- A typical initial template:

```
<xsl:template  match=“/” >
        <StudentList>
               <xsl:apply-templates />
        </StudentList>
</xsl:template>
```

Start with the root node – typically the first template to be used in a stylesheet

  - Outputs <StudentList> – </StudentList> tag pair
  - Applies templates to the *et*-children of the current node
  - Inserts whatever output is produced in-between <StudentList> and </StudentList>

Recursive Stylesheet Example

- As before: *list the names of students with* > 1 *courses*:

```
<?xml version=“1.0” ?>
<xsl:stylesheet  xmlns:xsl=“http://www.w3.org/1999/XSL/Transform”
                 xsl:version=“1.0” >
   <xsl:template  match=“/” >
        <StudentList>
               <xsl:apply-templates/>
        </StudentList>
   </xsl:template >
   <xsl:template  match=“//Student” >
      <xsl:if   test=“count(CrsTaken)  &gt;  1” >
        <FullName>
            <xsl:value-of   select=“*/Last” />
            <xsl:value-of   select=“*/First” />
        </FullName>
      </xsl if>
   </xsl:template>
   <xsl:template  match=“text()” >
   </xsl:template>
</xsl:stylesheet>
```

Initial template

The workhorse, does all the job

Empty template – no-op. Needed to block default template for text – later.

Example Dissected

- *Initial template*: starts off, applies templates to *et*-children. The only *et*-child is *Students* element
- Stylesheet has no matching template for *Students*!
- Use *default template*: For *e*-nodes *or* root (/) the default is to go down to the *et*-children:

```
<xsl:template  match = “ * | / ” >
        <xsl:apply-templates />
</xsl:template>
```

- Children of *Students* node are two *Student* nodes – the “workhorse” template matches!
  - For each such (*Student*) node output:

    <FullName>*Last*, *First*</FullName>

Example (cont’d)

- Consider this *expanded* document :

```
<Report>
  <Students>
      <Student StudId=“111111111” >
            … … …
      </Student>
      <Student StudId=“987654321” >
            … … …
      </Student>
  </Students>
  <Courses>
      <Course  CrsCode=“CS308” >
            <CrsName>Software Engineering</CrsName>
       </Course>
      … … …
  </Courses>
</Report>
```

Old part

New part

- Then the previous stylesheet has another branch to explore

Example (cont’d)

- No stylesheet template applies to *Courses*-element, so use the default template
- No explicit template applies to children, *Course*-elements – use the default again
- Nothing applies to *CrsName* – use the default
- The child of *CrsName* is a text node. If we used the default here: For text/attribute nodes the XSLT default is

```
<xsl:template  match=“text( ) | @*” >
        <xsl:value-of  select=“.” />
</xsl:template>
```

i.e., output the contents of text/attribute – we don’t want this!

This is why we provided the empty template for text nodes – to suppress the application of the default template

XSLT Evaluation Algorithm

- Very involved
- Not even properly defined in the official XSLT specification!
- More formally described in a research paper by Wadler – can only hope that vendors read this
- Will describe simplified version – will omit the *for-each* statement

XSLT Evaluation Algorithm (cont’d)

- Create root node, *OutRoot*, for the output document
- Copy root of the input document, *InRoot*, to output document: $InRoot^R$. Make $InRoot^R$ a child of *OutRoot*
    - Set current node variable: *CN* := *InRoot*
    - Set current node list: *CNL* := <*InRoot*>
  - *CN* : always the 1st node in *CNL*
  - When a node *N* is placed on *CNL*, its copy, N^R, goes to the output document (becomes a child of some node – see later)
    - N^R is a marker for where subsequent actions apply in the output document
    - Might be deleted or replaced later
- Find the *best matching template* for *CN* (or default template, if nothing applies)
- Apply this template to *CN* – next slide

XSLT Evaluation Algorithm –
Application of a Template

- Application of template can cause these changes:

Case A: CN^R is replaced by a subtree

Example: *CN* = *Students* node in our document.   Assume our stylesheet has the following template instead of the initial template (it thus becomes best-matching):

```
<xsl:template  match=“//Students” >
        <StudentList>
                <xsl:apply-templates />
        </StudentList>
</xsl:template>
```

Then:

- CN^R is replaced with *StudentList*
- Each child of *CN* (*Students* node) is copied over to the output tree as a child of *StudentList*

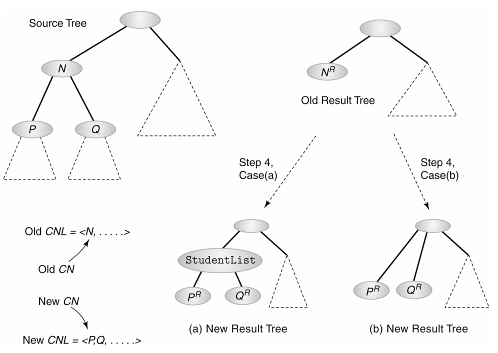
XSLT Evaluation Algorithm –
Application of a Template (cont'd)

Case B: CN^R is deleted and its children become children of the parent of CN^R

Example: The default template, below, deletes CN^R when applied to any node:

```
<xsl:template  match="* | /" >
        <xsl:apply-templates />
</xsl:template>
```

The Effect of apply-templates on Document Tree



(a) New Result Tree

(b) New Result Tree

XSLT Evaluation Algorithm (cont'd)

- In both cases (A & B):
  - If *CN* has no *et*-children, *CNL* becomes shorter
  - If it does have children, *CNL* is longer or stays the same length
  - The order in which *CN*'s children are placed on *CNL* is their order in the source tree
  - The new 1st node in *CNL* becomes the new *CN*
- Algorithm terminates when *CNL* is empty
  - Be careful – might not terminate (see next)

XSLT Evaluation Algorithm –Subtleties

- apply-templates instruction can have select attribute:
  - <xsl:apply-templates select="node()" /> – equivalent to the usual <xsl:apply-templates />
  - <xsl:apply-templates select="@* | text()" /> – instead of the *et*-children of *CN*, take *at*-children
  - <xsl:apply-templates select=".." /> – take the parent of *CN*
  - <xsl:apply-templates select="." /> – will cause an infinite loop!!
- Recipe to guarantee termination: make sure that *select* in apply-templates selects nodes only from a subtree of *CN*

Advanced Example

- *Example*: take any document and replace attributes with elements. So that

```
<Student  StudId="111111111">
  <Name>John Doe</Name>
  <CrsTaken  CrsCode="CS308"  Semester="F1997" />
</Student>
```

would become:

```
<Student>
  <StudId>111111111</StudId>
  <Name>John Doe</Name>
  <CrsTaken>
    <CrsCode>CS308</CrsCode> <Semester>F1997</Semester>
  </CrsTaken>
</Student>
```

Advanced Example (cont'd)

- *Additional requirement*: don't rely on knowing the names of the attributes and elements in input document – should be completely general. Hence:

1. Need to be able to output elements whose name is not known in advance (we don't know which nodes we might be visiting)
   - Accomplished with xsl:element instruction and Xpath functions current( ) and name( ):

```
<xsl:element  name="name(current())" >
        Where am I?
</xsl:element>
```

If the current node is *foobar*, will output:

```
<foobar>
        Where am I?
</foobar>
```

Advanced Example (cont'd)

2. Need to be able to copy the current element over to the output document
   - The *copy-of* instruction won't do: it copies elements over with all their belongings. But remember: *we don't want attributes to remain attributes*
   - So, use the copy instruction
     - Copies the current node to the output document, but without any of its children

```
<xsl:copy>
   … XSLT instructions, which fill in the body
      of the element being copied over …
</xsl:copy>
```

Advanced Example (cont'd)

```
<xsl:stylesheet … … …>
   <xsl:template match="node()">
         <xsl:copy>
            <xsl:apply-templates select="@*" />
            <xsl:apply-templates />
         </xsl:copy>
   <xsl:template>
    <xsl:template match="@*">
         <xsl:element name="name(current( ))" >
               <xsl:value-of select="." />
         </xsl:element>
   <xsl:template>
</xsl:stylesheet>
```

Process elements/text

Process a-children of current element

Process et-children of current element

Deal with attributes separately

Convert attribute to element

<… Attr="foo" >
becomes
<Attr>foo</Attr>

Limitations of XSLT as a Query Language

- Programming style unfamiliar to people trained on SQL
- Most importantly: Hard to do joins, i.e., *real* queries
  - Requires the use of variables (we didn't discuss)
  - Even harder than a simple nested loop (which one would use in this case in a language like C or Java)

XQuery – XML Query Language

- Integrates XPath with earlier proposed query languages: XQL, XML-QL
- SQL-style, not functional-style
- Much easier to use as a query language than XSLT
- Can do pretty much the same things as XSLT, but typically easier
- XQuery 1.0 standard late in 2002

XQuery Basics

- General structure:

```
FOR      variable declarations
WHERE    condition
RETURN   document
```

FLWR expression

- Example:

```
FOR $t IN document("http://xyz.edu/transcript.xml")/Transcript
WHERE   $t/CrsTaken/@CrsCode = "MAT123"
RETURN  $t/Student
```

- Result:

```
<Student StudId="111111111" Name="John Doe" />
<Student StudId="123454321" Name="Joe Blow" />
```

This document on next slide

---

transcript.xml

```
<Transcripts>
   <Transcript>
         <Student StudId="111111111"  Name="John Doe" />
         <CrsTaken  CrsCode="CS308"  Semester="F1997"  Grade="B" />
         <CrsTaken  CrsCode="MAT123"  Semester="F1997"  Grade="B" />
         <CrsTaken  CrsCode="EE101"  Semester="F1997"  Grade="A" />
         <CrsTaken  CrsCode="CS305"  Semester="F1995"  Grade="A" />
   </Transcript>
   <Transcript>
         <Student StudId="987654321"  Name="Bart Simpson" />
         <CrsTaken  CrsCode="CS305"  Semester="F1995"  Grade="C" />
         <CrsTaken  CrsCode="CS308"  Semester="F1994"  Grade="B" />
   </Transcript>
```

… … cont'd … …

transcript.xml (cont'd)

```
<Transcript>
        <Student StudId="123454321"  Name="Joe Blow" />
        <CrsTaken  CrsCode="CS315"  Semester="S1997"  Grade="A" />
         <CrsTaken  CrsCode="CS305"  Semester="S1996"  Grade="A" />
         <CrsTaken  CrsCode="MAT123"  Semester="S1996"  Grade="C" />
</Transcript>
<Transcript>
        <Student StudId="023456789"  Name="Homer Simpson" />
        <CrsTaken  CrsCode="EE101"  Semester="F1995"  Grade="B" />
         <CrsTaken  CrsCode="CS305"  Semester="S1996"  Grade="A" />
</Transcript>

</Transcripts>
```

XQuery Basics (cont'd)

- Previous query doesn't produce a well-formed XML document; the following does:

```
<StudentList>
{
      FOR  $t IN  document("transcript.xml")/Transcript
      WHERE  $t/CrsTaken/@CrsCode = "MAT123"
      RETURN  $t/Student
 }
 </StudentList>
```

FLWR inside XML

- FOR binds $t to Transcript elements one by one, filters using WHERE, then places Student-children as *e*-children of StudentList using RETURN

Document Restructuring with XQuery

- *Reconstruct lists of students taking each class using the* Transcript *records*:

```
FOR  $c  IN  distinct(document("transcript.xml")/CrsTaken)
RETURN
    <ClassRoster   CrsCode = {$c/@CrsCode}   Semester = {$c/@Semester}>
    {
      FOR  $t  IN  document("transcript.xml")/Transcript
      WHERE   $t/CrsTaken/@CrsCode = $c/CrsCode
                AND  $t/CrsTaken/@Semester = $c/@Semester
      RETURN   $t/Student
                  SORTBY ($t/Student/@StudId)
    }
    </ClassRoster>
    SORTBY ($c/@CrsCode)
```

FLWR inside RETURN – similar to query inside SELECT in OQL

Document Restructuring (cont'd)

- *Output elements have the form*:

```
<ClassRoster  CrsCode="CS305"  Semester="F1995" >
   <Student  StudId="111111111"  Name="John Doe" />
   <Student  StudId="987654321"  Name="Bart Simpson" />
</ClassRoster>
```

- *Problem*: the above element <u>will be output *twice*</u> – once when $c is bound to

```
<CrsTaken  CrsCode="CS305"  Semester="F1995"  Grade="A" />
```

and once when it is bound to

Bart Simpson's

John Doe's

```
<CrsTaken  CrsCode="CS305"  Semester="F1995"  Grade="C" />
```

Note: grades are different – distinct( ) won't eliminate transcript records that refer to same class!

Document Restructuring (cont'd)

- *Solution*: instead of

```
FOR  $c  IN  distinct(document("transcript.xml")/CrsTaken)
```

use

Document on next slide

```
FOR  $c  IN document("classes.xml")/CrsTaken
```

where classes.xml lists course offerings (course code/semester) *explicitly* (no need to extract them from transcript records).

Then $c is bound to each class exactly once, so each class roster will be output exactly once

http://xyz.edu/classes.xml

```
<Classes>
   <Class  CrsCode="CS308"  Semester="F1997" >
         <CrsName>SE</CrsName> <Instructor>Adrian Jones</Instructor>
   </Class>
   <Class  CrsCode="EE101"  Semester="F1995" >
         <CrsName>Circuits</CrsName> <Instructor>David Jones</Instructor>
   </Class>
   <Class  CrsCode="CS305"  Semester="F1995" >
         <CrsName>Databases</CrsName> <Instructor>Mary Doe</Instructor>
   </Class>
   <Class  CrsCode="CS315"  Semester="S1997" >
         <CrsName>TP</CrsName> <Instructor>John Smyth</Instructor>
   </Class>
   <Class  CrsCode="MAR123"  Semester="F1997" >
         <CrsName>Algebra</CrsName> <Instructor>Ann White</Instructor>
   </Class>
</Classes>
```

Document Restructuring (cont'd)

- *More problems*: the above query will list classes with no students. Reformulation that avoids this:

Test that classes aren't empty

```
FOR $c IN document("classes.xml")/CrsTaken
WHERE document("transcripts.xml")
            //CrsTaken[@CrsCode = $c/@CrsCode
                  and @Semester = $c/@Semester
RETURN
    <ClassRoster  CrsCode = {$c/@CrsCode}  Semester = {$c/@Semester>}
    {
      FOR $t IN document("transcript.xml")/Transcript
      WHERE  $t/CrsTaken/@CrsCode = $c/CrsCode
                AND $t/CrsTaken/@Semester = $c/@Semester
      RETURN  $t/Student  SORTBY ($t/Student/@StudId)
    } </ClassRoster>
  SORTBY ($c/@CrsCode)
```

XQuery Semantics

- So far the discussion was informal
- XQuery *semantics* defines what the expected result of a query is
- Defined analogously to the semantics of SQL

XQuery Semantics (cont'd)

- *Step 1*: Produce a list of bindings for variables
  - The FOR clause binds each variable to an *ordered* list of nodes specified by an XQuery expression.

    The expression can be:
    - An XPath expression
    - An XQuery query
    - A function that returns a list of nodes
  - End result of a FOR clause:
    - Ordered list of tuples of document nodes
    - Each tuple is a binding for the variables in the FOR clause

XQuery Semantics (cont'd)

Example (bindings):

- Let FOR declare $A and $B
- Bind $A to document nodes {v,w}; $B to {x,y,z}
- Then FOR clause produces the following list of bindings for $A and $B:
  - $A/v, $B/x
  - $A/v, $B/y
  - $A/v, $B/z
  - $A/w, $B/x
  - $A/w, $B/y
  - $A/w, $B/z

XQuery Semantics (cont'd)

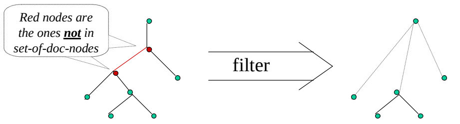
- *Step 2*: filter the bindings via the WHERE clause
  - Use each tuple-binding to substitute its conponents for variables; retain those bindings that make WHERE true
  - Example: WHERE $A/CrsTaken/@CrsCode = $B/Class/@CrsCode
    - Binding: $A/w, where w = <CrsTaken CrsCode="CS308" …/>
      $B/x, where x = <Class CrsCode="CS308" … />
    - Then w/CrsTaken/@CrsCode = x/Class/@CrsCode, so the WHERE condition is satisfied & binding retained

XQuery Semantics (cont'd)

- *Step 3*: Construct result
  - For each retained tuple of bindings, instantiate the RETURN clause
  - This creates a fragment of the output document
  - Do this for each retained tuple of bindings in sequence

The filter( ) Operator

- filter(*document*, *set-of-doc-nodes*)
  - *set-of-doc-nodes* specified using Xpath
  - Delete every node that *does not* occur in *set-of-doc-nodes* from *document*
    - *set-of-doc-nodes* is treated literally as a set of nodes; children not included
  - Connect disconnected children to appropriate ancestor



Red nodes are the ones ***not*** *in set-of-doc-nodes*

The filter( ) operator (cont'd)

- *Example*: filtering http://xyz.edu/classes.html

  filter(//Class, //Class | //Class/CrsName)

  yields:

  <Class><CrsName>SE</CrsName></Class>
  <Class><CrsName>Circuits</CrsName></Class>
  <Class><CrsName>Databases</CrsName></Class>
  <Class><CrsName>TP</CrsName></Class>
  <Class><CrsName>Algebra</CrsName></Class>

  Deleted nodes:

  /Classes/Class/@CrsCode, /Classes/Class/@Semester, /Classes/Class/Instructor

---

Fixing the Restructuring Query Using filter( )

Declare variable, a syntactic sugar

Get rid of @Grade and thus of duplicate CrsTaken elements

```
LET $ct := document("transcript.xml")/Transcript/CrsTaken
FOR $c IN distinct(filter($ct, $ct | $ct/@CrsCode | $ct/@Semester))
RETURN
   <ClassRoster  CrsCode = {$c/@CrsCode}  Semester = {$c/@Semester} >
   {
     FOR $t IN document("transcript.xml")/Transcript
     WHERE  $t/CrsTaken/@CrsCode = $c/CrsCode
               AND $t/CrsTaken/@Semester = $c/@Semester
     RETURN  $t/Student
                  SORTBY ($t/Student/@StudId)
   }
   </ClassRoster>
   SORTBY ($c/@CrsCode)
```

User-defined Functions

- Can define functions, even recursive ones
- Functions can be called from within a FLWR expression
- Body of function is an XQuery expression
- Result of expression is returned
  - Result can be a primitive data type (integer, string), an element, a list of elements, a list of arbitrary document nodes, …

XQuery Functions: Example

- Count the number of *e*-children recursively:

Function signature

```
DEFINE FUNCTION countNodes(element $e) RETURNS integer {
   RETURN
     IF empty($e/*) THEN 0
     ELSE
        sum(FOR $n IN $e/* RETURN countNodes($n))
          + count($e/*)
}
```

XQuery expression

Built-in functions sum, count, empty

Class Rosters (again) Using Functions

```
DEFINE FUNCTION  extractClasses(element $e)  RETURNS element* {
   FOR $c IN $e//CrsTaken
   RETURN <Class CrsCode={$c/@CrsCode} Semester={$c/@Semester} />
}
<Rosters>
    FOR $c IN
          distinct( FOR $d IN document("transcript.xml") RETURN extractClasses($d) )
    RETURN
       <ClassRoster  CrsCode = {$c/@CrsCode}  Semester = {$c/@Semester} >
       {
         LET $trs := document("transcript.xml")
         FOR $t IN $trs//Transcript[CrsTaken/@CrsCode=$c/@CrsCode and
                                                CrsTaken/@Semester=$c/@Semester]
         RETURN  $t/Student
         SORTBY ($t/Student/@StudId)
       }
       </ClassRoster>
</Rosters>
```

Converting Attributes to Elements with XQuery

- An XQuery reformulation of a previous XSLT query – much more straightforward (but ignores text nodes)

```
DEFINE FUNCTION convertAttributes(attribute $a) RETURNS element {
   RETURN element {name($a)} {value($a)}
}
FUNCTION convertElement($e) RETURNS AnyElement {
   RETURN element {name($a)}
     {
        { FOR $a IN $e/@* RETURN convertAttribute ($a) }
        IF empty($e/*) THEN $e/text( )
        ELSE { FOR $n IN $e/* RETURN convertElement($n) }
     }
}

RETURN convertElement(document("my-document")/*)
```

Computed element

The actual query:
Just a RETURN statement!!

Integration with XML Schema and Namespaces

- Let type FOO be defined in http://types.r.us/types.xsd:

Namespace

Location

```
SCHEMA "http://types.r.us at http://types.r.us/types.xsd"
NAMESPACE trs = "http://types.r.us"
NAMESPACE xsd = "http://www.w3.org/2001/XMLSchema"
FUNCTION doSomething( trs:FOO $x )
                              RETURNS xsd:string {
   … … …
}
```

Prefix for namespace

Grouping and Aggregation

- Does not use separate grouping operator
  - Recall that OQL does not need one either
  - Subqueries inside the RETURN clause obviate this need (like subqueries inside SELECT did so in OQL)
- Uses built-in aggregate functions count, avg, sum, etc. (some borrowed from XPath)

Aggregation Example

- *Produce a list of students along with the number of courses each student took*:

```
FOR $t IN document("transcripts.xml")//Transcript,
     $s IN $t/Student
LET  $c := $t/CrsTaken
RETURN
     <StudentSummary StudId = {$s/@StudId} Name = {$s/@Name}
                        TotalCourses = {count(distinct($c))} />
SORTBY (StudentSummary/@TotalCourses)
```

- The *grouping effect* is achieved because $c is bound to a *new* set of nodes for *each* binding of $t

Quantification in XQuery

- XQuery supports explicit quantification: SOME (∃) and EVERY (∀)
- *Example*:

```
FOR $t IN document("transcript.xml")//Transcript
WHERE SOME $ct IN $t/CrsTaken
             SATISFIES $ct/@CrsCode = "MAT123"
RETURN $t/Student
```

Almost equivalent to:

```
FOR $t IN document("transcript.xml")//Transcript,
     $ct IN $t/CrsTaken
WHERE $ct/@CrsCode = "MAT123"
RETURN $t/Student
```

- – *Not equivalent, if students can take same course twice*!

Implicit Quantification

- Note: in SQL, variables that occur in FROM, but not SELECT are implicitly quantified with ∃
- In XQuery, variables that occur in FOR, but not RETURN are similar to those in SQL. However:
  - In XQuery variables are bound to document nodes
    - Two nodes may look textually the same (e.g., two different instances of the same course element), but they are still different nodes and thus different variable bindings
    - Instantiations of the RETURN expression produced by binding variables to different nodes are output even if these instantiations are textually identical
  - In SQL a variable can be bound to the same value only once; identical tuples are not output twice (in theory)
  - *This is why the two queries in the previous slide are not equivalent*

Quantification (cont’d)

- Retrieve all classes (from classes.xml) where each student took MAT123
  - Hard to do in SQL (before SQL-99) because of the lack of explicit quantification

```
FOR  $c  IN  document(classes.xml)//Class
LET  $g := {  -- Transctipt records that correspond to class $c
   FOR  $t  IN  document(“transcript.xml”)//Transcript
   WHERE  $t/CrsTaken/@Semester = $c/@Semester
               AND  $t/CrsTaken/@CrsCode = $c/CrsCode
   RETURN  $t
             }
WHERE  EVERY  $tr  IN  $g  SATISFIES
                         NOT empty($tr[CrsTaken/@CrsCode=“MAT123])
RETURN  $c  SORTBY($c/@CrsCode)
```