XML and Web Data

CSE219, Computer Science III

Stony Brook University

http://www.cs.stonybrook.edu/~cse219

Content

- Semistructured data
- XML & DTD
- 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
- SQL/XML – XML extensions of SQL
- Java XML parsing example

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 <u>specifically designed</u> to work with XML documents rather than relational or object-oriented data
- XML is closely related to object-oriented and so-called *semistructured* data

Semistructured Data

- An HTML document to be displayed on the Web:

```
<dt>Name: John Doe
    <dd>Id: s111111111
    <dd>Address:  <ul>
                   <li>Number: 123</li>
                   <li>Street:    Main</li>
                 </ul>
</dt>
<dt>Name: Joe Public
    <dd>Id: s222222222
     … … … …
</dt>
```

HTML does not distinguish between attributes and values

What is Self-describing Data?

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

Data part:

(#123, [“Students”, {[“John”, s111111111, [123,”Main St”]],
[“Joe”, s222222222, [321, “Pine St”]] }
])

Schema part:

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

What is Self-Describing Data?

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

(#12345,
    [*ListName*: "Students",
     Contents: { [*Name*: "John Doe",
                    Id: "s111111111",
                    Address: [*Number*: 123, *Street*: "Main St."]] ,
                   [*Name*: "Joe Public",
                   Id: "s222222222",
                   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
    - Self-describing
    - Doesn't require a schema (but can be provided optionally)
- More:
  - DTDs – an older way to specify schema
  - XML Schema – a newer, more powerful (and <u>much</u> more complex!) way of specifying schema
  - Query and transformation languages:
    - XPath
    - XSLT
    - XQuery
    - SQL/XML

Overview of XML

- Like HTML, but any number of different tags can be used (up to the document author) – extensible
- 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 special
  - Some semantics can be specified using XML Schema (types); some using stylesheets (browser rendering)
- Unlike HTML, is intolerant to bugs
  - Browsers will render buggy HTML pages
  - *XML processors* are not supposed to process buggy XML documents

Example

attributes

```
<?xml  version=“1.0” ?>

<PersonList Type=“Student”  Date=“2002-02-02” >
    <Title  Value=“Student List” />
    <Person>
    … … …
    </Person>
    <Person>
    … … …
    </Person>
</PersonList>
```

elements

Root element

Element (or tag) names

- Elements are nested
- Root element contains all others

More Terminology

Opening tag

<Person Name = “John” Id = “s111111111”>

Content of Person

John is a nice fellow

“standalone” text, not very useful as data, non-uniform

<Address>

<Number>21</Number>

<Street>Main St.</Street>

</Address>

Nested element, child of Person

Child of Address, *Descendant of* Person

… … …

Parent of Address, *Ancestor of* number

</Person>

Closing tag: What is open must be closed

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. If it occurs,
    - It *must have an explicitly specified 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 (in a DTD – see later) 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 a unique element with matching ID attribute (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="s111111111">
      <Name><First>John</First><Last>Doe</Last></Name>
    <Status>U2</Status>
      <CrsTaken CrsCode="CS308" Semester="F1997" />
      <CrsTaken CrsCode="MAT123" Semester="F1997" />
    </Student>
    <Student StudId="s666666666">
      <Name><First>Joe</First><Last>Public</Last></Name>
    <Status>U3</Status>
      <CrsTaken CrsCode="CS308" Semester="F1994" />
      <CrsTaken CrsCode="MAT123" Semester="F1997" />
    </Student>
    <Student StudId="s987654321">
      <Name><First>Bart</First><Last>Simpson</Last></Name>
    <Status>U4</Status>
      <CrsTaken CrsCode="CS308" Semester="F1994" />
    </Student>
  </Students>
…… continued … …
```

ID

IDREF

Report Document

```
<Classes>
  <Class>
    <CrsCode>CS308</CrsCode> <Semester>F1994</Semester>
    <ClassRoster  Members="s666666666  s987654321" />
  </Class>
  <Class>
    <CrsCode>CS308</CrsCode> <Semester>F1997</Semester>
    <ClassRoster  Members="s111111111" />
  </Class>
  <Class>
    <CrsCode>MAT123</CrsCode> <Semester>F1997</Semester>
    <ClassRoster  Members="s111111111  s666666666" />
  </Class>
</Classes>
```

IDREFS

…… *continued* … …

Report Document

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 (*doesn't need to point to a real page*)
  - *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:

Default namespace

```
<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>
```

toy *namespace*

reserved keyword

Namespaces (cont'd.)

- 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 (cont'd.)

- 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.,
  - **xs** 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 <u>not required to check validity</u>, 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*…)/EMPTY/ANY >

Element's contents

<!ATTLIST *elt-name* *attr-name*

CDATA/ID/IDREF/IDREFS

#IMPLIED/#REQUIRED

>

An attr for elt

Type of attribute

Optional/mandatory

- Can define other things, like macros (called *entities* in the XML jargon)

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 CDATA #IMPLIED>
    <!ATTLIST Student StudId ID #REQUIRED>
    <!ATTLIST Course CrsCode ID #REQUIRED>
    <!ATTLIST CrsTaken CrsCode IDREF #REQUIRED>
    <!ATTLIST ClassRoster Members IDREFS #IMPLIED>
]>
```

Zero or more

Has text content

Empty element, no content

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 Document and Namespaces

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

- Uses standard XML syntax.
- http://www.w3.org/2001/XMLSchema – namespace for keywords used in a schema document (*not* an instance document), e.g., "*schema*", *targetNamespace*, etc.
- targetNamespace – names the namespace defined by the above schema.

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" >
    …
</Report>
```

Default namespace for instance document

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

Schema namespace

Schema location

- 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 <u>not binding</u> 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 the C language
  - Included schemas must have the same targetNamespace as the including schema
- schemaLocation – tells where to find the piece to be included

Simple Types

- *Primitive types*: *decimal*, *integer*, *Boolean*, *string*, ID, IDREF, etc. (defined in XMLSchema namespace)
- *Type constructors*: *list* and *union*
  - A simple way to derive types from primitive types (disregard the namespaces for now):

```
<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

targetNamespace = http://xyz.edu/Admin
xmlns:adm= http://xyz.edu/Admin

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

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

XML ID types always start with a letter

Prefix for the target namespace

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>
```

Schema Document That Defines 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

Complex Types

- Allows the definition of 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, Sets, Alternatives

- *Compositors*:
  - *sequence*, *all*, *choice* are required when element has at least 1 child element (= *complex content*)
- sequence
- all – can specify sets of elements
- choice – can specify alternative types

Sets

- Suppose the order of components in addresses is unimportant:

```
<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; only sets of elements, not bags.

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 at 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 (e.g., *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)
    - schemaLocation attribute required
  - *Import*:
    - Schemas are under the control of different groups
    - Target namespaces are different
    - The import statement must tell the importing schema what that target namespace is
    - schemaLocation attribute optional

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 Restriction 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 (i.e., 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

Defined

Used

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="studentType" >
      <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>
  </complexType>
  <element name="Student" type="fooAdm:studentType" />
```

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 or imported

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

No type name

```
<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>
```

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.

Basic XPath – for Key Specification

```
<Offerings>        -- current reference point
   <Offering>
        <CrsCode Section=“1”>CS532</CrsCode>

        <Semester><Term>Spring</Term><Year>2002</Year></Semest
   er>
   </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 *within* CrsCode *within* Offerings

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

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

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

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>
      … … key specification goes here – next slide … …
   </element>
   <element name="Courses" … />
  <sequence>
</complexType>
```

Example (cont'd)

- A key specification:

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

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

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

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

field *must return exactly one value per object specified by* selector

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

```
<keyref name="NoEmptyClasses" refer="adm:PrimaryKeyForClass" >
    <selector xpath="Student/CrsTaken" />
    <field xpath="@CrsCode" />
    <field xpath="@Semester" />
</keyref>
```

Target key

Source collection

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

XML Query Languages

- XPath – core query language. Very limited, a selection operator. Very useful, though: used in XML Schema, XSLT, XQuery, many other XML standards
- XSLT – a functional style document transformation language. Very powerful, very complicated
- XQuery – W3C standard. Very powerful, fairly intuitive, SQL-style.
- SQL/XML – attempt to marry SQL and XML, part of SQL:2003.

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

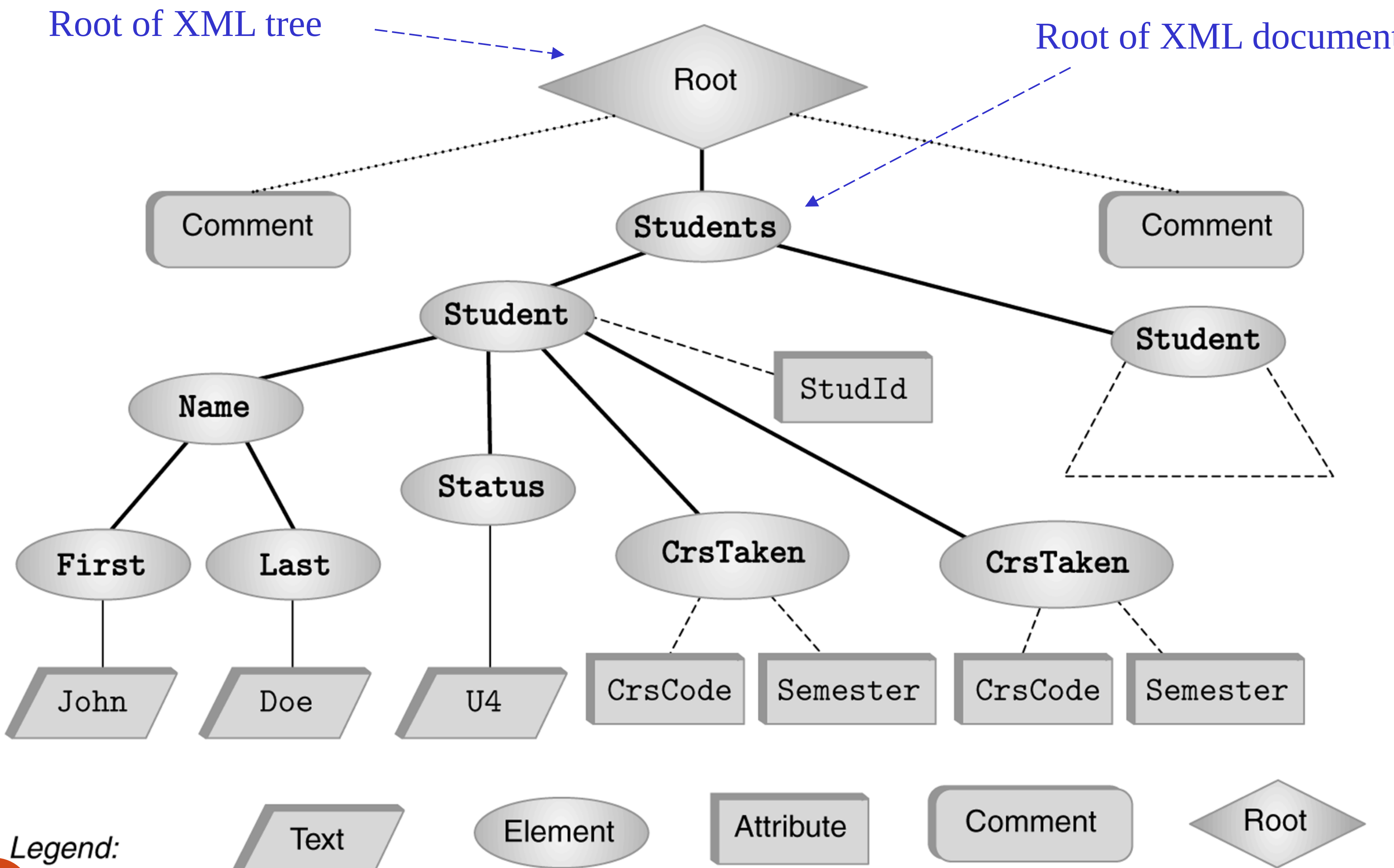
XPath

- 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 *new* node, which doesn't correspond to anything in the document
  - Internal nodes are elements
  - Leaves are either
    - Attributes
    - Text nodes
    - Comments
    - Other: processing instructions, etc.

XML Example

```
<?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>
```

XPath Document Tree



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

- An XPath expression takes a document tree as input and returns a multi-set of nodes of the tree
- Expressions that *start* with / are *absolute path expressions*
  - Expression / – returns root node of XPath tree
  - /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)

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 children of the root
- /Students/Student/Name/Last/text( ) – returns all t-children of Last e-children of …
- /comment( ) – returns comment nodes under root

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*
  - *ancestor, descendant, ancestor-or-self, descendant-or-self*
- *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

Algorithm

- locationStep1/locationStep2/…:
  - 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

Navigation Primitives

- 2nd CrsTaken child of 1st Student child of Students:
  /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
- The * wildcard:
  - * – any element: Student/*/text()
  - @* – any attribute: Students//@*

XPath Queries (selection predicates)

- 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] $\subseteq$ Axis::nodeSelector but contains only the nodes that satisfy predicate
- Built-in predicate: special predicates for string matching, set manipulation, etc.
- Built-in function: large assortment of functions for string manipulation, aggregation, etc.

XPath Queries – Examples

- Students who have taken CSE532:

  //Student[CrsTaken/@CrsCode="CSE532"]

  True if : "CSE532" ∈ //Student/CrsTaken/@CrsCode

- Complex example:

  //Student[Status="U3" and starts-with(.//Last, "A")
  and contains(.//@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
- 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="S2012"])

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*:

Processing instruction

Preamble

```
<?xml version="1.0" ?>
… … …
<?xml-stylesheet type="text/xsl"

href="http://xyz.edu/Report/report.xsl" ?>
… … …
<Report Date="2002-11-11">
… … …
</Report>
```

XSLT Example

- *Extract the list of all students* from a 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>
```

XSLT Example

```
<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
- *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
- 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 <u>smallest</u> (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

Recursive 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

- *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.

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

<u>Example</u>: *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*

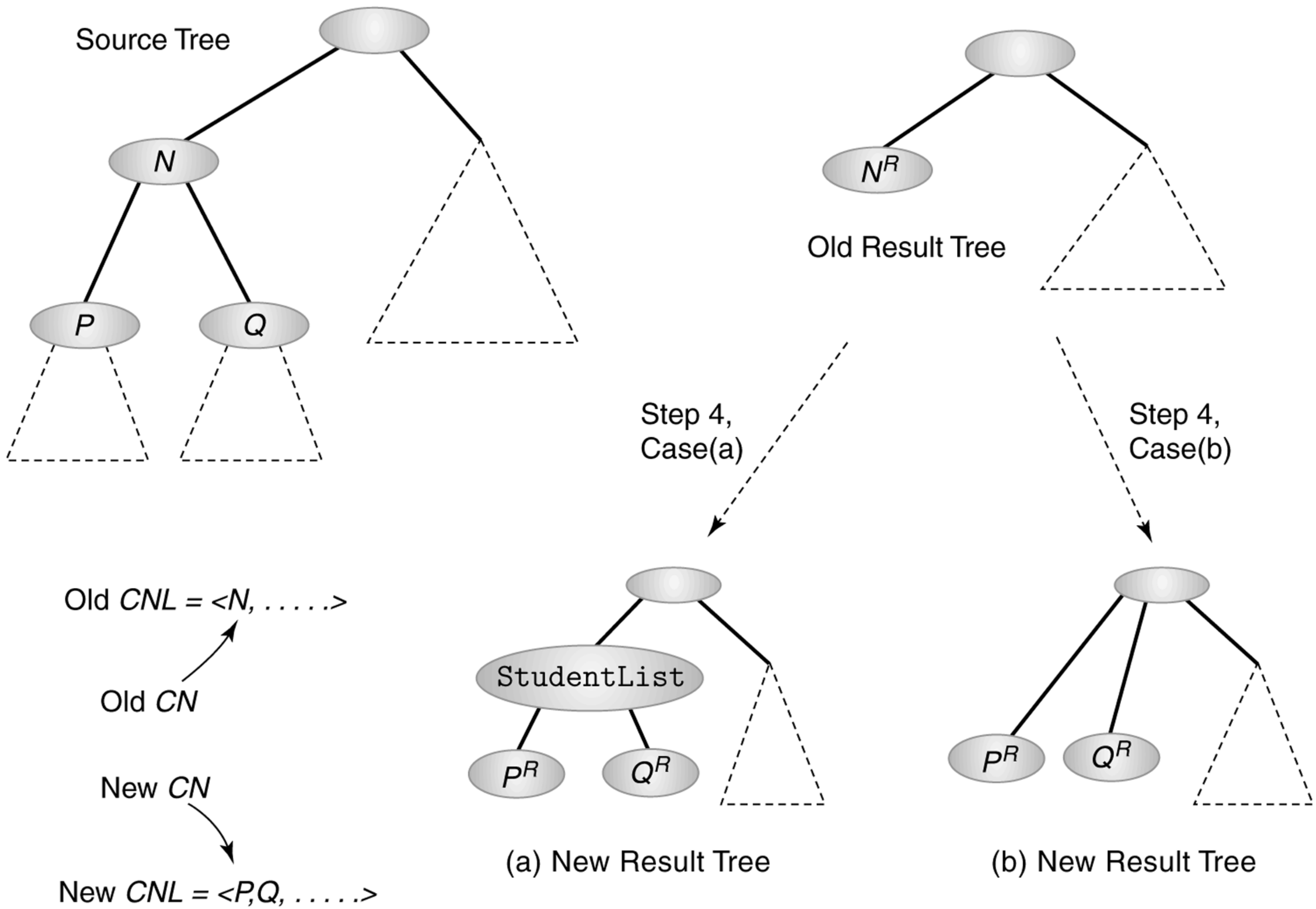
XSLT Evaluation Algorithm – Application of a Template

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



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 <u>without any of its children</u>

```
<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
  - 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 amd more, but typically easier
- 2004: XQuery 1.0

Consider 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

- General structure:

  FOR *variable declarations*
  WHERE *condition*
  RETURN *document*

XQuery expression

- Example:

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

comment

- Result:

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

XQuery Basics (cont'd)

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

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

Query 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

Consider 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>
```

Result

<StudentList>

<Student StudId="111111111" Name="John Doe" />

<Student StudId="123454321" Name="Joe Blow" />

<StudentList>

Document Restructuring with XQuery

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

```
FOR $c IN distinct-values(doc("transcript.xml")//CrsTaken)
RETURN
   <ClassRoster  CrsCode = {$c/@CrsCode}
                 Semester = {$c/@Semester}>
   {
      FOR $t IN doc("transcript.xml")//Transcript
      WHERE  $t/CrsTaken/[@CrsCode = $c/@CrsCode and
                          @Semester = $c/@Semester]
      RETURN  $t/Student
                ORDER BY $t/Student/@StudId
   }
   </ClassRoster>
   ORDER BY $c/@CrsCode
```

Query inside RETURN – similar to query inside SELECT

Consider 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>
```

Result

```
<ClassRoster  CrsCode=“CS305”  Semester=“F1995”>
        <Student StudId=“111111111”  Name=“John Doe” />
        <Student StudId=“987654321”  Name=“Bart Simpson” />
</ClassRoster>
<ClassRoster  CrsCode=“CS305”  Semester=“F1995”>
        <Student StudId=“111111111”  Name=“John Doe” />
        <Student StudId=“987654321”  Name=“Bart Simpson” />
</ClassRoster>
<ClassRoster  CrsCode=“CS308” Semester=“F1994”>
        <Student StudId=“987654321”  Name=“Bart Simpson” />
</ClassRoster>
<ClassRoster  CrsCode=“CS308” Semester=“F1997”>
        <Student StudId=“111111111”  Name=“John Doe” />
</ClassRoster>
<ClassRoster  CrsCode=“EE101”  Semester=“F1997”>
        <Student StudId=“111111111”  Name=“John Doe” />
</ClassRoster>
...
```

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" />

The statement distinct-values( ) won't eliminate transcript records that refer to same class BECAUSE the grades are different!!!

Document Restructuring (cont'd)

- *Solution*: instead of

```
FOR $c IN distinct-values(doc("transcript.xml")//CrsTaken)
```

use

```
FOR $c IN doc("classes.xml")//Class
```

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 doc("classes.xml")//Class
WHERE  doc("transcripts.xml")
                    //CrsTaken[@CrsCode = $c/@CrsCode
                         and  @Semester = $c/@Semester]
RETURN
   <ClassRoster  CrsCode = {$c/@CrsCode}  Semester = {$c/@Semester}> {
       FOR $t IN doc("transcript.xml")//Transcript
       WHERE  $t/CrsTaken[@CrsCode = $c/@CrsCode and
                          @Semester = $c/@Semester]
       RETURN  $t/Student  ORDER BY $t/Student/@StudId
   } </ClassRoster>
ORDER BY  $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 a *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 components 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

User-defined Functions

- Can define functions, even recursive ones
- Functions can be called from within an XQuery 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

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

XQuery expression

Built-in functions sum, count, empty

Class Rosters Using Functions

```
DECLARE FUNCTION  extractClasses($e AS element())  AS element()* {
    FOR $c IN $e//CrsTaken
    RETURN <Class CrsCode={$c/@CrsCode} Semester={$c/@Semester} />
}
<Rosters>
    FOR $c IN
        distinct-values(FOR $d IN doc("transcript.xml") RETURN extractClasses($d) )
    RETURN
        <ClassRoster  CrsCode = {$c/@CrsCode}  Semester = {$c/@Semester} >
        {
          LET $trs := doc("transcript.xml")
            FOR $t IN $trs//Transcript[CrsTaken/@CrsCode=$c/@CrsCode and
                                       CrsTaken/@Semester=$c/@Semester]
            RETURN $t/Student
          ORDER BY $t/Student/@StudId
        }
        </ClassRoster>
</Rosters>
```

Converting Attributes to Elements with XQuery

```
DECLARE FUNCTION convertAttributes($a AS attribute()) AS element() {
   RETURN element {name($a)} {data($a)}
}
DECLARE FUNCTION convertElement($e AS node()) AS element() {
   RETURN    element {name($e)}
          {
             { FOR $a IN $e/@* RETURN convertAttribute ($a) } ,
             IF empty($e/*) THEN $e/text( )
             ELSE { FOR $n IN $e/* RETURN convertElement($n) }
          }
}

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

Concatenate results

Computed element

The actual query: Just a RETURN statement!!

Integration with XML Schema and Namespaces

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

```
IMPORT SCHEMA  namespace trs = "http://types.r.us"
                              AT  "http://types.r.us/types.xsd";
DECLARE NAMESPACE  foo = "http://foo.org/foo";
DECLARE FUNCTION   local:doSomething($x  AS  trs:sometype)
                                                     AS  xs:string  {

FOR  $i  IN  fn:doc(...);
      ... ... ...
RETURN
    <foo:something>
           .........
    </foo:something>
}
```

Namespace

Location

Predefined namespace

Another namespace

Built-in functions have predefined namespaces

Local functions have predefined namespace

Grouping and Aggregation

- Does not use separate grouping operator
  - Subqueries inside the RETURN clause obviate this need
- 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 fn:doc("transcripts.xml")//Transcript,
        $s IN $t/Student
LET $c := $t/CrsTaken
RETURN
    <StudentSummary StudId = {$s/@StudId} Name = {$s/@Name}
                    TotalCourses = {fn:count(fn:distinct-values($c))} />
ORDER BY 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 fn:doc("transcript.xml")//Transcript
WHERE SOME $ct IN $t/CrsTaken
            SATISFIES $ct/@CrsCode = "MAT123"
RETURN $t/Student
```

"Almost" equivalent to:

```
    FOR $t IN fn:doc("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 <u>different nodes</u> are output <u>even if these instantiations are textually identical</u>
  - 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 fn:doc(classes.xml)//Class
LET $g := {          (: Transctipt records that correspond to class $c :)
   FOR $t IN fn:doc("transcript.xml")//Transcript
   WHERE $t/CrsTaken/@Semester = $c/@Semester
               AND $t/CrsTaken/@CrsCode = $c/@CrsCode
   RETURN $t
        }
WHERE EVERY $tr IN $g SATISFIES
                    NOT fn:empty($tr[CrsTaken/@CrsCode="MAT123])
RETURN $c ORDER BY $c/@CrsCode
```

SQL/XML – Extending Reach of SQL to XML Data

- In the past, SQL was extended for O-O:
  - added values for reference, tuple(row type), and collection(arrays), …
  - took over ODL and OQL standards of ODMG
- Currently, SQL is being extended for XML:
  - adding data types and functions to handle XML
  - will it bring the demise of XQuery?

Why SQL/XML

- Publish contents of SQL tables or entire DB as XML documents – need convention for translating primitive SQL data types
- Create XML documents out of SQL query results – need extension of SQL queries to create XML elements
- Store XML documents in relational DBs and query them – need extension of SQL to use XPath to access the elements of tree structures

Publishing Relations as XML Documents

- Current proposal:
  - no built-in functions to convert tables to XML
  - but can create arbitrary XML documents using extended SELECT statements
- Encoding relational data in XML:
  - Entire relation: an element named after the relation
  - Each row: an element named row
  - Each attribute: an element named after the attribute

Publishing Relations as XML Doc: Tables

Professor

Id	*Name*	*DeptId*
1024	Bob Smith	CS
3093	Amy Doe	EE
…		

<Professor>

<row>

<Id>1024</Id><Name>Bob Smith</Name><DeptId>CS<DeptId>

</row>

< row>

<Id>3093</Id><Name>Amy Doe</Name><DeptId>EE<DeptId>

</row >

…

</Professor>

Publishing Relations as XML Documents

SQL: CREATE TABLE Professor

Id: INTEGER,

Name: CHAR(50),

DeptId: CHAR(3)

XML Schema:

```
<schema xmlns="http://www.w3.org/2001/XMLSchema"
        targeNamespace="http://xyz.edu/Admin">
  <element name="Professor">
    <complexType>
      <sequence>
        <element name="row" minOccurs="0" maxOccurs="unbounded">
          <complexType>
            <sequence>
              <element name="Id" type="integer"/>
              <element name="Name" type="CHAR_50"/>
              <element name="DeptId" type="CHAR_3"/>
            </sequence>
          </complexType>
        </element>
      </sequence>
    </complexType>
  </element>
</schema>
```

Publishing Relations as XML Doc: Schema

- CHAR_*len*: standard conventions in SQL/XML for CHAR(*len*) in SQL.
  - For instance, CHAR_50 is defined as

```
<simpleType>
  <restriction base="string">
        <length value="50">
  </restriction>
</simpleType>
```

- A lot of the SQL/XML standard deals with such data conversion, and with user-defined types of XML, which are defined in SQL using CREATE DOMAIN.

Creating XML from Queries: Functions

XMLELEMENT, XMLATTRIBUTES

- An SQL query does not return XML directly. Produces *tables* that can have columns of type **XML**.

```
SELECT  P.Id,  XMLELEMENT (
    NAME  "Prof",                                  -- element name
    XMLATTRIBUTES (P.DeptId AS "Dept"),            -- attributes
    P.Name                                         -- content
  ) AS  Info
 FROM  Professor P
```

Produces tuples of the form

1024, <Prof Dept="CS">Bob Smith</Prof>

3093, <Prof Dept="EE">Amy Doe</Prof>

Creating XML Using Queries: Functions XMLELEMENT, XMLATTRIBUTES

- XMLELEMENT can be nested:

```
SELECT XMLELEMENT (NAME "Prof"
                XMLELEMENT(NAME "Id", P.Id),
                XMLELEMENT(NAME "Name", P.Name),
                XMLELEMENT(NAME "DeptId", P.DeptId),
               ) AS ProfElement
FROM   Professor  P
```

Produces tuples of the form

```
<Prof>
    <Id>1024</Id><Name>Bob Smith</Name><DeptId>CS</DeptId>
</Prof>
<Prof>
    <Id>3093</Id><Name>Amy Doe</Name><DeptId>EE</DeptId>
</Prof>
```

Creating XML Using Queries: Function XMLQUERY

```
SELECT XMLQUERY ('<Prof>
                    <Id>{$I}</Id><Name>{$N}</Name><DeptId>{$D}</DeptId>
                  </Prof>'          -- template with placeholder variables
                 PASSING BY VALUE
                   P.Id AS I,       -- values of  I substitute for placehoders
                   P.Name AS N,
                   P.DeptId AS D
                RETURNING SEQUENCE
                ) AS  ProfElement
 FROM Professor P
```

Can be expressions

- Placeholder can occur in positions of XML elements and attributes
- Expressions can be XML-generating expressions or SELECT statements
  - In the example above, could have

```
SELECT QUERY('<Prof>
                 {$I} <Name>{$N}</Name> …
              </Prof>'
              PASSING BY VALUE XMLELEMENT(NAME "Id", P.Id)   AS   I
              ….
```

- In general, the argument to XMLQUERY can include any XQuery expression (XPath or a full query)

Creating XML from Queries: Grouping without GROUP BY

- In XQuery: group elements as children of another element by putting a subquery in RETURN clause of parent query.
- In SQL/XML: group by putting SELECT inside XMLELEMENT in the SELECT clause of parent.
- Example: group the CrsTaken by student Ids

```
SELECT  XMLELEMENT (
     NAME "Student",
     XMLATTRIBUTES(S.Id AS "Id"),
     (SELECT  XMLELEMENT(NAME "CrsTaken",
                          XMLATTRIBUTES(T.CrsCode AS "CrsCode",
                                        T.Semester AS "Semester") )
      FROM  Transcript T
      WHERE S.Id=T.StudId))
FROM  Student  S
```

Returns a set of 1-tuples, not list of elements.
Waiting for the standard to resolve how to convert.

Creating XML from Queries: Grouping and XMLAGG

- Same example: group CrsTaken by student ids

```
SELECT  XMLELEMENT (
  NAME "Student",
  XMLATTRIBUTES(S.Id AS "Id"),
  XMLAGG(XMLELEMENT(Name "CrsTaken",
                              XMLATTRIBUTES(T.CrsCode AS "CrsCode",
                                                    T.Semester AS "Semester") )
        ORDER BY  T.CrsCode)  )
FROM  Student S, Transcript T
WHERE  S.Id = T.StudId
GROUP BY S.Id
```

Storing XML in Relational DB: Data Type XML

- Not stored as a string, but natively as a *tree structure*. Supports navigation via efficient storage and indexing.

```
CREATE TABLE StudentXML (
  Id INTEGER,
  Details       XML )
```

where Details attribute contains things of the form

```
<Student>
  <Name><First>Amy</First><Last>Doe</Last></Name>
  <Status>U4</Status>
  <CrsTaken CrsCode="305" Semester="F2003"/>
  <CrsTaken CrsCode="336" Semester="F2003"/>
</Student>
```

Storing XML in Relational DB: Data Type XML

- To validate, use

```
CREATE TABLE StudentXML (
   Id          INTEGER,
   Details     XML,
   CHECK(Details IS VALID ACCORDING TO SCHEMA
                 'http://xyz.edu/student.xsd') )
```

assuming the schema is stored at http://xyz.edu/student.xsd

Querying XML Stored in Relations: XMLEXISTS

- Tells whether the set of nodes returned by XPath expression is empty.
- Example: return Ids and names of students who have taken *a* course

```
SELECT   S.Id,   XMLEXTRACT(S.Details, '//Name')
FROM     StudentXML  S
WHERE    XMLEXISTS(XMLQUERY(
                        '$D//CrsTaken'
                        PASSING BY REF  S.Details AS D
                        RETURNING SEQUENCE))
```

Querying XML Stored in Relations (cont'd)

- Use XQuery expressions and XMLEXIST function.
- XMLQUERY can be both in SELECT and WHERE clauses.
- Example: return Ids and names of students who have status U3 and took MAT123:

```
SELECT  S.Id,  XMLQUERY(S.Details, '$D//Name'
                    PASSING BY REF  S.Details AS D
                    RETURNING SEQUENCE)
FROM   StudentXML  S
WHERE XMLEXISTS(XMLQUERY(
          'WHERE  $D//Status/text( ) ="U3"  AND
                  $D//CrsTaken/@CrsCode = "MAT124"
           RETURN $D'
          PASSING BY REF  S.Details AS  D
          RETURNING SEQUENCE ))
```

Modifying Data in SQL/XML:
XMLPARSE

- XML stored as appropriately indexed tree structure, but in SQL is specified as a sequence of characters – so need to parse:

```
INSERT INTO StudentXML(Id, Details)
VALUES(12343,
        XMLPARSE(
          '<Student>
              <Name><First>Bob</First><Last>Smith</Last></Name>
              <Status>U4</Status>
              <CrsTake CrsCode="CS305" Semester="F2003"/>
              <CrsTake CrsCode="CS339" Semester="S2004"/>
          </Student>' ) )
```

Modifying Data in SQL/XML:
IS VALID ACCORDING TO SCHEMA

- To validate inserted document:

```
INSERT  INTO  StudentXML(Id, Details)
 VALUES(12343,
            XMLPARSE(
               '<Student>
                    <Name><First>Bob</First><Last>Smith</Last></Name>
                    <Status>U4</Status>
                    <CrsTake CrsCode="CS305" Semester="F2003"/>
                    <CrsTake CrsCode="CS339" Semester="S2004"/>
                </Student>‘ )
            IS VALID ACCORDING TO SCHEMA ‘http://xyz.edu/Students.xsd’
```

XMLSERIALIZE: Reverse of XMLPARSE

- To convert XML back to a string.
  - Typically used to talk to a host language that does not understand XML
- XMLSERIALIZE is often used in embedded SQL in conjunction with *cursors*
  - Example: return Ids and names of professors. Professors' names are returned as '<Prof>Joe</Prof>'.

```
EXEC SQL DECLARE  GetProfessor  CURSOR FOR
 SELECT  P.Id,  XMLSERIALIZE(XMLELEMENT(Name "Prof", P.Name))
 FROM  Professor  P
```

This can then be processed by

```
EXEC SQL  GetProfessor  INTO  :profId, :name
```

XML Parsing example

- cities.xml:

```
<routes>
    <city>
            <name>CORK</name>
            <land>
                    <city>DUBLIN</city>
            </land>
            <sea></sea>
    </city>
    <city>
            <name>FAROER</name>
            <land></land>
            <sea>
                    <city>REYKJAVIK</city>
                    <city>SHETLAND_ISLANDS</city>
            </sea>
    </city>
    …
```

```
import javax.xml.parsers.DocumentBuilder;
import javax.xml.parsers.DocumentBuilderFactory;
import org.xml.sax.SAXException;
import java.io.File;
import java.io.IOException;
import javax.xml.parsers.ParserConfigurationException;
import org.w3c.dom.Document;
import org.w3c.dom.Node;
import org.w3c.dom.NodeList;
public class XMLParser {
  public static void main(String[] args) {
    try {
      DocumentBuilderFactory dbf = DocumentBuilderFactory.newInstance();
      DocumentBuilder db = dbf.newDocumentBuilder();
      Document doc = db.parse(new File("cities.xml"));
      Node root = doc.getElementsByTagName("routes").item(0);
      NodeList cardlist = root.getChildNodes();
      for (int i = 0; i < cardlist.getLength(); i++) {
        Node cardNode = cardlist.item(i);
        if (cardNode.getNodeType() == Node.ELEMENT_NODE) {
          NodeList cardAttrs = cardNode.getChildNodes();
          // one card
          for (int j = 0; j < cardAttrs.getLength(); j++) {
            if (cardAttrs.item(j).getNodeType() == Node.ELEMENT_NODE) {
              Node theNode = cardAttrs.item(j);
              switch (theNode.getNodeName()) {
              case "name":
                System.out.println("City name: " + theNode.getTextContent());
                break;
```

```
            case "land":
              NodeList landList = theNode.getChildNodes();
              for (int k = 0; k < landList.getLength(); k++) {
                if (landList.item(k).getNodeType() == Node.ELEMENT_NODE) {
                  System.out.println("Land neighbour: "
                        + landList.item(k).getTextContent());
                }
              }
              break;
             case "sea":
              NodeList seaList = theNode.getChildNodes();
              for (int k = 0; k < seaList.getLength(); k++) {
                if (seaList.item(k).getNodeType() == Node.ELEMENT_NODE) {
                  System.out.println("Sea neighbour: "
                        + seaList.item(k).getTextContent());
                }
              }
              break;
            }
          }
        }
      }
    }
  } catch (ParserConfigurationException | SAXException | IOException e) {
    e.printStackTrace();
  }
 }
}
```