XML Query Languages

Outline

- Semistructured data
- Introduction to XML
- Introduction to DTDs
- XPath – core query language for XML
- XQuery – full-featured query language for XML

Semistructured Data

- An HTML document to be displayed on the Web:

<dt>Name: John Doe

<dd>Id: s111111111

<dd>Address:

Number: 123

Street: Main

</dt>

<dt>Name: Joe Public

<dd>Id: s222222222

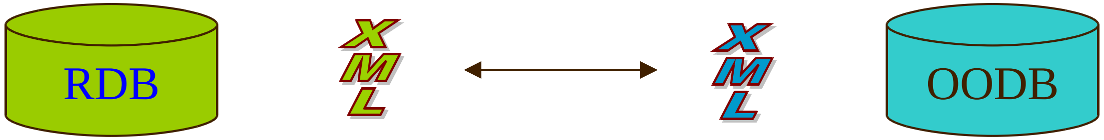
… … … …

</dt>

HTML does not distinguish between attributes and values

Why study XML?

- Huge demands for data exchange
  - across platforms
  - across enterprises
- Huge demands for data integration
  - heterogeneous data sources
  - data sources distributed across different locations
- XML (eXtensible Markup Language) has become the prime standard for data exchange on the Web and a uniform data model for integrated data.



Why not HTML? An Example

- Amazon publishes a catalog for books on sale
  - Data source: a relational database
  - Publishing: HTML pages generated from the relational database
- Customers want to query the catalog data:
  - They can only access the published Web pages (and hence need a parser)
  - They are only interested in information about books on Databases -- in SQL:

```
select   B
 from     book  B
 where    B.title LIKE “Database%”
```

What is wrong with HTML?

<h3> Books </h3> “Databases”

 Database Design for Mere Mortals Michael J. Hernandez

<i>Mar 13 2003 </i>

 Beginning Database Design: From Novice to Professional Clare Churcher
  …

What is wrong with HTML?

- A minor format change to the HTML document may break the parser – and yield wrong answer to the query
  - Why? HTML tags are
    - predefined and fixed
    - describing display format rather than structure of data
- HTML is good for presentation (human friendly), but does not help automatic data extraction by means of programs (queries)

An XML solution

```
<books>
  <book >
          <title>Database Design for Mere Mortals </title>
          <author>Michael J. Hernandez</author>
          <date>13/03/2003 </date>
  </book>
  <book id  =  “B2” >
          <title>Beginning Database Design: From Novice to
            Professional</title>
          <author>Clare Churcher</author>
  </book>
</books>
```

Semistructured Data cont'd

- To make the previous student list suitable for machine consumption on the Web, it should have these characteristics:
  - Be **object-like**
  - Be **schemaless** (not guaranteed 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)
- Data with these characteristics are referred to as **semistructured**.

What is Self-describing Data?

- Non-self-describing (relational, 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? cont'd

- *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."]] }
])

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

Empty element

Element (or tag) names

Root element

- Elements are nested
- Root element contains all others

More Terminology

Opening tag

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

    John is a nice fellow

    <Address>
       <Number>21</Number>
       <Street>Main St.</Street>
    </Address>
    … … …
</Person>
```

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

Nested element, child of Person

Child of Address, *Descendant of* Person

Parent of Address, *Ancestor of* number

Content of Person

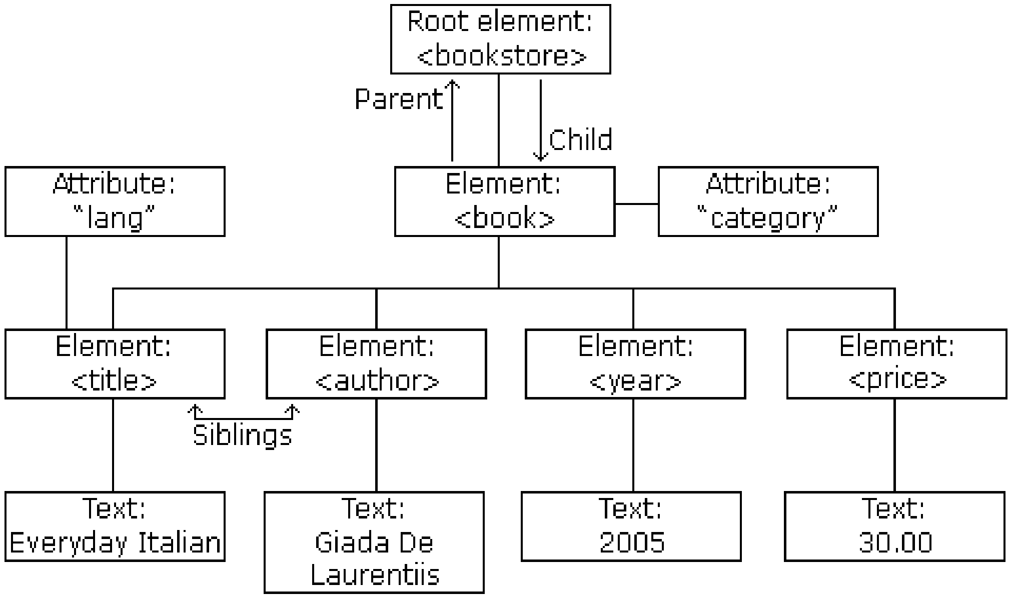
Closing tag:
What is open must be closed

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)*

Tree Structure of XML

```
<bookstore>
    <book category="COOKING">
        <title lang="en">Everyday Italian</title>
        <author>Giada De Laurentiis</author>
        <year>2005</year>
        <price>30.00</price>
    </book>
    <book category="CHILDREN">
        <title lang="en">Harry Potter</title>
        <author>J K. Rowling</author>
        <year>2005</year>
        <price>29.99</price>
    </book>
    <book category="WEB">
        <title lang="en">Learning XML</title>
        <author>Erik T. Ray</author>
        <year>2003</year>
        <price>39.95</price>
    </book>
</bookstore>
```



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 a unique element with matching ID attribute
    - If attr1 has type ID and attr2 has type IDREF then we <u>can</u> 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*">

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  Book [
      … … …
]>
<Book> … … … </Book>
```

- DTD specified as a standalone thing

```
<?xml  version="1.0" ?>
<!DOCTYPE  Book  "http://csc343.com/book.dtd">
<Book> … … … </Book>
```

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
                         Semester  CDATA #REQUIRED >
    <!ATTLIST  ClassRoster  Members  IDREFS  #IMPLIED>
]>
```

Zero or more

Has text content

Empty element, no content

Same attribute in different elements

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 (cont'd)

```
<Classes>
  <Class>
     <CrsCode>CS308</CrsCode> <Semester>F1994</Semester>
     <ClassRoster  Members="s666666666  987654321" />
  </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 cont'd

ID

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

Limitations of DTDs

- Don’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

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 – W3C standard.
  - Very powerful, fairly intuitive, SQL-style
- SQL/XML – attempt to marry SQL and XML, part of SQL:2003

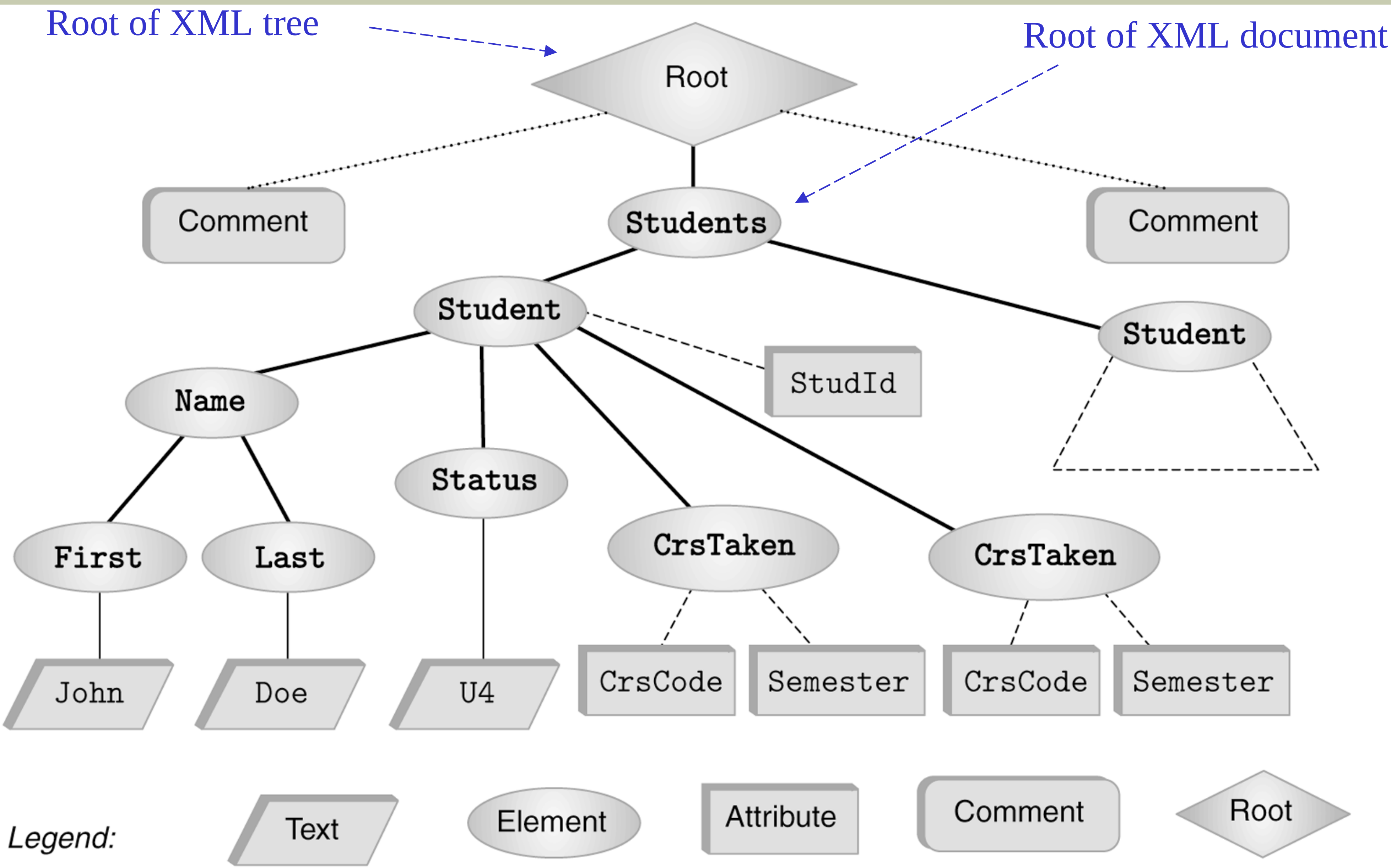
Why Query XML?

- 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 *<u>new</u>* node, which doesn't correspond to anything in the document
  - Internal nodes are elements
  - Leaves are either
    - 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 from earlier

```
<?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*.
- **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**
  - /
  - /Students/Student
  - /Student

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**
  - **/** – 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
  - ./foo/bar
  - ../abc/cde
- Expressions that don't start with **/** are *relative* (to the current node)

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
- /Students/Student/Name/Last/text( )
- XPath provides means to select other document components as well

Attributes, Text, etc.

Denotes an attribute

- /Students/Student/@StudtId – 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 …
- XPath provides means to select other document components as well

Overall Idea and Semantics

- 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 = "CSC343"]

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

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:
    - sFind 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 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)

- 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] $\subseteq$ 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 CSC343:

  //Student[CrsTaken/@CrsCode="CSC343"]

  True if : "CSC343" $\in$ //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

XQuery – XML Query Language

- Integrates XPath with earlier proposed query languages: XQL, XML-QL
- SQL-style, not functional-style
- 2007: XQuery 1.0

XQuery Basics: FLOWR Expression

- General structure:

FOR *variable declarations*
LET *variable declarations*
WHERE *condition*
ORDER BY *list*
RETURN *document*

XQuery expression

XQuery Basics: FLOWR Expression

- Example:

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

comment

This document on next slides

- Result:

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

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

Query inside XML

Document Restructuring with XQuery

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

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

     }
     </ClassRoster>
```

Query inside RETURN

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" />

John Doe's

  - and once when $c is bound to

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

Bart Simpson's

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

Document Restructuring cont'd

- *Solution*: instead of

for $c in doc("transcript.xml")//CrsTaken

use

for $c in doc("classes.xml")//Class

Document on next slide

- 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://uoft.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:

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

Test that classes aren't empty

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

Grouping and Aggregation

- Does not use separate grouping operator
- 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))} />
```

- 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 $\exists$
- 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
  - 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 := {          (: Transcript 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
```

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

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, …