Chapter 12
Query Languages for XML

XPath, XQuery, XSLT

XPath(2.0), XQuery(1.0), XSLT(2.0) share the same function library.

Overview

- Querying on XML data

1. **Xpath**: a simple language for describing sets of similar paths in a graph of semi-structured data.
2. **Xquery**: an extension of Xpath that adopts something of the style of SQL.
3. XSLT: for translation from XML to XML and XML to HTML

The XPath/XQuery Data Model

- Corresponding to the fundamental "relation" of the relational model is: *sequence of items*.
- An *item* is either:
  1. A primitive *value*, e.g., integer or string.
  2. A *node* (defined next).

Principal Kinds of Nodes

1. *Document nodes* represent entire documents.
2. *Elements* are pieces of a document consisting of some opening tag, its matching closing tag (if any), and everything in between.
3. *Attributes* names that are given values inside opening tags.

Document Nodes

- Formed by doc(URL) or document(URL).
- Example: doc(/usr/class/cs145/bars.xml)
- All XPath (and XQuery) queries refer to a doc node, either explicitly or implicitly.
  - Example: key definitions in XML Schema have Xpath expressions that refer to the document described by the schema.

DTD for Running Example

```
<!DOCTYPE BARS [
  <!ELEMENT BARS (BAR*, BEER*)>
  <!ELEMENT BAR (PRICE+)>
     <!ATTLIST BAR name ID #REQUIRED>
  <!ELEMENT PRICE (#PCDATA)>
     <!ATTLIST PRICE theBeer IDREF #REQUIRED>
  <!ELEMENT BEER EMPTY>
     <!ATTLIST BEER name ID #REQUIRED>
     <!ATTLIST BEER soldBy IDREFS #IMPLIED>
]>
```

Example: Document

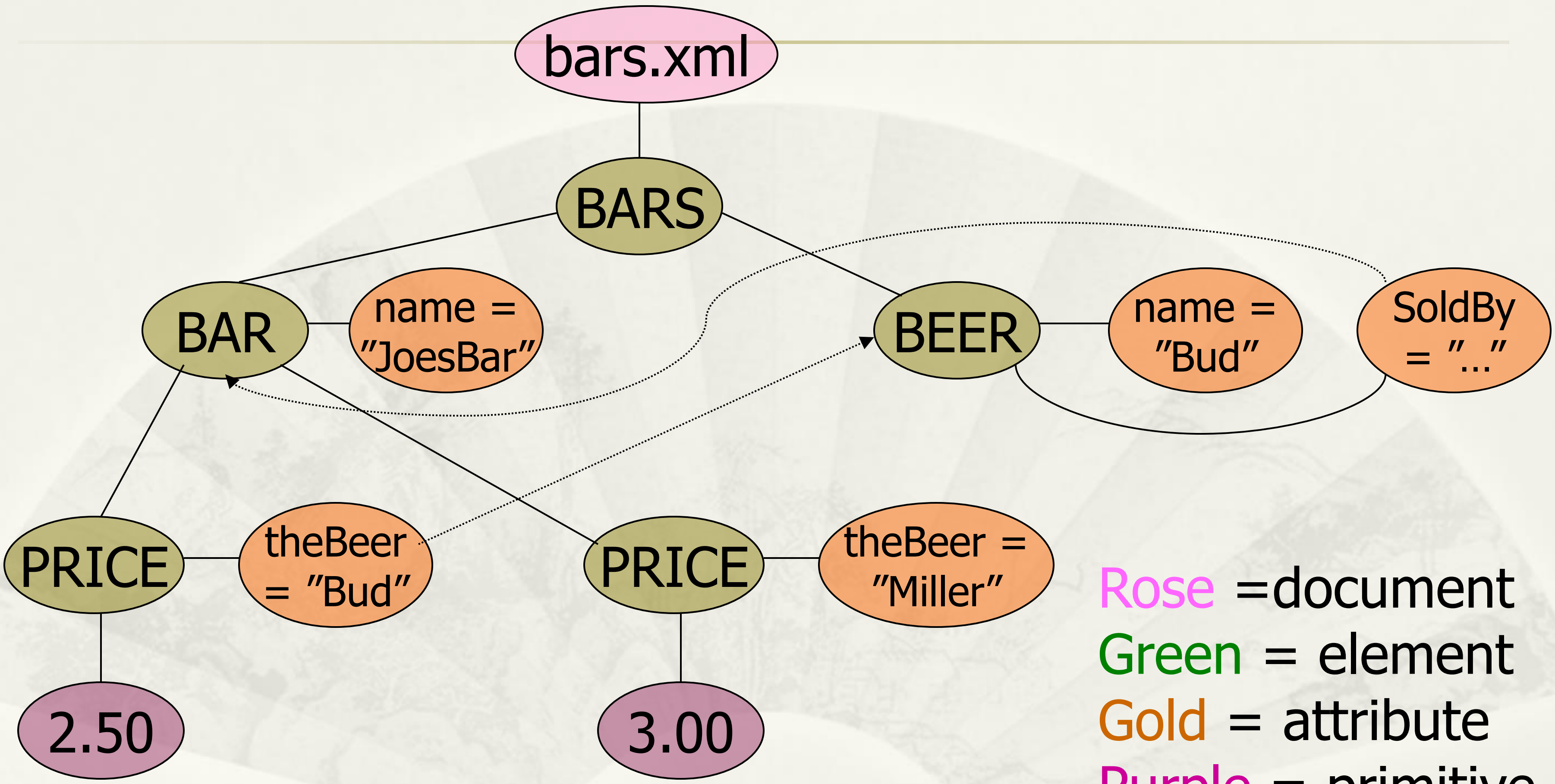
```
<BARS>
  <BAR name = ” JoesBar” >
     <PRICE theBeer = ” Bud” >2.50</PRICE>
     <PRICE theBeer
  = ” Miller” >3.00</PRICE>
  </BAR> …
  <BEER name = ” Bud”  soldBy = ” JoesBar
     SuesBar … ” /> …
</BARS>
```

An element node

An attribute node

Document node is all of this, plus the header (<? xml version…).

Nodes as Semistructured Data



Rose =document
Green = element
Gold = attribute
Purple = primitive value

Paths in XML Documents

- XPath is a language for describing paths in XML documents.
- The result of the described path is a sequence of items.

Path Expressions

- Simple path expressions are sequences of slashes (/) and tags, starting with /.
  - Example: /BARS/BAR/PRICE
- Construct the result by starting with just the doc node and processing each tag from the left.

Evaluating a Path Expression

- Assume the first tag is the root.
- Scan the whole tree.
- Suppose we have a sequence of items, and the next tag is *X*.
  - For each item that is an element node, replace the element by the subelements with tag *X*.

Example: /BARS

```
<BARS>
  <BAR name = ” JoesBar” >
    <PRICE theBeer = ” Bud” >2.50</PRICE>
    <PRICE theBeer
  = ” Miller” >3.00</PRICE>
  </BAR> …
  <BEER name = ” Bud”  soldBy = ” JoesBar
    SuesBar … ” /> …
</BARS>
```

One item, the BARS element

Example: /BARS/BAR

<BARS>

<BAR name = ” JoesBar” >

<PRICE theBeer =” Bud” >2.50</PRICE>

<PRICE theBeer = ” Miller” >3.00</PRICE>

</BAR> …

<BEER name = ” Bud” soldBy = ” JoesBar SuesBar …” /> …

</BARS>

This BAR element followed by all the other BAR elements

Example: /BARS/BAR/PRICE

```
<BARS>
  <BAR name = ” JoesBar” >
    <PRICE theBeer =” Bud” >2.50</PRICE>
    <PRICE theBeer
  = ” Miller” >3.00</PRICE>
  </BAR> …
  <BEER name = ” Bud”  soldBy = ” JoesBar
    SuesBar …” /> …
</BARS>
```

These PRICE elements followed by the PRICE elements of all the other bars.

Attributes in Paths

- Instead of going to subelements with a given tag, you can go to an attribute of the elements you already have.
- An attribute is indicated by putting @ in front of its name.

Example: /BARS/BAR/PRICE/data(@theBeer)

```
<BARS>
  <BAR name = ” JoesBar” >
    <PRICE theBeer = ” Bud” >2.50</PRICE>
    <PRICE theBeer = ” Miller” >3.00</PRICE>
  </BAR> …
  <BEER name = ” Bud”  soldBy = ” JoesBar
    SuesBar …” /> …
</BARS>
```

These attributes contribute ”Bud” ”Miller” to the result, followed by other theBeer values.

Sequences ends in an attribute

- When a path expression ends in **an attribute**, the result is typically a sequence of values of primitive type, for example.

/BARS/BAR/PRICE/data (@theBeer)

“Bud Miller” as the output

Paths that Begin Anywhere

- If the path starts from the document node and begins with //*X*, then the first step can begin at the root or any subelement of the root, as long as the tag is *X*.

Example: //PRICE

```
<BARS>
  <BAR name = "JoesBar">
    <PRICE theBeer ="Bud">2.50</PRICE>
    <PRICE theBeer = "Miller">3.00</PRICE>
  </BAR> …
  <BEER name = "Bud" soldBy = "JoesBar
    SuesBar …" /> …
</BARS>
```

These PRICE elements and any other PRICE elements in the entire document

Wild-Card *

- A star (*) in place of a tag represents any one tag.
- Example: /*/*/PRICE represents all price objects at the third level of nesting.

Example: /BARS/*

This BAR element, all other BAR elements, the BEER element, all other BEER elements

```
<BARS>
<BAR name = ” JoesBar” >
   <PRICE theBeer = ” Bud” >2.50</PRICE>
   <PRICE theBeer
= ” Miller” >3.00</PRICE>
</BAR> …
<BEER name = ” Bud”  soldBy = ” JoesBar
   SuesBar … ” /> …
</BARS>
```

Selection Conditions

- A condition inside [...] may follow a tag.
- If so, then only paths **that have that tag and also satisfy the condition** are included in the result of a path expression.

Example: Selection Condition

- /BARS/BAR/PRICE[. < 2.75]

```
<BARS>
  <BAR name = ” JoesBar” >
     <PRICE theBeer = ” Bud” >2.50</PRICE>
     <PRICE theBeer = ” Miller” >3.00</PRICE>
  </BAR> …
```

The current element.

The condition that the PRICE be < $2.75 makes this price but not the Miller price part of the result.

Example: Attribute in Selection

- /BARS/BAR/PRICE[@theBeer = ”Miller”]

```
<BARS>
  <BAR name = ”JoesBar”>
    <PRICE theBeer = ”Bud”>2.50</PRICE>
    <PRICE theBeer = ”Miller”>3.00</PRICE>
  </BAR> …
```

Now, this PRICE element is selected, along with any other prices for Miller.

Axes

- In general, path expressions allow us to start at the root and execute steps to find a sequence of nodes at each step.
- At each step, we may follow any one of several *axes*.
- The default axis is child:: --- go to all the children of the current set of nodes.

Example: Axes

- /BARS/BEER is really shorthand for /BARS/child::BEER .
- @ is really shorthand for the attribute:: axis.
  - Thus, /BARS/BEER[@name = ” Bud”] is shorthand for /BARS/BEER[attribute::name = ” Bud”]

More Axes

- Some other useful axes are:
  1. parent:: = parent(s) of the current node(s).
  2. descendant-or-self:: = the current node(s) and all descendants.
     - Note: // is really shorthand for this axis.
  3. ancestor::, ancestor-or-self, etc.
  4. self (the dot).

Classroom Exercises

<Bookstore>

-<Book Price=″85″ ISBN=″ISBN-0-13-713526-2″>

<Title>A First Course in Database Systems</Title>

<Authors><Author><First_Name>Jeffrey</First_Name><Last_Name>Ullman</Last_Name></Author><Author><First_Name>Jennifer</First_Name><Last_Name>Widom</Last_Name></Author></Authors>

</Book>-

<Book Price=″100″ ISBN=″ISBN-0-13-815504-6″>

<Title>Database Systems: The Complete Book</Title>

<Authors><Author><First_Name>Hector</First_Name><Last_Name>Garcia-Molina</Last_Name></Author>
<Author><First_Name>Jeffrey</First_Name><Last_Name>Ullman</Last_Name></Author><Author><First_Name>Jennifer</First_Name><Last_Name>Widom</Last_Name></Author></Authors>

<Remark> Buy this book bundled with ″A First Course″ - a great deal! </Remark>

</Book></Bookstore>

Classroom Exercises (bookstore)

- All books costing less than $90
- Titles of books costing less than $90
- Titles of books costing less than $90 where "Ullman" is an author.

Answer 1

- All books costing less than $90

```
doc("Bookstore.xml")/Bookstore/Book[@Price < 90]
```

Result:

```
<Book  Price="85" ISBN="ISBN-0-13-713526-2">
<Title>A First Course in Database Systems</Title>
<Authors><Author><First_Name>Jeffrey</First_Name><Last_Name>Ullman</Last_Name></Author><Author><First_Name>Jennifer</First_Name><Last_Name>Widom</Last_Name></Author></Authors>
</Book>
```

Answer 2

- Titles of all books costing less than $90

```
doc("Bookstore.xml")/Bookstore/Book[@Price < 90]/Title
```

Result:

<Title>A First Course in Database Systems</Title>

Answer 3

- Titles of books costing less than $90 where "Ullman" is an author.

```
doc("Bookstore.xml")/Bookstore/Book[@Price < 90 and
Authors/Author/Last_Name = "Ullman"]/Title
```

Result:

<Title>A First Course in Database Systems</Title>

XQuery

- XQuery extends XPath to a query language that has power similar to SQL.
- Uses the same sequence-of-items data model.
- XQuery is an expression language.
  - Like relational algebra --- any XQuery expression can be an argument of any other XQuery expression.

More About Item Sequences

* XQuery will sometimes form sequences of sequences.
* All sequences are flattened.
* Example: (1 2 () (3 4)) = (1 2 3 4).

Empty sequence

FLWR Expressions

1. One or more for and/or let clauses.
2. Then an optional where clause.
3. A return clause.

---

let allows temporary variables, and has no equivalent in SQL

for ⇔ SQL **from**

where ⇔ SQL **where**

return ⇔ SQL **select**

Semantics of FLWR Expressions

- Each for creates a loop.
- let produces only a local definition.
- At each iteration of the nested loops, if any, evaluate the where clause.
- If the where clause returns TRUE, invoke the return clause, and append its value to the output.

FOR Clauses

for <variable> in <expression>, . . .

- Variables begin with $.
- A for-variable takes on each item in the sequence denoted by the expression, in turn.
- Whatever follows this for is executed once for each value of the variable.

Example: FOR

Our example [BARS document]

"Expand the en-closed string by replacing variables and path exps. by their values."

```
for $beer in
  document("bars.xml")/BARS/BEER/@name
return
  <BEERNAME> {$beer} </BEERNAME>
```

- $beer ranges over the name attributes of all beers in our example document.
- Result is a sequence of BEERNAME elements: <BEERNAME>Bud</BEERNAME> <BEERNAME>Miller</BEERNAME> . . .

Use of Braces {}

* When a variable name like $x, or an expression, could be text, we need to surround it by braces to avoid having it interpreted literally.
  * Example: <A>$x</A> is an A-element with value "$x", just like <A>foo</A> is an A-element with "foo" as value.
  * <A> {$x}</A> return the value of $x

Use of Braces — (cont.)

- `return $x` is unambiguous:
  - return the element of `$x` represents

LET Clauses

let <variable> := <expression>, . . .

- Value of the variable becomes the *sequence* of items defined by the expression.
- Note let does not cause iteration; for does.

Example: LET

```
let $d := document("bars.xml")
let $beers := $d/BARS/BEER/@name
return
  <BEERNAMES> {$beers} </BEERNAMES>
```

- Returns one element with all the names of the beers, like:

<BEERNAMES>Bud Miller …</BEERNAMES>

Order-By Clauses

- FLWR is really FLWOR: an order-by clause can precede the return.
- Form: order by <expression>
  - With optional ascending or descending.
- The expression is evaluated for each assignment to variables.
- Determines placement in output sequence.

Example: Order-By

* List all prices for Bud, lowest first.

```
let $d := document(”bars.xml”)
for $p in
  $d/BARS/BAR/PRICE[@theBeer=”Bud”]
order by $p
return $p
```

Generates bindings for $p to PRICE elements.

Order those bindings by the values inside the elements (automatic coersion).

Each binding is evaluated for the output. The result is a sequence of PRICE elements.

Remember: SQL ORDER BY

- SQL works the same way; it's the result of the FROM and WHERE that get ordered, not the output.
- Example: Using R(a, b),

```
SELECT b FROM R
WHERE b > 10
ORDER BY a;
```

Then, the b-values are extracted from these tuples and printed in the same order.

R tuples with b>10 are ordered by their a-values.

Predicates

- Normally, conditions imply existential quantification.
- Example: /BARS/BAR[@name] means "all the bars that have a name."
- Example: /BARS/BEER[@soldAt = "JoesBar"] gives the set of beers that are sold at Joe's Bar.

Example: Comparisons

- How to produce the PRICE elements (from all bars) for all the beers that are sold by Joe’s Bar?
- Output: BBP elements with the names of the bar and beer as attributes and the price element as a subelement.

<BBP *bar*= “joe’s bar” *beer* = “Bud”> 3.4 </BBP>

Strategy

1. Create a triple for-loop, with variables ranging over all BEER elements, all BAR elements, and all PRICE elements within those BAR elements.
2. Check that the beer is sold at Joe’ s Bar and that the name of the beer and theBeer in the PRICE element match.
3. Construct the output element.

The Query

```
let $bars := doc(”bars.xml”)/BARS
for $beer in $bars/BEER
for $bar in $bars/BAR
for $price in $bar/PRICE
where $beer/@soldBy = ”JoesBar” and
  $price/@theBeer = $beer/@name
return <BBP bar = {$bar/@name} beer
  = {$beer/@name}>{$price}</BBP>
```

True if ”JoesBar” appears anywhere in the sequence

Strict Comparisons

- To require that the things being compared are sequences of only one element, use the Fortran comparison operators:
  - eq, ne, lt, le, gt, ge.
- Example: $beer/@soldAt eq "JoesBar" is true only if Joe's is the only bar selling the beer.

Comparison of Elements and Values

- When an element is compared to a primitive value, the element is treated as its value, if that value is atomic.
- Example: /BARS/BAR[@name="JoesBar"]/PRICE[@theBeer="Bud"] eq "2.50"

  is true if Joe charges $2.50 for Bud.

Comparison of Two Elements

- It is insufficient that two elements look alike.
- Example:

  /BARS/BAR[@name="JoesBar"]/

  PRICE[@theBeer="Bud"] eq
  /BARS/BAR[@name="SuesBar"]/

  PRICE[@theBeer="Bud"]

  is false, even if Joe and Sue charge the same for Bud.

Comparison of Elements – (cont.)

- For elements to be equal, they must be the same, physically, in the implied document.
- Important: elements are really pointers to sections of particular documents, not the text strings appearing in the section.

Getting Data From Elements

- To compare the values of elements, rather than their location in documents.
- To extract just the value (e.g., the price itself) from an element E, use data(E).

Example: data()

- Modify the return for “find the prices of beers at bars that sell a beer Joe sells” to produce an empty BBP element with price as one of its attributes.

```
return <BBP bar = {$bar/@name} beer
= {$beer/@name} price =
{data($price)} />
```

Instead of

```
return <BBP bar = {$bar/@name} beer
= {$beer/@name}>{$price}</BBP>
```

Eliminating Duplicates

- Use function **distinct-values** applied to a sequence.
- this function strips tags away from elements and compares the string values.
  - But it doesn’t restore the tags in the result.

Example: All the Distinct Prices

```
return distinct-values(
  let $bars = doc(”bars.xml”)
  return $bars/BARS/BAR/PRICE
)
```

Remember: XQuery is an expression language. A query can appear any place a value can.

Quantifier Expressions

some $x in E_1 satisfies E_2

1. Evaluate the sequence E_1.
2. Let $x (any variable) be each item in the sequence, and evaluate E_2.
3. Return TRUE if E_2 has TRUE for at least one $x.

- Analogously:

every $x in E_1 satisfies E_2

Example: Some

- The bars that sell at least one beer for less than $2.

```
for $bar in
    doc("bars.xml")/BARS/BAR
where some $p in $bar/PRICE
  satisfies $p < 2.00
return $bar/@name
```

Notice: where $bar/PRICE < 2.00 would work as well.

Example: Every

- The bars that sell no beer for more than $5.

```
for $bar in
    doc("bars.xml")/BARS/BAR
where every $p in $bar/PRICE
  satisfies $p <= 5.00
return $bar/@name
```

Branching Expressions

- if (E_1) then E_2 else E_3 is evaluated by:
  - Compute E_1.
  - If true, the result is E_2; else the result is E_3.
- Example: the PRICE subelements of $bar, provided that bar is Joe's.

```
if($bar/@name eq "JoesBar")
then $bar/PRICE else ()
```

Empty sequence. Note there is no if-then expression.

Document Order

* Comparison by document order: << and >>.

* Example: $d/BARS/BEER[@name=" Bud"] << $d/BARS/BEER[@name=" Miller"] is true iff the Bud element appears before the Miller element in the document $d.

Set Operators

* union, intersect, except operate on sequences of nodes.
  * Meanings analogous to SQL.
  * Result eliminates duplicates.
  * Result appears in document order.

Classroom Exercises (1)

- Titles of books costing less than $90 where ‘ullman is an author
- Find the book whose price is below the average.
- See the bookstore scheme.

Titles of books costing less than $90 where ‘ullman is an author

```
for $b in
  doc("Bookstore.xml")/Bookstore/Book
where $b/@Price < 90  and
  $b/Authors/Author/Last_Name = "Ullman"
return $b/Title
```

Find the book whose price is below the average

```
let $a :=
  avg(doc("Bookstore.xml")/Bookstore/Boo
  k/@Price)
for $b in
  doc("Bookstore.xml")/Bookstore/Book
where $b/@Price < $a
return <Book> { $b/Title } <Price>
  {$b/data(@Price) } </Price>  </Book>
```

XSLT

- XSLT (extensible stylesheet language - transforms) is another language to process XML documents.
- Transform XML into an HTML page that could be displayed.
- It can also transform XML -> XML, thus serving as a query language.

XSLT Programs

- Like XML Schema, an XSLT program is itself an XML document.
- XSLT has a special namespace of tags, usually indicated by xsl:.

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<xsl:stylesheet version="1.0"
xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
```

Templates

- The xsl:template element describes a set of elements (of the document being processed) and what should be done with them.
- The form: <xsl:template match = *path* > … </xsl:template>

Attribute match gives an XPath expression describing how to find the nodes to which the template applies.

Example: BARS Document -> Table

- To convert the bars.xml document into an HTML document that looks like the Sells(bar, beer, price) relation.
- The first template will match the root of the document and produce the table without any rows.

The Template for the Root

```
<xsl:template match = "/">
  <TABLE><TR>
    <TH>bar</th><TH>beer</th>
    <TH>price</th></tr>
  </table>
</xsl:template>
```

Template matches only the root.

Output of the template is a table with the attributes in the header row, no other rows.

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Outline of Strategy

1. Inside the HTML for the table is xsl:apply-templates to extract data from the document.
2. From each BAR, use an xsl:variable *b* to remember the bar name.
3. xsl:for-each PRICE subelement, generate a row, using *b*, and xsl:value-of to extract the beer name and price.

Recursive Use of Templates

- An XSLT document usually contains many templates.
- Start by finding the first one that applies to the root.
- Any template can have within it <xsl:apply-templates/>, which causes the template-matching to apply recursively from the current node.

Apply-Templates

- Attribute select gives an XPath expression describing the subelements to which we apply templates.
- Example: <xsl:apply-templates select = " BARS/BAR" /> says to follow all paths tagged BARS, BAR from the current node and apply all templates there.

Example: Apply-Templates

```
<xsl:template match = ″/″>
  <TABLE><TR>
    <TH>bar</TH><TH>beer</TH>
    <TH>price</TH></TR>
  <xsl:apply-templates select =
    ″BARS″ />
  </TABLE>
</xsl:template>
```

Extracting Values

- <xsl:value-of select = XPath expression /> produces a value to be placed in the output.
- Example: suppose we are applying a template at a BAR element and want to put the bar name into a table.

```
<xsl:value-of select = "@name" />
```

Variables

- We can declare x to be a variable with <xsl:variable name = " x" />.
- Example:

```
<xsl:variable name = "bar">
  <xsl:value-of select = "@name" />
</xsl:variable>
```

within a template that applies to BAR elements will set variable bar to the name of that bar.

Using Variables

- Put a $ in front of the variable name.
- Example: <TD>$bar</TD>

Completing the Table

1. We' ll apply a template at each BAR element.
2. This template will assign a variable b the value of the bar, and iterate over each PRICE child.
3. For each PRICE child, we print a row, using b, the theBeer attribute, and the PRICE itself.

Iteration

- <xsl:for-each select = Xpath expression> …
</xsl:for-each>
executes the body of the for-each at each child of the current node that is reached by the path.

The Template for BARS

A variable for each bar

```
<xsl:template match = ”BAR”>
  <xsl:variable name = ”b”>
     <xsl:value-of select = ”@name” />
  </xsl:variable>
 <xsl:for-each select = ”PRICE”>
    <TR><TD>$b</td><TD>
      <xsl:value-of select = ”@theBeer” />
    </td><TD>
      <xsl:value-of select = ”data(.)” />
    </td></tr>
 </xsl:for-each>
</xsl:template>
```

Constructs a bar-beer-price row.

Iterates over all PRICE subelements of the bar.

This element

Summarization

* **XPath**: describe paths from the root of the document by sequences of tags.
* **XQuery**: query language for XML based on Xpath.
* XSLT: for transformations of XML documents.