

XML and Databases

Lecture 12
XQuery – XML Query Language

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Thanks to Sherif Sakr
for all the following XQuery slides.

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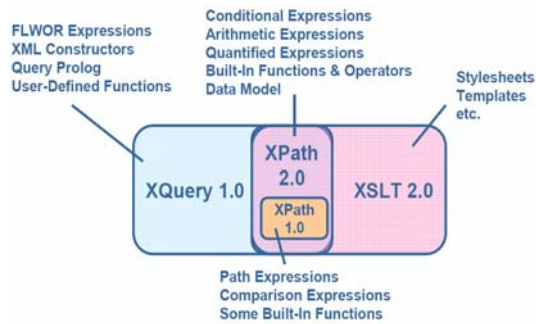
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Why do we need a new query language?

Relational Data, SQL	XML
Flat (rows and columns)	Nested and Hierarchical
Data is uniform and repetitive	Data is highly variable
Info schema for meta data	Self describing, meta data distributed through doc
Uniform query results	Heterogeneous query results
Rows in table are unordered	Elements in document are ordered
Data is usually dense	Data can be sparse

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XQuery, XSLT and XPath



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XQuery

- XQuery is a **declarative** language in which a query is represented as an **expression**.
- XQuery expressions can be nested with full generality.

```

FLWOR Expression
for $d in distinct-values(doc("ord.xml")//item/@dept)
let $items := doc("ord.xml")//item[dept = $d]
order by $d
return <department name="{ $d }"
    totalQuantity="{sum($items/quantity)}"/>

Path Expression
doc("ord.xml")//item/@dept
doc("ord.xml")//item[dept = $d]

Element Constructor
<department name="{ $d }"
totalQuantity="{sum($items/quantity)}"/>

Variable Reference
$d, $items

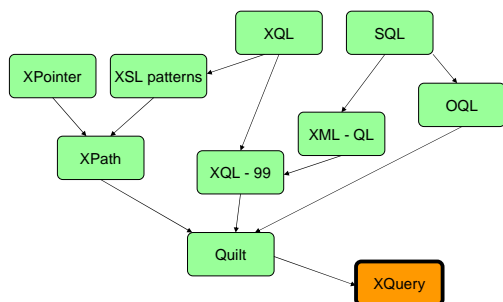
Comparison Expression
dept = $d

```

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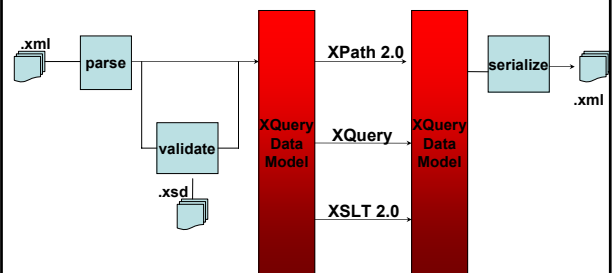
XQuery

- XQuery is based on OQL, SQL, XML-QL, XPath languages.



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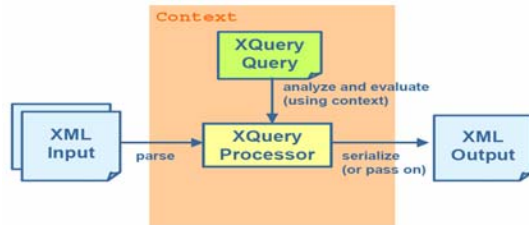
XML Data model life cycle



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XQuery

- The input and output of an XQuery are instances of the XML Query Data Model.



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XML Input

- Could be:
 - Text files that are XML documents.
 - Fragments of XML documents that are received from the web using a URI.
 - A collection of XML documents that are associated with a particular URI.
 - Data stored in native XML databases.
 - Data stored in relational databases that have an XML front-end.
 - In-memory XML documents.

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XQuery Data Model

- The XQuery language is designed to operate over ordered, *finite sequences of items* as its principal data type.
- The evaluation of any XQuery expression yields an ordered sequence of $n \geq 0$ items.
- These *items* can be:
 - Atomic values (integers, strings, ..., etc)
 - Unranked XML tree nodes.

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Items and Ordered Sequences

- A sequence of n items X_i is written in parentheses and comma-separated form
 (X_1, X_2, \dots, X_n)
- A single item X and the singleton sequence (X) are equivalent.
- Sequences *can not* contain other sequences (nested sequences are implicitly *flattened*)
 $(0, (), (1, 2), (3)) = (0, 1, 2, 3)$
 $(0, 1) \neq (1, 0)$
- Sequences *can* contain *duplicates*
 $(0, 1, 1, 2)$
- Sequences may be *heterogeneous*
 $(42, "foo", 4.2, <a>)$

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XQuery = ½ Programming Language + ½ Query Language

- Programming language** features:
 - Explicit iteration and variable bindings (for, let, ...).
 - Recursive, user-defined functions.
 - Regular expressions, strong [static] typing.
 - Ordered sequences (much like lists or arrays).
- Query language** features:
 - Filtering.
 - Grouping.
 - Joins.

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Some Uses for XQuery

- Extracting information from a database for use in web service.
- Generating summary reports on data stored in XML database.
- Searching textual documents on the web for relevant information.
- Transforming XML data to XHTML format to be published on the web.
- Pulling data from different databases to be used for application integration.
- Splitting up an XML document into multiple XML documents.

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XQuery Syntax Rules

- XQuery is a case-sensitive language.
- Keywords are in lower-case.
- No special end-of-line character.
- Every expression has a value and no side effects.
- Expressions are fully composable.
- Expressions can raise error.
- Comments look like this

(: This is an XQuery Comment :)

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XQuery Expressions

- Path expressions.
- FLWOR expressions.
- Expressions involving operators and functions.
- Conditional expressions.
- Quantified expressions.
- List constructors.
- Element constructors.
- Expressions that test or modify datatypes

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XQuery Expressions

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Path Expression

- In a sense, the *traversal* or *navigation* of trees of XML nodes lies at the core of every XML query language.
- XQuery embeds **XPath** as its tree navigation sub-language.
- Every XPath expression is a correct XQuery expression.
- Since navigation expressions extract (potentially huge volumes of) nodes from input XML documents, efficient XPath implementation is a prime concern to any implementation of an XQuery processor.

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Path Expression

- Each path consists of one or more **steps**, syntactically separated by /
$$s_0/s_1/. . . /s_n$$
- Each step acts like an operator that, given a **sequence of nodes** (the context set), evaluates to a **sequence of nodes**.
- XPath defines the result of each path expression to be *duplicate free* and *sorted in document order*.

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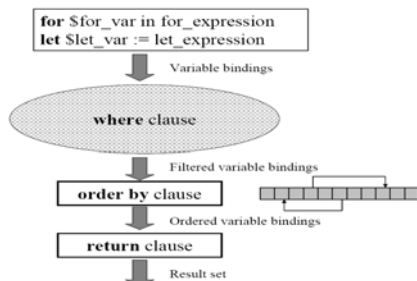
XQuery Expressions

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FLWOR Expression

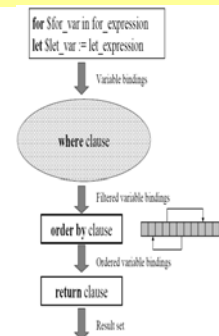
- A FLWOR expression binds some expressions, applies a predicate, and constructs a new ordered result.



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FLWOR Expression

- The **for** construct **successively binds** each item of an expression (**expr**) to a variable (**var**), generating a so-called **tuple stream**.
- This tuple stream is then **filtered** by the **where** clause, retaining some tuples and discarding others.
- The **return** clause is evaluated **once for every tuple** still in the stream.
- The result of the expression is an **ordered sequence** containing the **concatenated** results of these evaluations.



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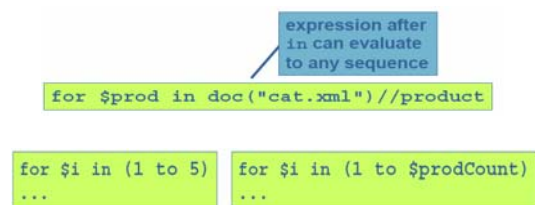
FLWOR Expression (Variables)

- Variables are identified by a name preceded by a **\$** sign.
- Variables are defined in several places
 - FLWOR Expression.
 - Query prologs.
 - Outside the query by the processor.
 - Function signatures.

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for Clauses

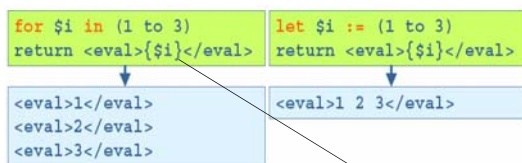
- Iteratively binds the variable to each item returned by the **in** expressions.
- The rest of the expression is evaluated once for each item returned.
- Multiple **for** clauses are allowed in the same FLWOR expression.



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let Clauses

- Convenient way to bind variables.
- Does not result in iteration.



Brackets are used for variables inside element construction expressions

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where Clauses

- Used to filter results.
- Can contain many sub-expressions.
- Evaluates to a Boolean value.
- If true, **return** clause is evaluated.

```
where $prod/number > 100
  and starts-with($prod/name, "L")
  and exists($prod/colorChoices)
  and ($prodDept="ACC" or $prodDept="WMN")
```

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order by Clauses

- Only way to sort results in XQuery.
- Order by
 - Atomic values, or
 - Nodes that contain individual atomic values.
- Can specify multiple values to sort on.

```
for $item in doc("ord.xml")//item
order by $item/@dept, $item/@num
return $item
```

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- ```
for $item in doc("ord.xml")//item
order by $item/@dept, $item/@num
return $item
```

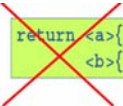
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# return Clauses

- The value that is to be returned

```
for $prod in doc("cat.xml")//product
return $prod/name
```

- Single expression only. Multiple expressions are to be combined into single sequence.



```
return <a>{$i}
 {$j}
```

```
return (<a>{$i},
 {$j})
```

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- ~~return <a>{\$i}</a>  
      <b>{\$j}</b>~~

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# FLWOR Expression

**Iteration**

```

for $x in (3,2,1)
return ($x,"*")

```

⇒ (3,"\*",2,"\*",1,"\*")

```

for $x in (3,2,1)
return $x,"*"

```

⇒ (3,2,1,"\*")

```

for $x in (3,2,1)
return for $y in ("a","b")
return ($x,$y)

```

(3,"a",3,"b",  
2,"a",2,"b",  
1,"a",1,"b")

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# FLWOR Expression

```
Query: for $a in document("bib.xml")//article
where $a/year < 1996
return
 <early_paper>
 <fstAuth>{$a/authors/author[1]/text()}</fstAuth>
 {$a/title}
 </early_paper>
```

```
Results: <early_paper>
 <fstAuth>Maurice Bach</fstAuth>
 <title>Design of the UNIX Operating System</title>
</early_paper>
<early_paper>
 <fstAuth>Serge Arbitboul</fstAuth>
 <title>Foundations of Databases</title>
</early_paper>
```

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# FLWOR Expression: Test?

- What is the result of the following FLWOR expression?  
  
for \$x in (1, 2, 3, 4) where \$x < 4 return  
  
for \$y in (10, 20) return  
  
(\$x, \$y)

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## FLWOR Expression (Multiple Variables)

- Use comma to separate multiple **in** expressions.
- **return** clause evaluated for each combination of variable values.

```
for $i in (1, 2), $j in (11, 12)
return <eval>i is {$i} and j is {$j}</eval>
```

```
<eval>i is 1 and j is 11</eval>
<eval>i is 1 and j is 12</eval>
<eval>i is 2 and j is 11</eval>
<eval>i is 2 and j is 12</eval>
```

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## FLWOR Expression

- In a sense, FLWOR takes the role of the **SELECT-FROM-WHERE** block in SQL.
- The versatile FLWOR is used to express:
  - Nested Iterations.
  - Joins between sequences.
  - Groupings.
  - Orderings beyond document order.

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## Inner Joins

```
for $book in document("bib.xml")//book,
 $quote in document("quotes.xml")//listing
where $book/isbn = $quote/isbn
return
 <book>
 { $book/title }
 { $quote/price }
 </book>
```

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## Outer Joins

```
for $book in document("bib.xml")//book
return
 <book>
 { $book/title }
 {
 for $review in document("reviews.xml")//review
 where $book/isbn = $review/isbn
 return $review/rating
 }
 </book>
```

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## Aggregation - Grouping

- **for** iterates on a sequence, binds a variable to each node.
- **let** binds a variable to a sequence as a whole.
- Together, they are used for representing aggregation and grouping expressions.

```
for $book in document("bib.xml")//book
let $a := $book/author
where contains($book/publisher, "Addison-Wesley")
return
 <book>
 {
 $book/title,
 <count> Number of authors: { count($a) } </count>
 }
 </book>
```

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## FLWOR vs. Path

**Path:** `document("bib.xml")//article[@year = 1996]`

**FLWOR:** `for $a in document("bib.xml")//article
where $a/year < 1996
return $a`

- **Path expression** is great if you want to copy or retrieve certain element and attributes as is.
- **FLWOR Expression**
  - Allow sorting.
  - Allow adding elements/attributes to results.
  - More verbose, but can be clearer.

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## XQuery Expressions

- Path Expressions.
- FLWOR Expressions.
- Expressions involving operators and functions .
- Conditional expressions.
- Quantified expressions.
- List constructors.
- Element Constructors.
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## XQuery Operators and Functions

- Infix and prefix operators (+, -, \*, ...).
- Parenthesized expressions.
- Arithmetic and logical operators.
- Collection operators **UNION**, **INTERSECT** and **EXCEPT**.
- Infix operators **BEFORE** and **AFTER** (<<, >>).
- User functions can be defined in XQuery.

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## XQuery Arithmetic

- **Infix operators**: +, -, \*, div, idiv (integer division)
- operators first **atomize** their operands, then perform **promotion** to a common numeric type.
- if at least one operand is (), the result is ().

### Examples and pitfalls

```
<x>1</x> + 41 => 42.0
() + 42 => ()
(1,2) - (2,3) => $ (type error)
x-42 => ./child::x-42 (use x..-42)
x/y => ./child::x/child::y (use x div y)
```

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## XQuery Comparisons

- Any XQuery expression evaluates to a **sequence** of items. Consequently, many XQuery concepts are prepared to accept sequences (as opposed to single items).

### General Comparisons

The **general comparison**  $e_1 \theta e_2$  with

$$\theta \in \{=, !=, <, <=, >=, >\}$$

yields **true()** if *any* of the items in the sequences  $e_{1,2}$  compare true (*existential semantics*).

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## General and Value Comparisons

### General comparison examples

```
(1,2,3) > (2,4,5) => true()
(1,2,3) = 1 => true()
() = 0 => false()
2 <= 1 => false()
(1,2,3) != 3 => true()
(1,2) != (1,2) => true()
not((1,2) = (1,2)) => false()
```



### Value comparisons

The six **value comparison operators** eq, ne, lt, le, ge, gt compare *single items by value* (atomization!):

```
2 gt 1.0 => true()
<x>42</x> eq <y>42</y> => true()
(0,1) eq 0 => $ (type error)
```

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## More Comparisons

- **Note:** The existential semantics of the general comparison operators may lead to unexpected behavior:



### Surprises

```
(1,2,3) = (1,3) => true()a
("2",1) = 1 => true() or $ (impl. dependent)
```

<sup>a</sup>For an *item-by-item* comparison use **deep-equal()**.

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## Node Comparisons

### Node comparison

**Node comparisons** based on *identity* and *document order*:

```
e1 is e2 nodes e1,2 identical?
e1 << e2 node e1 before e2?
e1 >> e2 node e1 after e2?
```

### Node comparison examples

```
<x>42</x> eq <x>42</x> => true()
<x>42</x> is <x>42</x> => false()
root(e1) is root(e2) => nodes e1,2 in same tree?
let $a := <x><y/></x>
return $a << $a/y => true()
```

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## XQuery Comparisons

Value	comparing single values Untyped data => string	<code>eq, ne, lt, le, gt, ge</code>
General	Existential quantification Untyped data => coerced to other operand's type	<code>=, !=, &lt;=, &lt;, &gt;, &gt;=</code>
Node	for testing identity of single nodes	<code>is, isnot</code>
Order	testing relative position of one node vs. another (in document order)	<code>&lt;&lt;, &gt;&gt;</code>

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## Logical Expression

- Logical Operators "**and**" and "**or**".
- The concept of **Effective Boolean Value(EBV)** is key to evaluating logical expressions.
  - EBV of an empty sequence is **false**.
  - EBV of a non-empty sequence containing only nodes is **true**.
  - EBV is the value of the expression if the expression evaluates to a value of type **xs:boolean**.
  - EBV is an error in every other case.  
eg: The expression "()" and true() evaluates to false(since () is false)

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## XQuery: Built-in Functions

- Over 100 functions built into XQuery.
- String-related
  - substring, contains, concat,...
- Date-related
  - current-date, month-from-date,...
- Number-related
  - round, avg, sum, ...
- Sequence-related
  - index-of, distinct-values,...
- Node-related
  - data, empty,...
- Document-related
  - doc, collection, ...
- Error Handling
  - error, exactly-one, ...
- ....

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## XQuery: User-Defined Functions

- XQuery expressions can contain **user-defined functions** which **encapsulate** query details.
- User-defined functions may be collected into **modules** and then '**import**'ed by a query.

### Declaration of $n$ -ary function $f$ with body $e$

```
declare function f ($ p_1 as t_1 , ..., $ p_n as t_n) as t_0 { e }
```

- ▷ If  $t_i$  is omitted, it defaults to item()\*.
- ▷ The pair  $(f, n)$  is required to be unique (overloading).
- ▷ Atomization is applied to the  $i$ -th parameter if  $t_i$  is atomic.

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## User-Defined Functions Example

### Reverse a sequence

Reversing a sequence does not inspect the sequence's items in any way:

```
declare function reverse($seq)
{ for $i at $p in $seq
 order by $p descending
 return $i
};

reverse((42, "a", , doc("foo.xml")))
```

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## XQuery Expressions

- Path expressions.
- FLWOR expressions.
- Expressions involving operators and functions .
- Conditional expressions.
- Quantified expressions.
- List constructors.
- Element constructors.
- Expressions that test or modify datatypes

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## Conditional Expression

- **Syntax:**  
`if (expr1) then expr2 else expr3`
- if **EBV** of *expr1* is true, the conditional expression evaluates to the value of *expr2*, else it evaluates to the value of *expr3*.
- Parentheses around *if* expression (*expr1*) are required.
- *else* is always required but it can be just *else ()*.
- Useful when structure of information returned depends on a condition.
- Can be nested and used anywhere a value is expected.  

```
if ($book/@year < 1980)
then <old>{$x/title}</old>
else <new>{$x/title}</new>
```

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## Conditional Expression

- Used as an alternative way of writing the FLWOR expressions.

**FLWOR:** `for $a in document("bib.xml")//article  
where $a/year < 1996  
return $a`

**Conditional:** `for $a in document("bib.xml")//article  
return  
if ($a/year < 1996)  
then $a  
else ()`

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- **Quantified expressions.**
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## Quantified Expressions

- **Syntax:**  
`[some | every] $var in expr satisfies test_expr`
- Quantified expressions evaluate to a **boolean** value.
- **Evaluation:**
  - *\$var* is bound to each of the items in the sequence resulting from *expr*.
  - For each binding, the *test\_expr* is evaluated.
  - In case of
    - **Existential quantification** ("some"), if at least one evaluation of *test\_expr* evaluates "true", the entire expression evaluates "true".
    - **Universal quantification** ("every"), all evaluations of *test\_expr* must result in an **EBV** of "true" for the expression to return "true".

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## Quantified Expressions

- **Existential Quantification**
  - Give me all books where "Sailing" appear at least once in the same paragraph.

```
for $b in document("bib.xml")//book
where some $p in $b//para satisfies(contains($p,"Sailing"))
return $b/title
```

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## Quantified Expressions

- **Universal Quantification**
  - Give me all books where "Sailing" appears in every paragraph.

```
for $b in document("bib.xml")//book
where every $p in $b//para satisfies(contains($p,"Sailing"))
return $b/title
```

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## XQuery List Constructors

- A list may be constructed by enclosing zero or more expressions in square brackets, separated by commas.
- For example, `[$x, $y, $z]` denotes a list containing three members represented by variables.
- `[]` denotes an empty list.

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## XQuery Operators on Data Types

- `INSTANCEOF` returns True if its first operand is an instance of the type named in its second operand.  
`$x INSTANCEOF integer`
- `CAST` is used to convert a value from one datatype to another.  
`CAST AS integer (x DIV y)`
- `TREAT` causes the query processor to treat an expression as though its datatype were a subtype of its static type.  
`TREAT AS Cat($mypet)`

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## Library Modules

- Separate XQuery documents that contain function definitions.
- Why?
  - Reusing functions among many queries.
  - Defining standard libraries that can be distributed to a variety of query users.
  - Organizing and reducing the size of query modules.

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## Library Modules

```
main module
import module
namespace strings = "http://datypic.com/strings"
at "http://datypic.com/strings/lib.xq";

<results>strings:trim(doc("cat.xml")//name[1])</results>

library module
module namespace strings = "http://datypic.com/strings";
declare function strings:trim($arg as xs:string?)
as xs:string? {
 (: ...function body here... :)
};
```



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## Global Variables

- Declared and bound in the query prolog and used through the query.
- Can be
  - Referenced in a function that is declared in that module.
  - Referenced in other modules that import the module.

```
declare variable $maxNumItems := 3;
declare variable $ordDoc := doc("ord.xml");

for $item in
 $ordDoc//item[position() <= $maxNumItems]
return $item
```

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To play around a bit with XQuery, you can use Exist Demo  
<http://demo.exist-db.org/sandbox/sandbox.xql#>

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## Resources

- W3C XQuery  
<http://www.w3.org/TR/xquery.html>
- W3C XML Query Use Cases  
<http://www.w3.org/TR/xmlquery-use-cases.html>
- W3C XML Query Requirements  
<http://www.w3.org/TR/xmlquery-req.html>
- W3C XML Query Data Model  
<http://www.w3.org/TR/query-datamodel.html>
- W3C XML Query Algebra  
<http://www.w3.org/TR/query-algebra.html>

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## Resources (Books)

- Kay, Micheal. *XPath 2.0 Programmer's Reference*. Wrox, 2004.
- Katz, Howard et al. *XQuery from the experts*. Addison-Wesley, 2003.
- Walmsley, Priscilla, *XQuery*. O'Reilly 2006.

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## Resources (Implementations)

- Saxon  
<http://saxonica.com/>
- Galax  
<http://www.galaxquery.org/>
- X-Hive  
<http://www.x-hive.com/xquery/>
- IPSI-XQ  
[http://www.ipsi.fraunhofer.de/oasys/projects/ipsi-xq/index\\_e.html](http://www.ipsi.fraunhofer.de/oasys/projects/ipsi-xq/index_e.html)
- MonetDB/XQuery  
<http://monetdb.cwi.nl/XQuery/>

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## Other Resources

- Mailing Lists
  - [talk@xquery.com](mailto:talk@xquery.com)
  - [www-gl@w3.org](http://www-gl@w3.org)
- Examples
  - <http://www.xqueryfunctions.com/>

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END  
Lecture 12

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