XML Technologies

XQuery: More than Just a Query Language!

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XQuery Versions

Version 2.0 ...was skipped (as XPath 2.0 was already out)

Version 3.0

- enhanced FLWOR expressions
- error handling: `try`/`catch`
- HOF (higher-order functions):
  - inline functions
  - dynamic function calls
  - named function references
  - partial function applications

Version 3.1

- (*immutable*) maps: `map{...}`
- (*immutable*) arrays: `[...]`
- lookup operator: `?`
- arrow operator: `=>`
- string constructor: ``` ``[...]`` ```
- embedded JSON support (functions, serialization)

FLWOR Expressions: Tuples

Semantics

- FLWOR iterations can be regarded as *tuple streams*
- a tuple stream is an ordered sequence of zero or more *tuples*
- a tuple is a set of *variables*, each of which is bound to a *value*
- a value (as you know?) is a sequence of zero or more *items*

Example

♨
```
for $a in (2,3)
for $b in (4,5)
let $c := ($a,$b) (: ignored :)
return $a * $b
```

- Tuple stream with 4 tuples:

  $a: 2, $b: 4, $c: (2,4)

  $a: 2, $b: 5, $c: (2,5)

  $a: 3, $b: 4, $c: (3,4)

  $a: 3, $b: 5, $c: (3,5)

☞ Result: 8, 10, 12, 15

FLWOR Expressions: Windows

Semantics

- windows are an essential feature in *streaming languages* (e.g. SPL)
- windows allow you to process *sub-sequences* of iterated tuples
- two types of windows exist:
  - *sliding* windows: may overlap (items of a stream may be contained in *more than one* window)
  - *tumbling* windows: each item will only be passed on once

Examples

♨
```
for sliding window $w in (1 to 4)
      start at $s when true()
        end at $e when $e - $s = 2
return string-join($w, '/')
```
☞ Result: 1/2/3, 2/3/4, 3/4, 4

♨
```
for tumbling window $w in (1 to 4)
      start at $s when true()
        end at $e when $e - $s = 2
return string-join($w, '/')
```
☞ Result: 1/2/3, 4

FLWOR Expressions: Windows

Syntax (simplified)

```
Window   ::= for (Tumbling | Sliding)
Tumbling ::= tumbling window $Name in Expr Start End?
Sliding  ::= sliding  window $Name in Expr Start End
Start    ::=     start Vars when Expr
End      ::= only? end Vars when Expr
Vars     ::= ($Name)? (at $Name)? (previous $Name)? (next $Name)?
```

- if `only end` is specified, remaining items may be skipped
- the `current`, `previous` and `next` item may be bound to a variable

```
for tumbling window $w in (1 to 10)
    start $c previous $p next $n when $c mod 2 = 0
return string-join(($p,$c,$n), '/')
```

What do you expect as the result?

FLWOR Expressions: Grouping

Semantics

- query results are partitioned into groups of tuples whose *grouping keys* are *equivalent*
- grouping keys are the atomized values of *grouping variables* (values must be single items)
- equivalent means: `$var1 eq $var2` must yield true
- an expression can be *bound* to the grouping variable

Example I

♨
```
for $n in (66,99,66)
group by $n
return $n
```

☞ Result: 66, 99

- grouping variable: `$n`
- grouping keys: 66, 99, 66
- equivalent query: `distinct-values((66,99,66))`

FLWOR Expressions: Grouping

Example II

```
for $n at $p in (66,99,66)
group by $n
return ($n,$p)
```

☞ The result is: 66, 1, 3, 99, 2

Example III

```
for $n in (66,99,66)
let $x := 1
group by $x := 1
return count($n)
```

✎ What is the result?

Example IV

Based on the Factbook document*:

```
for $cntr in //country
group by $size := xs:integer(
  math:log10($cntr/@population))
order by $size descending
return element countries {
  attribute size { $size },
  $cntr/name
}
```

✎ Describe the expected output!

* files.basex.org/xml/factbook.zip

FLWOR Expressions: Counting, Empty Sequences

Counting

- the `count` clause enables you enumerate FLWOR loops
- in contrast to `at` (XQuery 1.0), count can occur everywhere

Example

```
for $n at $p in (8,0,8)
where $n = 8
count $c
return $c || '/' || $p
```

☞ Result: 1/1, 2/3

Allowing Empty

- derived from SQL
- if the input is empty, *loops once* and binds *empty sequence* to variable

Example

```
for $n in ()
return count($n),
for $n allowing empty in ()
return count($n)
```

✎ What is the result?

Error Handling

Try/Catch Expression

- essential feature for dealing with *unexpected behavior*
- can be restricted to certain error codes

Generic Case

```
try { expr1 }
catch * { expr2 }
```

Catching Specific Errors

```
try { 1 + '' }
catch err:XPTY0004 {
  'Typing!'
}
```

Catching Additional Information

```
try { file:read-text('x.txt') }
catch * {
 'code:' || $err:code ||
 ',msg:' || $err:description
}
```

Higher-Order Functions

Functions in XQuery 1.0:

- have a name (are *named*)
- are *statically* declared
- values are sequences of:
  - nodes: `element()`, `text()`, ...
  - atomic values: `xs:string`, ...
- which function is called must be known *beforehand*

Functions in XQuery 3.x:

- can be unnamed (*anonymous*)
- can be declared *on-the-fly*
- values can be *functions*:
  - function that takes a function as argument: `fn:for-each`
  - functions that returns a function: `fn:function-lookup`
- function to be evaluated can be chosen *dynamically*:
  `let $f := ... return $f()`

Functions Items

In XQuery:

- an item can be a *function item*
- each function item has
  - a *name*, possibly absent (`()`)
  - an *arity* (number of arguments)
  - a *function type*, which specifies argument and result types
    e.g. `function(xs:integer) as xs:boolean`
- types of function items:
  inline functions, *named function references*, *partially applied functions*

In other functional languages:

- a very common concept
- also called
  - lambda (-abstraction), λ
  - inline function
  - anonymous function
- present in Java 8, Python, Haskell, Matlab, C#, ...

Functions Items: Syntax

Inline function

```
function($arg as type, ...)
  as type {
  ...
}
```

- creates an *unnamed* function item
- functions and variables from the *outer scope* can be used (☞ closure)
- type declarations (`as ...`) are optional (as usual)

Named function reference

```
function-name#arity
```

- returns a function item for a *pre-declared* function
- example:

```
let $substr := fn:substring#2
return $substr('World', 2)
```

- equivalent to:

```
function($string, $start) {
  fn:substring($string, $start)
}('World', 2)
```

Functions Items: Syntax

Partial Function Application

```
function-name($x1, ..., ?, ..., $xn)
```

- *partially applies* arguments to a function (item)
- creates a new *function item* with a reduced number of arguments
- example:

```
let $chop-first := fn:substring(?, 2)
return $chop-first('World')
```

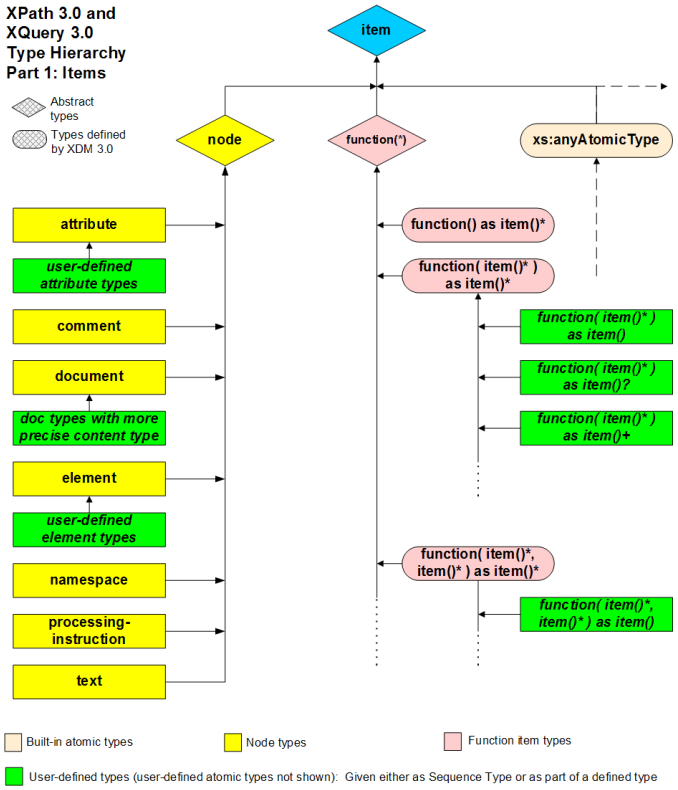
- equivalent to:

```
function($string) {
  fn:substring($string, 2)
}('World')
```

Function Types

- check function type:
  ```
  $f instance of function(*),
  $f instance of function(...) as ...
  ```
- retrieve name and number of arguments of a function:
  ```
  for $f in (fn:count#1, math:pi#0)
  return (function-name($f),
          function-arity($f))
  ```
- function types can be arbitrarily nested:
  ```
  function(function() as xs:integer)
     as function() as xs:boolean
  ```

✎ What is the type of `true#0` ?



HOF: Applications

Abstraction

- HOFs can be used to extract patterns into library functions: *iteration*, *recursion schemes*
- HOFs can be used to build data structures: *arrays*, *trees*, ...

Example: Newton's Method

- Task: calculate the square root of a number
- Newton's method:
  - start with an initial guess
  - while the guess is not good enough:
    - come up with a better guess by improving upon the old one
    - repeat

Newton's Method

```
declare function local:square-root($n as xs:double, $eps as xs:double) {
  local:square-root($n, 1, $eps)
};

declare function local:square-root($n, $guess, $eps) {
  let $new := $n div ($guess)
  let $diff := abs($n - $guess * $guess)
  return if($diff lt $eps) then $guess else
    let $better-guess := ($guess + $new) div 2
    return local:square-root($n, $better-guess, $eps)
};

(: call function with input number and newton epsilon :)
local:square-root(1000, 1)
```

Newton's Method II

Now the same for cube roots...

- seems easy:
  - adapt the part saying if the guess is good enough
  - adapt the code that calculates the new guess
- most things stay the same:
  - checking the current guess
  - calculating a new one
  - calling the function recursively

Newton's Method II

```
declare function local:cube-root($n as xs:double, $eps as xs:double) {
  local:cube-root($n, 1, $eps)
};

declare function local:cube-root($n, $guess, $eps) {
  let $new := $n div ($guess * $guess)
  let $diff := abs($n - $guess * $guess * $guess)
  return if($diff lt $eps) then $guess else
    let $better-guess := ($guess + $new) div 2
    return local:cube-root($n, $better-guess, $eps)
};

(: call function with input number and newton epsilon :)
local:cube-root(1000, 1)
```

Newton's Method III

Abstracting out the pattern

- problem:
  - lots of *redundant* code
- way out:
  - *factor out* Newton's method
  - *abstract* over the parts of the code that change with function items
- advantages:
  - more *concise*, more *general*
  - *reusable* for similar problems
  - can be put in a *library*

```
declare function local:newtons-method(
  $guess
    as item()*,
  $good-enough
    as function(item()*) as xs:boolean,
  $improve
    as function(item()*) as item()*
) as item()* {
  if($good-enough($guess))
  then
    $guess
  else
    let $better := $improve($guess)
    let $average := ($guess + $better) div 2
    return local:newtons-method(
      $average, $good-enough, $improve)
};
```

Newton's Method III

```
declare function local:square-root($n as xs:double, $eps as xs:double) {
  local:newtons-method(
    1,
    function($guess) { abs($n - $guess * $guess) lt $eps },
    function($guess) { $n div $guess }
  )
};

declare function local:cube-root($n as xs:double, $eps as xs:double) {
  local:newtons-method(
    1,
    function($guess) { abs($n - $guess * $guess * $guess) lt $eps },
    function($guess) { $n div ($guess * $guess) }
  )
};
```

Newton's Method IV

Abstracting again

- *redundant code* has been eliminated, but...
- there's an even *more general* pattern in it:
  - start with an *initial value*
  - *repeatedly update* it until a condition holds
  - ☞ similar to a `while` loop

```
declare function local:repeat-until(
  $condition
    as function(item()*) as xs:boolean,
  $current
    as item()*,
  $update
    as function(item()*) as item()*
) as item()* {
  if($condition($current))
  then
    $current
  else
    let $next := $update($current)
    return local:repeat-until(
      $next, $condition, $update)
};
```

Newton's Method IV

```
declare function local:newtons-method(
  $guess as item()*,
  $good-enough as function(item()*) as xs:boolean,
  $improve as function(item()*) as item()*
) as item()* {
  local:repeat-until(
    $good-enough,
    $guess,
    function($curr) {
      let $better-guess := $improve($guess)
      return ($guess + $better-guess) div 2
    }
  )
};
```

Pre-Defined Functions

Some common programming patterns have been standardized:

Official functions

- the XQuery 3.0 specification defines various higher-order functions[1]
- use the `fn` prefix
- most work on *sequences*
- will be presented next

BaseX functions

- separate module for additional higher-order functions[2]
- use the `hof` prefix
- mostly inspired by the *Haskell Prelude* module
- *sorting*, *top-k queries*, ...

[1] http://www.w3.org/TR/xpath-functions-30
[2] http://docs.basex.org/wiki/Higher-Order_Functions_Module

Pattern I: Examples

Increment integers in a sequence

```
declare function local:inc(
  $ints as xs:integer*
) as xs:integer* {
  for $i in $ints return $i + 1
};
```

Retrieve names of elements

```
declare function fn:names(
  $elements as element()*
) as xs:string* {
  for $e in $elements
  return name($e)
};
```

Lower-case sequence of strings

```
declare function local:lower-all(
  $lines as xs:string*
) as xs:string* {
  for $l in $lines
  return fn:lower-case($l)
};
```

✎ Home work... Rewrite with fn:for-each

Pattern I

fn:for-each($seq, $f)

- applies a user-defined function to *each item* of a sequence
- restricted form of a *FLWOR expression*
- equivalent to the *map operator*: `$seq ! $f(.)`

XQuery implementation

```
declare function local:for-each(
  $seq as item()*,
  $f as function(item()) as item()*
) as item()* {
  for $i in $seq
  return $f($i)
};
```

Example

```
fn:for-each(
  (1.25, 19.84),
  floor#1
) ⇢ (1, 19)
```

Pattern II: Examples

Remove non-positive values

```
declare function local:positive(
  $doubles as xs:double*
) as xs:double* {
  for $d in $doubles
  where $d > 0
  return $d
};
```

Return strings starting with 'A'

```
declare function fn:strings-with-a(
  $strings as xs:string*
) as xs:string* {
  for $s in $strings
  where starts-with($s, 'A')
  return $s
};
```

✎ Home work... Rewrite with fn:filter

Pattern II

fn:filter($seq, $pred)

- returns all items of a sequence for which a *predicate function* returns `true`
- kind of superfluous, as XPath predicates are shorter: `$seq[$f(.)]`

XQuery implementation

```
declare function local:filter(
  $seq as item()*,
  $f as function(item()) as xs:boolean
) as item()* {
  for $i in $seq
  where $f($i)
  return $i
};
```

Example

```
fn:filter(
  1 to 10,
  function($x) { $x * $x < 10 }
) ⇝ (1, 2, 3)
```

Pattern III: Examples

Vector addition

```
declare function local:add-vectors(
  $vec1 as xs:double*,
  $vec2 as xs:double*
) as xs:double* {
  for $x at $p in $vec1
  let $y := $vec2[$p]
  return $x + $y
};
```

Enumerate lines in a file

```
declare function fn:enumerate-lines(
  $numbers as xs:integer*,
  $lines as xs:string*
) as xs:string* {
  for $line at $p in $lines
  let $nr := $numbers[$p]
  return concat($nr,': ',$line)
};
```

✎ Home work... Rewrite with fn:for-each-pair

Pattern III

fn:for-each-pair($seq1, $seq2, $f)

- combines the elements of two sequences pairwise with a user-defined function:
  - stops when the shorter list ends
  - also known as zipping function

✎ What does this do?

```
every $bool in
  fn:for-each-pair(
    $seq, $seq[position() > 1],
    function($x,$y) { $x < $y }
  ) satisfies $bool
```

XQuery implementation

```
declare function local:for-each-pair(
  $seq1 as item()*,
  $seq2 as item()*,
  $f as function(item(),item()) as item()
) as item()* {
  for $i in
    1 to min(count($seq1),count($seq2))
  return $f($seq1[$i], $seq2[$i])
};
```

Example

```
fn:for-each-pair(
  ('foo','bar'), (2,3), substring#2
) ⇝ ('oo', 'r')
```

Pattern IV: Examples

Sum up a numbers of a sequence

```
declare function local:sum(
  $nums as xs:double*
) as xs:double {
  let $head := head($nums)
  let $tail := tail($nums)
  return if(empty($tail)) then
    $head
  else
    $head + local:sum($tail)
};
```

Concatenate strings

```
declare function local:concat(
  $strs as xs:string*
) as xs:string {
  if(empty($strs)) then
    ''
  else
    $strs[1] || local:concat(
      $strs[position() > 1]
    )
};
```

✎ Home work... Rewrite with fn:fold-(left|right)

Pattern IV

fold-right($seq, $start, $f)

- starts with an initial value
- consumes the input sequence right-to-left:
  - the value `$start` is used as the *rightmost* value
  - each new item is combined with the *accumulator* using `$f`

XQuery implementation

```
declare function local:fold-right(
  $seq as item()*,
  $start as item()*,
  $f as function(item(),item()*) as item()*
) as item()* {
  if(empty($seq)) then $start
  else $f(
    head($seq),
    local:fold-right(tail($seq),$start,$f))
};
```

Example

```
fn:fold-right((1 to 5), 1,
  function($i, $res) { $res * $i }
) ⇢ 120
```

Pattern IV

fold-left($seq, $start, $f)

- starts with an initial value
- consumes the input sequence left-to-right:
  - the value `$start` is used as the *leftmost* value
  - each new item is combined with the *accumulator* using `$f`
  - in comparison to fold-right, the accumulator comes *before* the new item

XQuery implementation

```
declare function local:fold-left(
  $seq as item()*,
  $start as item()*,
  $f as function(item()*,item()) as item()*
) as item()* {
  if(empty($seq)) then $start
  else local:fold-left(
    tail($seq),
    $f($start, head($seq)),
    $f)
};
```

Example

```
fn:fold-left((0, 4, 0, 4), 0,
  function($i, $d) { 10 * $i + $d }
) ⇢ 404
```

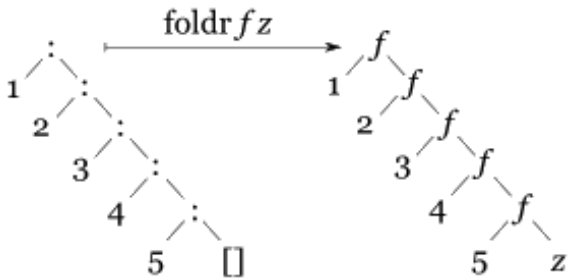
Pattern IV

Evaluation order

```
fn:fold-right((1,2,3), 42, $f)
⇢ $f(1,$f(2,$f(3,42)))
```

Pseudo code

```
$res ← $start
foreach($x in reverse($seq)) {
  $res ← $f($x,$res)
}
return $res
```

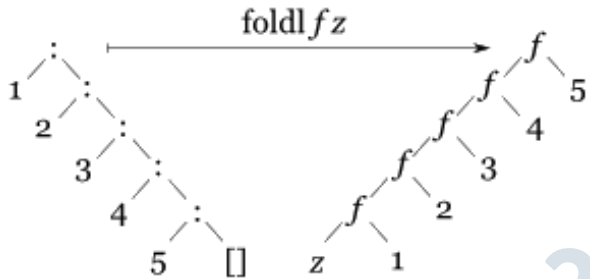


Evaluation order

```
fn:fold-left((1,2,3), 42, $f)
⇢ $f($f($f(42,1),2),3)
```

Pseudo code

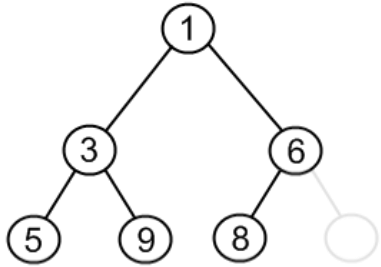
```
$res ← $start
foreach($x in $seq) {
  $res ← $f($res,$x)
}
return $res
```



HOF: Data Structures

With XQuery 1.0

- modelling *structured data*, like trees, is hardly possible with plain sequences
  - ☞ remember: sequences are always flattened
  - possibly realizable via tricks, e.g. `(1,3,<sep/>,9,6)`
- XML is great at representing trees, but contents can only be *textual*:
  - when storing, data needs to be *serialized*, and item types need to be remembered
  - when retrieving, data needs to be *parsed* and cast to the original type




```
<node id="1">
  <node id="3">
    <node id="5"/>
    <node id="9"/>
  </node>
  <node id="6">
    <node id="8"/>
    <empty/>
  </node>
</node>
```

HOF: Data Structures

With function items

As *inline functions* capture the variables from their environment, they can be used as simple data containers:

- values are not *serialized*
- structure can be expressed as *control flow* inside the function

See here what's possible:
http://github.com/LeoWoerteler/xq-modules

Example I: pair of sequences

```
declare namespace pair = 'pair';
declare function pair:new($s1, $s2) {
  function($first as xs:boolean) {
    if($first) then $s1 else $s2
  }
};
declare function pair:first($pair) {
  $pair(true())
};
declare function pair:second($pair) {
  $pair(false())
};
(: retrieve first sequence of pair :)
pair:first(pair:new(1 to 4, 5 to 9))
```

HOF: Data Structures

Example II: arrays

```
declare namespace array = 'array';
declare function array:new($seq) as function(*) {
  function($pos as xs:integer?) {
    if(exists($pos)) then $seq[$pos]
    else count($seq)
  }
};
declare function array:length($array as function(*)) as xs:integer {
  $array(())
};
declare function array:get($array as function(*), $pos as xs:integer) as item()? {
  $array($pos)
};
(: retrieve first sequence of pair :)
array:get(array:new(1 to 5), 3)
```

XQuery 3.1: Data Structures

Map

- available in nearly *every language*
- *unordered* collection of *key/value pairs*; keys are *distinct*

XQuery maps

- maps are *function items*!
- maps are *immutable*! ✎ Why?
  Implemented in BaseX as Hash Trie

☞ *sets* can be simulated by storing dummy values

Examples

- empty map: `map { }`
- map with initial entries:
  `map { 'A':(1,2), 456:<a/> }`
- access entry (via *function argument*):
  ```
  let $map := map { 'A':1 }
  return $map('A')
  ```
- dynamically create map:
  `map:merge((1 to 5) ! map {.:.})`

✎ What are the resulting entries?

XQuery 3.1: Data Structures

Array

- very *basic* data structure
- ordered collection of *values*, accessible by *index*
- arrays can be *nested*

XQuery arrays

- index starts with 1
- arrays are *function items!*
- arrays are *immutable*!
  Implemented in BaseX as Finger Tree

Examples

- empty array: `[]`
- array with initial entries:
  `[ 1,(2,3),(),[4] ]`
- access entry (via *function argument*):
  ```
  let $array := [ 1,(2,3) ]
  return $array(2)
  ```
- dynamically create array:
  ```
  array { 1 to 5 },
  array:join((1 to 5) ! [.])
  ```

✎ What are the resulting entries?

XQuery 3.1: Syntactic Sugar

Lookup operator (?)

- access values of maps and arrays without parentheses

Example

```
let $map := map { 'R':'red',
  'G':'green', 'B':'blue'
}
return (
  $map?R, (: 'red' :)
  $map?*  (: all values :)
)
```

☞ Result: red, red, green, blue

Context-based lookup

- if no left operator is specified, a value will be looked up in the current context item

Example

```
(map { 'name':'Guðrún',
       'city':'Reykjavík' },
 map { 'name':'Hildur',
       'city':'Akureyri' }
)[?name = 'Hildur']?city
```

☞ Result: Akureyri

XQuery 3.1: Syntactic Sugar

Arrow operator (=>)

- *applies* a value to a function
- value is used as *first argument* to the function

Equivalent examples

♨
```
string-join(
  tokenize(' h e l l o '),
'-')
```

♨
```
' h e l l o '
=> tokenize()
=> string-join('-')
```

☞ Result: `h-e-l-l-o`

String constructor (``[...]```)

- inspired by *here document* literals of the Unix shell/script languages
- generate strings that contain XQuery delimiters

Equivalent examples

♨ `"'live' & ""direct"""`

♨ `'''live'' & "direct"'`

♨ ``['live' & "direct"]``

☞ Result: `'live' & "direct"`