MIE-PDB.16: **Advanced Database Systems**

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Lecture 5

XML Databases: XPath, XQuery

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Lecture Outline

XQuery and XPath

- Data model
- Query expressions
  - Paths
  - Comparisons
  - Constructors
  - FLWOR expressions
  - Conditions
  - Quantifiers

Introduction

XPath = *XML Path Language*

- **Navigation in an XML tree,**
  selection of nodes by a variety of criteria
- Versions: 1.0 (1999), 2.0 (2010), 3.0 (2014), **3.1** (March 2017)
- W3C recommendation
  - https://www.w3.org/TR/xpath-31/

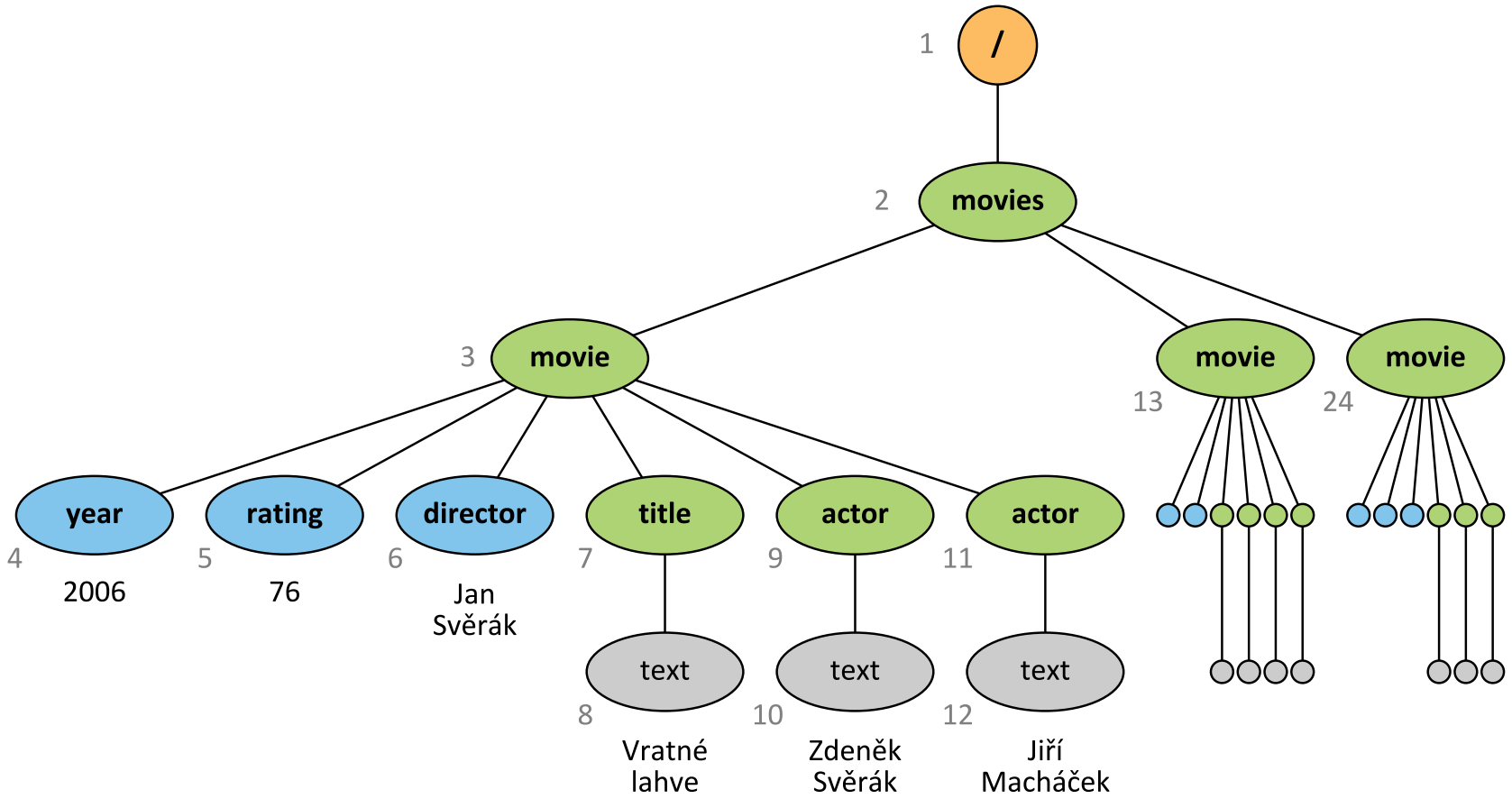
XQuery = *XML Query Language*

- **Complex functional query language**
- Contains XPath
- Versions: 1.0 (2007), 3.0 (2014), **3.1** (March 2017)
- W3C recommendation
  - https://www.w3.org/TR/xquery-31/

Sample Data

```
<?xml version="1.1" encoding="UTF-8"?>
<movies>
  <movie year="2006" rating="76" director="Jan Svěrák">
    <title>Vratné lahve</title>
    <actor>Zdeněk Svěrák</actor>
    <actor>Jiří Macháček</actor>
  </movie>
  <movie year="2000" rating="84">
    <title>Samotáři</title>
    <actor>Jitka Schneiderová</actor>
    <actor>Ivan Trojan</actor>
    <actor>Jiří Macháček</actor>
  </movie>
  <movie year="2007" rating="53" director="Jan Hřebejk">
    <title>Medvídek</title>
    <actor>Jiří Macháček</actor>
    <actor>Ivan Trojan</actor>
  </movie>
</movies>
```

Sample Data


1
/
2
movies
3
movie
13
movie
24
movie
year
4
2006
rating
5
76
director
6
Jan
Svěrák
title
7
text
8
Vratné
lahve
actor
9
text
10
Zdeněk
Svěrák
actor
11
text
12
Jiří
Macháček

Data Model

XDM = *XQuery and XPath Data Model*

- **XML tree** consisting of **nodes** of different kinds
  - Document, element, attribute, text, …
- **Document order** / reverse document order
  - The order in which nodes appear in the XML file
    - I.e. nodes are numbered using a **pre-order depth-first traversal**

Query result

- Each query expression is evaluated to a sequence

Data Model

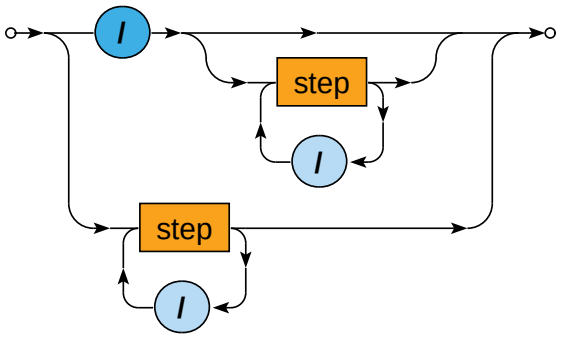
Sequence = **ordered collection of nodes and/or atomic values**

- Can be **empty**
  - E.g.: `()`
- Automatically **flattened**
  - E.g.: `(1, (), (2, 3), (4))` ⇔ `(1, 2, 3, 4)`
- Standalone items are treated as singleton sequences
  - E.g.: `1` ⇔ `(1)`
- Can be **mixed**
  - But usually just nodes, or just atomic values
- **Duplicate items** are allowed
  - More precisely…
    - Duplicate nodes are removed
    - Duplicate atomic values are preserved

Path Expressions

Path expression

- Describes navigation within an XML tree
- Consists of individual navigational steps



- **Absolute** paths = path expressions starting with /
  - Navigation starts at the document node
- **Relative** paths
  - Navigation starts at an explicitly specified node / nodes

Path Expressions

Examples

Absolute paths

```
/
```

```
/movies
```

```
/movies/movie
```

```
/movies/movie/title/text()
```

```
/movies/movie/@year
```

Relative paths

```
actor/text()
```

```
@director
```

Path Expressions

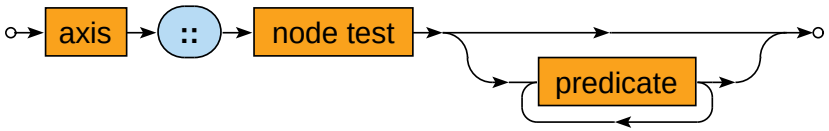
Evaluation of path expressions

- Let P be a **path expression**
- Let C be an initial **context set**
  - If P is **absolute**, then C contains just the document node
  - Otherwise (i.e. P is **relative**) C is given by the user or context
- If P does not contain any step
  - Then C is the **final result**
- Otherwise (i.e when P contains **at least one step**)
  - Let S be the **first step**, P' the **remaining steps** (if any)
  - Let $C' = \{\}$
  - For each node $u \in C$:
    evaluate S with respect to u and add the result to C'
  - Evaluate P' with respect to C'

Path Expressions

Step

- Each step consists of (up to) 3 components



- **Axis**
  - Specifies the **relation of nodes** to be selected for a given node u
- **Node test**
  - **Basic condition** the selected nodes must further satisfy
- **Predicates**
  - **Advanced conditions** the selected nodes must further satisfy

Path Expressions: Axes

Axis

- Specifies the relation of nodes to be selected for a given node

Forward axes

- `self`, `child`, `descendant(-or-self)`, `following(-sibling)`
- The order of the nodes corresponds to the document order

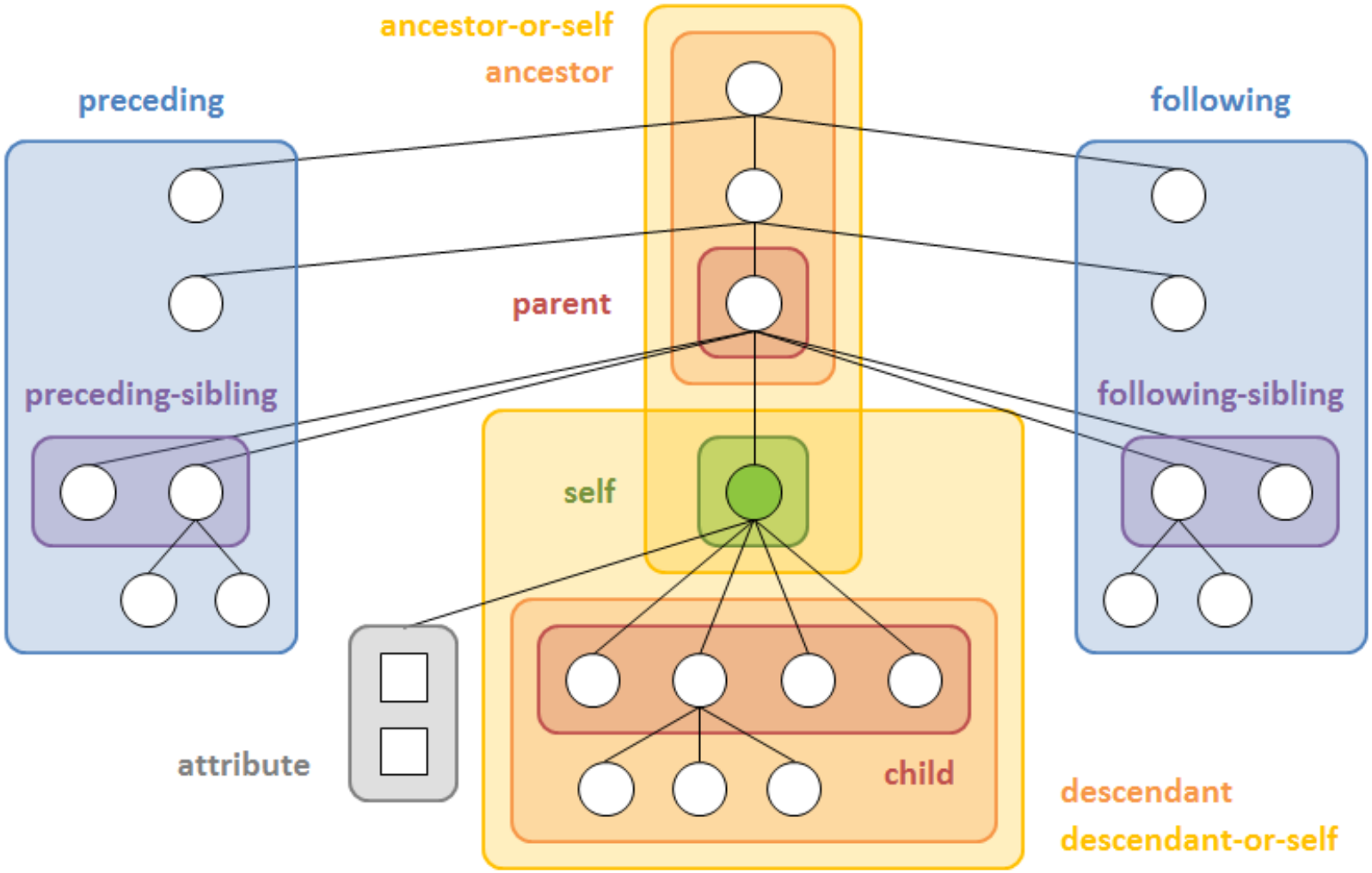
Reverse axes

- `parent`, `ancestor(-or-self)`, `preceding(-sibling)`
- The order of the nodes is reversed

Attribute axis

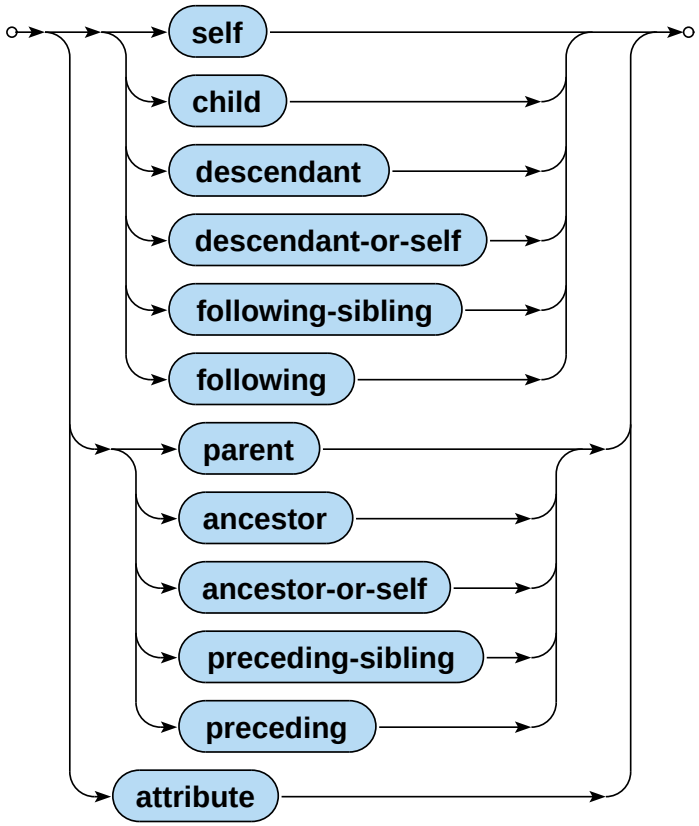
- `attribute` – the only axis that selects attributes

Path Expressions: Axes



Path Expressions: Axes

Available **axes**



Path Expressions

Examples

Axes

```
/child::movies
```

```
/child::movies/child::movie/child::title/child::text()
```

```
/child::movies/child::movie/attribute::year
```

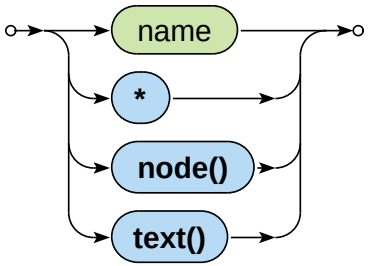
```
/descendant::movie/child::title
```

```
/descendant::movie/child::title/following-sibling::actor
```

Path Expressions: Node Tests

Node test

- Filters the nodes selected by the axis using basic tests



Available node tests

- `name` – all elements / attributes with a given name
- `*` – all elements / attributes
- `node()` – all nodes (i.e. no filtering takes place)
- `text()` – all text nodes

Path Expressions

Examples

Node tests

```
/movies
```

```
/child::movies
```

```
/descendant::movie/title/text()
```

```
/movies/*
```

```
/movies/movie/attribute::*
```

Path Expressions: Predicates

Predicate

- Further filters the nodes based on advanced conditions

- When **more predicates** are provided, they must all be satisfied

Commonly used conditions

- **Comparisons**
- **Path expressions**
  - Treated as `true` when evaluated to a non-empty sequence
- **Position tests**
  - Based on the order as defined by the axis, starting with 1
- **Logical expressions**: `and`, `or`, `not` connectives

Path Expressions

Examples

Predicates

```
/movies/movie[actor]
```

```
/movies/movie[actor]/title/text()
```

```
/descendant::movie[count(actor) >= 3]/title
```

```
/descendant::movie[@year > 2000 and @director]
```

```
/descendant::movie[@director][@year > 2000]
```

```
/descendant::movie/actor[position() = last()]
```

Path Expressions: Abbreviations

Multiple (mostly syntax) **abbreviations** are provided

- …/… (i.e. no axis is specified) ⇔ …/`child::`…
- …/`@`… ⇔ …/`attribute::`…
- …/`.`… ⇔ …/`self::node()`…
- …/`..`… ⇔ …/`parent::node()`…
- …`//`… ⇔ …`/descendant-or-self::node()/`…
- …/…`[number]`… ⇔ …/…`[position() = number]`…

Path Expressions

Examples

Abbreviations

```
/movie/title
```

```
/child::movie/child::title
```

```
/movie/@year
```

```
/child::movie/attribute::year
```

```
/movie/actor[2]
```

```
/child::movie/child::actor[position() = 2]
```

```
//actor
```

```
/descendant-or-self::node()/child::actor
```

Path Expressions: Conclusion

Path expressions

- Absolute / relative

Step components

- Axis
- Node test
- Predicates

Path expression result

- Evaluated **from left to right, step by step**
- **Result of the entire path expression** is the result of its **last step**
- Nodes are ordered in the **document order**
- **Duplicate nodes** are removed (based on the identity of nodes)

Comparison Expressions

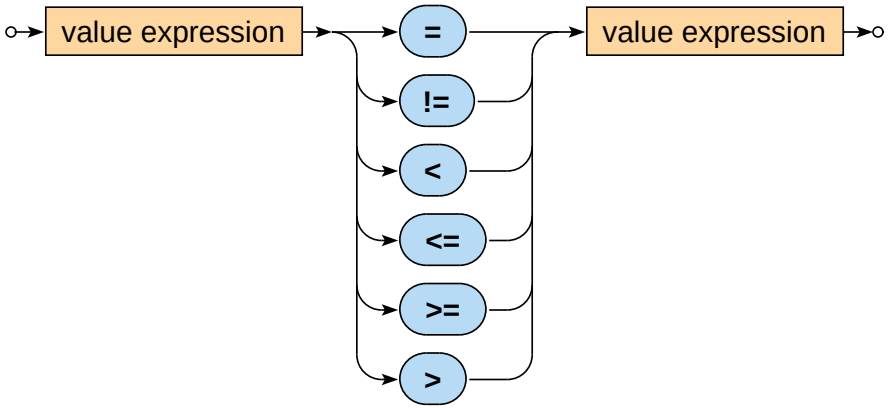
Comparisons

- **General** comparisons
  - Two sequences of values are expected to be compared
  - =, !=, <, <=, >=, >
  - E.g.: `(0,1) = (1,2)`
- **Value** comparisons
  - Two standalone values (singleton sequences) are compared
  - `eq`, `ne`, `lt`, `le`, `ge`, `gt`
  - E.g.: `1 lt 3`
- **Node** comparisons
  - `is` – tests identity of nodes
  - <<, >> – test positions of nodes (preceding, following)
  - Similar behavior as in case of value comparisons

Comparison Expressions

General comparison (**existentially quantified** comparisons)

- **Both the operands can be evaluated to sequences of values of any length**
- The result is `true` if and only if there exists at least one pair of individual values satisfying the given relationship



Comparison Expressions

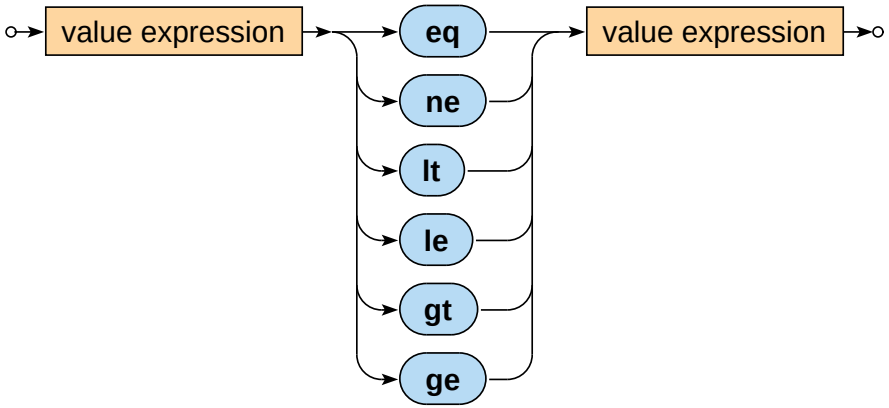
General comparison: examples

- $[\![\texttt{(1) < (2)}]\!] = \texttt{true}$
- $[\![\texttt{1 < (2)}]\!] = \texttt{true}$
- $[\![\texttt{(1) < (1,2)}]\!] = \texttt{true}$
- $[\![\texttt{(1) < ()}]\!] = \texttt{false}$
- $[\![\texttt{(0,1) = (1,2)}]\!] = \texttt{true}$
- $[\![\texttt{(0,1) != (1,2)}]\!] = \texttt{true}$

Comparison Expressions

Value comparison

- **Both the operands are expected to be evaluated to singleton sequences**
  - Then these values are mutually compared in a standard way
- Empty sequence () is returned…
  - when at least one operand is evaluated to an empty sequence
- Type error is raised…
  - when at least one operand is evaluated to a longer sequence



Comparison Expressions

Value comparison: examples

- $[\![$ `(1) le (2)` $]\!] =$ `true`
- $[\![$ `1 le (2)` $]\!] =$ `true`
- $[\![$ `(1) le ()` $]\!] =$ `()`
- $[\![$ `(1) le (1,2)` $]\!] \Rightarrow$ `error`
- $[\![$ `() le (1,2)` $]\!] =$ `()`

Comparison Expressions

Value and general comparisons

- Atomization of values – takes place automatically
  - Atomic values are preserved untouched
  - Nodes are transformed to atomic values
- In particular…
  - **Element node is transformed to a string with concatenated text values it contains** (even indirectly)
    - E.g.: `<movie year="2006">Vratné lahve</movie>` is atomized to a string `Vratné lahve`
    - Note that attribute values are not included!
  - **Attribute node is transformed to its value**
  - **Text node is transformed to its value**

Comparison Expressions

Value and general comparisons: examples

- $[\![$ `<a>5</a> eq <b>5</b>` $]\!] =$ `true`
- $[\![$ `<a>12</a> = <a><b>1</b>2</a>` $]\!] =$ `true`
- $[\![$ `<a t="1">5</a> lt 3` $]\!] =$ `false`

Expressions

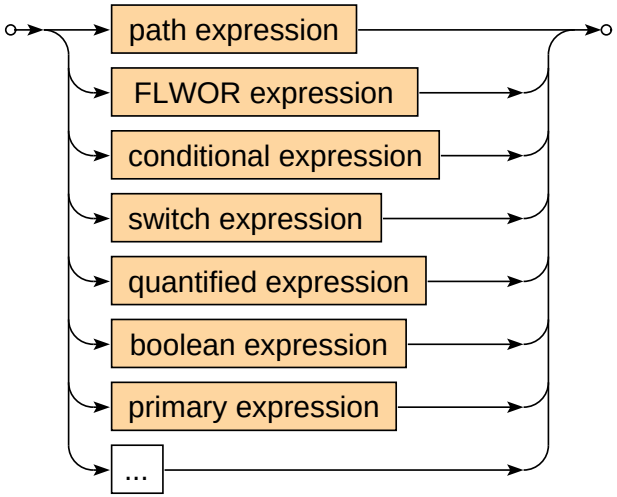
XQuery expressions

- **Path** expressions (traditional XPath)
  - Selection of nodes of an XML tree
- **FLWOR** expressions
  - `for … let … where … order by … return …`
- **Conditional** expressions
  - `if … then … else …`
- **Quantified** expressions
  - `some|every … satisfies …`

Expressions

XQuery expressions

- **Boolean** expressions
  - `and`, `or`, `not` logical connectives
- **Primary** expressions
  - Literals, variable references, function calls, **constructors**, …
- …



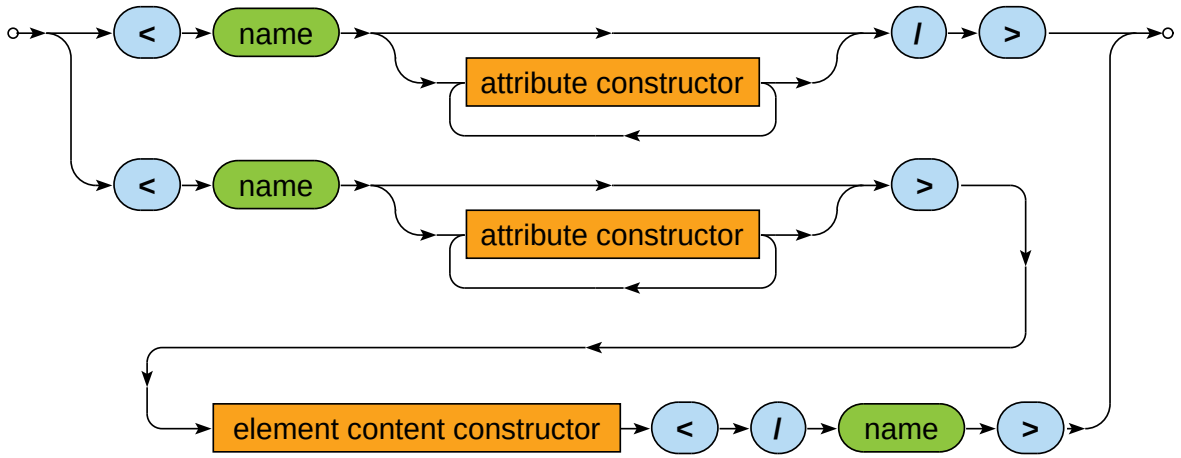
Constructors

Constructors

- Allow us to **create new nodes for elements, attributes, …**
- **Direct** constructor
  - Well-formed XML fragment with **nested query expressions**
    - E.g.: `<movies>{ count(//movie) }</movies>`
  - **Names of elements and attributes must be fixed**, their content can be dynamic
- **Computed** constructor
  - Special syntax
    - E.g.: `element movies { count(//movie) }`
  - **Both names and content can be dynamic**

Constructors

Direct constructor

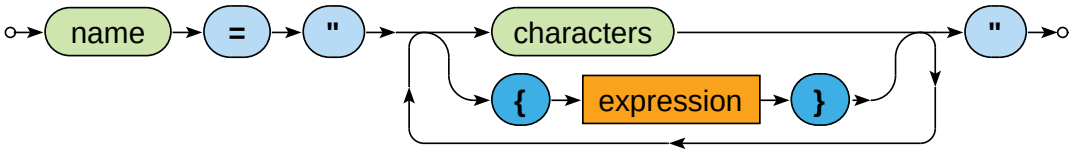


- Both **attribute value and element content** may contain an arbitrary number of **nested query expressions**
  - Enclosed by curly braces {}
  - Escaping sequences: {{ and }}

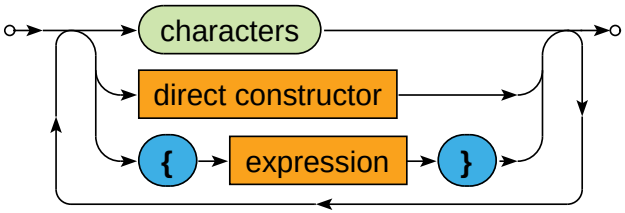
Constructors

Direct constructor

- Attribute



- Element content



Constructors

Example: Direct Constructor

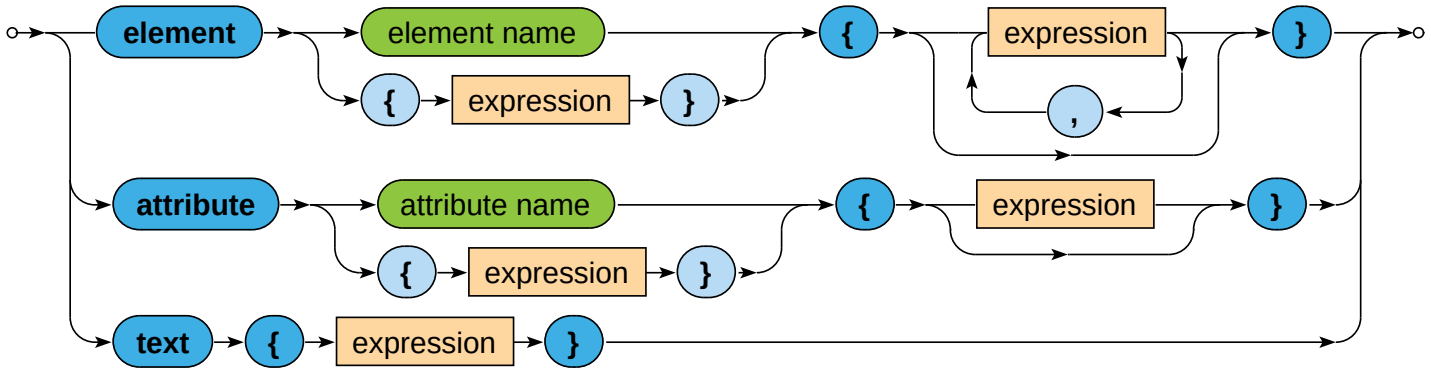
Create a summary of all movies

```
<movies>
  <count>{ count(//movie) }</count>
  {
    for $m in //movie
    return
      <movie year="{ data($m/@year) }">{ $m/title/text() }</movie>
  }
</movies>
```

```
<movies>
  <count>3</count>
  <movie year="2006">Vratné lahve</movie>
  <movie year="2000">Samotáři</movie>
  <movie year="2007">Medvídek</movie>
</movies>
```

Constructors

Computed constructor



Constructors

Example: Computed Constructor

Create a summary of all movies

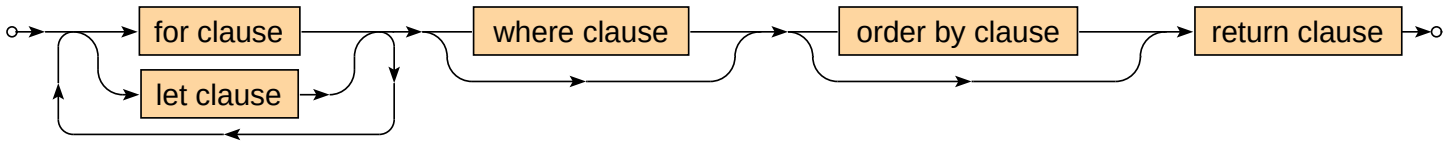
```
element movies {
  element count { count(//movie) },
  for $m in //movie
  return
    element movie {
      attribute year { data($m/@year) },
      text { $m/title/text() }
    }
}
```

```
<movies>
  <count>3</count>
  <movie year="2006">Vratné lahve</movie>
  <movie year="2000">Samotáři</movie>
  <movie year="2007">Medvídek</movie>
</movies>
```

FLWOR Expressions

FLWOR expression

- Versatile construct allowing for **iterations over sequences**



Clauses

- `for` – selection of items to be iterated over
- `let` – bindings of auxiliary variables
- `where` – conditions to be satisfied (by a given item)
- `order by` – order in which the items are processed
- `return` – result to be constructed (for a given item)

FLWOR Expressions

Example

Find titles of movies with rating *75* and more

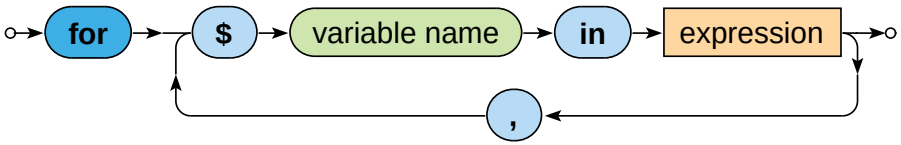
```
for $m in //movie
let $r := $m/@rating
where $r >= 75
order by $m/@year
return $m/title/text()
```

```
Samotáři
Vratné lahve
```

FLWOR Clauses

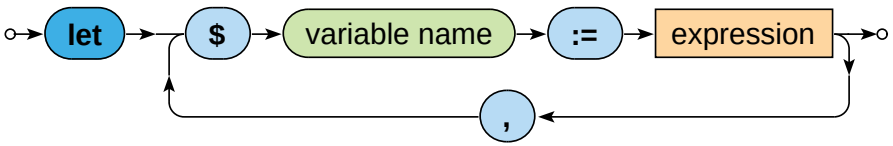
For clause

- Specifies a **sequence of values or nodes to be iterated over**
- Multiple sequences can be specified at once
  - Then the behavior is identical as when more single-variable `for` clauses would be provided



Let clause

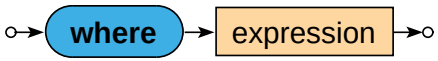
- Defines one or more auxiliary **variable assignments**



FLWOR Clauses

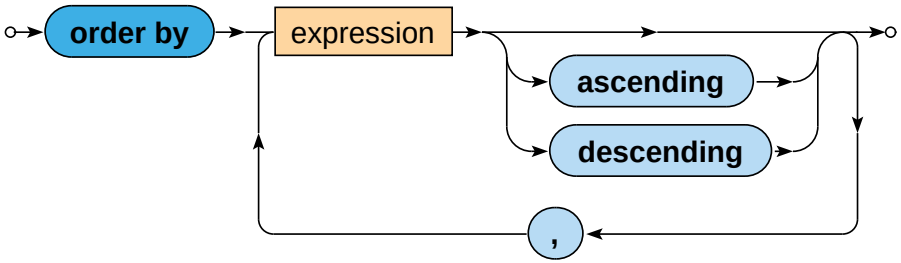
Where clause

- Allows to describe complex **filtering conditions**
- Items not satisfying the conditions are skipped



Order by clause

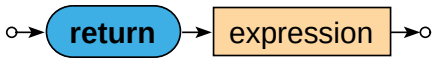
- Defines the **order in which the items are processed**



FLWOR Clauses

Return clause

- **Defines how the result sequence is constructed**
- Evaluated once for each suitable item



Various supported **use cases**

- Querying, joining, grouping, aggregation, integration, transformation, validation, …

FLWOR Examples

Find titles of movies filmed in *2000* or later such that they have at most 3 actors and a rating above the overall average

```
let $r := avg(//movie/@rating)
for $m in //movie[@rating >= $r]
let $a := count($m/actor)
where ($a <= 3) and ($m/@year >= 2000)
order by $a ascending, $m/title descending
return $m/title
```

```
<title>Vratné lahve</title>
<title>Samotáři</title>
```

FLWOR Examples

Find movies in which each individual actor stared

```
for $a in distinct-values(//actor)
return <actor name="{ $a }">
         {
           for $m in //movie[actor[text() = $a]]
           return <movie>{ $m/title/text() }</movie>
         }
       </actor>
```

```
<actor name="Zdeněk Svěrák">
  <movie>Vratné lahve</movie>
</actor>
<actor name="Jiří Macháček">
  <movie>Vratné lahve</movie>
  <movie>Samotáři</movie>
  <movie>Medvídek</movie>
</actor>
...
```

FLWOR Examples

Construct an HTML table with data about movies

```
<table>
  <tr><th>Title</th><th>Year</th><th>Actors</th></tr>
  {
    for $m in //movie
    return
      <tr>
        <td>{ $m/title/text() }</td>
        <td>{ data($m/@year) }</td>
        <td>{ count($m/actor) }</td>
      </tr>
  }
</table>
```

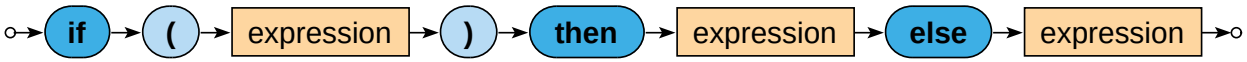
FLWOR Examples

Construct an HTML table with data about movies

```
<table>
  <tr><th>Title</th><th>Year</th><th>Actors</th></tr>
  <tr><td>Vratné lahve</td><td>2006</td><td>2</td></tr>
  <tr><td>Samotáři</td><td>2000</td><td>3</td></tr>
  <tr><td>Medvídek</td><td>2007</td><td>2</td></tr>
</table>
```

Conditional Expressions

Conditional expression



- Note that the `else` branch is compulsory
  - Empty sequence `()` can be returned if needed

Example

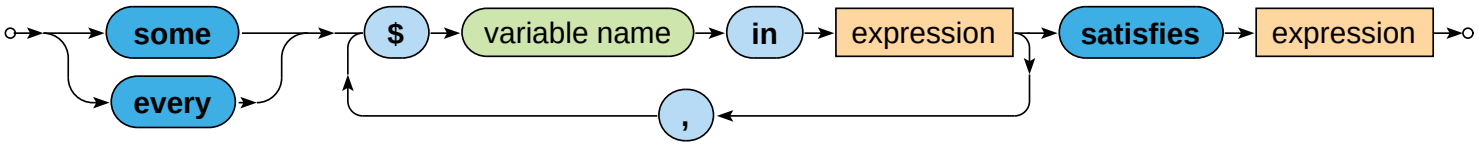
```
if (count(//movie) > 0)
then <movies>{ string-join(//movie/title, ", ") }</movies>
else ()
```

```
<movies>Vratné lahve, Samotáři, Medvídek</movies>
```

Quantified Expressions

Quantifier

- Returns `true` if and only if…
  - in case of `some` **at least one item**
  - in case of `every` **all the items**
- … of a given sequence/s **satisfy the provided condition**



Quantified Expressions

Examples

Find titles of movies in which *Ivan Trojan* played

```
for $m in //movie
where
  some $a in $m/actor satisfies $a = "Ivan Trojan"
return $m/title/text()
```

```
Samotáři
Medvídek
```

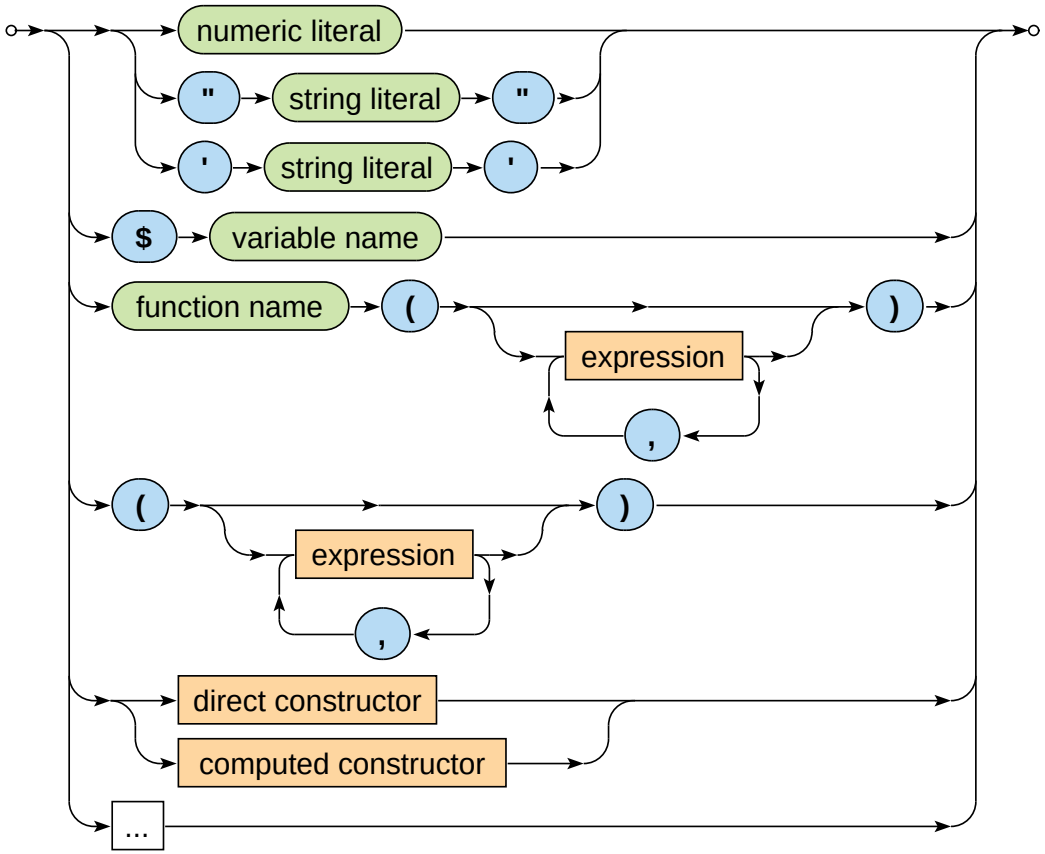
Find names of actors who played in all movies

```
for $a in distinct-values(//actor)
where
  every $m in //movie satisfies $m/actor[text() = $a]
return $a
```

```
Jiří Macháček
```

Primary Expressions

Primary expression



Final Observations

XQuery

- **Keywords** must always be in **lowercase**
- XQuery is a **functional query language**
- Whenever `expression` is mentioned in any diagram, expression of any kind can be used (without any limitations)

Lecture Conclusion

XPath expressions

- Absolute / relative paths
- Axes, node tests, predicates

XQuery expressions

- Constructors: direct, computed
- FLWOR expressions
- Conditional, quantified, comparison, …