NDBI049: **Query Languages**

http://www.ksi.mff.cuni.cz/~svoboda/courses/NDBI049/

Lecture 8

XPath

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Lecture Outline

XML data format

- Elements, attributes

XPath and XQuery

- Data model
- Query expressions
  - **Path expressions**
  - **Comparison expressions**
  - Variable assignments
  - Iteration expressions
  - Set operations
  - …

XML

Extensible Markup Language

Introduction

XML = *Extensible Markup Language*

- **Representation and interchange of semi-structured data**
  - + a family of related technologies, languages, specifications, …
- Derived from **SGML**, developed by **W3C**, started in 1996
- Design goals
  - Simplicity, generality and usability across the Internet
- File extension: ***.xml**, content type: `text/xml`
- Versions: 1.0 and 1.1
- W3C recommendation
  - http://www.w3.org/TR/xml11/

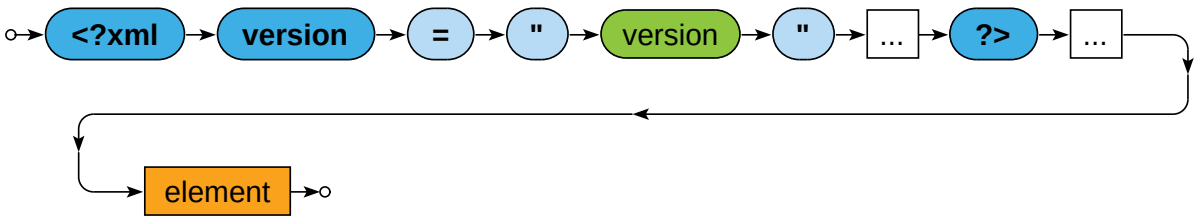
Example

```
<?xml version="1.1" encoding="UTF-8"?>
<movie year="2007">
  <title>Medvídek</title>
  <actors>
    <actor>
      <firstname>Jiří</firstname>
      <lastname>Macháček</lastname>
    </actor>
    <actor>
      <firstname>Ivan</firstname>
      <lastname>Trojan</lastname>
    </actor>
  </actors>
  <director>
    <firstname>Jan</firstname>
    <lastname>Hřebejk</lastname>
  </director>
</movie>
```

Document Structure

Document

- Prolog: XML version + some other stuff
- Exactly one root element
  - Contains other nested elements and/or other content



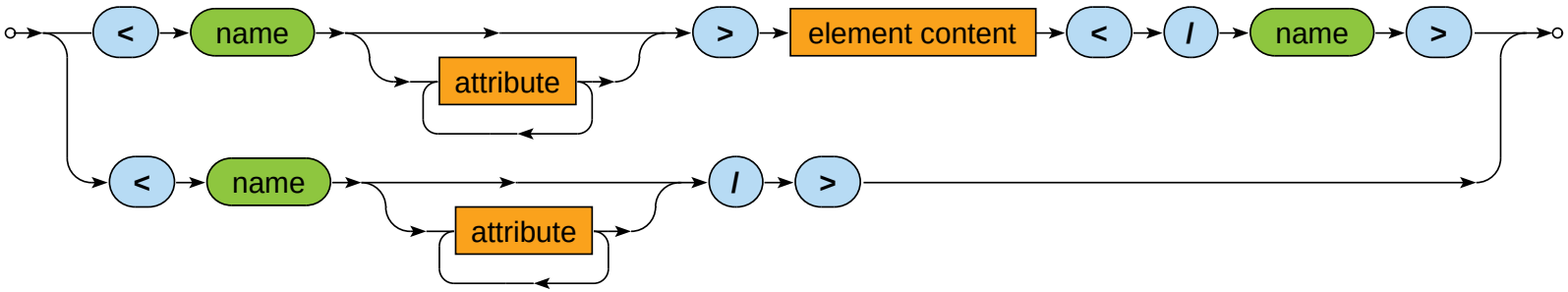
Example

```
<?xml version="1.1" encoding="UTF-8"?>
<movie>
  ...
</movie>
```

Constructs

Element

- Marked using **opening and closing tags**
  - … or just an abbreviated tag in case of empty elements
- Each element can be associated with a **set of attributes**



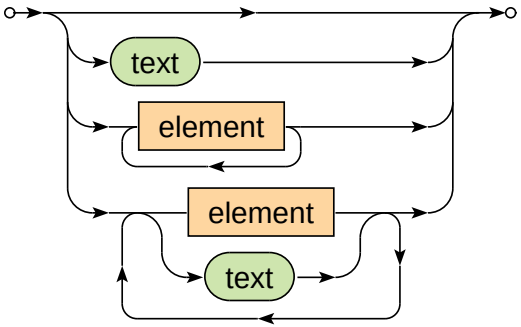
Examples

```
<title>...</title>
<actors/>
```

Constructs

Types of element content

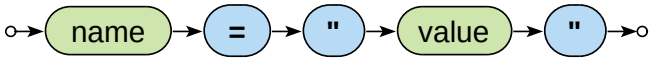
- **Empty** content
- **Text** content
- **Element** content
  - Sequence of nested elements
- **Mixed** content
  - Elements arbitrarily interleaved with text values



Constructs

Attribute

- Name-value pair



Escaping sequences (predefined entities)

- Used within values of attributes or text content of elements
- E.g.:
  - `<` for <
  - `>` for >
  - `&quot;` for "
  - …

XML Conclusion

XML constructs

- Basic: element, attribute, text
- Additional: comment, processing instruction, …

Schema languages

- DTD, XSD (*XML Schema*), RELAX NG, Schematron

Query languages

- XPath, XQuery, XSLT

XML formats = particular languages

- XSD, XSLT, XHTML, DocBook, ePUB, SVG, RSS, SOAP, …

XPath and XQuery

Introduction

XPath = *XML Path Language*

- **Navigation and selection of nodes**
- Versions: 1.0 (1999), 2.0 (2010), 3.0 (2014), **3.1** (March 2017)
- W3C recommendation
  - https://www.w3.org/TR/xpath-31/

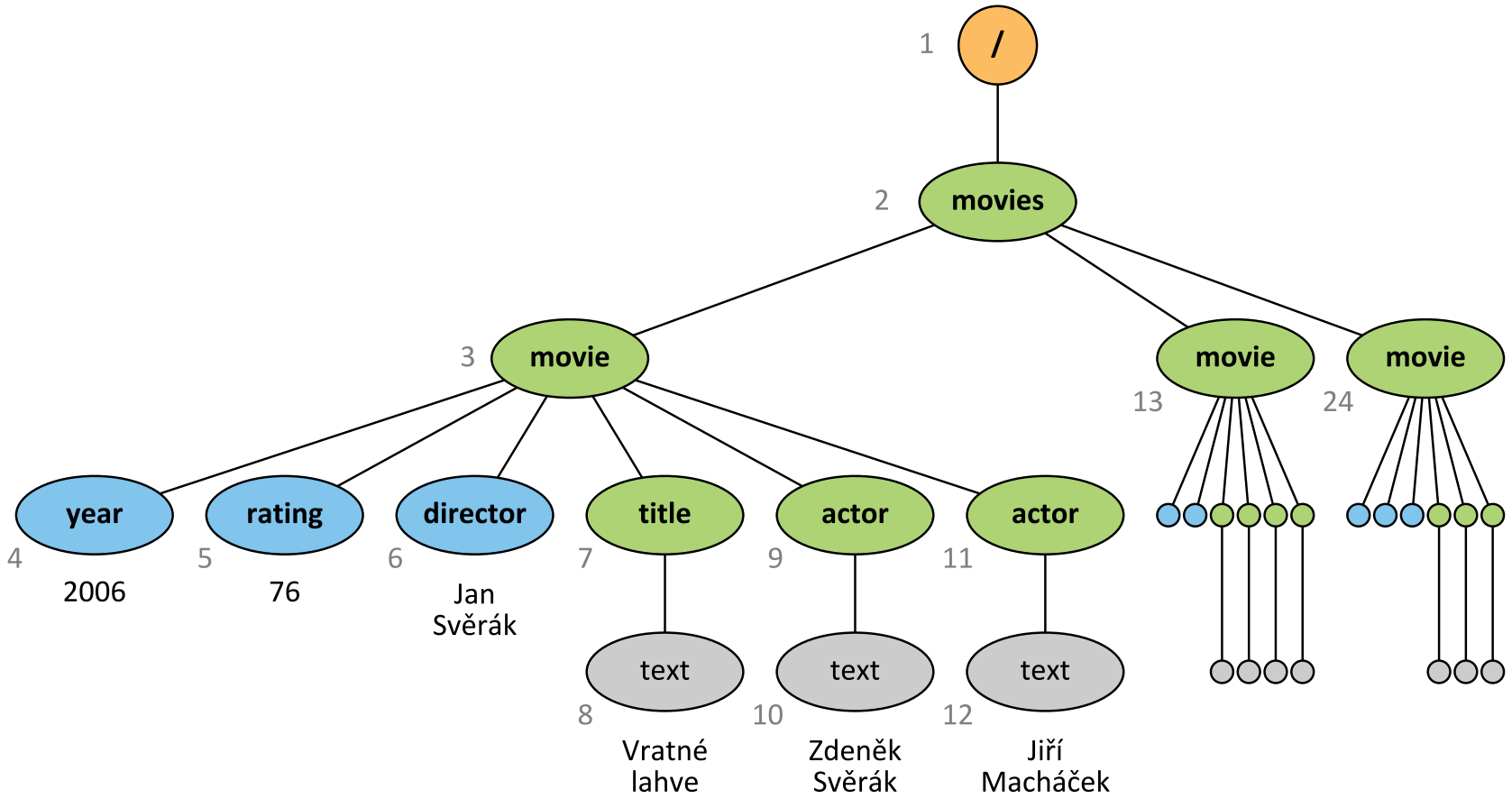
XQuery = *XML Query Language*

- **Complex queries and transformations**
- 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
<?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
4
year
2006
5
rating
76
6
director
Jan
Svěrák
7
title
8
text
Vratné
lahve
9
actor
10
text
Zdeněk
Svěrák
11
actor
12
text
Jiří
Macháček

Data Model

XDM = *XQuery and XPath Data Model* (XPath 2.0, XQuery 1.0)

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

Query result

- Each query expression is evaluated to a sequence

Data Model

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

- Can be **mixed**
  - But usually just nodes, or just atomic values
- Are automatically **flattened**
  - E.g.: `(2, (), (4, 1, (3)), (1))` ⇔ `(2, 4, 1, 3, 1)`
- Can be **empty**
  - E.g.: `()`
- Standalone items are treated as **singleton sequences**
  - E.g.: `1` ⇔ `(1)`
- Can have **duplicate items**

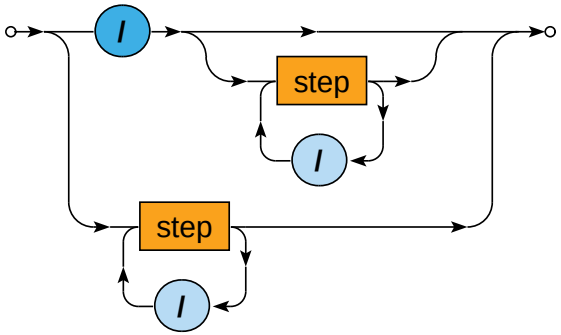
XPath

XML Path Language

Path Expressions

Path expression

- Allows for navigation within an XML tree
- Consists of **navigational steps**



- **Absolute** paths: start with /
  - Navigation starts at the **document node**
- **Relative** paths
  - Navigation starts at an implicitly specified context node

Path Expressions: Examples

Absolute path expressions

```
/
```

```
/movies
```

```
/movies/movie
```

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

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

Relative path expressions

```
actor/text()
```

```
@director
```

Path Expressions

Evaluation of a path expression P

- … with respect to the initial **context sequence** C

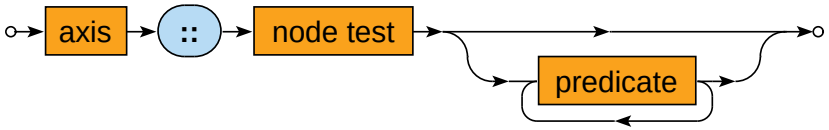
---

1 **if** P does not contain any step **then**
2 **return** C (we already have the final result)
3 **else** (when P contains at least one step)
4 let S be the first step and P' the remaining steps (if any)
5 let $C' = \langle\rangle$ be an empty sequence
6 **foreach** context node $u \in C$ **do**
7 evaluate S with respect to u and add the selected items $C_u{}'$ to C'
8 **return** evaluate P' with respect to C'

Path Expressions: Steps

Navigational step

- Each step consists of up to 3 components

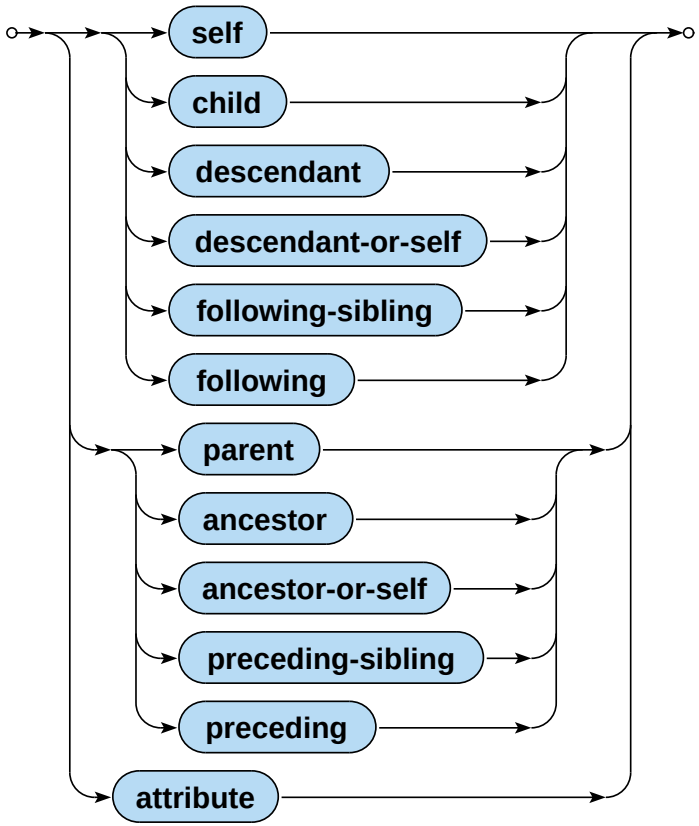


- **Axis**
  - **Relation of nodes** to be selected for a given context node u
- **Node test**
  - **Basic condition** these selected nodes must satisfy
- **Predicates**
  - **Advanced conditions** these nodes must further satisfy

Path Expressions: Axes

Axis

- Selects nodes that are reachable from a given context node



Path Expressions: Axes

`child` axis

- Selects **children** of a given context node
  - Note that attributes are not considered to be child nodes!
- Used as the **default axis** (when omitted)

```
/movies/child::movie
```

`attribute` axis

- Selects **attributes** of a given context node
  - Note that this is the only axis that can select attributes!

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

`self` axis

- Selects just the current **context node**

Path Expressions: Axes

`descendant(-or-self)` axes

- Select all (non-attribute) **nodes in a subtree** of a given context node excluding / including itself

```
/descendant::actor/text()
```

`parent` axis

- Selects the **parent node** of a given context node

`ancestor(-or-self)` axes

- Select all **ancestors** of a given context node
  - I.e., the parent, the parent of the parent, and so on, until the document node, excluding / including the context node itself

Path Expressions: Axes

`preceding-sibling` and `following-sibling` axes

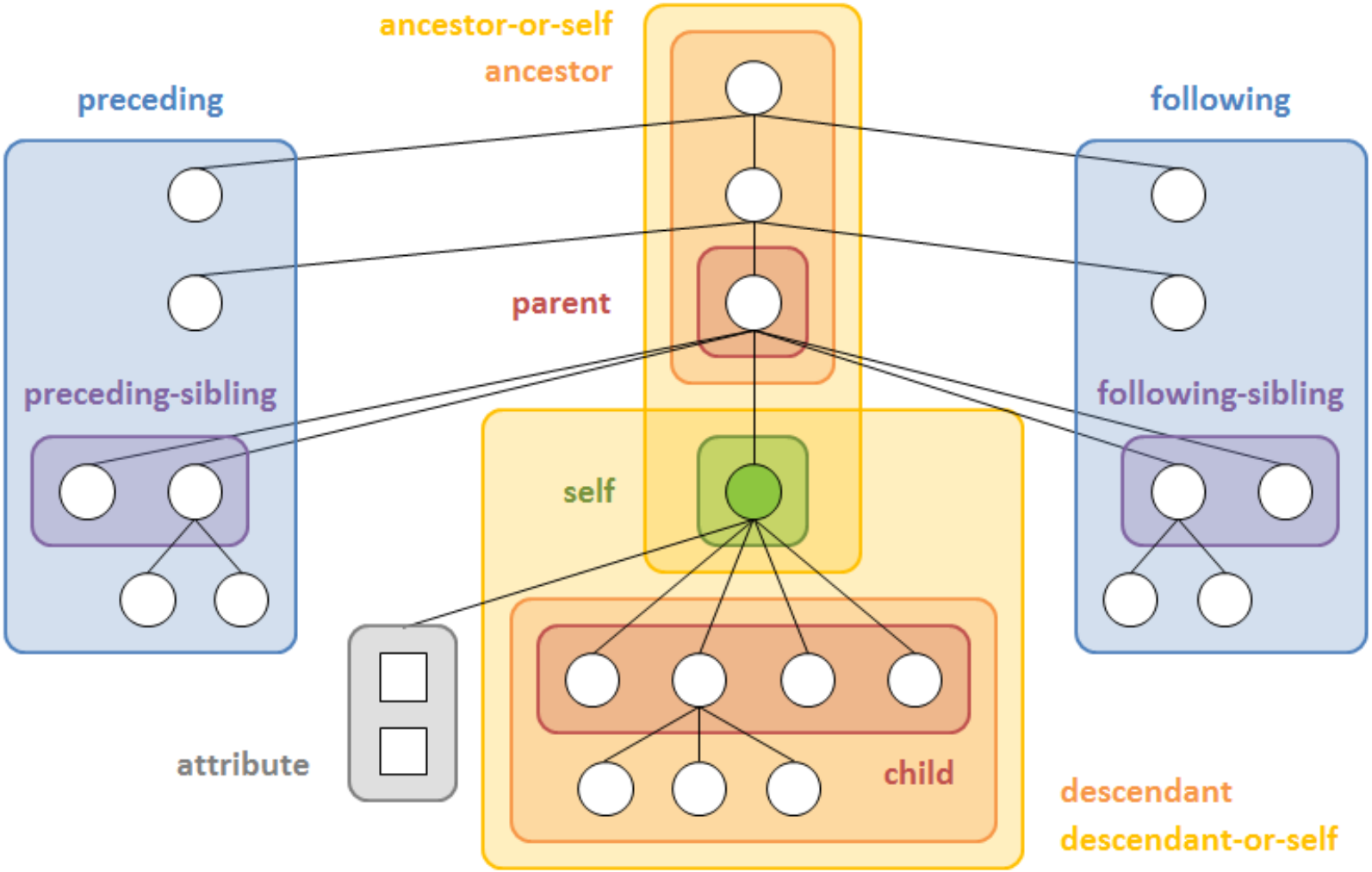
- Select all **siblings** of a given context node that occur before / after this context node in the document order

```
/descendant-or-self::movie/title/following-sibling::actor
```

`preceding` and `following` axes

- Select all (non-attribute) **nodes that occur before / after** a given context node in the document order, excluding nodes returned by the `ancestor` / `descendant` axis

Path Expressions: Axes



Path Expressions: Axes

Forward axes

- `self`, `child`, `descendant(-or-self)`, `following(-sibling)`
- Nodes are returned in the **document order**

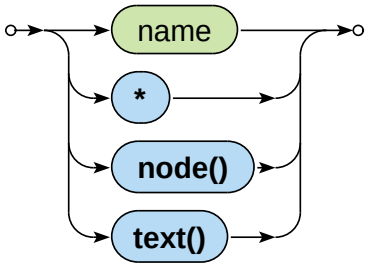
Reverse axes

- `parent`, `ancestor(-or-self)`, `preceding(-sibling)`
- Nodes are returned in the **reverse document order**

Path Expressions: Node Tests

Node test

- Filters the nodes selected by the axis using a basic condition
  - Only **names and kinds** of nodes can be tested



`name`: elements / attributes with a given name

```
/movies
```

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

Path Expressions: Node Tests

`*`: all elements / attributes

```
/movies/*
```

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

`text()`: all text nodes

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

`node()`: all nodes

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

Path Expressions: Predicates

Predicates

- Additional filtering of the nodes based on advanced conditions

- When **multiple predicates** are provided…
  - They must all be satisfied
  - They are evaluated one by one, from left to right

Commonly used **conditions**

- Path existence tests, comparisons, position tests
- Logical expressions
- …

Path Expressions: Predicates

Path existence tests

- Relative or absolute path expressions
  - Relative path expressions are evaluated with respect to the node for which a given predicate is tested
- Treated as `true` when evaluated to a **non-empty sequence**

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

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

Comparisons

- General, value, or node comparison expressions

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

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

Path Expressions: Predicates

Position tests

- Allow for filtering of items based on context positions
  - Numbered starting with 1
  - Always relative to the current context (intermediate result)
  - Base order is implied by the axis used

```
/descendant::movie/actor[position() = 1]
```

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

Logical expressions

- `and`, `or`, `not` connectives

```
/movies/movie[@year > 2000 and @director]
```

```
/movies/movie[@director][@year > 2000]
```

Path Expressions: Abbreviations

Omitted axis: the default `child` axis is assumed

```
/movies/movie/title
```

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

Attributes: `@` ⇔ `attribute::`

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

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

Descendants: `//` ⇔ `/descendant-or-self::node()/`

```
/movies//child::actor
```

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

Path Expressions: Abbreviations

Context item: `.` ⇔ `self::node()`

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

```
/movies/movie[self::node()//actor]
```

Parent: `..` ⇔ `parent::node()`

Position tests: `[number]` ⇔ `[position() = number]`

```
/movies/movie/child::actor[2]
```

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

```
/movies/movie[actor][last()]
```

```
/movies/movie[actor][position() = last()]
```

Path Expressions: Conclusion

Evaluation of path expressions

- Evaluated **from left to right, step by step**
  - Result of the entire expression is the **result of the last step**

Only one of the following can be returned…

- Sequence of **nodes**
  - Always sorted in the **document order**
  - **Duplicate nodes are removed**
    - Based on the identities of nodes
- Sequence of **atomic values**
  - The order as well as duplicate values are both preserved

$\Rightarrow$ the returned sequences will never be mixed

Comparison Expressions

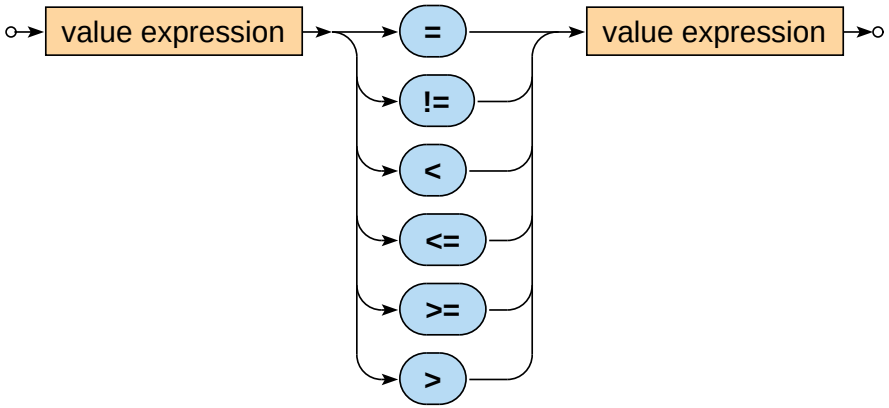
Comparisons

- **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 the case of value comparisons

Comparison Expressions

General comparisons (**existentially quantified** comparisons)

- Both the operands can be evaluated to **sequences of items** of any length



- The result is `true` if and only if **there exists at least one pair of individual items** satisfying a given relationship

Comparison Expressions: Examples

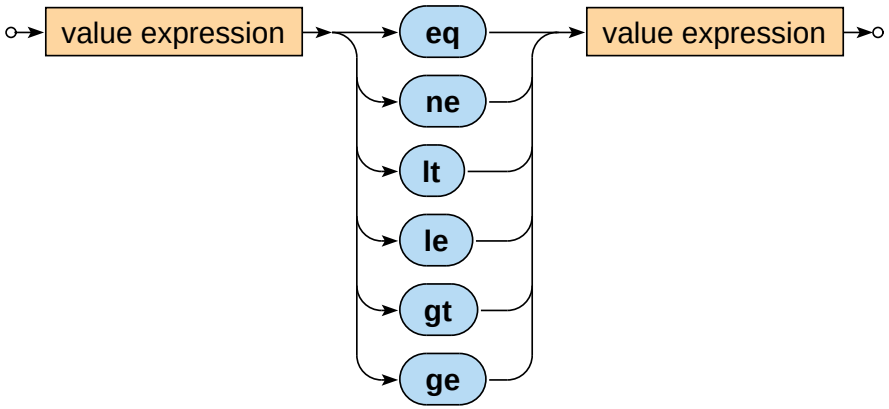
General comparisons

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

Comparison Expressions

Value comparisons

- Both the operands must be evaluated to **singleton sequences**



- **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: Examples

Value comparisons

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

Comparison Expressions

Value and general comparisons

- **Atomization of values** – applied 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 in the document order
    - E.g.: `<movie year="2006">Vratné lahve</movie>` is atomized to a string `Vratné lahve`
    - I.e., attribute values and element names are not included!
  - **Attribute** node is transformed to its value
  - **Text** node is transformed to its value

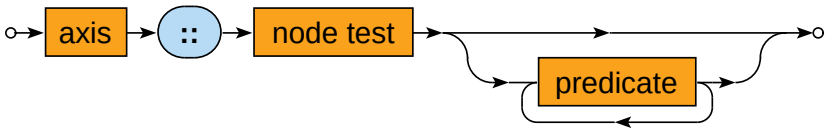
Comparison Expressions: Examples

Value and general comparisons

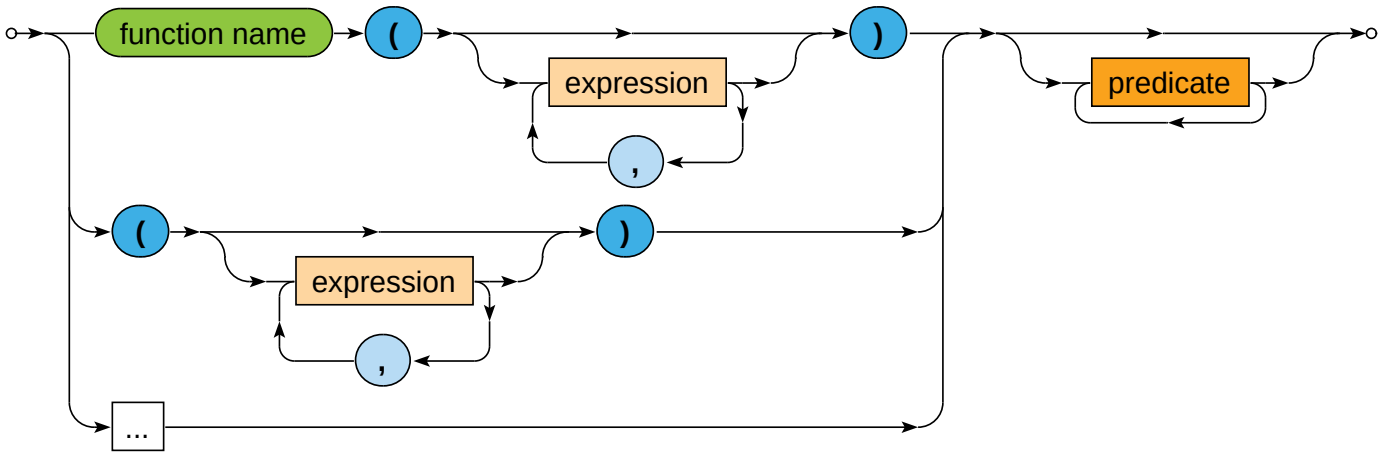
- $[\![$ `<a>5</a> eq <b>5</b>` $]\!] = \texttt{true}$
- $[\![$ `<a>12</a> = <a><b>1</b>2</a>` $]\!] = \texttt{true}$
- $[\![$ `<a t="1">3</a> lt 5` $]\!] = \texttt{true}$

Path Operator

Navigational steps in path expressions



- Extended functionality (XPath 2.0)
  - **Function calls**, **sequence constructors**, …
  - Must not yield mixed sequences (nodes and atomic values)



Path Operator: Examples

Numbers of actors who appeared in the individual movies

```
/movies/movie/count(actor)
```

```
2
3
2
```

Flat sequence of interleaved movie titles and years of filming

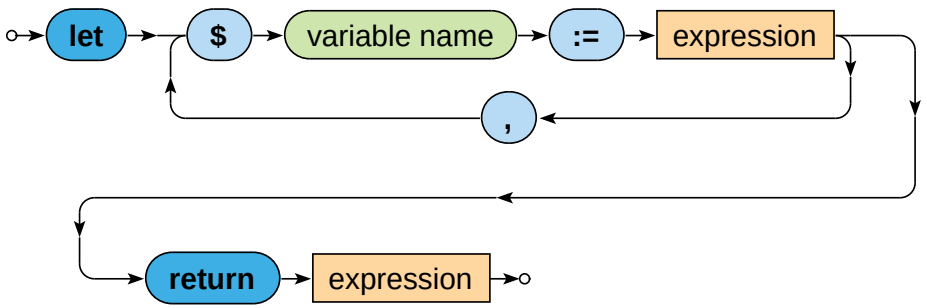
```
/movies/movie/(title, @year)/data(.)
```

```
2006
Vratné lahve
2000
Samotáři
2007
Medvídek
```

Variable Assignments

Let expression (XPath 2.0, XQuery 1.0 FLWOR)

- Allows for **assignment** of one or more **variables**
  - $ is used to denote variables
- These variables can then be accessed later on



- Returns the result of the evaluated `return` clause

Variable Assignments: Example

Find titles of movies with at least average rating

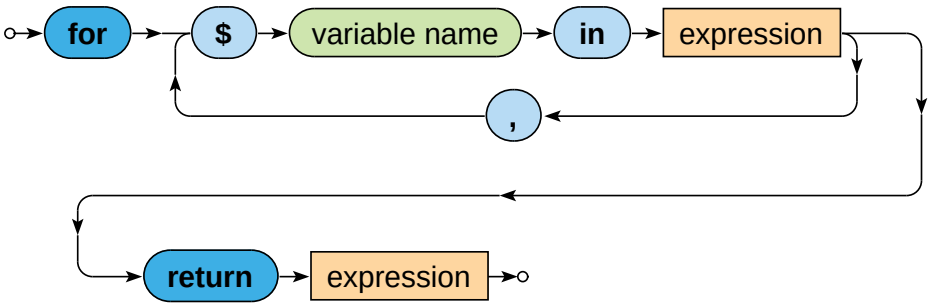
```
let $a := avg(//movie/@rating)
return //movie[@rating >= $a]/title/text()
```

```
Vratné lahve
Samotáři
```

Iteration Expressions

For expression (XPath 2.0, XQuery 1.0 FLWOR)

- Allows for the **iteration** over **items** of an input sequence / **tuples of items** when more input sequences are provided



- Returns a flat sequence containing results of the `return` clause evaluated for each input item / tuple of items

Iteration Expressions: Example

Numbers of actors who appeared in movies filmed in *2000* or later

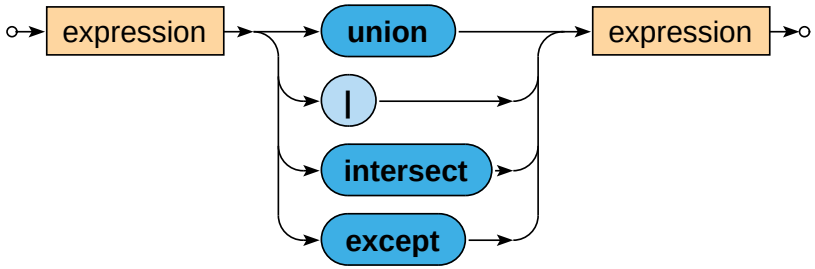
```
for $m in //movie[@year >= 2000]
return count($m/actor)
```

```
2
3
2
```

Set Operations

Traditional **set operations** (XPath 2.0)

- Only applicable on sequences of nodes (not atomic values)!
- Duplicate nodes are removed



Union

- Nodes that occur in either of the operands

Intersection

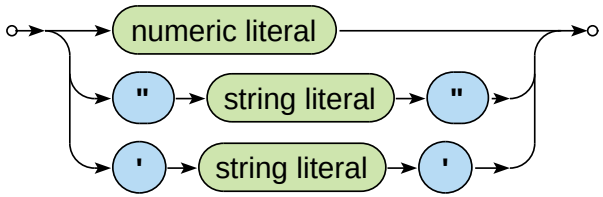
- Nodes that occur in both the operands

Difference

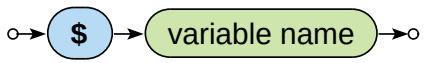
- Nodes that occur in the first operand but not in the second one

Primary and Other Expressions

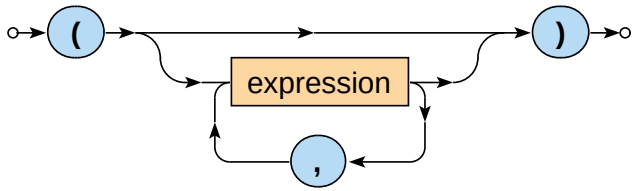
Literals



Variable reference

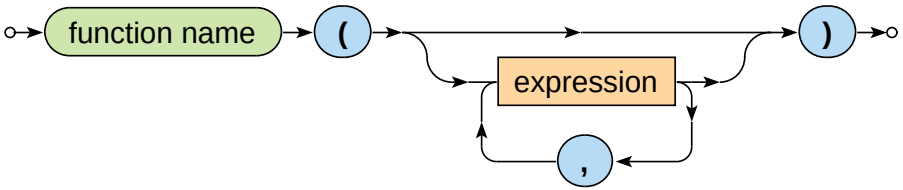


Sequence constructor



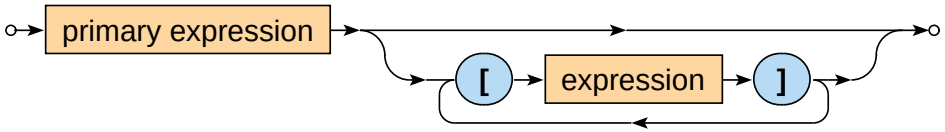
Primary and Other Expressions

Function call



Postfix expression

- Allows to add **predicates** to primary expressions
  - I.e., **variable references**, **sequence constructors**, …



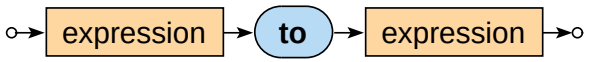

```
$movies[actor]
```

```
(//actor)[last()]
```

Primary and Other Expressions

Range expression

- Allows to generate a **sequence of consecutive integers**




```
/movies/movie[@year = 2011 to 2020]
```

Arithmetic expressions

Conditional expression

Quantified expressions

- Allow to simulate the **existential and universal quantifiers**

Predefined Functions

`data($items)`

- Performs the **atomization of values** in a sequence

`avg($items)`, `sum($items)`, `min($items)`, `max($items)`

- Calculates the **average** / **sum** / **minimum** / **maximum**

`name($node)`

- Returns the **name of an element or attribute** node

`position()` and `last()`

- Returns the current **context position** / **context size**

`string-join($items, $separator)`

- Returns a **string with concatenated atomized values**

`doc($uri)`

- Returns the **document node** for a specified XML file

Lecture Conclusion

XPath

- **Path expressions**
  - Absolute and relative paths
  - Axes, node tests, and predicates
- **Comparison expressions**
  - General, value, and node comparisons
- For and let expressions
- Set operations
  - Union, intersection, difference
- Primary expressions
- …