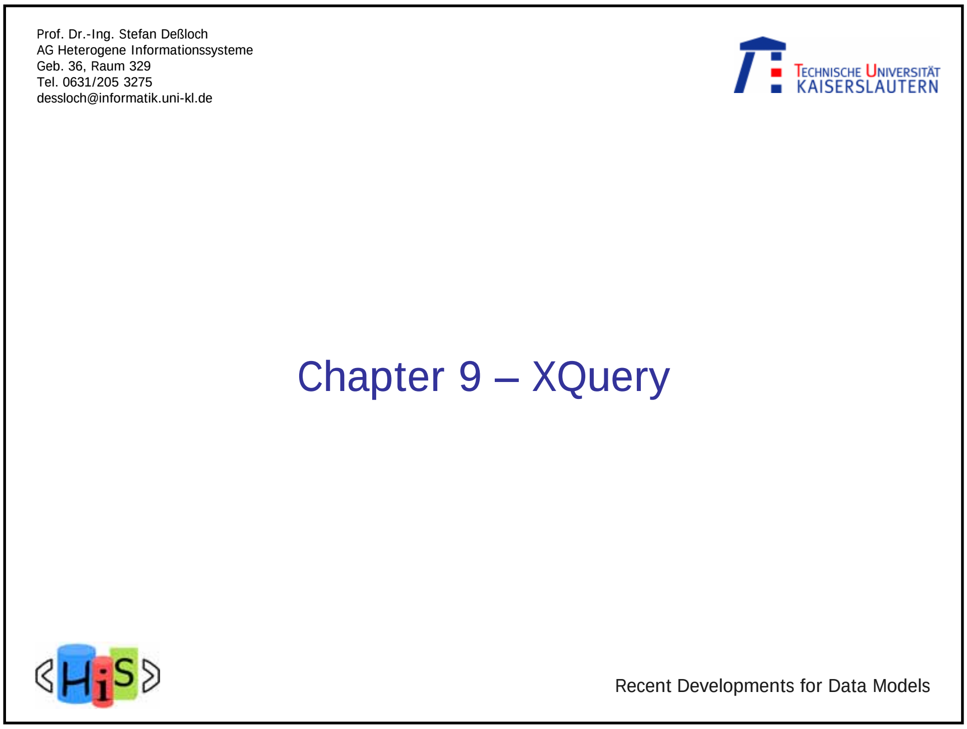

Prof. Dr.-Ing. Stefan Deßloch
AG Heterogene Informationssysteme
Geb. 36, Raum 329
Tel. 0631/205 3275
dessloch@informatik.uni-kl.de

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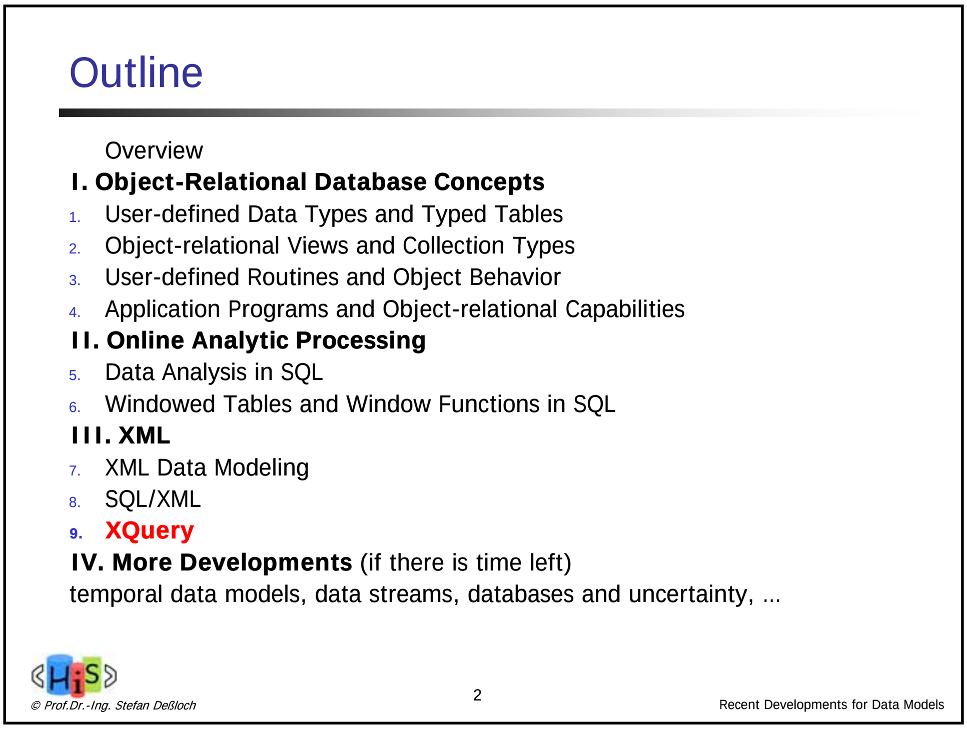
Chapter 9 – XQuery

Recent Developments for Data Models



Outline

Overview

I. Object-Relational Database Concepts

1. User-defined Data Types and Typed Tables
2. Object-relational Views and Collection Types
3. User-defined Routines and Object Behavior
4. Application Programs and Object-relational Capabilities

II. Online Analytic Processing

5. Data Analysis in SQL
6. Windowed Tables and Window Functions in SQL

III. XML

7. XML Data Modeling
8. SQL/XML
9. **XQuery**

IV. More Developments (if there is time left)

temporal data models, data streams, databases and uncertainty, ...

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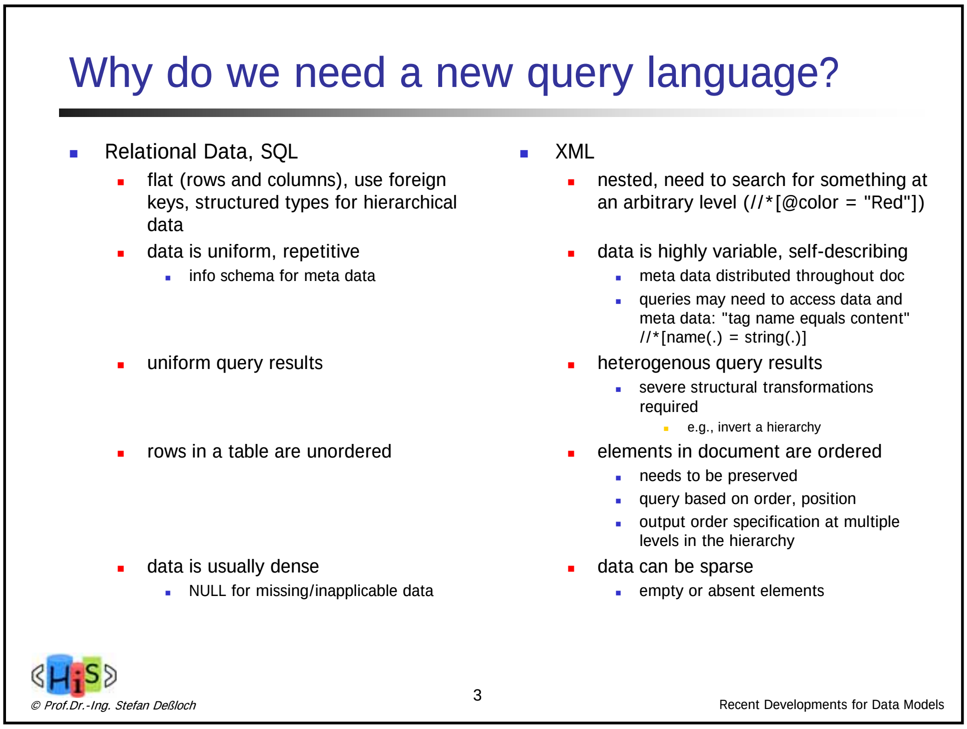
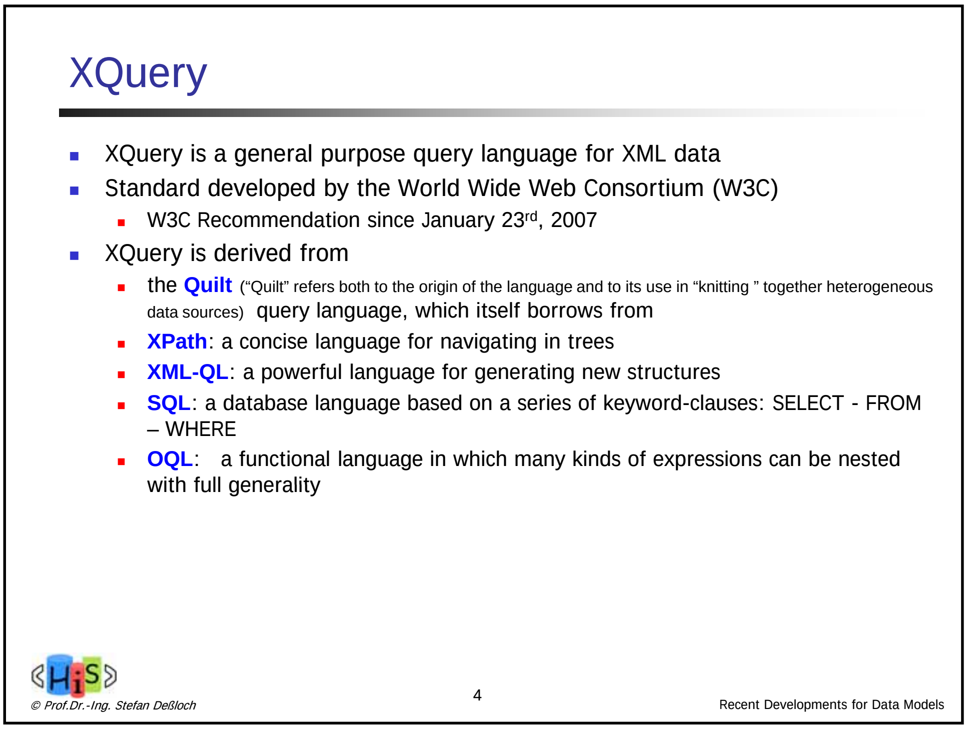


Why do we need a new query language?

- Relational Data, SQL
  - flat (rows and columns), use foreign keys, structured types for hierarchical data
  - data is uniform, repetitive
    - info schema for meta data
  - uniform query results
  - rows in a table are unordered
  - data is usually dense
    - NULL for missing/inapplicable data
- XML
  - nested, need to search for something at an arbitrary level (//*[@color = "Red"])
  - data is highly variable, self-describing
    - meta data distributed throughout doc
    - queries may need to access data and meta data: "tag name equals content" //*[name(.) = string(.)]
  - heterogenous query results
    - severe structural transformations required
      - e.g., invert a hierarchy
  - elements in document are ordered
    - needs to be preserved
    - query based on order, position
    - output order specification at multiple levels in the hierarchy
  - data can be sparse
    - empty or absent elements



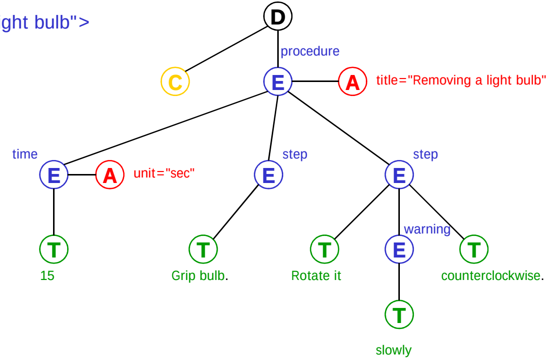
XQuery

- XQuery is a general purpose query language for XML data
- Standard developed by the World Wide Web Consortium (W3C)
  - W3C Recommendation since January 23rd, 2007
- XQuery is derived from
  - the **Quilt** ("Quilt" refers both to the origin of the language and to its use in "knitting " together heterogeneous data sources) query language, which itself borrows from
  - **XPath**: a concise language for navigating in trees
  - **XML-QL**: a powerful language for generating new structures
  - **SQL**: a database language based on a series of keyword-clauses: SELECT - FROM – WHERE
  - **OQL**: a functional language in which many kinds of expressions can be nested with full generality

Tree Model of XML Data

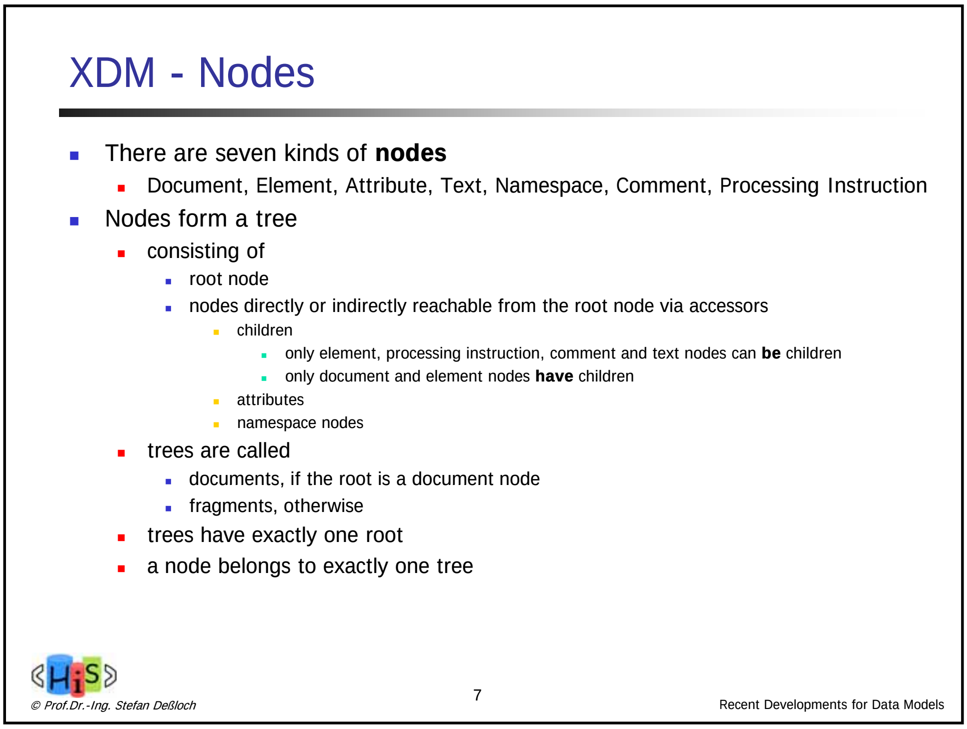
- Query and transformation languages are based on a **tree model** of XML data
- An XML document is modeled as a tree, with **nodes** corresponding to elements, attributes, text, etc.
- Example:

```
<?xml version = "1.0"?>
<!-- Requires one trained person -->
<procedure title = "Removing a light bulb">
  <time unit = "sec">15</time>
  <step>Grip bulb.</step>
  <step>
    Rotate it
    <warning>slowly</warning>
    counterclockwise.
  </step>
</procedure>
```



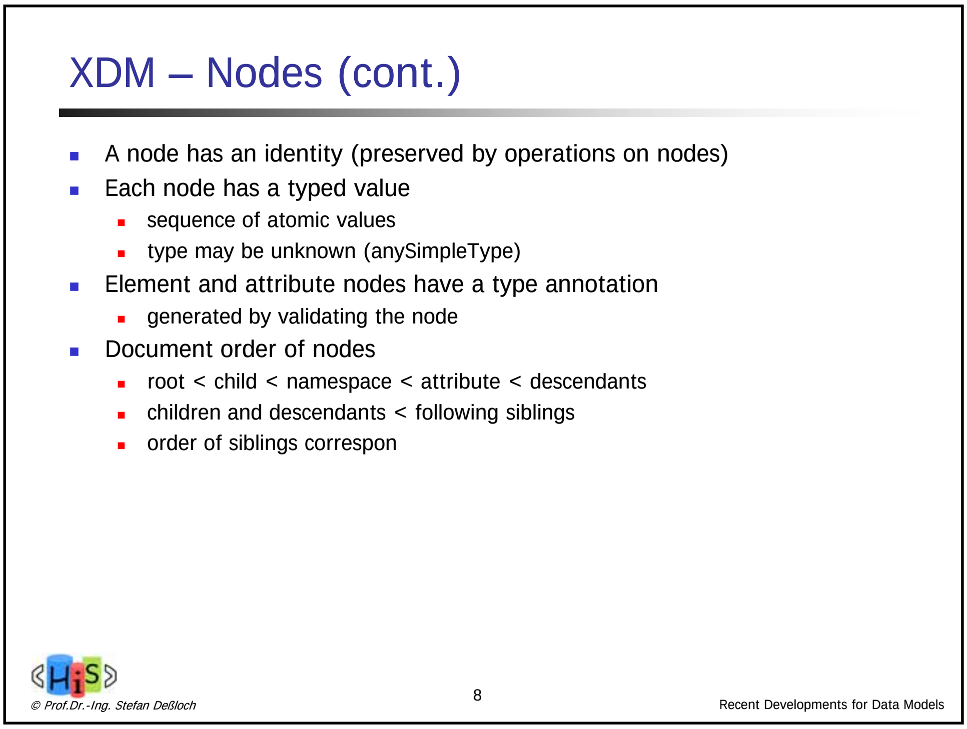
XQuery Data Model (XDM)

- Builds on a tree-based model, but extends it to support sequences of items
  - represent collections of documents and complex values
  - reflect (intermediate) results of query evaluation
  - closure property
    - XQuery queries and expressions operate on/produce instances of the XDM
- Based on XML Schema for precise type information
- XDM **instance**
  - ordered **sequence** of zero or more **items**
  - can contain heterogenous values
  - cannot be nested – all operations on sequences automatically "flatten" sequences
    - no distinction between an item and a sequence of length 1
  - may contain duplicate nodes (see below)
- An **item** is a **node** or an **atomic value**
- **Atomic values** are typed values
  - XML Schema simple types
  - important for representing results of intermediate expressions in the data model



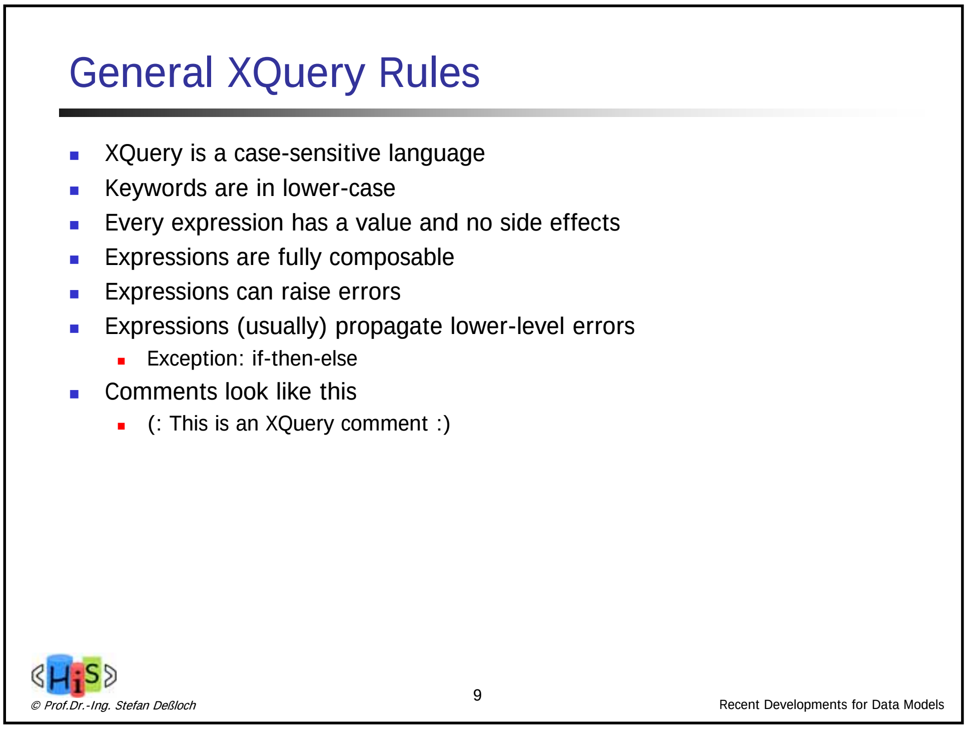
XDM - Nodes

- There are seven kinds of **nodes**
  - Document, Element, Attribute, Text, Namespace, Comment, Processing Instruction
- Nodes form a tree
  - consisting of
    - root node
    - nodes directly or indirectly reachable from the root node via accessors
      - children
        - only element, processing instruction, comment and text nodes can **be** children
        - only document and element nodes **have** children
      - attributes
      - namespace nodes
  - trees are called
    - documents, if the root is a document node
    - fragments, otherwise
  - trees have exactly one root
  - a node belongs to exactly one tree



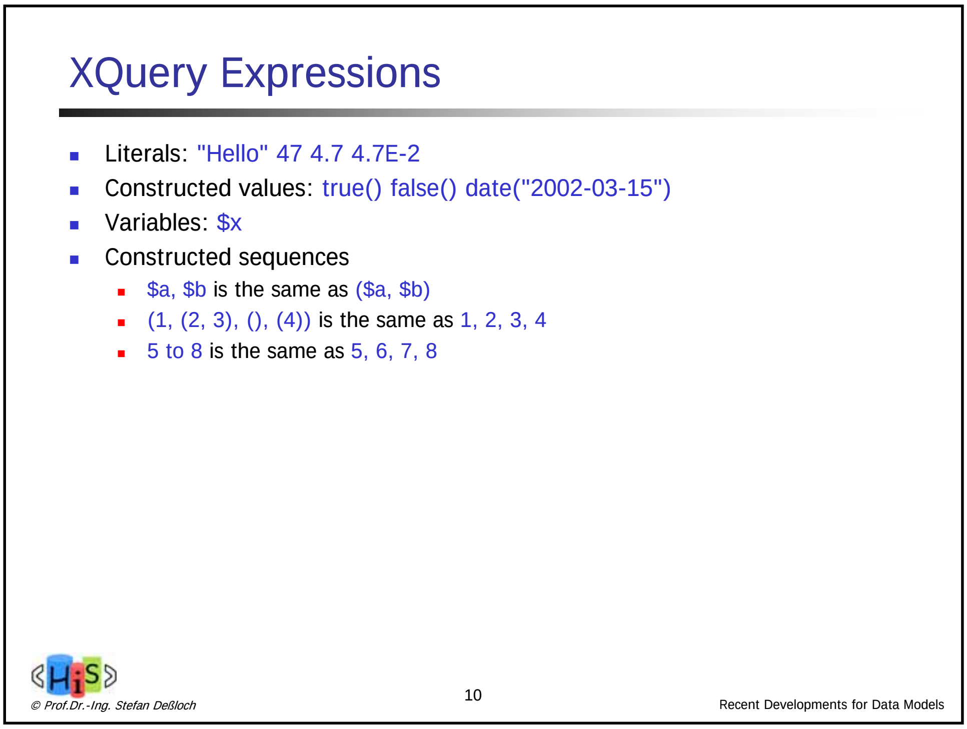
XDM – Nodes (cont.)

- A node has an identity (preserved by operations on nodes)
- Each node has a typed value
  - sequence of atomic values
  - type may be unknown (anySimpleType)
- Element and attribute nodes have a type annotation
  - generated by validating the node
- Document order of nodes
  - root < child < namespace < attribute < descendants
  - children and descendants < following siblings
  - order of siblings correspon



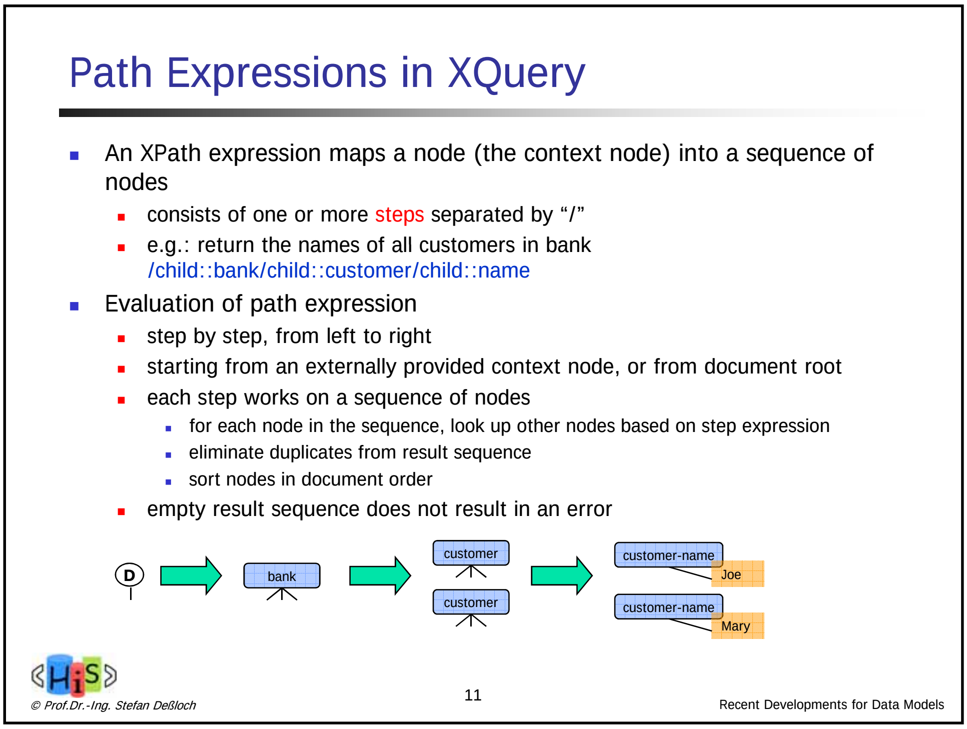
General XQuery Rules

- XQuery is a case-sensitive language
- Keywords are in lower-case
- Every expression has a value and no side effects
- Expressions are fully composable
- Expressions can raise errors
- Expressions (usually) propagate lower-level errors
    - Exception: if-then-else
- Comments look like this
    - (: This is an XQuery comment :)



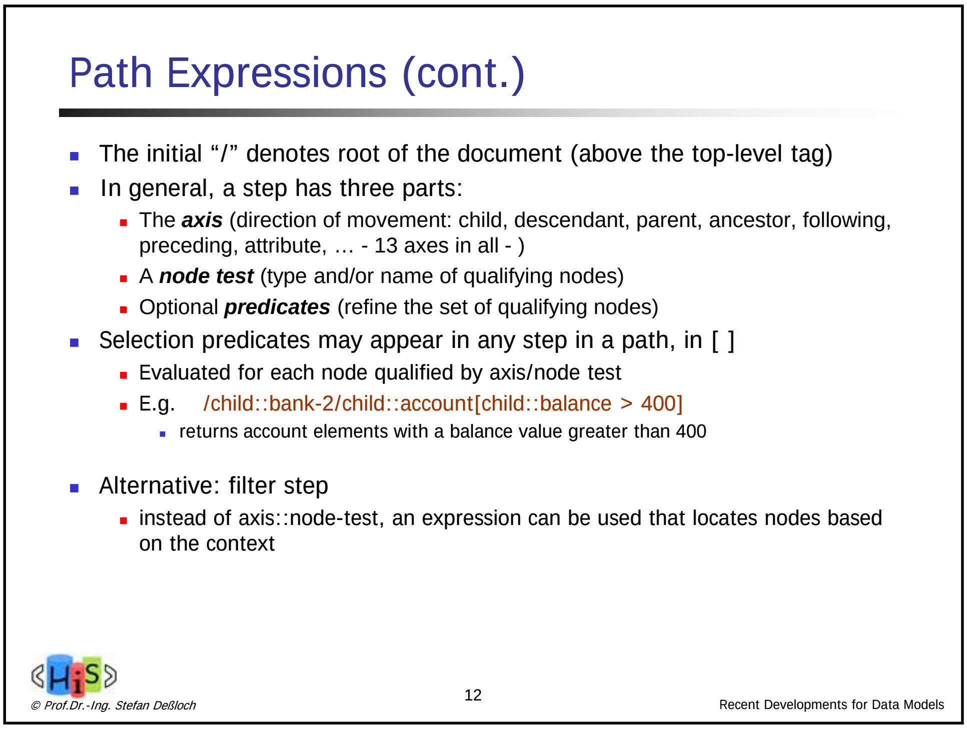
XQuery Expressions

- Literals: "Hello" 47 4.7 4.7E-2
- Constructed values: true() false() date("2002-03-15")
- Variables: $x
- Constructed sequences
    - $a, $b is the same as ($a, $b)
    - (1, (2, 3), (), (4)) is the same as 1, 2, 3, 4
    - 5 to 8 is the same as 5, 6, 7, 8



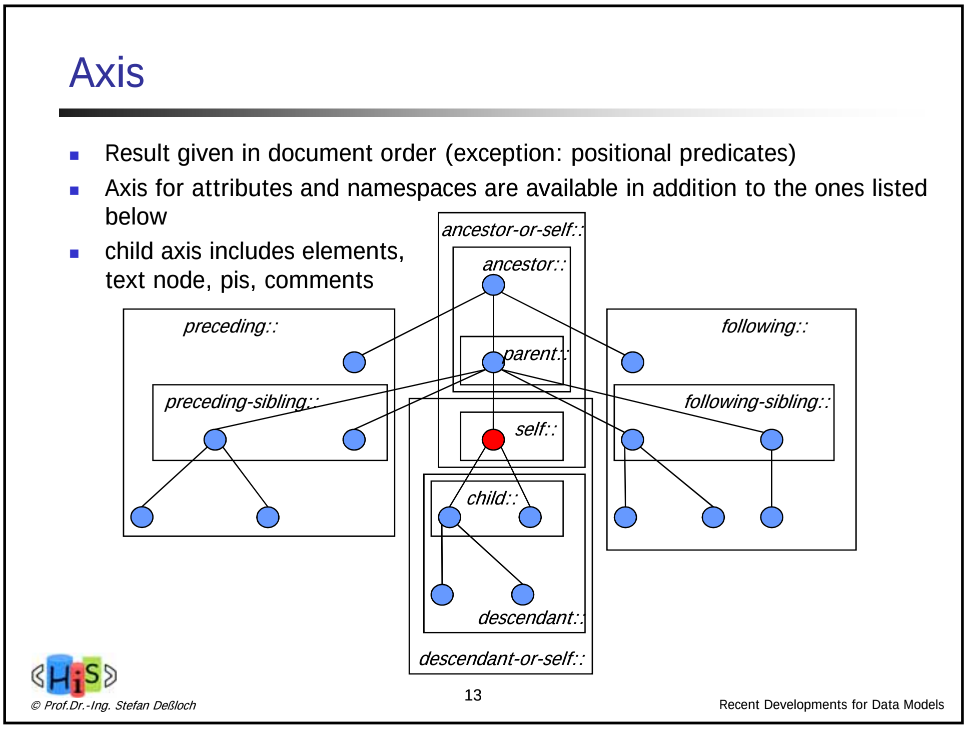
Path Expressions in XQuery

- An XPath expression maps a node (the context node) into a sequence of nodes
  - consists of one or more steps separated by “/”
  - e.g.: return the names of all customers in bank
    /child::bank/child::customer/child::name
- Evaluation of path expression
  - step by step, from left to right
  - starting from an externally provided context node, or from document root
  - each step works on a sequence of nodes
    - for each node in the sequence, look up other nodes based on step expression
    - eliminate duplicates from result sequence
    - sort nodes in document order
  - empty result sequence does not result in an error



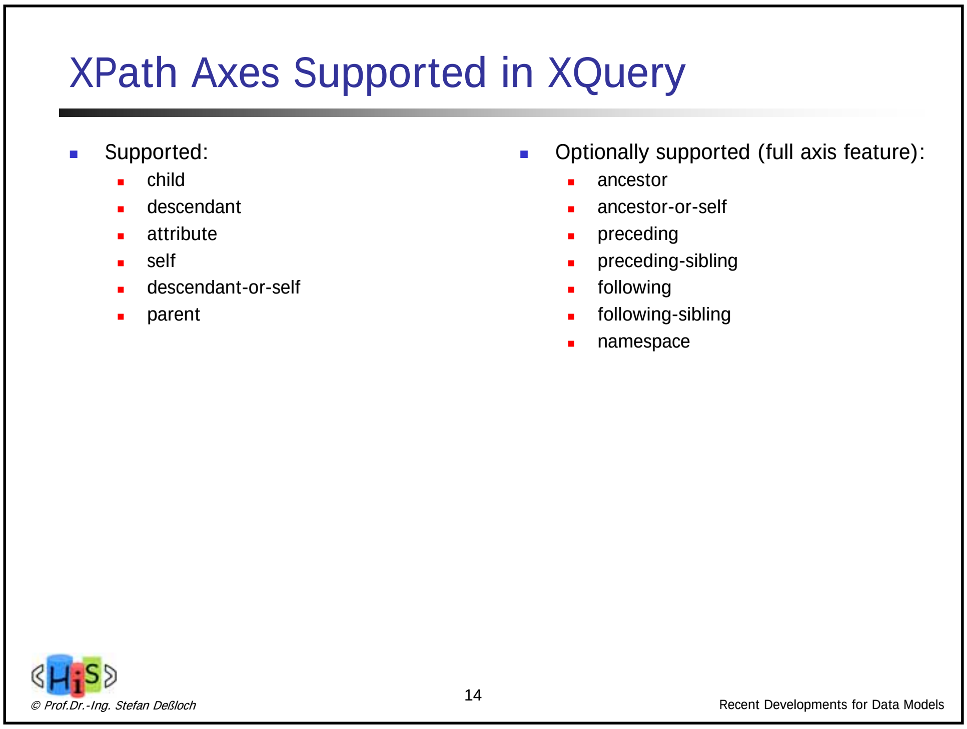
Path Expressions (cont.)

- The initial “/” denotes root of the document (above the top-level tag)
- In general, a step has three parts:
  - The ***axis*** (direction of movement: child, descendant, parent, ancestor, following, preceding, attribute, … - 13 axes in all -)
  - A ***node test*** (type and/or name of qualifying nodes)
  - Optional ***predicates*** (refine the set of qualifying nodes)
- Selection predicates may appear in any step in a path, in [ ]
  - Evaluated for each node qualified by axis/node test
  - E.g. /child::bank-2/child::account[child::balance > 400]
    - returns account elements with a balance value greater than 400
- Alternative: filter step
  - instead of axis::node-test, an expression can be used that locates nodes based on the context



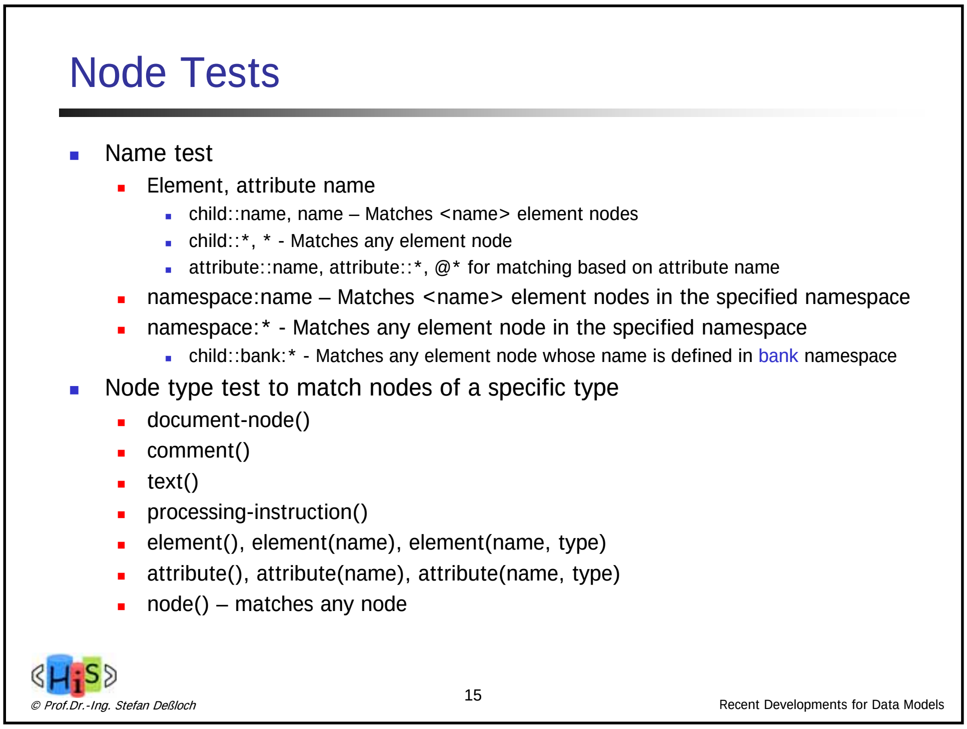
Axis

- Result given in document order (exception: positional predicates)
- Axis for attributes and namespaces are available in addition to the ones listed below
- child axis includes elements, text node, pis, comments



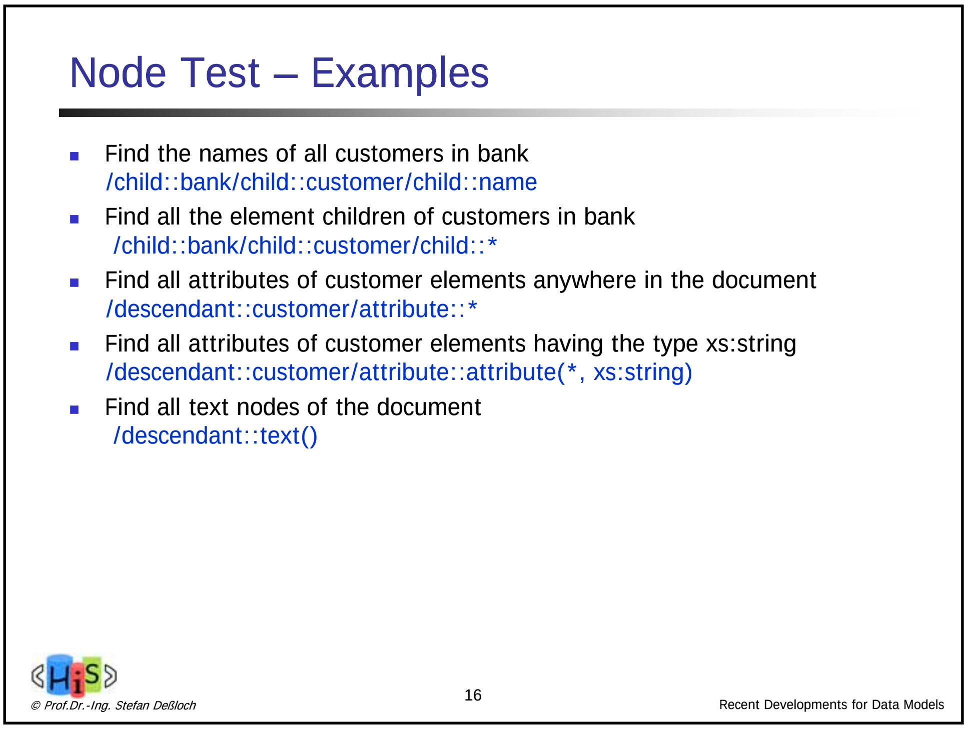
XPath Axes Supported in XQuery

- Supported:
  - child
  - descendant
  - attribute
  - self
  - descendant-or-self
  - parent
- Optionally supported (full axis feature):
  - ancestor
  - ancestor-or-self
  - preceding
  - preceding-sibling
  - following
  - following-sibling
  - namespace



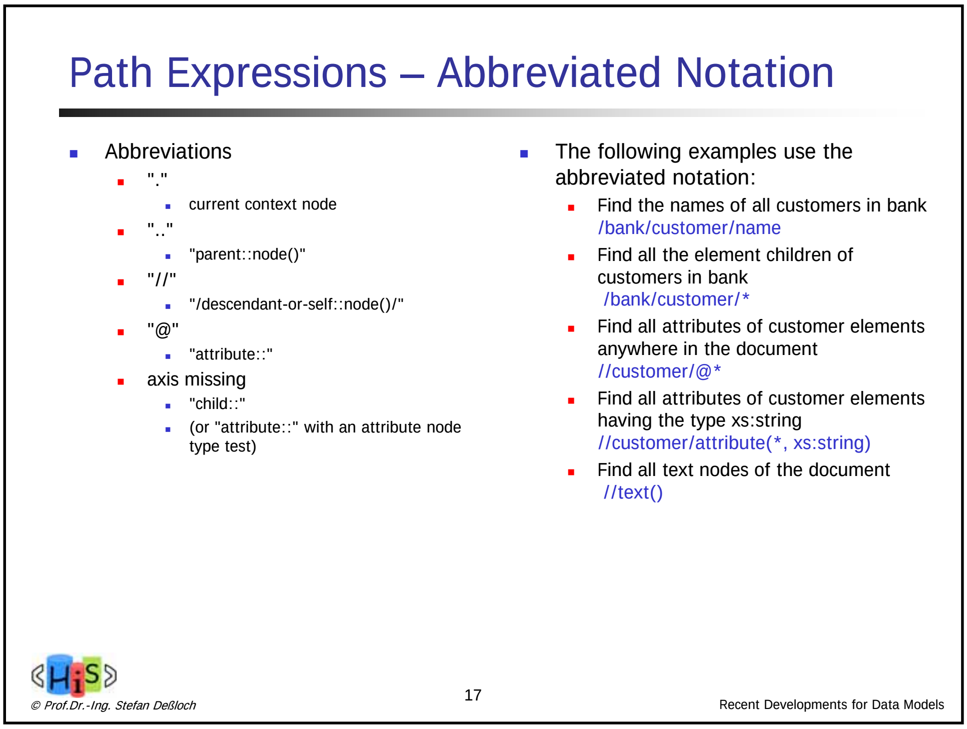
Node Tests

- Name test
  - Element, attribute name
    - child::name, name – Matches <name> element nodes
    - child::*, * - Matches any element node
    - attribute::name, attribute::*, @* for matching based on attribute name
  - namespace:name – Matches <name> element nodes in the specified namespace
  - namespace:* - Matches any element node in the specified namespace
    - child::bank:* - Matches any element node whose name is defined in bank namespace
- Node type test to match nodes of a specific type
  - document-node()
  - comment()
  - text()
  - processing-instruction()
  - element(), element(name), element(name, type)
  - attribute(), attribute(name), attribute(name, type)
  - node() – matches any node



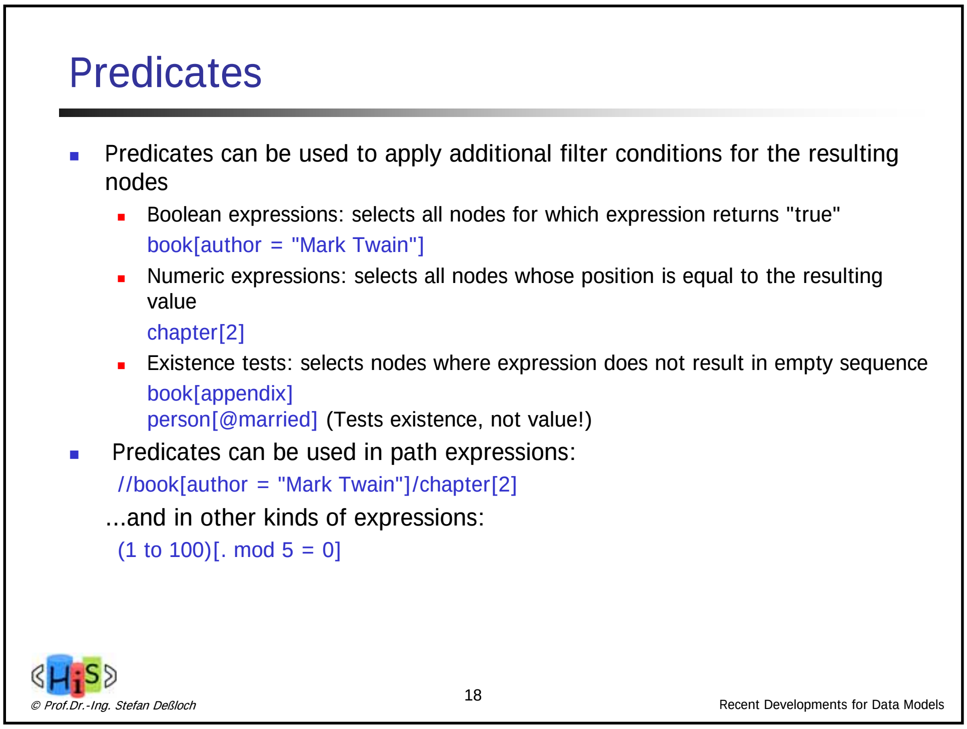
Node Test – Examples

- Find the names of all customers in bank
  /child::bank/child::customer/child::name
- Find all the element children of customers in bank
  /child::bank/child::customer/child::*
- Find all attributes of customer elements anywhere in the document
  /descendant::customer/attribute::*
- Find all attributes of customer elements having the type xs:string
  /descendant::customer/attribute::attribute(*, xs:string)
- Find all text nodes of the document
  /descendant::text()



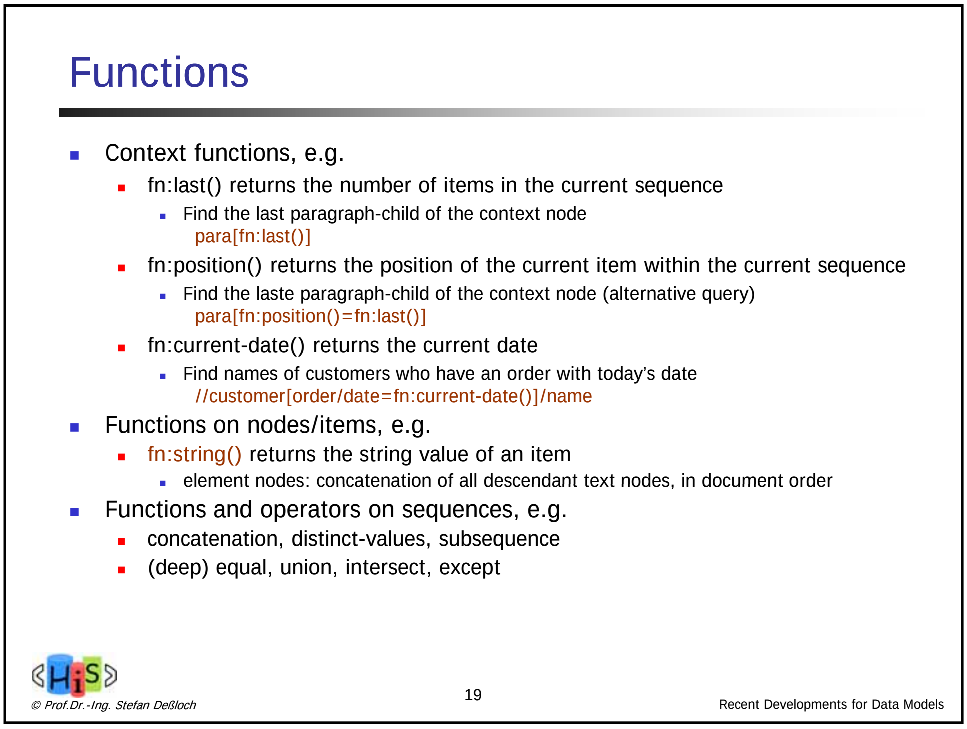
Path Expressions – Abbreviated Notation

- Abbreviations
  - "."
    - current context node
  - ".."
    - "parent::node()"
  - "//"
    - "/descendant-or-self::node()/"
  - "@"
    - "attribute::"
  - axis missing
    - "child::"
    - (or "attribute::" with an attribute node type test)
- The following examples use the abbreviated notation:
  - Find the names of all customers in bank
    /bank/customer/name
  - Find all the element children of customers in bank
    /bank/customer/*
  - Find all attributes of customer elements anywhere in the document
    //customer/@*
  - Find all attributes of customer elements having the type xs:string
    //customer/attribute(*, xs:string)
  - Find all text nodes of the document
    //text()



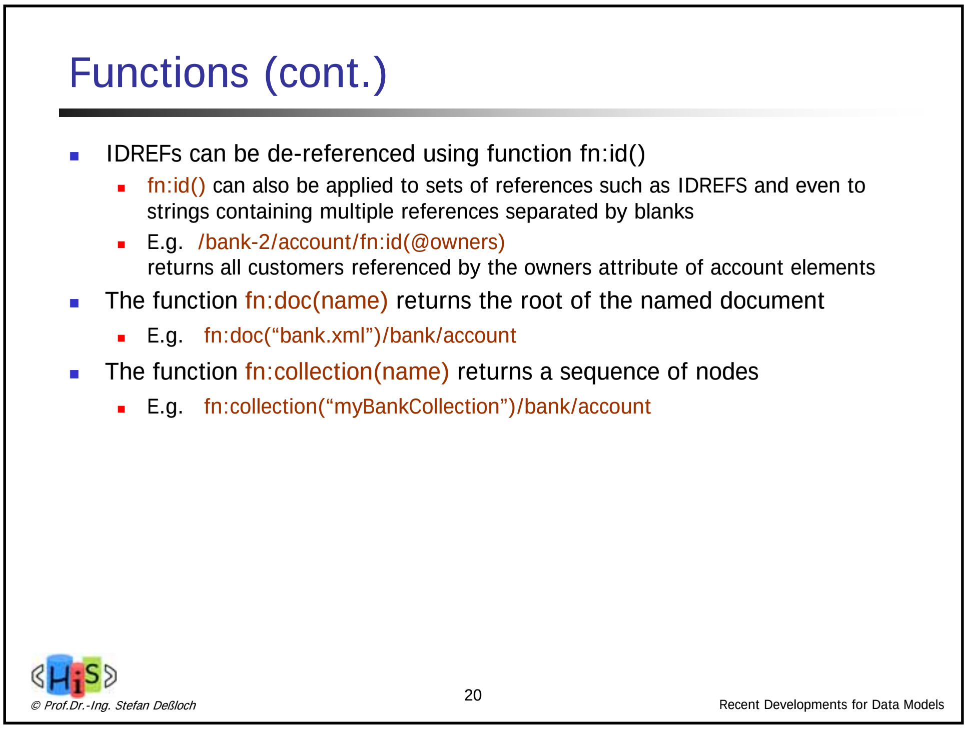
Predicates

- Predicates can be used to apply additional filter conditions for the resulting nodes
  - Boolean expressions: selects all nodes for which expression returns "true"
    book[author = "Mark Twain"]
  - Numeric expressions: selects all nodes whose position is equal to the resulting value
    chapter[2]
  - Existence tests: selects nodes where expression does not result in empty sequence
    book[appendix]
    person[@married] (Tests existence, not value!)
- Predicates can be used in path expressions:
  //book[author = "Mark Twain"]/chapter[2]
  ...and in other kinds of expressions:
  (1 to 100)[. mod 5 = 0]



Functions

- Context functions, e.g.
  - fn:last() returns the number of items in the current sequence
    - Find the last paragraph-child of the context node
      para[fn:last()]
  - fn:position() returns the position of the current item within the current sequence
    - Find the laste paragraph-child of the context node (alternative query)
      para[fn:position()=fn:last()]
  - fn:current-date() returns the current date
    - Find names of customers who have an order with today's date
      //customer[order/date=fn:current-date()]/name
- Functions on nodes/items, e.g.
  - fn:string() returns the string value of an item
    - element nodes: concatenation of all descendant text nodes, in document order
- Functions and operators on sequences, e.g.
  - concatenation, distinct-values, subsequence
  - (deep) equal, union, intersect, except



Functions (cont.)

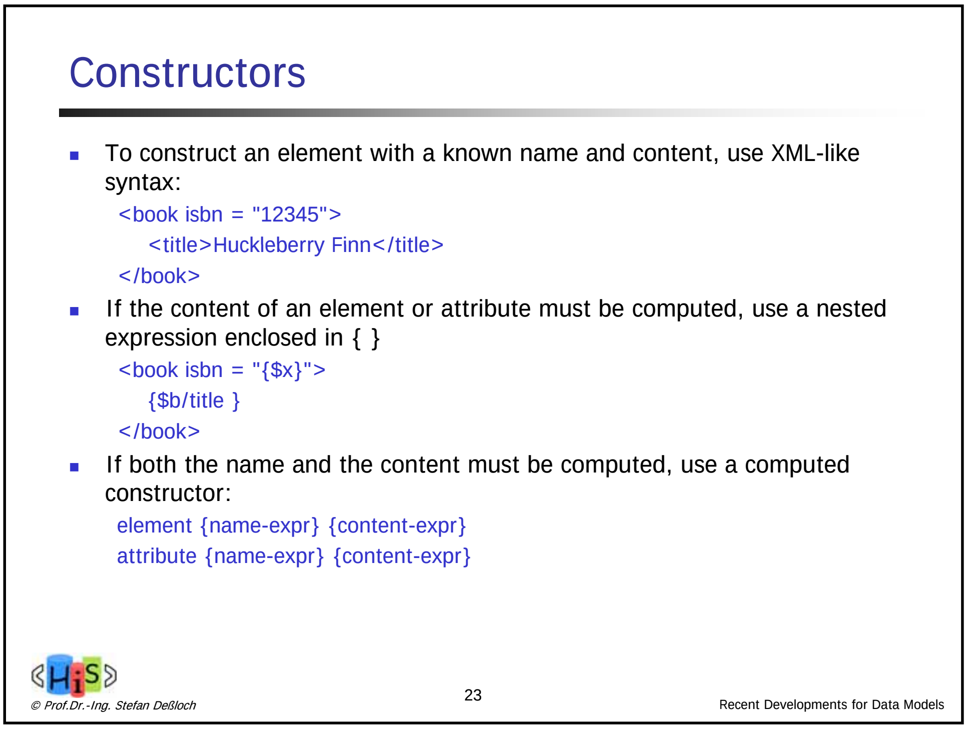
- IDREFs can be de-referenced using function fn:id()
  - fn:id() can also be applied to sets of references such as IDREFS and even to strings containing multiple references separated by blanks
  - E.g. /bank-2/account/fn:id(@owners)
    returns all customers referenced by the owners attribute of account elements
- The function fn:doc(name) returns the root of the named document
  - E.g. fn:doc("bank.xml")/bank/account
- The function fn:collection(name) returns a sequence of nodes
  - E.g. fn:collection("myBankCollection")/bank/account

More Expressions

- Arithmetic operators: + - * div idiv mod
  - Extract typed value from node
  - Multiple values => error
  - If operand is ( ), return ( )
  - Supported for numeric and date/time types
- Comparison operators
  - eq ne gt ge lt le compare single atomic values
  - = != > >= < <= implied existential semantics
  - is   is not compare two nodes based on identity
  - <<   >> compare two nodes based on document order

Logical Expressions

- Operators: and or
- Function: not( )
- Return TRUE or FALSE (2-valued logic)
- "Early-out" semantics (need not evaluate both operands)
- Result depends on Effective Boolean Value of operands
  - If operand is of type boolean, it serves as its own EBV
  - If operand is ( ), zero, or empty string, EBV is FALSE
  - In any other case, EBV is TRUE
- Note that EBV of a node is TRUE, regardless of its content (even if the content is FALSE)!



Constructors

- To construct an element with a known name and content, use XML-like syntax:

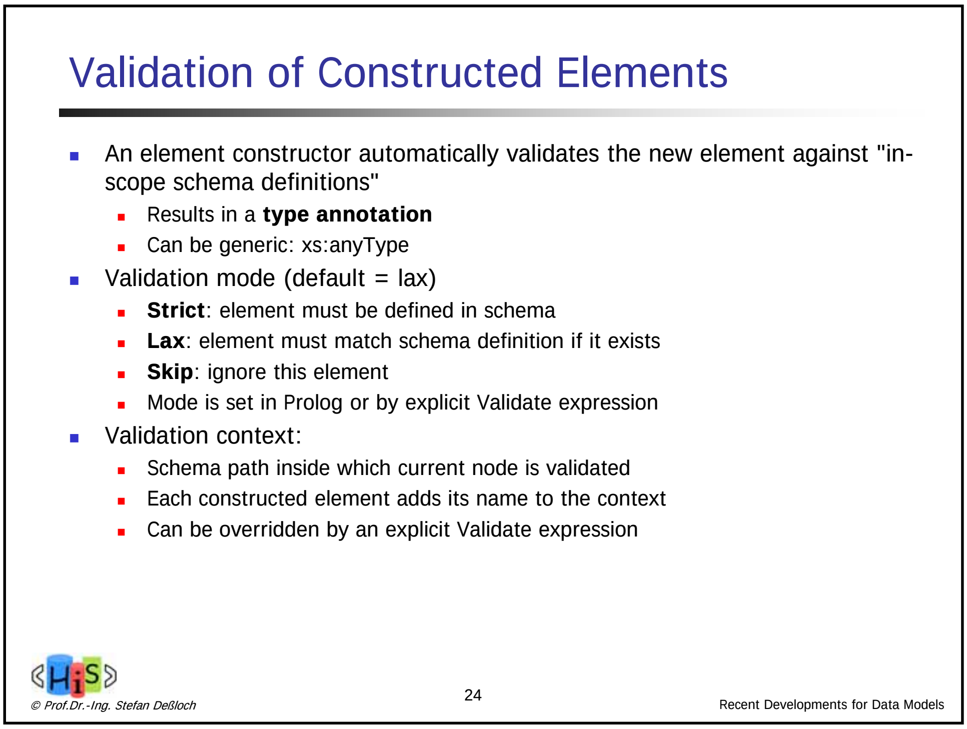
```
<book isbn = "12345">
    <title>Huckleberry Finn</title>
</book>
```

- If the content of an element or attribute must be computed, use a nested expression enclosed in { }

```
<book isbn = "{$x}">
    {$b/title }
</book>
```

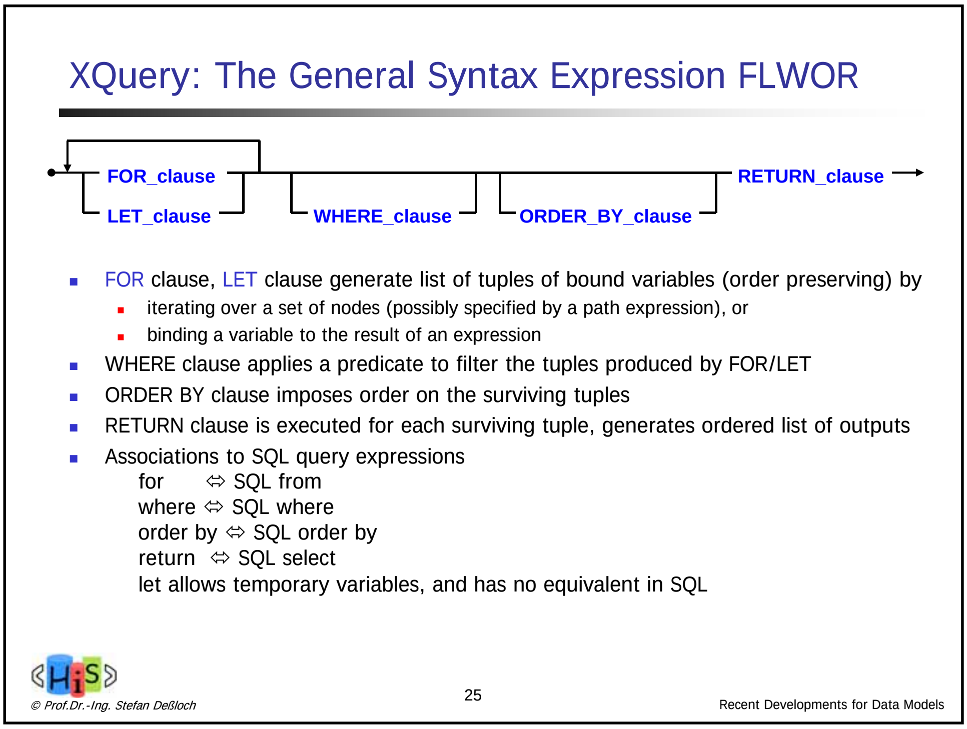
- If both the name and the content must be computed, use a computed constructor:

```
element {name-expr} {content-expr}
attribute {name-expr} {content-expr}
```



Validation of Constructed Elements

- An element constructor automatically validates the new element against "in-scope schema definitions"
  - Results in a **type annotation**
  - Can be generic: xs:anyType
- Validation mode (default = lax)
  - **Strict**: element must be defined in schema
  - **Lax**: element must match schema definition if it exists
  - **Skip**: ignore this element
  - Mode is set in Prolog or by explicit Validate expression
- Validation context:
  - Schema path inside which current node is validated
  - Each constructed element adds its name to the context
  - Can be overridden by an explicit Validate expression

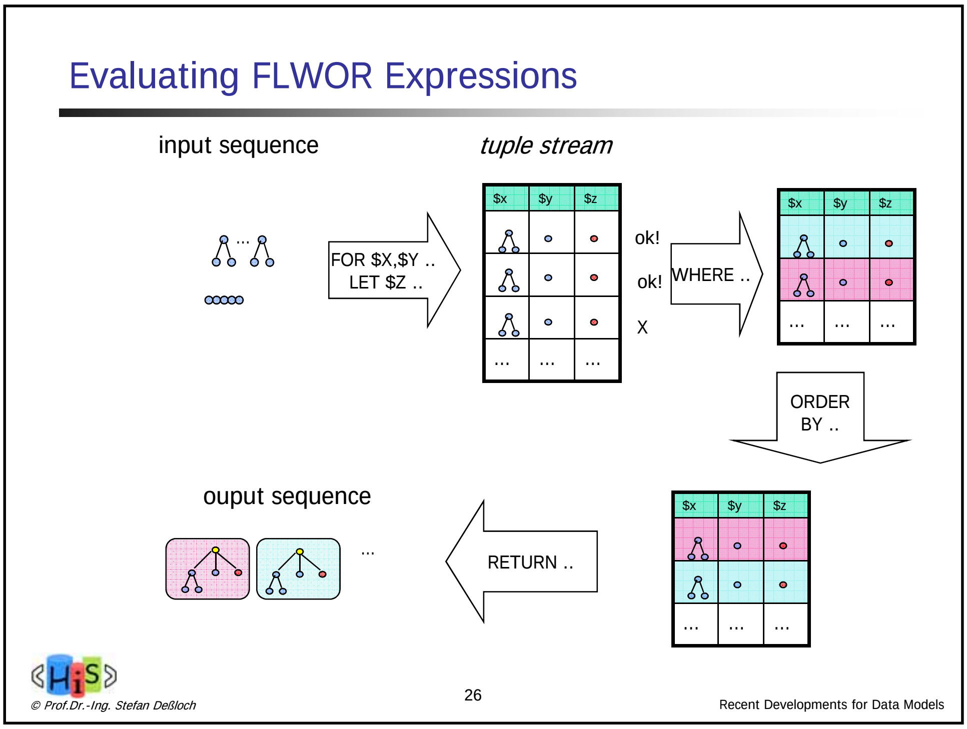


XQuery: The General Syntax Expression FLWOR

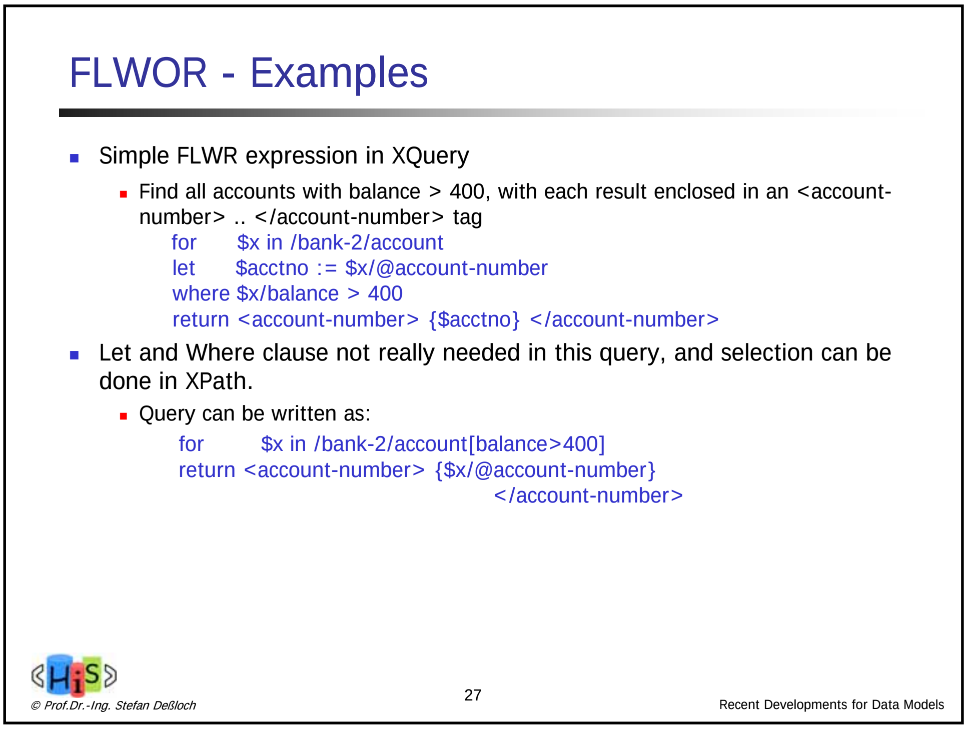
FOR_clause
LET_clause
WHERE_clause
ORDER_BY_clause
RETURN_clause

- FOR clause, LET clause generate list of tuples of bound variables (order preserving) by
  - iterating over a set of nodes (possibly specified by a path expression), or
  - binding a variable to the result of an expression
- WHERE clause applies a predicate to filter the tuples produced by FOR/LET
- ORDER BY clause imposes order on the surviving tuples
- RETURN clause is executed for each surviving tuple, generates ordered list of outputs
- Associations to SQL query expressions

  for ⇔ SQL from
  where ⇔ SQL where
  order by ⇔ SQL order by
  return ⇔ SQL select
  let allows temporary variables, and has no equivalent in SQL



Evaluating FLWOR Expressions



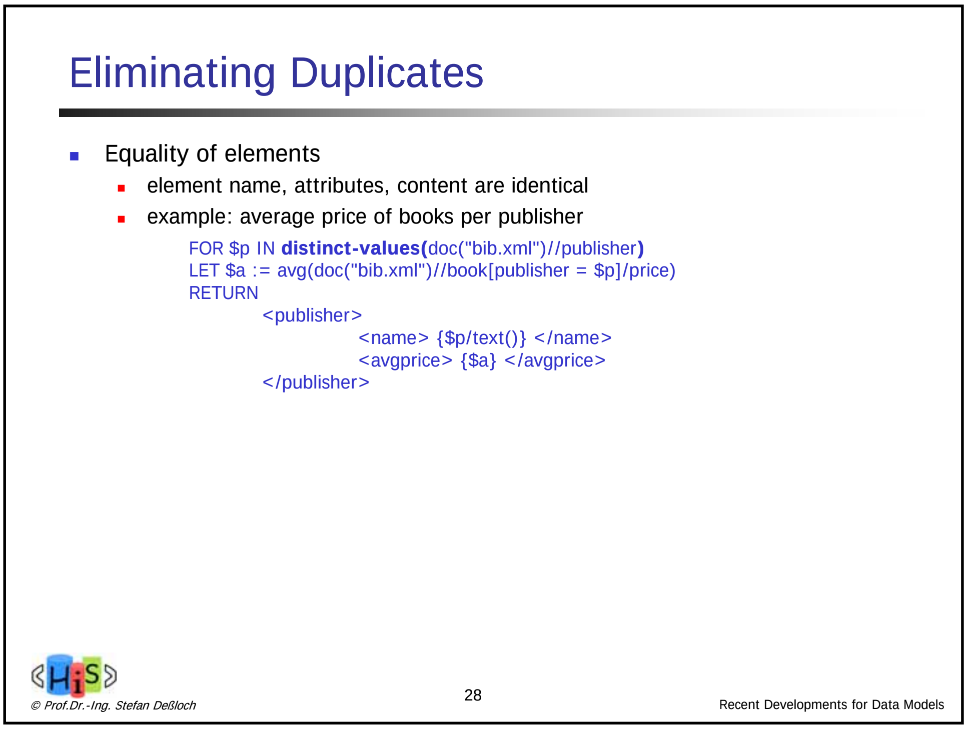
FLWOR - Examples

- Simple FLWR expression in XQuery
  - Find all accounts with balance > 400, with each result enclosed in an <account-number> .. </account-number> tag

```
for      $x in /bank-2/account
let      $acctno := $x/@account-number
where $x/balance > 400
return <account-number> {$acctno} </account-number>
```

- Let and Where clause not really needed in this query, and selection can be done in XPath.
  - Query can be written as:

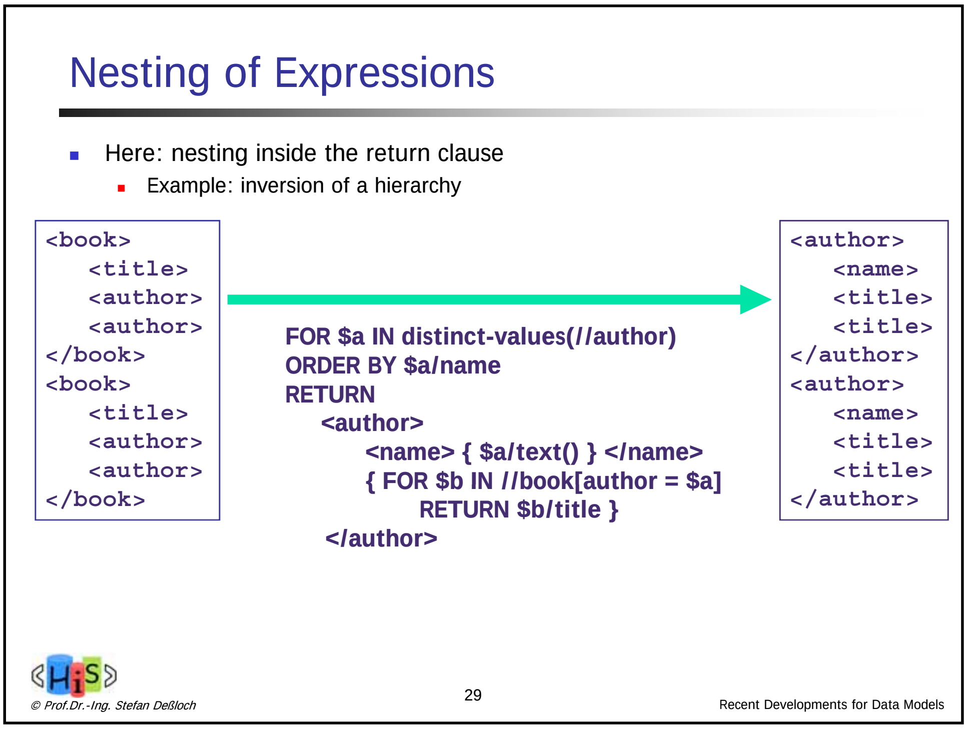
```
for        $x in /bank-2/account[balance>400]
return <account-number> {$x/@account-number}
                                          </account-number>
```



Eliminating Duplicates

- Equality of elements
  - element name, attributes, content are identical
  - example: average price of books per publisher

```
FOR $p IN distinct-values(doc("bib.xml")//publisher)
LET $a := avg(doc("bib.xml")//book[publisher = $p]/price)
RETURN
           <publisher>
                          <name> {$p/text()} </name>
                          <avgprice> {$a} </avgprice>
           </publisher>
```



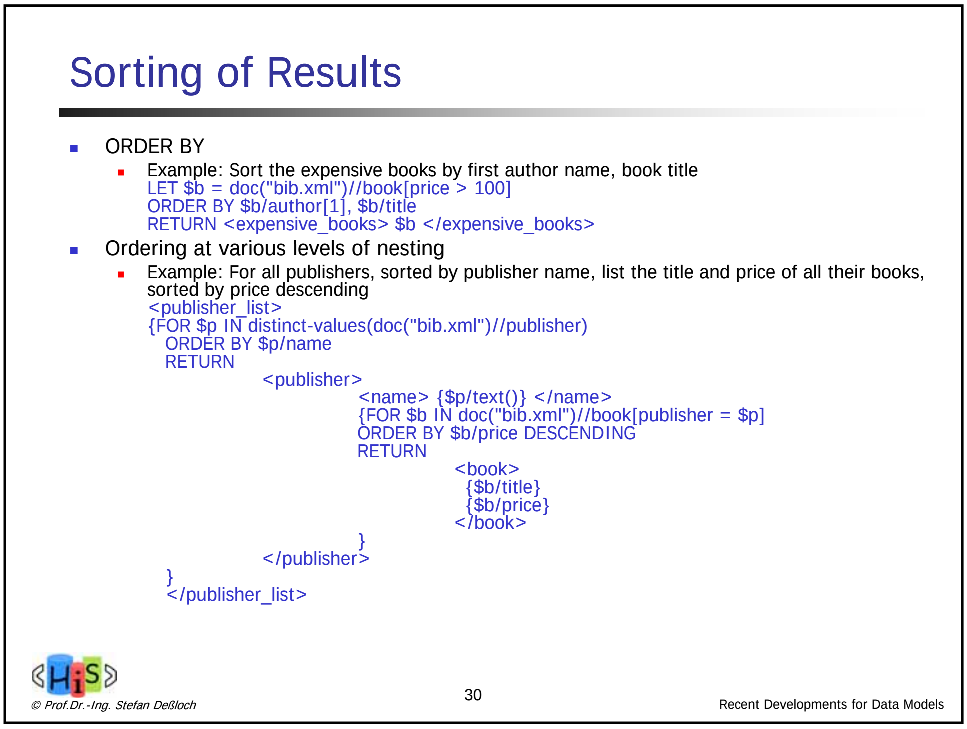
Nesting of Expressions

- Here: nesting inside the return clause
  - Example: inversion of a hierarchy

```
<book>
   <title>
   <author>
   <author>
</book>
<book>
   <title>
   <author>
   <author>
</book>
```

```
FOR $a IN distinct-values(//author)
ORDER BY $a/name
RETURN
   <author>
      <name> { $a/text() } </name>
      { FOR $b IN //book[author = $a]
          RETURN $b/title }
   </author>
```

```
<author>
   <name>
   <title>
   <title>
</author>
<author>
   <name>
   <title>
   <title>
</author>
```



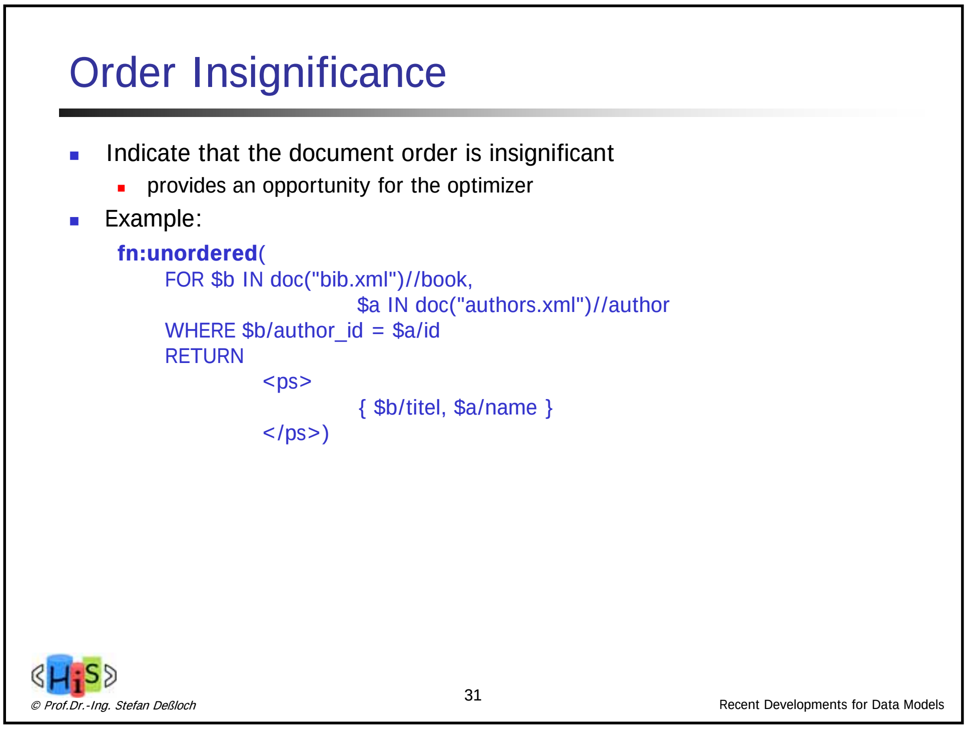
Sorting of Results

- ORDER BY
  - Example: Sort the expensive books by first author name, book title

```
LET $b = doc("bib.xml")//book[price > 100]
ORDER BY $b/author[1], $b/title
RETURN <expensive_books> $b </expensive_books>
```

- Ordering at various levels of nesting
  - Example: For all publishers, sorted by publisher name, list the title and price of all their books, sorted by price descending

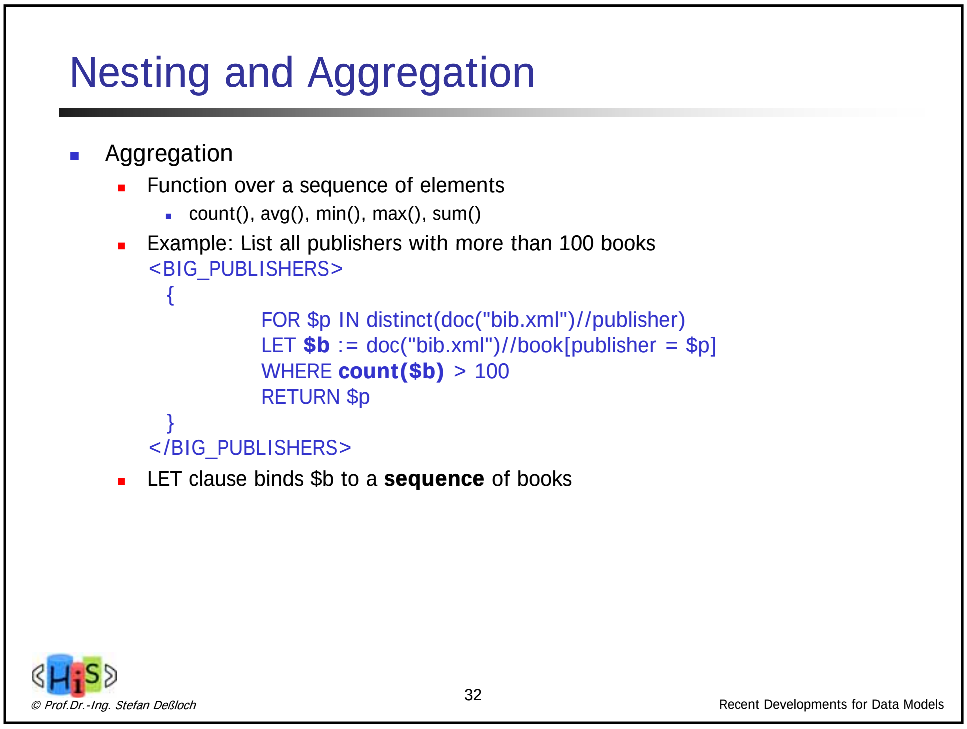
```
<publisher_list>
{FOR $p IN distinct-values(doc("bib.xml")//publisher)
   ORDER BY $p/name
   RETURN
           <publisher>
                   <name> {$p/text()} </name>
                   {FOR $b IN doc("bib.xml")//book[publisher = $p]
                   ORDER BY $b/price DESCENDING
                   RETURN
                           <book>
                             {$b/title}
                             {$b/price}
                           </book>
                   }
           </publisher>
   }
   </publisher_list>
```



Order Insignificance

- Indicate that the document order is insignificant
  - provides an opportunity for the optimizer
- Example:

```
fn:unordered(
      FOR $b IN doc("bib.xml")//book,
                        $a IN doc("authors.xml")//author
      WHERE $b/author_id = $a/id
      RETURN
                  <ps>
                        { $b/titel, $a/name }
                  </ps>)
```



Nesting and Aggregation

- Aggregation
  - Function over a sequence of elements
    - count(), avg(), min(), max(), sum()
  - Example: List all publishers with more than 100 books

```
<BIG_PUBLISHERS>
  {
            FOR $p IN distinct(doc("bib.xml")//publisher)
            LET $b := doc("bib.xml")//book[publisher = $p]
            WHERE count($b) > 100
            RETURN $p
  }
</BIG_PUBLISHERS>
```

  - LET clause binds $b to a **sequence** of books

XQuery: Joins

- Joins are specified in a manner very similar to SQL

```
for   $a  in  /bank/account,
      $c  in  /bank/customer,
      $d  in  /bank/depositor
where $a/account-number = $d/account-number
    and $c/customer-name = $d/customer-name
return <cust-acct>{ $c $a }</cust-acct>
```

- The same query can be expressed with the selections specified as XPath selections:

```
for   $a in /bank/account
      $c in /bank/customer
      $d in /bank/depositor[
                     account-number =$a/account-number and
                     customer-name = $c/customer-name]
return <cust-acct>{ $c $a }</cust-acct>
```

XQuery: Outer Join

- Example: List all suppliers. If a supplier offers medical items, list the descriptions of the items

```
FOR $s IN doc("suppliers.xml")//supplier
ORDER BY $s/name
RETURN
   <supplier>
     { $s/name,
       FOR $ci IN doc("catalog.xml")//item[supp_no = $s/number],
           $mi IN doc("medical_items.xml")//item[number = $ci/item_no]
       RETURN $mi/description
     }
   </supplier>
```

- Problem with full outer join: nesting forces asymmetric representation
  - produce a two-part document, enclosed by a <master_list> element
  - query needs a separate expression for computing the "orphan" items

Quantified Expressions

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

```
FOR $b IN //book
WHERE SOME $p IN $b//para SATISFIES (contains($p, "Sailing")
                              AND contains($p, "Windsurfing"))
RETURN $b/title
```

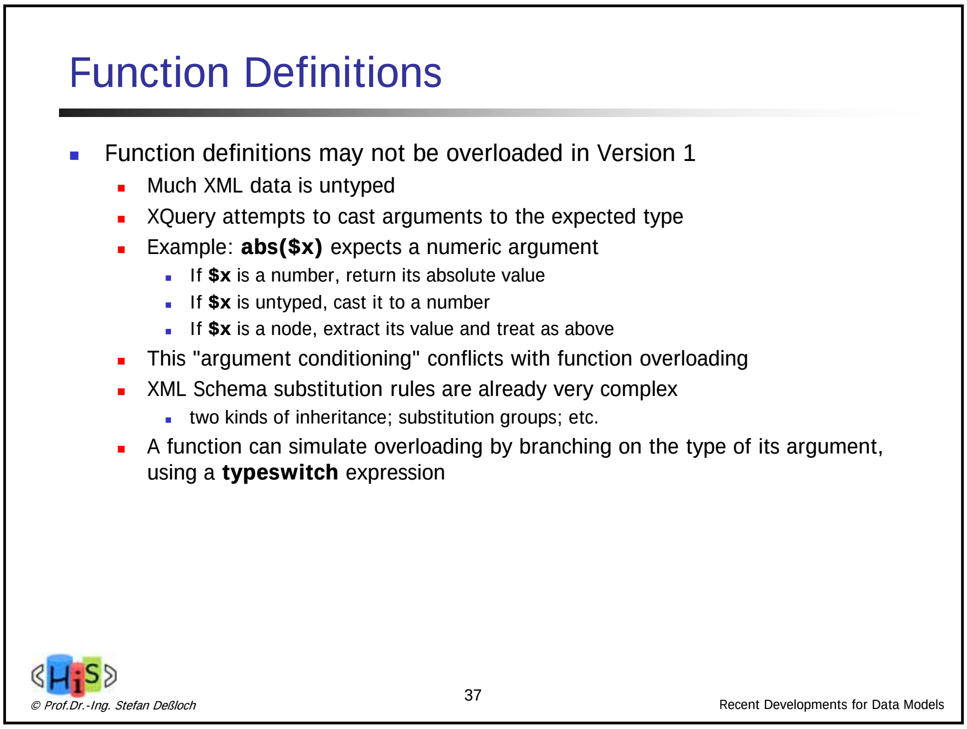
- Universal Quantification
  - Give me all books where "Sailing" appears in every paragraph

```
FOR $b IN //book
WHERE EVERY $p IN $b//para SATISFIES contains($p, "Sailing")
RETURN $b/title
```

Defining and Using Functions

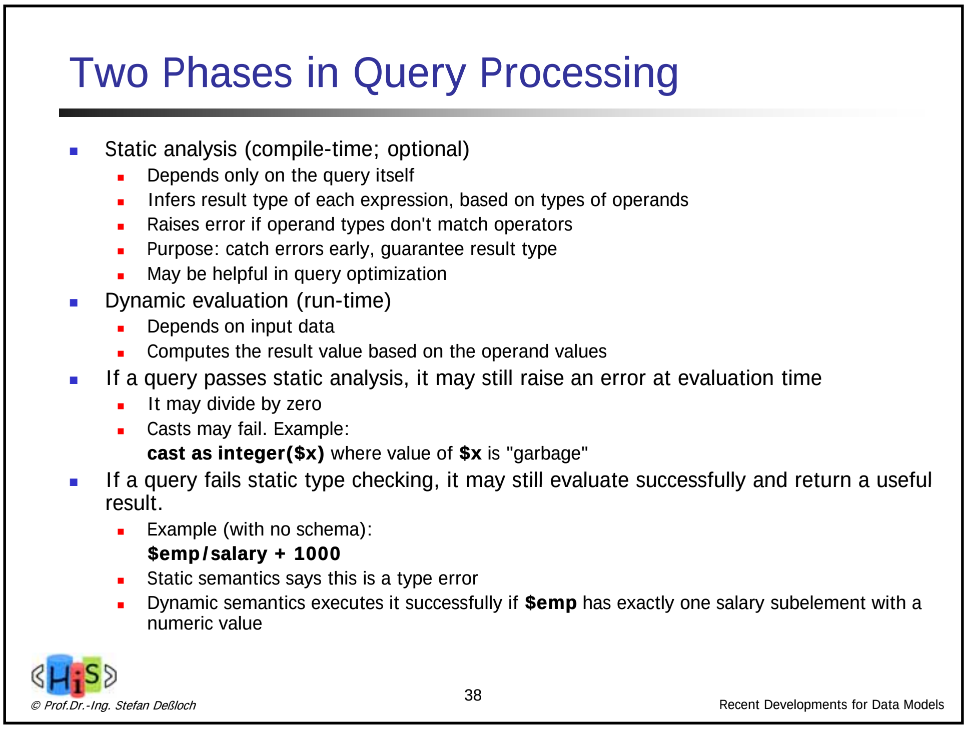
- Predefined Functions
  - XPath/XQuery function library, e.g., doc( )
  - aggregation functions: avg, sum, count, max, min
  - additional functions: distinct-values( ), empty( ), ...
- User-defined Functions
  - Example: compute maximal path length in "bib.xml"

```
DECLARE FUNCTION local:depth($e AS node()) AS xs:integer
{
  (: A node with no children has depth 1 :)
  (: Otherwise, add 1 to max depth of children :)
  IF (empty($e/*))
              THEN 1
              ELSE 1 + fn:max( FOR $c IN $e/* RETURN local:depth($c) )
  };
LET $h := doc("bib.xml")
RETURN
              <depth>{ local:depth($h) }</depth>
```



Function Definitions

- Function definitions may not be overloaded in Version 1
  - Much XML data is untyped
  - XQuery attempts to cast arguments to the expected type
  - Example: **abs($x)** expects a numeric argument
    - If **$x** is a number, return its absolute value
    - If **$x** is untyped, cast it to a number
    - If **$x** is a node, extract its value and treat as above
  - This "argument conditioning" conflicts with function overloading
  - XML Schema substitution rules are already very complex
    - two kinds of inheritance; substitution groups; etc.
  - A function can simulate overloading by branching on the type of its argument, using a **typeswitch** expression



Two Phases in Query Processing

- Static analysis (compile-time; optional)
  - Depends only on the query itself
  - Infers result type of each expression, based on types of operands
  - Raises error if operand types don't match operators
  - Purpose: catch errors early, guarantee result type
  - May be helpful in query optimization
- Dynamic evaluation (run-time)
  - Depends on input data
  - Computes the result value based on the operand values
- If a query passes static analysis, it may still raise an error at evaluation time
  - It may divide by zero
  - Casts may fail. Example:
    cast as integer($x) where value of **$x** is "garbage"
- If a query fails static type checking, it may still evaluate successfully and return a useful result.
  - Example (with no schema):
    $emp/salary + 1000
  - Static semantics says this is a type error
  - Dynamic semantics executes it successfully if **$emp** has exactly one salary subelement with a numeric value

Summary

- Characteristics of XML (from a data modeling perspective)
  - data/meta-data integration, schema flexibility, heterogeneity, nesting, ordering, ...
- XQuery provides a powerful initial step towards an XML query language that reflect the above characteristics
- XQuery Data Model (XDM)
  - builds on XML tree structure, introduces sequences and atomic values
  - basis for XQuery processing, supports closure property
- Major query language constructs
  - path expressions
  - constructors
  - FLWOR expressions
- Problem: lack of an algebraic foundation

XQuery - Status

- XQuery is a w3c recommendation since January 2007
- Ongoing work
  - Insert, Update, Delete
    - candidate recommendation since March 2008
  - Full-text support
    - candidate recommendation since May 2008
  - Host language bindings, APIs
    - XQuery API for JavaTM (XQJ)
    - problem to overcome: tradtional XML processing API is based on well-defined documents
    - proposed final draft since October 2007
- Future Work
  - View definitions, DDL