XML Technologies

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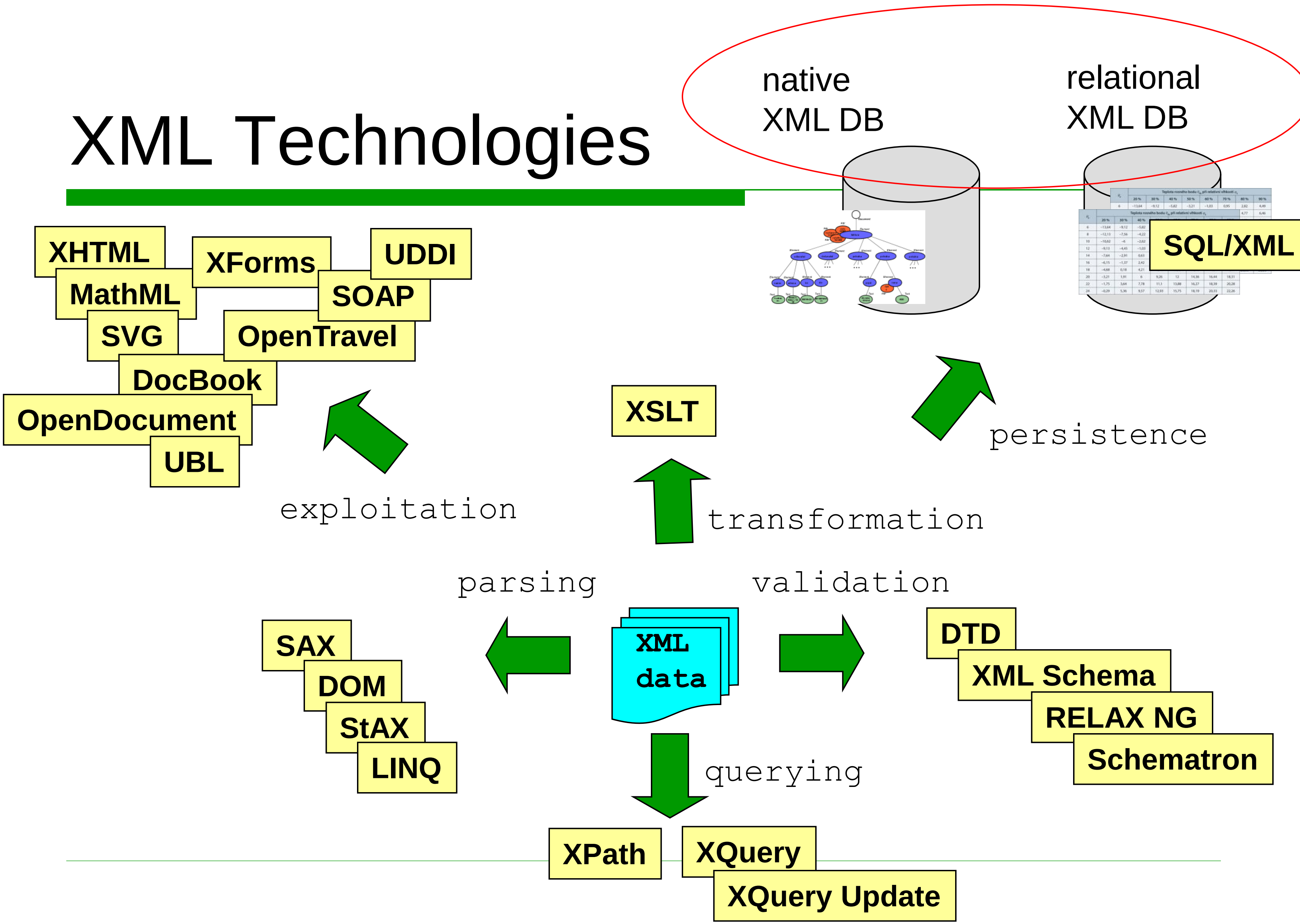
Outline

- Introduction to XML format, overview of XML technologies
- DTD
- XML data models
- Interfaces for XML data
- XPath
- XSLT
- XQuery, XQuery Update
- XML schema languages
- SQL/XML
- An overview of standard XML formats
- XML data persistence

XML Technologies



Why XML Database?

- Motivation: requirements of applications
  - Processing of external data
    - Web pages, other textual data, structured data
  - E-commerce
    - Lists of goods, personalized views of the lists, orders, invoices, …
  - Integration of heterogeneous information resources
    - Integrated processing of data from Web pages and from relational databases
- Main reason: storing XML data into databases means management of huge volumes of XML data in an efficient way

Documents vs. Databases

World of documents	World of databases
many small documents	several huge databases
usually static	usually dynamic
implicit structure - tagging	explicit structure - schema
suitable for humans	suitable for machines

Documents vs. Databases

Documents	Databases
editing	updating
printing	
lexical checking	data cleaning
word count	
information retrieval	querying
searching	storing/transforming

Documents and Structured Data

- The border between the world of documents and world of databases is not exact
  - In some proposals both kinds of access are possible
  - Somewhere in the middle we can find formatting languages and semi-structured data
- Semi-structured data are defined as data which are not sorted (have arbitrary order), which are not complete (have optional parts) and whose structure can "unpredictably" change
  - Web data, HTML pages, Bibtex files, biological and chemical data
  - XML data are a kind of semi-structured data

Classification of XML Documents

- The basic classification of XML documents results from their origin and the way they were created
  - data-oriented
  - document-oriented
  - hybrid
- For the particular classes different ways of implementations are suitable

Data-oriented XML Documents

- Usually created and processed by machines
- Regular, deep structure
  - Fully structured data
- They do not contain
  - Mixed-content elements
  - CDATA sections
  - Comments
  - Processing instructions
- The order of sibling elements is often unimportant
- Example: database exports, catalogues, …

Data-oriented XML Documents

```
<book id="12345">
  <title>All I Really Need To Know I Learned in
Kindergarten</title>
  <author>
    <name>Robert</name>
    <surname>Fulghum</surname>
  </author>
  <edition title="Argo">
    <year>2003</year>
    <ISBN>80-7203-538-X</ISBN>
  </edition>
  <edition title="Argo">
    <year>1996</year>
    <ISBN>80-7203-028-0</ISBN>
  </edition>
</book>
```

Document-oriented XML Documents

- Usually created and processed by humans
- Irregular, less structured
  - Semi-structured data
- Often contain
  - Mixed-content elements
  - CDATA sections
  - Comments
  - Processing instructions
- The order of sibling elements is crucial
- Example: XHTML web pages

Document-oriented XML Documents

```
<book id="12345">
  <title>All I Really Need To Know I Learned in Kindergarten</title>
  <author>Robert Fulghum</author>
  <description>A new, edited and extended publication published on the occasion of the fifteen anniversary of the first edition</description>
  <Text>
    <p>Fifteen years after publishing of <q>his</q> <i>Kindergarten</i> Robert Fulghum has decided to read it once again, now in <i>2003</i>.</p>
    <p>He wanted to find out whether and, if so, to what extent his opinions have changed and why. Finally, he modified and extended his book to...</p>
  <Text>
</book>
```

Implementation Approaches

- Differ according to the type of documents
  - Exploit typical features
  - Problem: hybrid documents
    - Ambiguous classification
- Document-oriented techniques

vs.

- Data-oriented techniques

Document-oriented Techniques (1)

- We need to preserve the document as whole
  - Order of sibling elements
  - Comments, CDATA sections, ...
  - Even whitespaces
    - For legal documents
- Round tripping – storing a document into a database and its retrieval
  - The level of round tripping says to what extent the documents are similar
    - The higher level, the higher similarity
  - In the optimal case they are equivalent

Document-oriented Techniques (2)

- LOB
  - Storing of the whole document into a BLOB / CLOB column
    - Possible in all known database systems

  (+) The highest level of round tripping, fast retrieval of the whole document, extending of XML data with database features

  (–) No XML operations
    - The data need to be extracted from the DB and pre-processed
- XML data type
  - Like a LOB with the support for XML operations
    - XML querying, XML full-text search
    - Requires special indices (numbering schemas)
  - SQL/XML

Document-oriented Techniques (3)

- Native XML databases (NXD)
  - Natural support for XML operations
    - XML query languages, XML update operations, DOM/SAX interfaces, …
    - Focus on document-oriented aspects
      - Comments, CDATA sections, …
  - The logical model is based on XML
    - i.e. we work with trees
  - The physical model can be, e.g., relational
    - i.e. we can physically store the trees, e.g., into relations

  (+) Good level of round tripping

  (–) The index (numbering schema) is (<u>used to be</u>) several times bigger than the data, necessity to start from scratch (transactions, replication, multi-user access, query optimization, …)

Data-oriented Techniques (1)

- Idea: The data are stored in a relational database management system (RDBMS)
  - Mapping method – transforms the data into relations (and back)
  - XML queries over XML data → SQL queries over relations
  - The result of SQL query → XML document
- Exploit data-oriented aspects (low level of round tripping)
  - It is not necessary to preserve the document as a whole
    - Order of sibling elements is ignored, document-oriented constructs (comments, whitespaces, …) are ignored, …
  - No (little) support for mixed-content elements

Data-oriented Techniques (2)

- Middleware
  - A separate software which ensures transformation of XML data between XML documents and relations
- XML-enabled database
  - RDBMS with functions and extensions for XML data support

- Special related approach: XML data binding
  - Methods for binding of XML data and objects
  - For each element type a separate class
    - Its attributes and subelements form properties of the class
    - I.e. it is not a DOM tree of objects!

Numbering Schemas

A numbering schema of a tree model of a document is a function which assigns each node a unique identifier that serves as a reference to that node for indexing and query evaluation

- Enable fast evaluation of selected relationships among nodes of XML document
  - Ancestor-descendant
  - Parent-child
  - Element-attribute
  - …
  - Depth of the node
  - Order among siblings
  - …

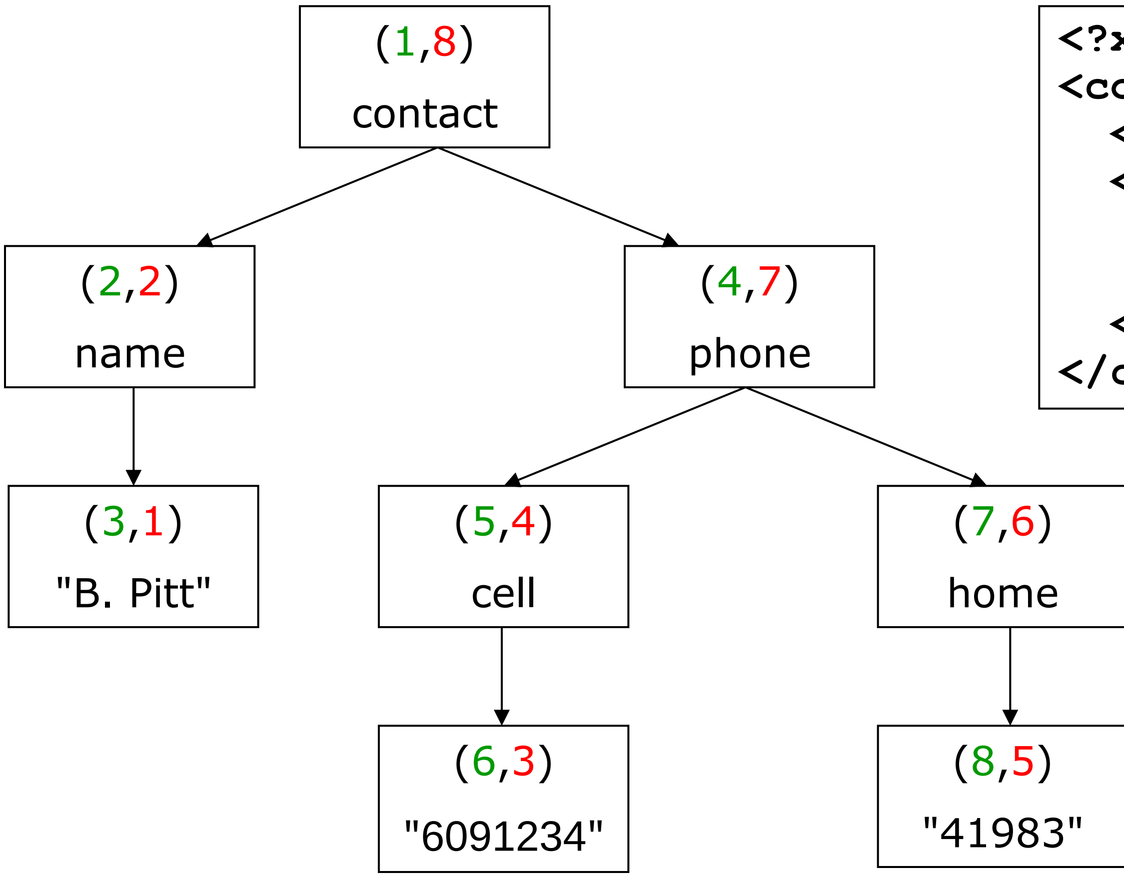
Numbering Schemas

- Sequential numbering schema
  - The identifiers are assigned to the nodes as soon as they are added to the system sequentially, starting from 1
- Structural numbering schema
  - Enables to preserve and evaluate a selected relationship among any two nodes of the document
  - Often it is expected to enable fast searching for all occurrences of such a relationship in the document

Numbering Schemas

- Stable numbering schema
  - A schema which does not have to be modified (except for preserving its local features) when the structure of the respective data changes
    - i.e., on insertion/deletion of nodes
- A schema of a structural numbering schema
  - Is an ordered pair (p, L), where p is a binary predicate and L is an invertible function which for the given XML tree model T = (N, E) assigns each node v ∈ N a binary sequence L(v).
  - For each pair of nodes u, v ∈ N predicate p(L(u), L(v)) is satisfied if v is in a particular relationship with u.
    - e.g. v is a descendant of u
  - Particular numbering schema: particular p and L

Dietz Numbering

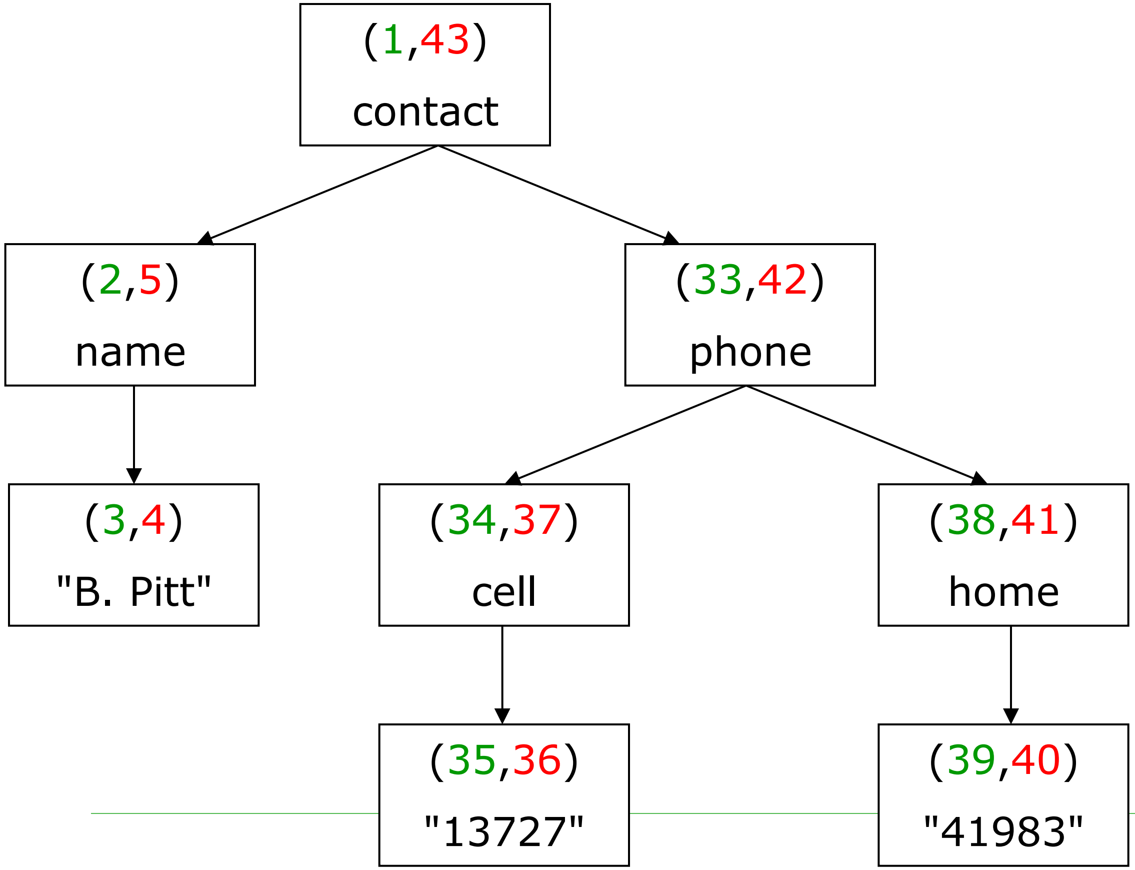



```
<?xml version="1.0"?>
<contact>
  <name>B. Pitt</name>
  <phone>
    <cell>6091234</cell>
    <home>41983</home>
  </phone>
</contact>
```

Dietz Numbering

- Preorder traversal
  - Child nodes of a node follow their parent node
- Postorder traversal
  - Parent node follows its child nodes
- Construction of a numbering schema
  - Each node $v \in N$ is assigned with a pair (x,y) denoting preorder and postorder order
  - Node $v \in N$ having $L(v) = (x,y)$ is a descendant node of node u having $L(u) = (x',y')$ if $x' < x$ & $y' > y$

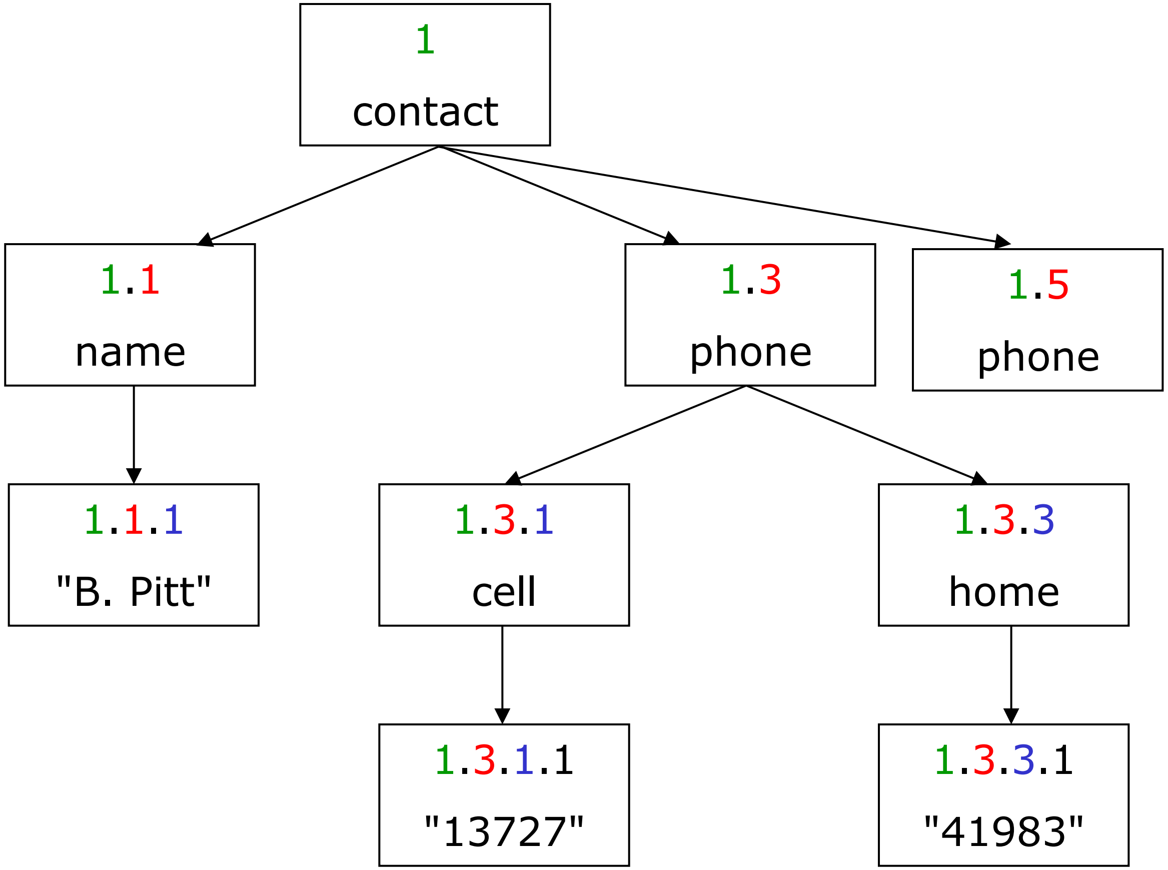
Depth-first (DF) Numbering



preorder traversal +

- assigning (u_{min}, u_{max}), where
  - u_{min} is the time of visiting a node
  - u_{max} is the time of leaving a node
- Predicate is the same as in the previous case

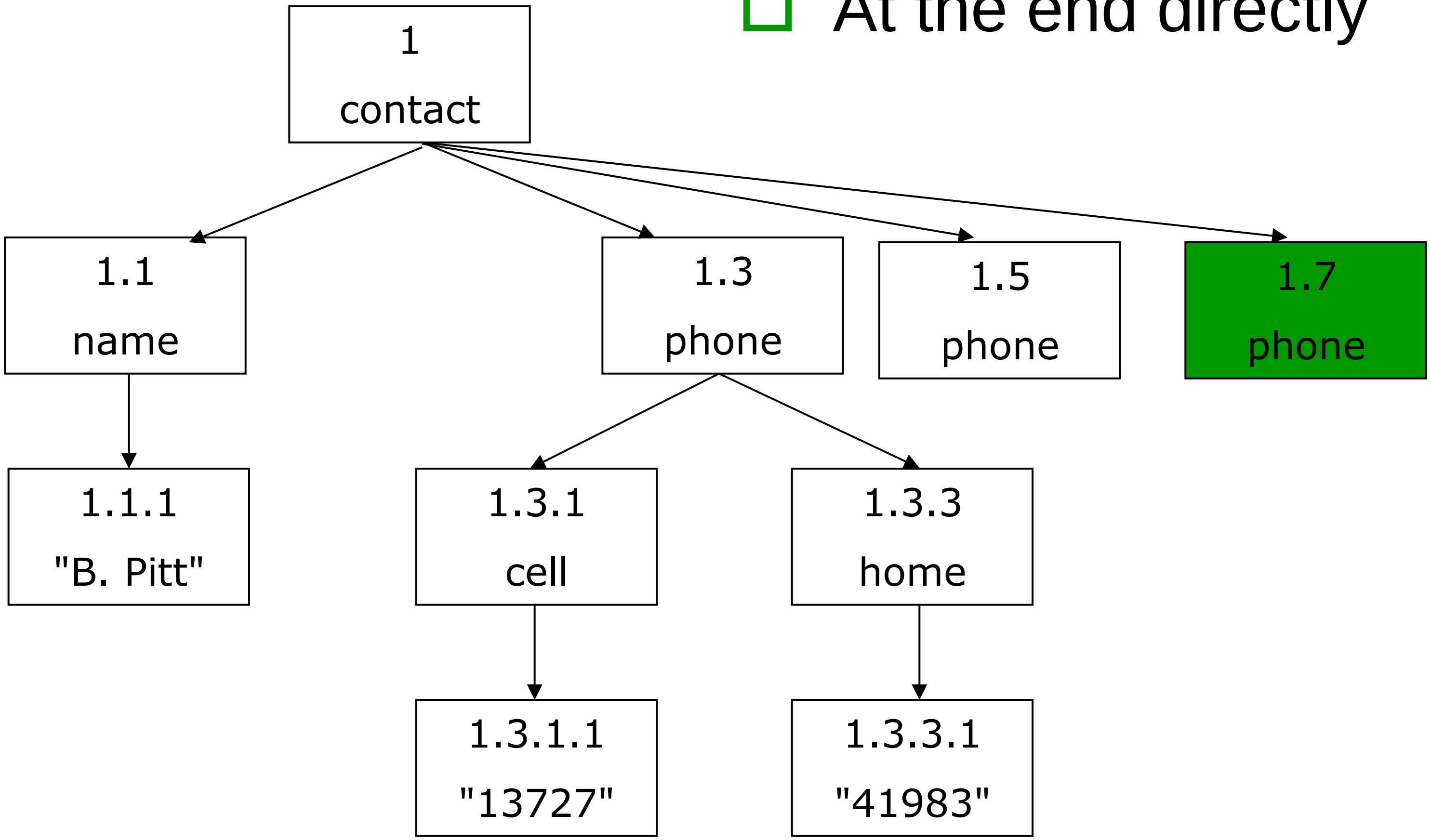
ORDPATH



- New level of tree = new level of numbering
- We use only odd numbers
- The predicate corresponds to searching a substring

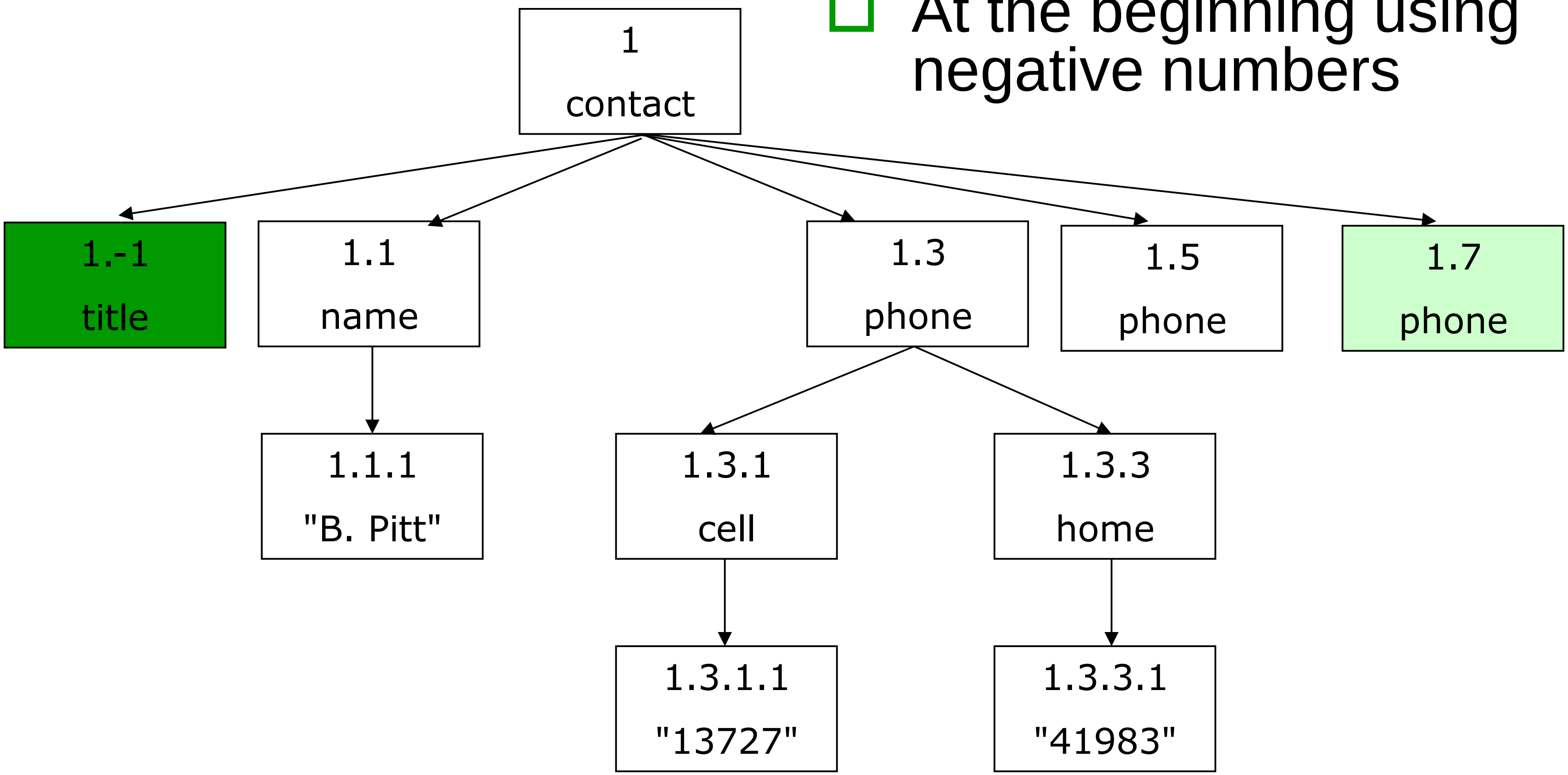
ORDPATH – Insert

- At the end directly



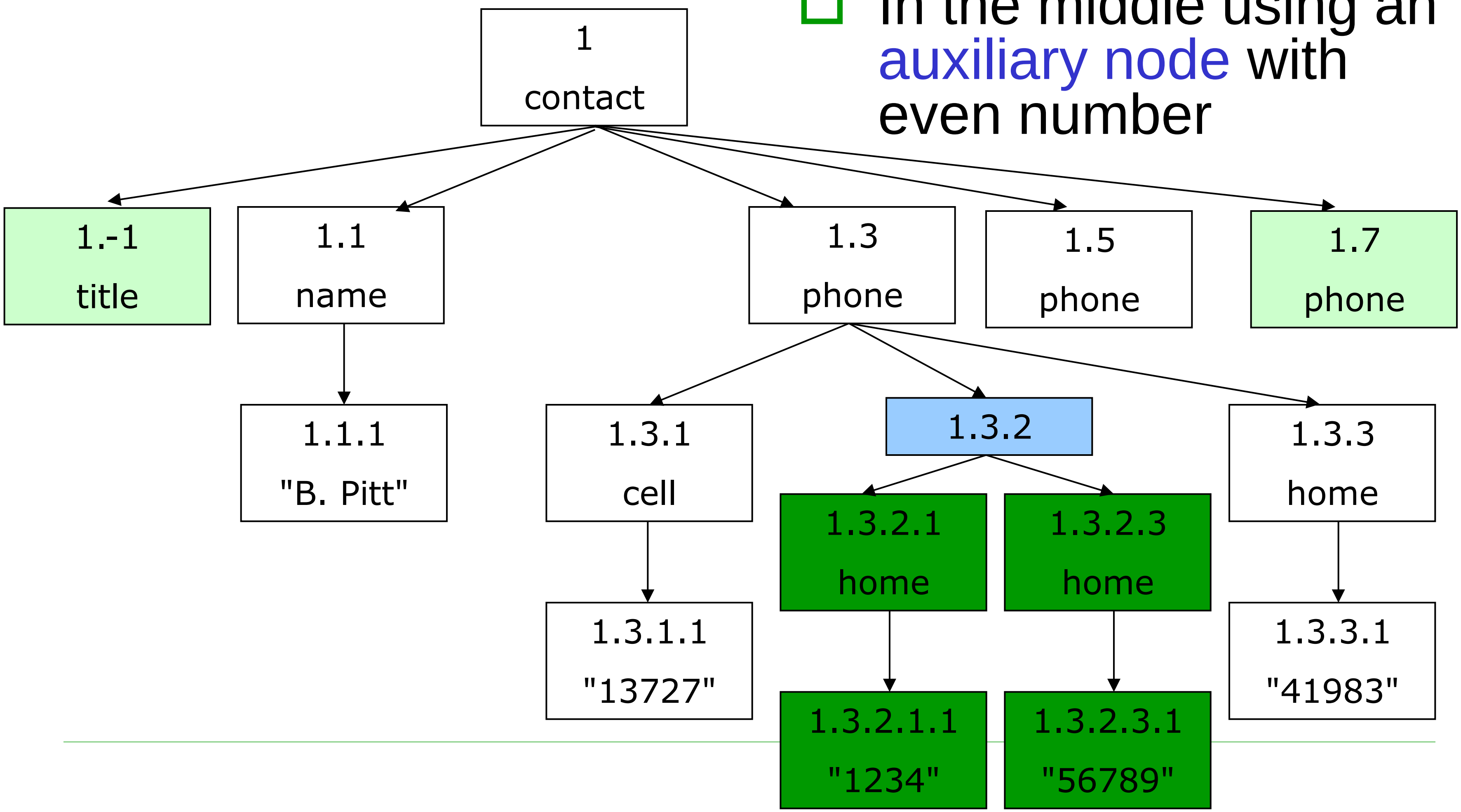
ORDPATH – Insert

- At the beginning using negative numbers



ORDPATH – Insert

- In the middle using an auxiliary node with even number



XML Databases

- What we want: persistent storage of XML data
- General classification:
  - Based on a file system
  - Based on an object model
  - Based on (object-)relational databases
    - XML-enabled databases
    - Exploit a mapping method between XML data and relations
  - Native XML databases
    - Exploit a suitable data structure for hierarchical tree data
    - Usually a set of numbering schemas

XML Databases

- The most efficient approaches are the native ones
  - Reason: From the beginning they target the XML data structure
    - They are based on it
  - Disadvantage: We need to start from scratch
    - The databases are not only about storing the data, but also transactions, versioning, multi-user access, replication, …
- An alternative intuitive idea: Exploitation of a mature and verified technology of (object-) relational databases

Mapping Methods

- Methods for transformation between XML data and relations
- Further classification:
  A. Generic – mapping regardless XML schema of the stored XML data
  B. Schema-driven – mapping based on XML schema of the stored XML data
     - DTD, XML Schema
  C. User-defined – mapping provided by the user

A. Generic Methods

- Do not exploit XML schema of the stored data
  - Idea: Not all data have a schema
- Approaches:
  1. A relational schema for a particular type of (collection of) XML data
     - e.g. Table-based mapping
  2. A general relational schema for any type of (collection of) XML data
     - View XML data as a general tree
       - We store the tree
     - e.g. Generic-tree mapping, Structure-centred mapping, Simple-path mapping

Table-based Mapping (1)

```
<Tables>
     <Table_1>
        <Row>
           <Column_1>...</Column_1>
           ...
           <Column_n>...</Column_n>
        </Row>
        ...
     </Table_1>
     ...
     <Table_n>
        <Row>
           <Column_1>...</Column_1>
           ...
           <Column_m>...</Column_m>
        </Row>
        ...
     </Table_n>
  </Tables>
```

Table-based Mapping (2)

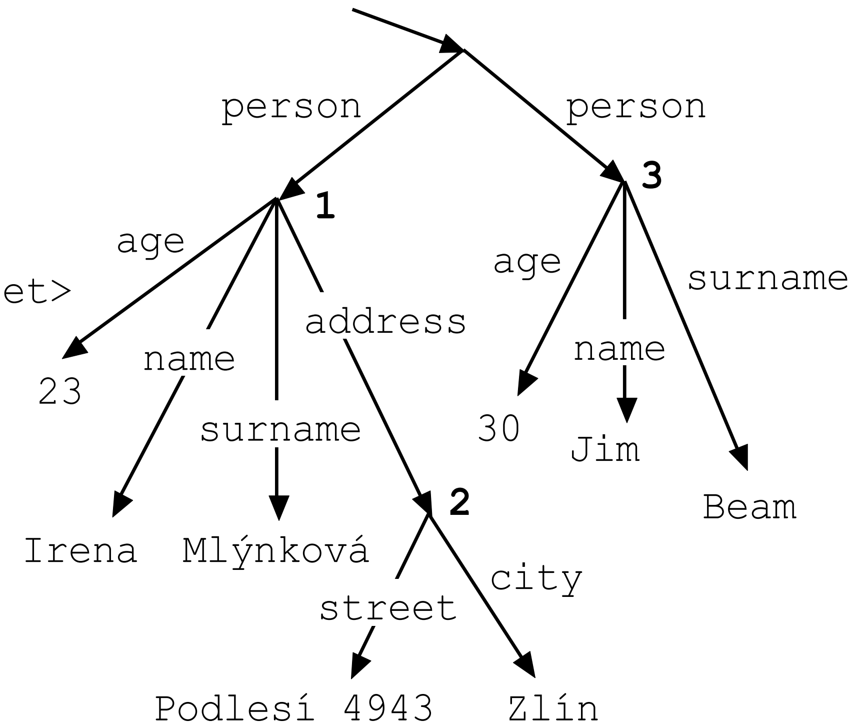
- Trivial case
- The schema is an implicit part of the data
  - Only a limited set of documents can be stored
- Typical usage: data transfer among multiple databases
- There exist also more complex schemas, but the idea is the same
  - Basically again usage of (an implicit) schema

Generic-tree Mapping (1)

- The target relational schema enables to store any kind of XML data
  - Regardless their XML schema
- XML document ↔ directed tree
  - Inner nodes have an ID
  - Leaves carry values of attributes or text nodes
  - Outgoing edges of a node represent subelements/attributes of the element represented by ingoing edge of the same node
  - Edges are labeled with element/attribute names

Generic-tree Mapping (2)

```
...
<person id=1 age=23>
  <name>Irena</name>
  <surname>Mlýnková</surname>
  <address id=2>
    <street>Podlesí 4943</street>
    <city>Zlín</city>
  </address>
</person>
<person id=3 age=30>
  <name>Jim</name>
  <surname>Beam</surname>
</person>
...
```

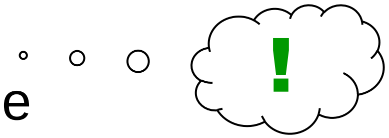


Generic-tree Mapping (3)

- Edge mapping
  - **Edge (sourceID, order, label, type, targetID)**
    - Type: inner edge, element/attribute edge, …

```
Edge (..., (1, 2, "name", element, -1), ...
           (1, 4, "address", inner, 2), ...)
```

- Attribute mapping
  - Attribute = name of the edge



  - **$\text{Edge}_{\text{attribute}}$ (sourceID, order, type, targetID)**

$\text{Edge}_{\text{name}}$`(..., (1, 2, element, -1), ...`
`(3, 2, element, -1), ...)`

Generic-tree Mapping (4)

- Universal mapping
  - **`Uni (sourceID,`** $order_{a1}$, $type_{a1}$, $targetID_{a1}$, ... $order_{ak}$, $type_{ak}$, $targetID_{ak}$)
    - Outer join of tables from attribute mapping
    - a_1, ... a_k are all the attribute names in the XML document
  - Too many null values
- Normalized universal mapping
  - The universal table contains for each name just one record
  - Others (i.e. multi-value attributes) are stored in overflow tables
    - From edge mapping

Generic-tree Mapping (5)

- How do we store the leaf values?
  1. Special value tables, each for each data type used
  2. Value columns in the previous tables
     - Many null values (for each data type an extra column)
     - Or we ignore data types
- Other options
  - Combination of previous approaches
  - E.g. attribute mapping for frequent attributes and edge mapping for other

Structure-centred Mapping (1)

- XML document ↔ directed tree
  - All nodes have the same structure:

    N = (t, l, c, n), where

    - t is the type of node (i.e. ELEM, ATTR, TXT, ...)
    - l is the label of node (if exists)
    - c is text content of node (if exists)
    - n = $\{N_1, \ldots N_m\}$ is (possibly empty) list of child nodes
- Variants of the algorithm = variants of storing the list of child nodes
  - Aim: efficient operations

Structure-centred Mapping (2)

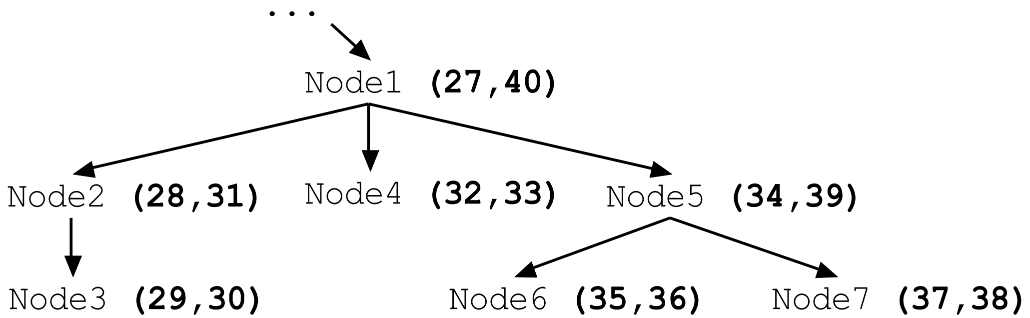
1. Keys and foreign keys
   - Each node is assigned with an ID (key) and ID of its parent node (foreign key)

   (+) Simple, efficient updates

   (–) Inefficient queries (joins of many tables)

2. DF values
   - Node ID = pair (DF_{min}, DF_{max})
     - DF_{min} = the time of visiting a node
     - DF_{max} = the time of leaving a node

Structure-centred Mapping (3)



(+) Efficient querying and reconstruction of a node

- E.g. v is a descendant of u, if $u_{min} < v_{min}$ and $v_{max} < u_{max}$
- The nodes can be ordered totally

(–) Inefficient updates

- In the worst case we need to re-number the whole tree

Structure-centred Mapping (4)

$$\sigma = \cfrac{1}{q_k + \cfrac{1}{\cdots \cfrac{}{q_2 + \cfrac{1}{q_1}}}}$$

3. SICF (simple continued fraction) values
   - SICF node identifier = σ, where $q_i \in N$ $(i = 1, \ldots k)$
     - Sequence $\langle q_1, \ldots q_k \rangle$ identifies the node
   - For root node: SICF ID $\sigma = \langle s \rangle$, $s > 1$
   - For all other nodes:

     If node u has SICF ID = $\langle q_1, \ldots q_m \rangle$ and n child nodes $u_1, \ldots u_n$, then SICF ID of i-th child node is $\langle q_1, \ldots q_m, i \rangle$
     - Resembles to ORDPATH
     - Does not have its advantages
       - We do not use the “trick” with odd and even numbers

(+) we have a more precise structural information

(–) like in the previous case

Simple-path Mapping (1)

- Assumption: XPath queries
- Idea: We can store all paths to all nodes in the documents
  - So-called simple paths

```
<SimpleAbsolutePathUnit> ::= <PathOp> <SimplePathUnit> |
                             <PathOp> <SimplePathUnit> '@' <AttName>
<PathOp>                 ::= '/'
<SimplePathUnit>         ::= <ElementType> |
                             <ElementType> <PathOp> <SimplePathUnit>
```

- Just a simple path is not sufficient information
  - It does not contain information about position/order of node in the document

Simple-path Mapping (2)

- Relational schema:
  - `Element (IDdoc, IDpath, Order, Position)`
  - `Attribute (IDdoc, IDpath, Value, Position)`
  - `Text (IDdoc, IDpath, Value, Position)`
  - `Path (IDpath, Value)`
    - `Order` of an element within its sibling nodes
    - `Position` of a word in a text is an integer value
    - `Position` of a tag is a real number
      - integral part = position of the closest preceding word
      - decimal fraction = position within tags following the closest preceding word

(+) Efficient processing of XPath queries

- Implementation of '//' using SQL LIKE

B. Schema-driven Mapping (1)

- Based on existence of an XML schema
  - Usually DTD or XML Schema
- Algorithm:
  1. XML schema is mapped to relational schema
  2. XML data valid against the XML schema are stored into relations
     - i.e., for data with different structure (XML schema) we have a different relational schema
- Aim: We want to create an optimal schema with "reasonable" amount of tables and null values and which corresponds to the source XML schema

B. Schema-driven Mapping (2)

- General characteristics of the algorithms:
  1. For each element we create a relation consisting of its attributes
  2. Subelements with maximum occurrence of one are (instead of to separate tables) mapped to tables of parent elements
     - so-called inlining
  3. Elements with optional occurrence $\rightarrow$ nullable columns
  4. Subelements with multiple-occurrence $\rightarrow$ separate tables
     - Element-subelement relationships are mapped using keys and foreign keys
  5. Alternative subelements $\rightarrow$
     - separate tables (analogous to the previous case) or
     - one universal table (with many nullable fields)

B. Schema-driven Mapping (3)

5. Order of sibling elements (if necessary) → special column
6. Mixed-content elements usually not supported
   - Would require many columns with nullable fields
7. Despite the previous optimizations a reconstruction of an element requires joining several tables.

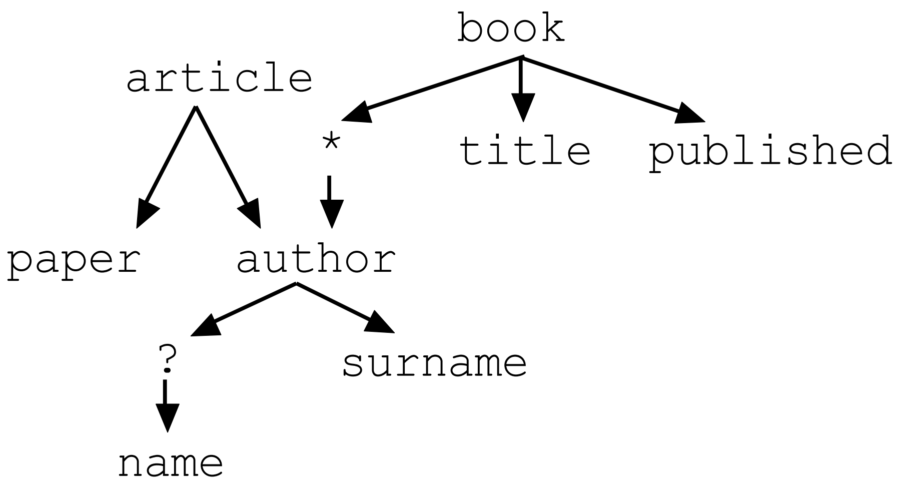
- Most of the techniques use an auxiliary graph
- Classification:
  - Fixed methods – exploit information only from schema
    - Basic, Shared and Hybrid
  - Flexible methods – exploit other information
    - LegoDB mapping, Hybrid object-relational mapping

Algorithms Basic, Shared and Hybrid (1)

- Continuous improvements of mapping a DTD to relational schema
  - One of the first approaches
- DTD graph – auxiliary structure for creation of a relational schema
  - Nodes = elements (occur 1x) / attributes / operators
  - Directed edges = relationships element-subelement / element-attribute / element-operator / operator-element
- Note: DTD is first "flattened" and simplified
  - Contains only operators * and ? (+ $\rightarrow$ *, a|b $\rightarrow$ a?,b?)
  - A classical trick

Algorithms Basic, Shared and Hybrid (2)

```
<!ELEMENT author(name?,surname)>
<!ELEMENT name(#PCDATA)>
<!ELEMENT surname(#PCDATA)>
<!ELEMENT book(author*,title)>
<!ATTLIST book published CDATA>
<!ELEMENT title(#PCDATA)>
<!ELEMENT article(author)>
<!ATTLIST article paper CDATA>
```



Algorithm Basic

- Naïve approach
- Rules:

1. For each element in the document create a separate relation
   - Motivation: The root element can be any element in the DTD
2. For each element inline as many child nodes as possible
   - We do not inline only child nodes of operator '*' and recursive subelements – they are stored in separate relations

(–) Too many relations

- E.g. for our sample element **`author`** we would create two relations corresponding to two places of its usage within **`book`** and **`article`**

Algorithm Shared

- Idea: We want to map each element only once
- Rules:
  1. Nodes with an in-degree of one are inlined to parent relations.
  2. Nodes with an in-degree of zero are stored in separate relations
     - They are not reachable from any other node
  3. Repeated elements are stored in separate relations.
  4. Of all mutually recursive elements having an in-degree one, one of them is stored in a separate relation.
  5. The problem of inlined elements, which can become roots of an instance XML document, is solved using a flag for each element that indicates this situation.
- E.g. For our sample DTD graph we would create 3 relations **`author`**, **`book`**, **`article`**

(–) The number of relations can be further reduced in some cases

Algorithm Hybrid

- Combination of maximum inlining of Basic and sharing in Shared
- Rules:
  1. \- 5. Same as in Shared
  6. In addition, we inline elements with an in-degree greater than one, that are neither recursive nor reached through a "*" node.
- E.g. in our sample DTD graph it does not have any effect, but if **`book`** has only one **`author`**, it does
- Further extension:
  - Storing of order of elements
    - Into special columns
  - Mapping of integrity constraints
    - ?, list of values, ID, IDREF, IDREFS, ...
    - [NOT] NULL, CHECK, UNIQUE, PRIMARY/FOREIGN KEY, ...

LegoDB Mapping (1)

- Idea: For the given XML schema we create a space of possible mappings and we select the optimal one for the given application
- Application:
  - Sample XML documents
  - Sample XML queries + their significance
- One step:
  1. We apply a selected transformation on the given XML schema S_{old}
     - We get a new XML schema S_{new}
  2. XML schema S_{new} is mapped (using a fixed method) to relational schema S_{rel}
  3. Sample queries are evaluated with regard to S_{rel}
  4. $S_{old} = S_{new}$

LegoDB Mapping (2)

- The space of possible XML transformations is infinite
  - Heuristics, greedy search strategies, …
- XML transformations
  - Inlining / outlining
  - (a,(b|c)) = (a,b|a,c)
  - (a+) = (a,a*)
  - (a|b) $\subseteq$ (a?,b?)
  - ~ = (a|(~!a)), where ~ means any element and ~!a any element except for a
- The static mapping is similar to Hybrid algorithm

LegoDB Mapping (3)

(+) The most efficient mapping for the specified application

(–) If the application changes (the user starts to specify different queries)

- Efficiency can be worse than in case of a fixed mapping
- Modification of a schema is not an easy task

Hybrid Object-relational Mapping (1)

- Motivation: Data in XML documents are semi-structured $\rightarrow$ classical decomposition of unstructured parts leads to inefficient queries
  - i.e., we create many tables which we have to join to retrieve the data
- Solution
  - Structured parts of the data are mapped into relations
  - Unstructured parts are stored into special XML data types
    - Data type for XML fragments
    - Support for XML operations
    - Motivation for SQL/XML data type XML
  - or BLOB if we do not need XML operations
- Core problem of the algorithm: Which parts of the document are unstructured?

Hybrid Object-relational Mapping (2)

- Approach:
  1. Creating of DTD graph G_1
  2. For each node we evaluate the measure of significance ϖ
  3. Subgraphs denoted with unstructured nodes are replaced with an auxiliary attribute for XML type $\rightarrow$ DTD graph G_2
     1. The node is not a leaf
     2. The node and its descendants have ϖ < LOD
        - Level of detail
     3. The node dose not have a parent node that would satisfy the conditions
  4. Graph G_2 is statically mapped to a relational schema

Hybrid Object-relational Mapping (3)

$$\varpi = \frac{1}{2}\varpi_S + \frac{1}{4}\varpi_D + \frac{1}{4}\varpi_Q$$

- Meaning of the variables:
  - ϖ_S (weight derived from the DTD structure)
    - The combination of values expressing the position of the element/attribute in the graph
  - ϖ_D (weight derived from the existing XML data)
    - The ratio of the number of documents containing the element/attribute and the absolute number of documents
  - ϖ_Q (weight derived from the queries)
    - The ratio of the number of queries containing the element/attribute and the absolute number of queries

(+) and (–) like in the previous case

C. User-defined Mapping

- The whole mapping process is defined by the user
- Algorithm:
  1. The user creates the target relational schema
  2. The user specifies the required mapping (using a system-dependent interface)
     - Usually a declarative interface, annotations in XML schemas, special query languages, ...

(+) The most flexible approach

- The user knows what (s)he wants

(–) The user must know several advanced technologies, the definition of an optimal relational schema is not an easy task

User-driven Mapping (1)

- An attempt to solve the disadvantages of user-defined mapping
- Idea: an implicit method + user-defined local changes
  - Annotation of schema = user denotes fragments (subtrees) whose storage strategy should be modified
  - Pre-defined set of allowed changes of mapping
    - Usually a set of attributes and their values
- Example – system XCacheDB

User-driven Mapping – XCacheDB (2)

- **`INLINE`** – inline the fragment into parent table
- **`TABLE`** – store the fragment into a separate table
- **`BLOB_ONLY`** – store the fragment into a BLOB column
- **`STORE_BLOB`** – store the fragment implicitly + into a BLOB column
- **`RENAME`** – change the name of table of column
- **`DATATYPE`** – change the data type of the column

Current State of the Art of XML Databases

- Native databases vs. XML-enabled databases
  - The difference is fading away
- Oracle DB, IBM DB2, MS SQL Server – the storage is defined by the user
  - BLOB
  - Native XML storage (typically parsed XML data + ORDPATH numbering schema)
  - Decomposition into relations – fixed schema-driven or user-driven
    - Currently user-driven annotations often denoted as obsolete
- Standard bridge between XML and relational world: SQL/XML