NPRG036
# XML Technologies

Lectures 11 and 12
# XML Databases

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# Lecture Outline

- **XML persistence**
  - Introduction
  - XML databases
  - Numbering schemes
  - Mapping techniques

# 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**

- many small documents
- usually static
- implicit structure
  - tagging
- suitable for humans

**World of databases**

- several huge databases
- usually dynamic
- explicit structure
  - schema
- 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 (used to be) 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
  - …

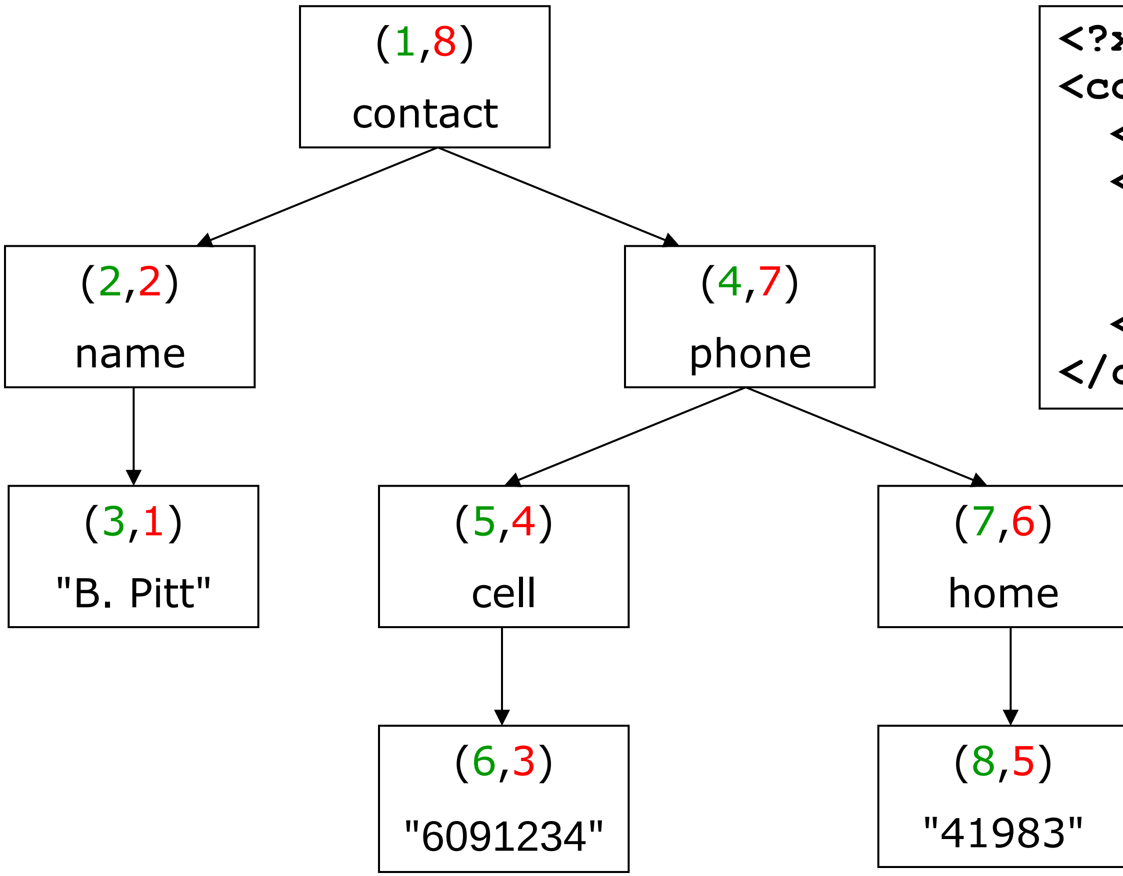
# Numbering Schemas

- 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 $v \in N$ a binary sequence L(v).
  - For each pair of nodes u, $v \in N$ 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

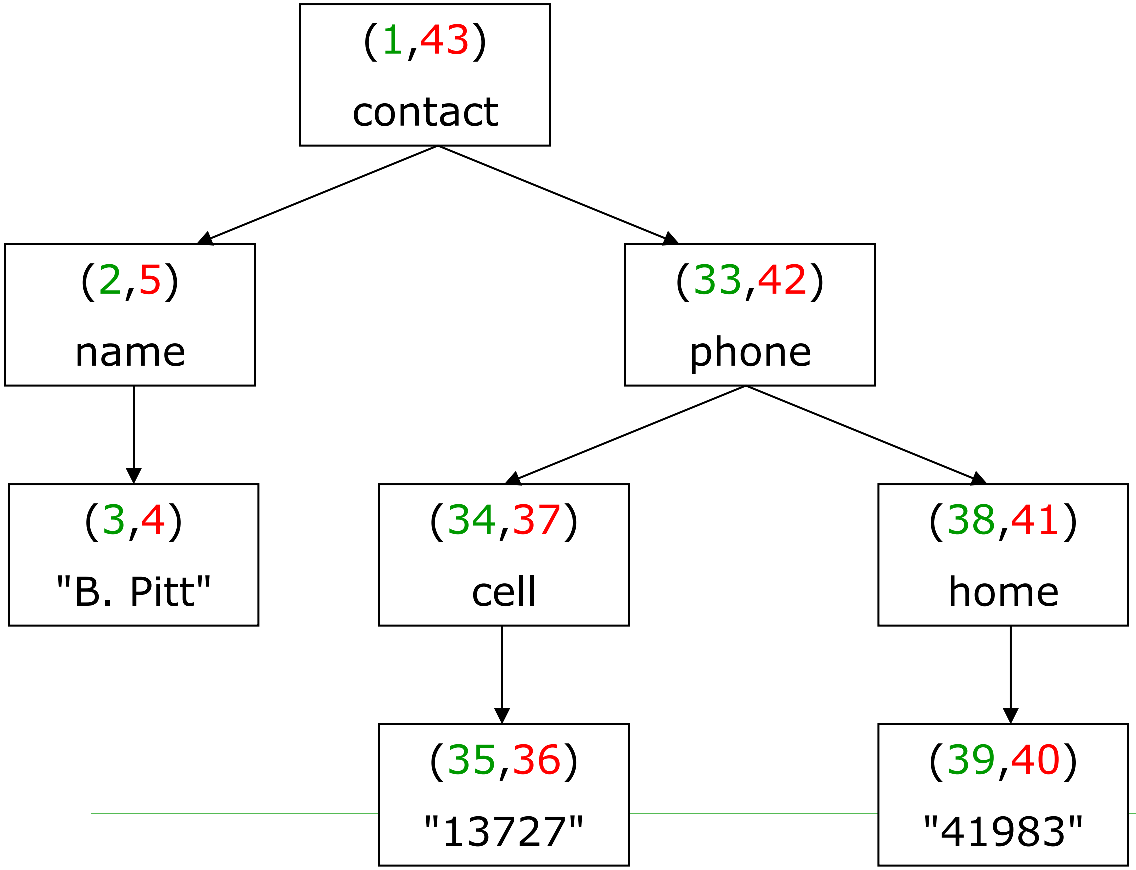



```xml
<?xml version="1.0"?>
<contact>
  <name>B. Pitt</name>
  <phone>
    <cell>6091234</cell>
    <home>41983</home>
  </phone>
</contact>
```

# 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 $x' < x$ & $y' > y$

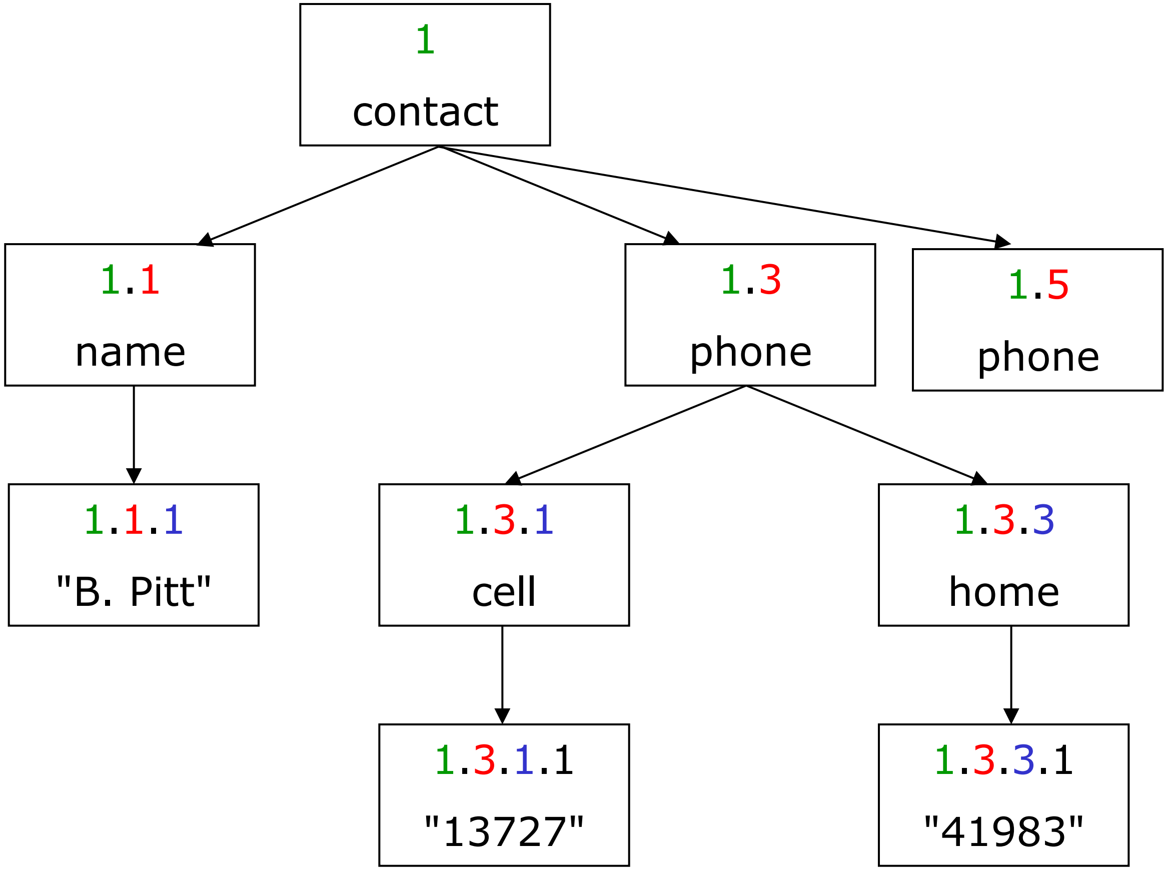
# Depth-first (DF) Numbering




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

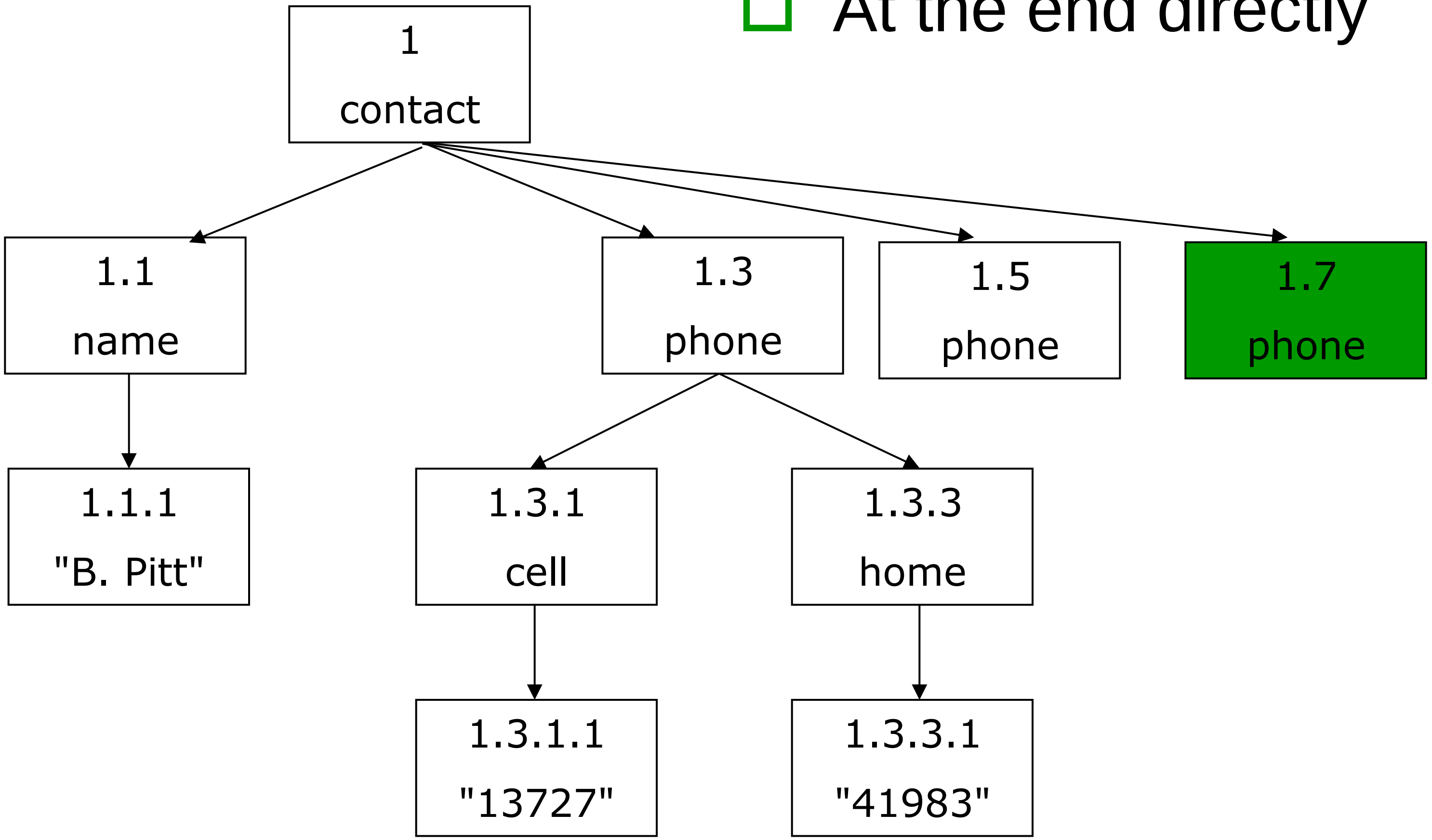
# ORDPATH




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

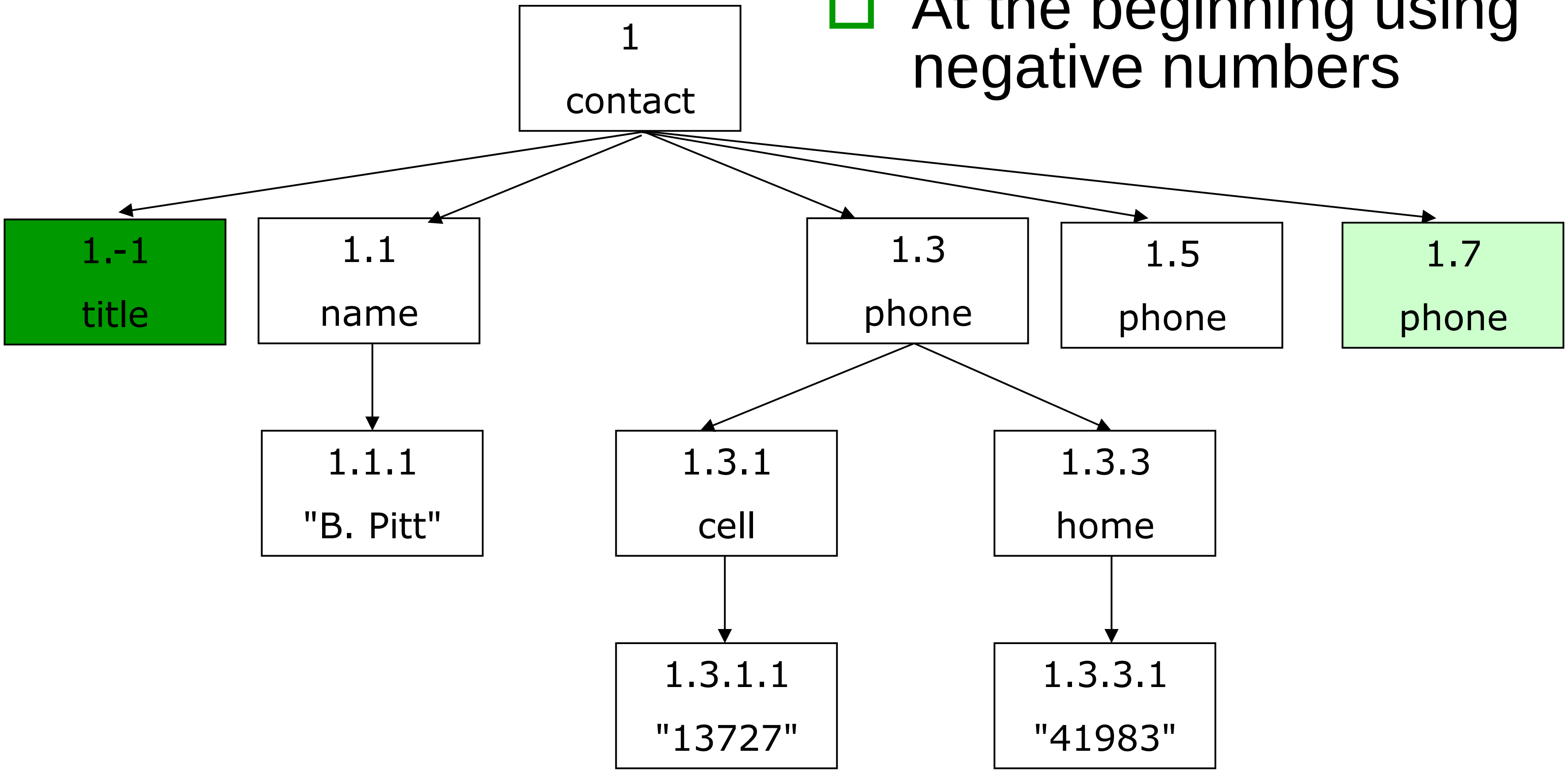
# ORDPATH – Insert

- At the end directly



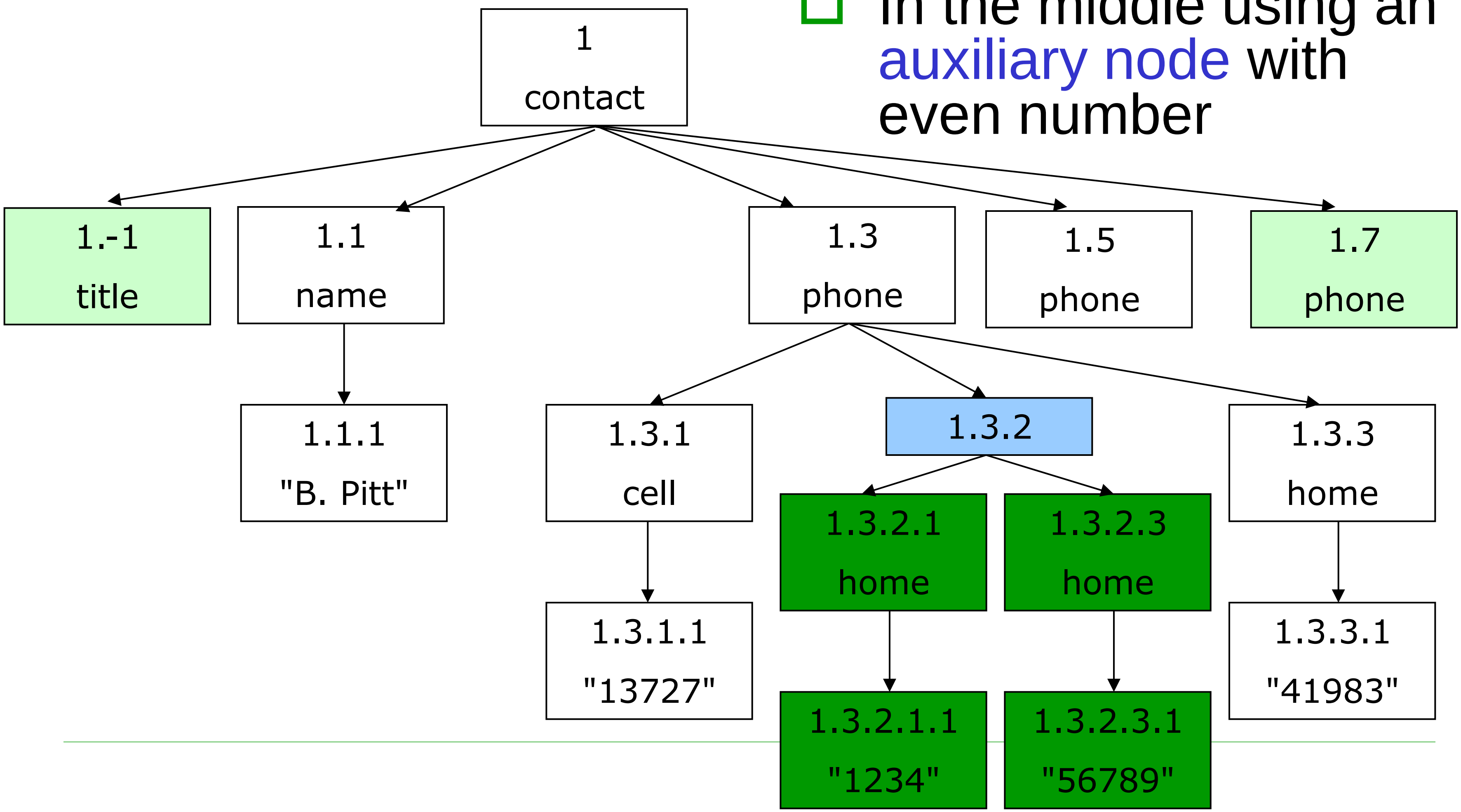
# ORDPATH – Insert

- 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 <u>native</u> 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 <u>regardless XML schema</u> of the stored XML data
  B. Schema-driven – mapping <u>based on XML schema</u> of the stored XML data
     - DTD, XML Schema
  C. User-defined – mapping provided <u>by the user</u>

# 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)

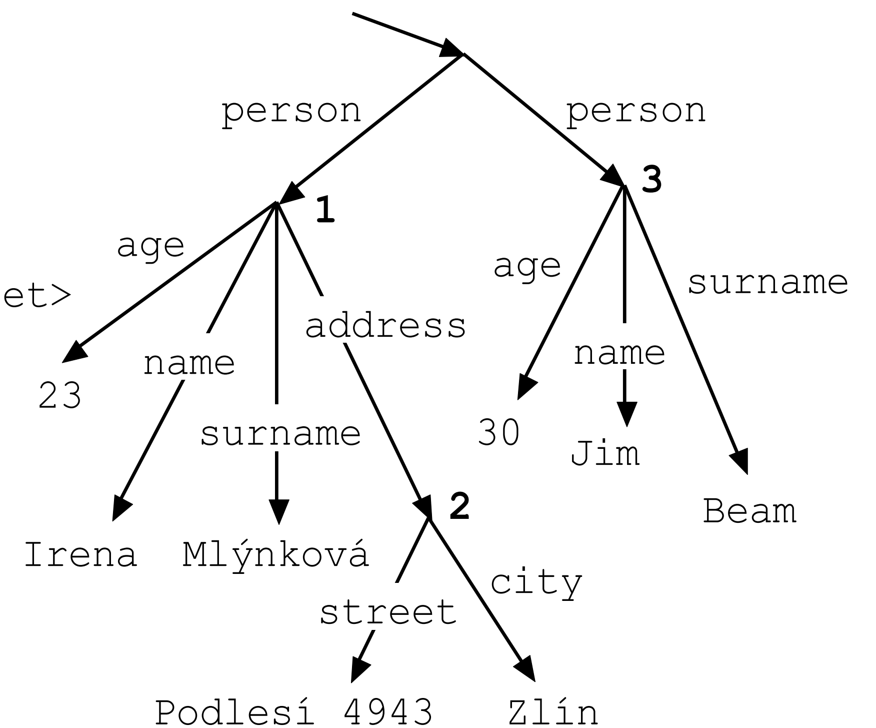
- Trivial case
- The schema is an implicit part of the data
  - Only a limited set of documents can be stored
- Typical usage: data transfer among multiple databases
- There exist also more complex schemas, but the idea is the same
  - Basically again usage of (an implicit) schema

# 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>
...
```

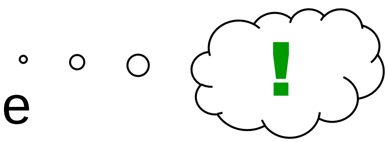


# Generic-tree Mapping (3)

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




**Edge$_{name}$(..., (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
    - $a_1, \ldots a_k$ 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

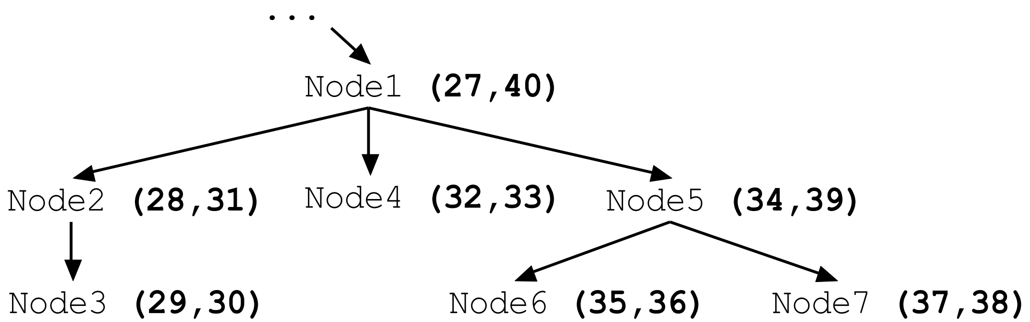
# Structure-centred Mapping (2)

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 = $\sigma$, where $q_i \in N$ ($i = 1, ... k$)
     - Sequence $<q_1, ... q_k>$ identifies the node
   - For root node: SICF ID $\sigma = <s>$, $s > 1$
   - For all other nodes:

     If node $u$ has SICF ID = $<q_1, ... q_m>$ and $n$ child nodes $u_1, ... u_n$, then SICF ID of $i$-th child node is $<q_1, ... q_m, i>$
     - 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.

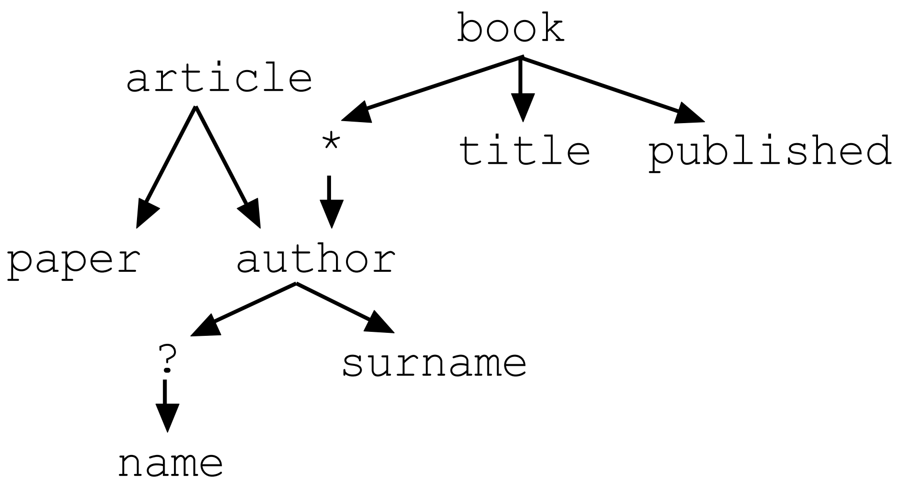
- Most of the techniques use an auxiliary graph
- Classification:
  - Fixed methods – exploit information only from schema
    - Basic, Shared and Hybrid
  - Flexible methods – exploit other information
    - LegoDB mapping, Hybrid object-relational mapping

# 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 <u>document</u> 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 → 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 $\varpi$
  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 $\varpi$ < 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:
  - $\varpi_S$ (weight derived from the DTD structure)
    - The combination of values expressing the position of the element/attribute in the graph
  - $\varpi_D$ (weight derived from the existing XML data)
    - The ratio of the number of documents containing the element/attribute and the absolute number of documents
  - $\varpi_Q$ (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