A Logic-Based Approach to XML Data Integration with “lazy materialization”

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Situation

- Project Background: F-Logic
  - Experiences in deductive, object-oriented database languages
  - early semi-structured/self-describing data model
  - integration of semi-structured data in F-Logic/FLORID
- XML: Internet-wide data format,
  distributed, autonomous sources
- XPathLog: Logic Programming style language (2001)
  Implementation: LoPiX (Logic Programming in XML)
- materialization vs. virtual approach?
- intermediate solution: partly materialized + linked

Example: Mondial

```
<mondial>
  <country car_code="B"
    capital="cty-Brussels"
    memberships="org-eu org-nato ..">
    <name>Belgium</name>
    <population>
      10170241
    </population>
    <city id="cty-Brussels"
      country="B">
      <name>Brussels</name>
      <population year="95">
        951580
      </population>
    </city>
    :
  </country>
  <organization id="org-eu"
      headq="cty-Brussels">
    <name>Europ. Union</name>
    <abbrev>EU</abbrev>
    <members type="member"
      country="GR F E A D I B L . . . "/>
    <members type="applicant"
      country="AL CZ . . . "/>
  </organization>
  <organization id="org-nato"
    headq="cty-Brussels" . . . >
    :
  </organization>
  :
  :
  :
</mondial>
```

Data Integration with XPathLog

XPathLog (VLDB/DBPL/FMLDO 2001):
Logic Programming style XML query/integration language

- Datalog-style extension of XPath
  - XPathLog is the Horn fragment of XPath-Logic
  - Syntax and Semantics of queries extend XPath with variable bindings

```
?- //country[name/text()→N1 and
             @car_code→C]//city/name/text()→N2.
N1/“Belgium”   C/“B”   N2/“Brussels”
N1/“Belgium”   C/“B”   N2/“Antwerp”
⋮
```

Rules

Logic Programming language:

$$\text{head}(V_1,\ldots,V_n) \text{ :- } \text{body}(V_1,\ldots,V_n)$$

Rule Heads

Constructive semantics of definite XPathLog expressions for generating data and structure:

- only *child*, *sibling* and *attribute*-axes

"/" and "[. . .]" as Constructors:

- *host*[*property*$\rightarrow$*value*] modifies *host*
- *host*/*property remainder*
  generates a new subelement *property* to *host* that satisfies *remainder* (possibly complex structure)

Example: Generating Structures

- complex expressions in the head:

/country[@car_code→“BAV” and name[text()→“Bavaria”]].

⇓

<country car_code=“BAV”>
<name>Bavaria</name>
</country>

- complex expressions are decomposed into atoms (introduce new local variables)

//country→_C,

_C[@car_code→“BAV”], _C[name→_N],

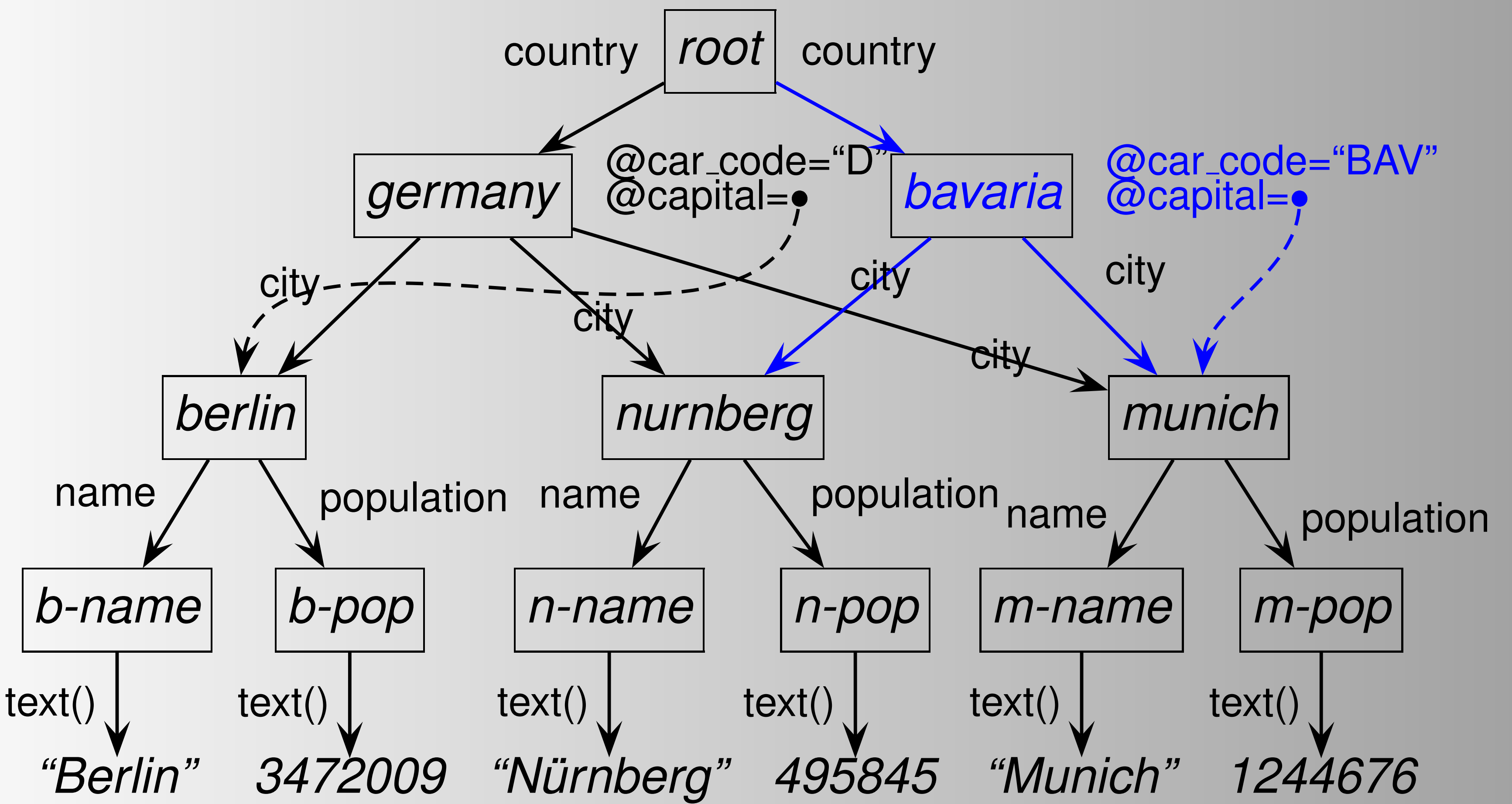
_N[text()→“Bavaria”].

Data Integration

Requires operations that are not compatible with the XML model:

- add new subelement relationships
- “fuse” elements from different sources
- define synonyms for names

Adding Subelement Relationships

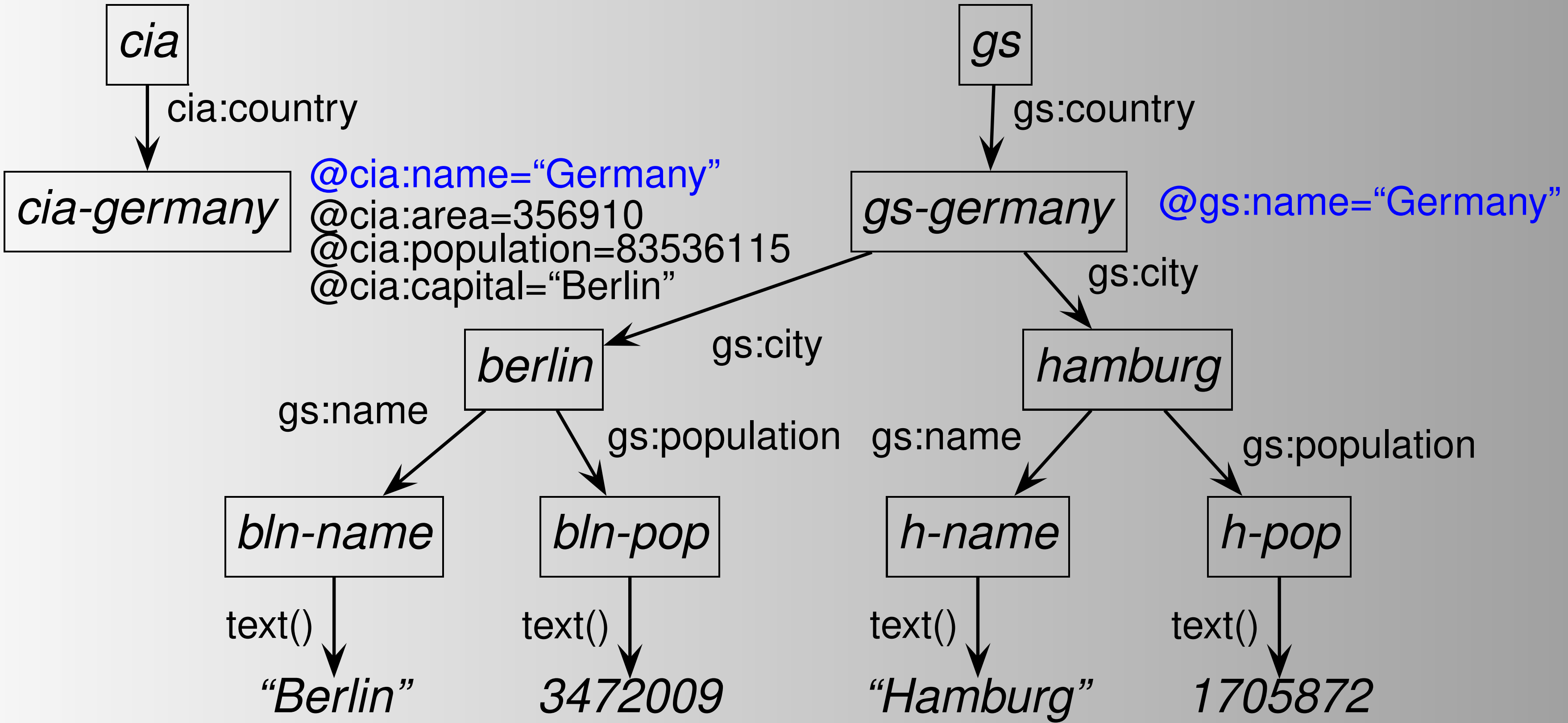


- Elements have multiple parents
- efficient *in-place* restructuring and integration

Element Fusion

Data Sources describing countries:

- cia: name, area, population and capital (by name)
- gs: cities with name, population



Synonyms

- some properties of the namespaced sources are taken to the result completely – with another name

  cia:name = name.　　　　cia:area = area.

  cia:population = population.　　　　cia:text() = text().

- does not generate new element or attribute nodes,
- but “only” additional navigation paths

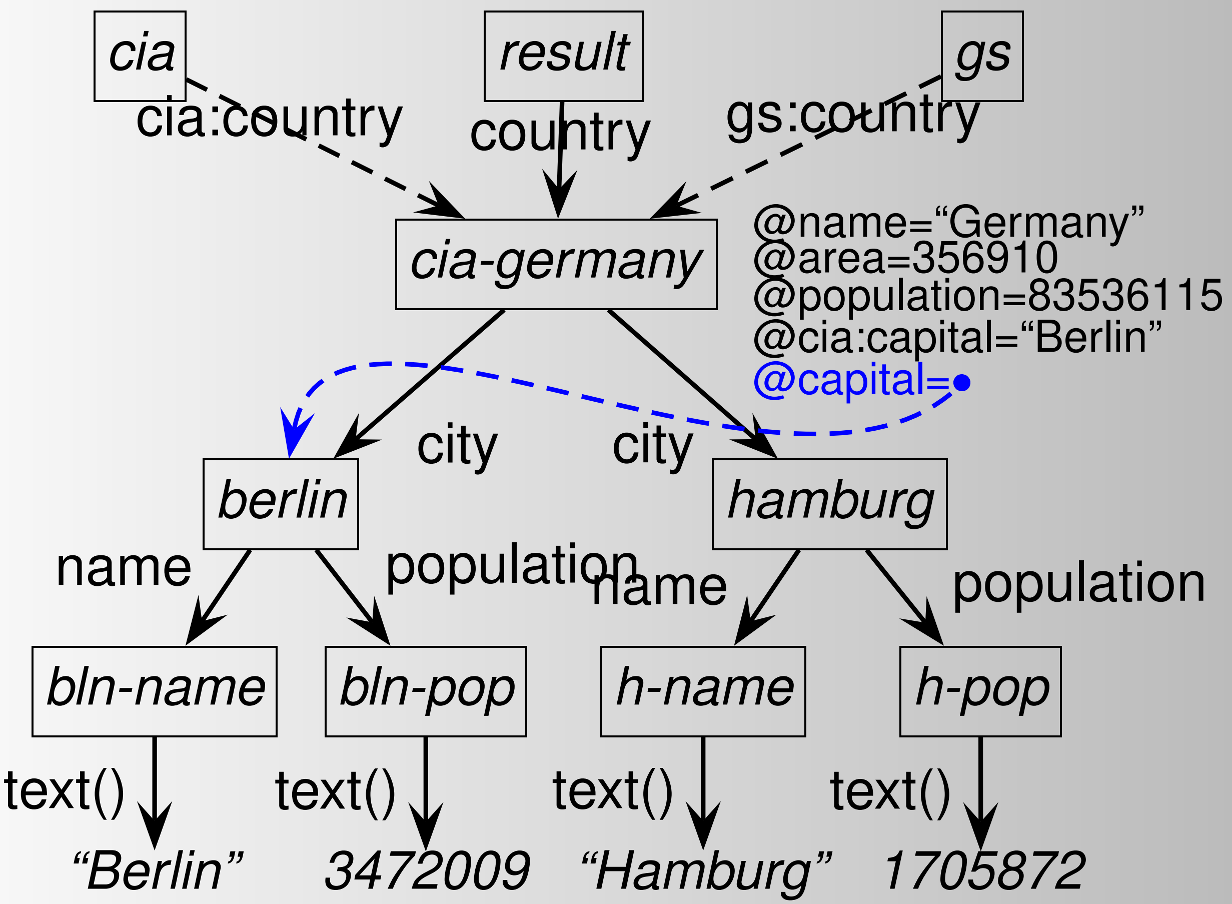
Element Fusion

- elements represent the same real-world entity in different sources
- fuse elements into a unified element:

$$e_1 = e_2$$

```
result[country→C1], C1 = C2 :-
      cia/cia:country→C1[@cia:name→N],
      gs/gs:country→C2[@gs:name→N].
```

Element Fusion: Example



C[@capital→City] :-

result/country→C[@cia:capital→Name and

city→City[name/text()=Name]].

Integration by Materialization

“Three-level”-Model

- “basic” layer: source(s) provide tree structures,
  - optionally with namespaces
- “internal” layer: “XTreeGraph”
  - overlapping trees, multiple parents
  - add subelement links
  - fuse elements/merge subtrees
  - synonyms for properties
- “export” layer: result trees as views/projections:
  - a root node
  - signature (derivable from DTD or XML Schema)

Advantages

- Logic/rule-based syntax & semantics
  "what you write is what you get"
- declarative semantics for generating XML with XPath
  - expressive and flexible language
  - queries against metadata/schema
  - integration operators: element fusion and synonyms
- concise, intuitive, executable specification = program

Current implementation: LoPiX

(Logic Programming in XML)

- bottom-up stratified semantics
  operational executable semantics/specification of integration process;
- computes/materializes integrated database

Strategy: Selective "Lazy" Materialization

Combination with "Virtual"-Strategy

- do not materialize whole database,
- use subtrees of the original sources

<country car_code="D">
  name: reference to name element in cia:Germany
  area: reference to population element in cia:Germany
  capital: reference to cia:Berlin
  city-subelements: references to city subelements in gs:Germany
</country>

- less space-consuming
- incorporates data changes in autonomous sources

Partially Virtual Strategy

- representation in the database:
  - references into XML sources expressed by XPointer
  - integrated by XLinks,
  - interpreted as embedded view fragments
- actual “load” only when actually changed
  - materialize minimal fragment
  - represent unchanged parts by links
- do not change the language:
  “integrate” XLinks into data model and query language

Simple Links

- similar to the HTML <A href="..."> construct.

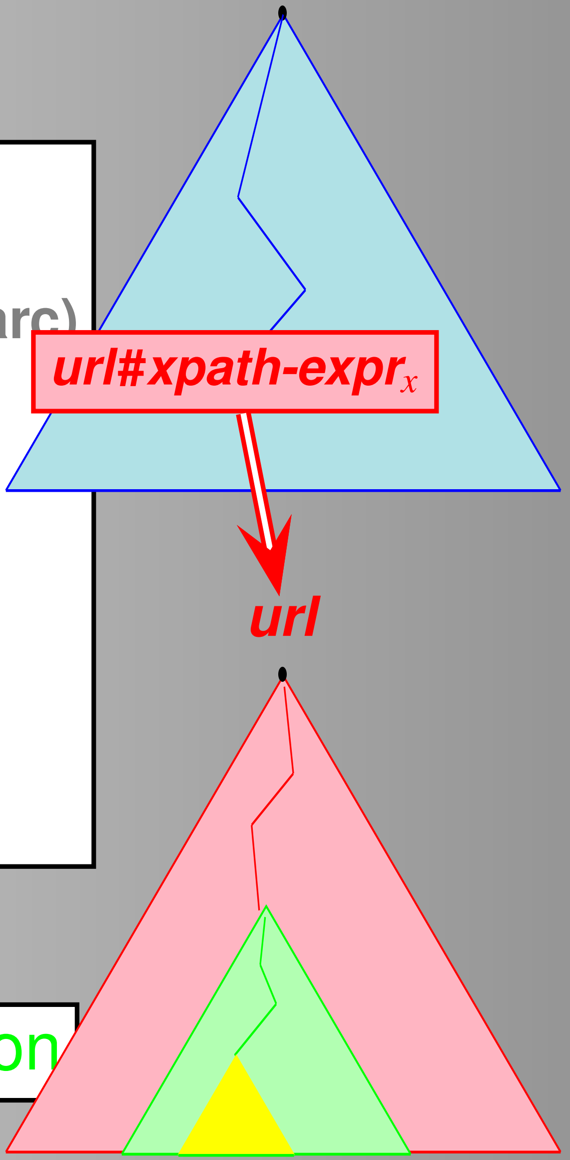
Headquarters of organizations:

```
<!ELEMENT organization (... headq ...)>
<!ELEMENT headq EMPTY>
<!ATTLIST headq xlink:type (simple|extended|locator|arc)
                           #FIXED "simple"
                xlink:href CDATA #REQUIRED >

<organization abbrev="EU">
   <headq xlink:href=
          "file:cities-B.xml#//city[name='Brussels']"/>
   :
</organization>
```

query:

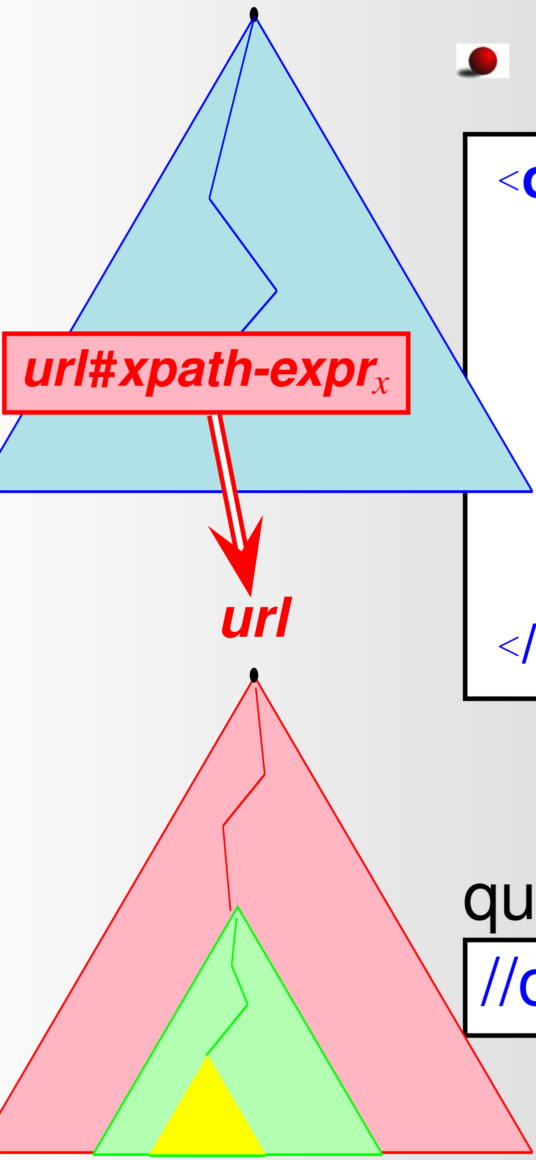
```
//organization[@abbrev="EU"]/headq/??/population
```



A Data Model for Linked Documents

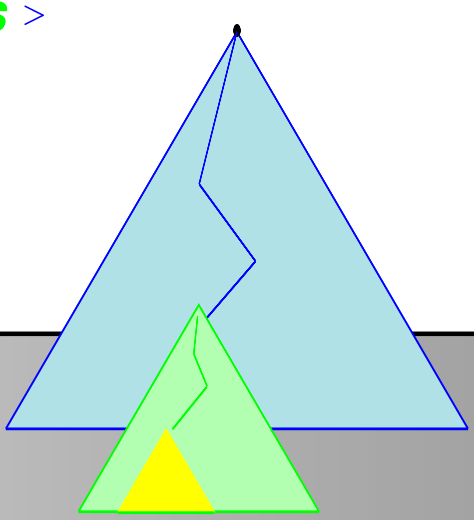
- abstract data model makes the links transparent:
  (WWW 2002, BTW 2003)
- each link can be seen as a view definition
  - integrates external schemata
  - embedded views implicitly accessible as subtrees or by reference attributes
    (specified by attributes to the link element)
  - queried by standard XPath/XPathLog expressions

Transparent Links



- regard link elements to be *transparent*

```
<organization abbrev="EU">
   <headq xlink:type="simple"
            href="file:cities-B.xml#//city[name='Brussels']"
            attributes of Brussels >
        contents of Brussels
   </headq>
   :
</organization>
```



query:

```
//organization[@abbrev="EU"]/headq/population
```

Integration Strategy

- if a subtree is “used”, represent it as a link in the partially integrated internal database
- rule bodies: implicitly resolve the link
- rule heads/view updates: access view, and load as far as necessary into the internal database
- use of links also inside the internal database makes it possible to store data as an XML tree
- logical link semantics then simulates the XTreeGraph
- implementable based on standard XML software (extend XPath interpretation by resolving XLinks)

Questions ??