Interactive Inference of XML Schemas

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Introduction

- XML = a standard for data representation and manipulation
  - XML documents + XML schema
    - DTD, XML Schema, Schematron, RELAX NG, ...
- Why schema?
  - Known structure, valid data, ...
  - Limited complexity $\Rightarrow$ optimization
- Problems of real-world data:
  - Users do not use schemas at all
    - Schema = a kind of documentation
  - XML Schema (W3C) language is not used
- Solution: Automatic inference of XML schema S_D for a given set of documents D

Mlynkova, Toman, Pokorny: Statistical Analysis of Real XML Data Collections. COMAD 2006, New Delhi, India. Tata McGraw-Hill Publishing Co. Ltd., 2006. ISBN 0-07-063374-6.

Existing Approaches

- Fact: XML schema = extended context-free grammar

- Classical steps:
  1. Derivation of initial grammar (IG)
     - For each element E and its subelements $E_1, E_2, \ldots, E_n$ we create production $E \rightarrow E_1\ E_2 \ldots E_n$
  2. Clustering of rules of IG
  3. Construction of prefix tree automaton (PTA) for each cluster
  4. Generalization of PTAs
     - Merging state algorithms
     - Multiple solutions:
       - We need to **evaluate the quality of a solution**
       - Too general vs. too restrictive
  5. Expressing the inferred REs in target XML schema language
     - Most common: Direct rewriting of REs to content models

Example (1)

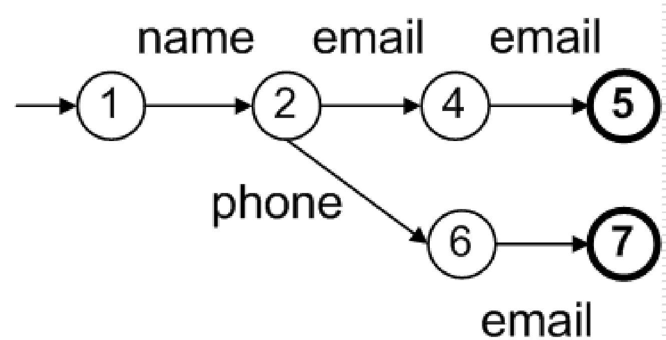
```
...
<person id="123">
  <name>
    <first>Irena</first>
    <surname>Mlynkova</surname>
  </name>
  <email>irena.mlynkova@gmail.com</email>
  <email>irena.mlynkova@mff.cuni.cz</email>
</person>
<person id="456" holiday="yes">
  <name>
    <surname>Necasky</surname>
    <first>Martin</first>
  </name>
  <phone>123-456-789</phone>
  <email>martin.necasky@mff.cuni.cz</email>
</person>
...
```

person → name email email
person → name phone email

name → first surname
name → surname first

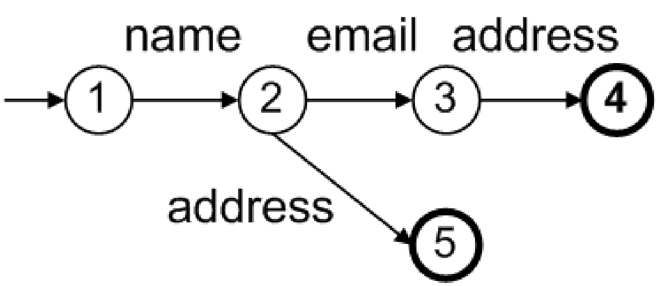
first → PCDATA
surname → PCDATA
email → PCDATA
phone → PCDATA

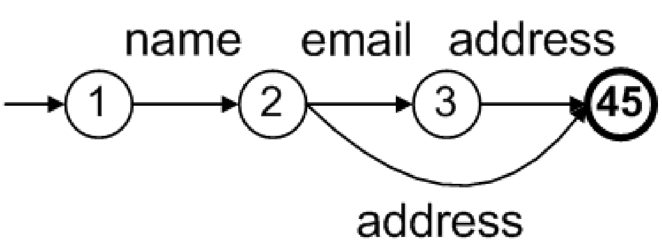
person:



Example (2)

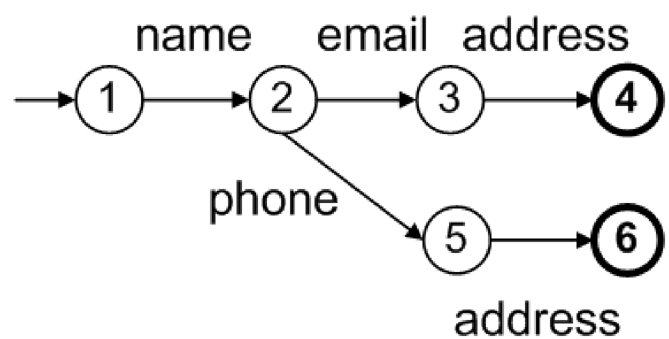
person → name email address
person → name address

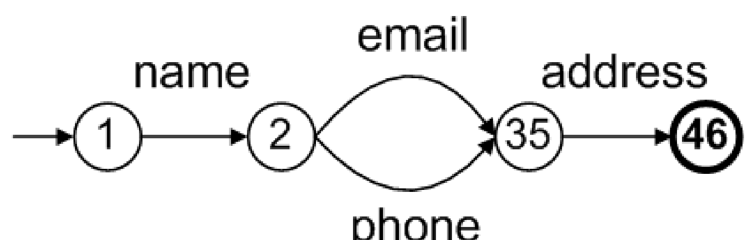




person → name email? address

person → name email address
person → name phone address





person → name (email | phone) address

Our Approach = *SchemaBuilder*

- Observation 1: Most of existing approaches infer DTDs or simple XML Schema constructs
  - Focus on content models (= regular expressions)
  - But:
    - The languages are richer
      - XML Schema, Schematron, RELAX NG
    - Can provide more precise information (optimization)
- Observation 2: Evaluation of quality of a schema is not natural
- Idea: Exploitation of user interaction
  - More natural result
  - Exploitation of advanced constructs

User Interaction

```
<bicycles>
    <bicycle>
        <wheel/>
        <wheel/>
    </bicycle>
    <bicycle>
        <wheel/>
        <wheel/>
    </bicycle>
</bicycles>
```

- <u>Problems</u>:
  - User is an expert in the problem domain
    - Not in the algorithm
  - User is lazy
  - User makes mistakes
- Two extreme cases:
  - User provides a setting (weights, amounts, sizes, ...)
    - Too general
    - Cannot cover all the cases
      - Context, semantics
  - User participates in every step of the algorithm and chooses from the possibilities
    - Too much work, too many choices

STEP 1. Clustering of Elements

- Options:
  - According to element names
  - According to context
    - Path to the root element
  - According to element subtrees

```
<author>
  <name>
    <first>Arthur</first>
    <middle>Conan</middle>
    <last>Doyle</last>
  </name>
</author>
```

```
<book>
  <name>Sherlock Holmes</name>
</book>
```

Our Approach

- Observation: XML Schema
  1. Elements in the same context can have different schema
  2. Elements in different contexts can have the same schema
- Main features:
  - We cluster elements according to context (1)
    - Not just element names
  - We cluster according to tree edit distance (TED) between element trees (2)
    - Regardless the context
  - User interaction
  - Type inference

User Interaction

- Two extreme cases:
  - Threshold(s) for similarity of element names, contexts, TED, ...
  - User decides on every initial cluster
- *SchemaBuilder*:
  - User decisions, but only on subset of clusters
  - Two thresholds: automatic decision $\leq T_1 <$ user decision $\leq T_2 <$ do not cluster
  - Exploitation of data semantics
    - Reduction of user decisions

Type Inference

- XML Schema:
  - Content of element E can be derived from content of element F
    - Extension – extending the content model
      - Optional/compulsory items
    - Restriction – reducing the amount of instances
- *SchemaBuilder*:
  - Cannot be done automatically in general
  - Observation: Inheritance is used, but not often/complex
    - → User marks elements with mutually derived types
  - Main task: Checking correctness of such marking

STEP 2: Schema Generalization

- Input: Set of clusters C_1, C_2, ..., C_k + marked inheritance

  ⇓

  PTA + merging state algorithm

  ⇓

- Output: A set of schemes S_1, S_2, ..., S_l
- SchemaBuilder: PTA +
  - Inheritance state – preserves the inheritance
  - Permutation state – represents unordered sequence of elements (XML Schema)
  - Group state – globally referenced particle

Merging State Algorithm

- Combinatorial optimization problem (COP)
  - A search space Σ_i of solutions (feasible region)
    - Generalizations of S^{init}_i (PTA)
  - A set Ω_i of constraints over Σ
    - Features of XML Schema language
  - Evaluation function $f : \Sigma_i \rightarrow R^+$ (objective function)
    - MDL (Minimum Description Length) principle
- Σ_i is theoretically infinite → heuristics → suboptimal solution
  - ACO (Ant Colony Optimization)

Ant Colony Optimization (ACO)

- Idea: Artificial ants iteratively search space Σ_i and improve S^{init}_i
- Ant
  - Searches a subspace of Σ_i until it "dies"
    - After performing N_{ant} steps
  - Spreads "pheromone"
    - Positive feedback = how good solution it has found so far
    - Negative feedback = how good solution it has found in this iteration
  - Exploits spread pheromone of other ants to select next step
    - Step = a possible way of schema generalization
    - Selected randomly, probability is given by f

SchemaBuilder Steps of Ant

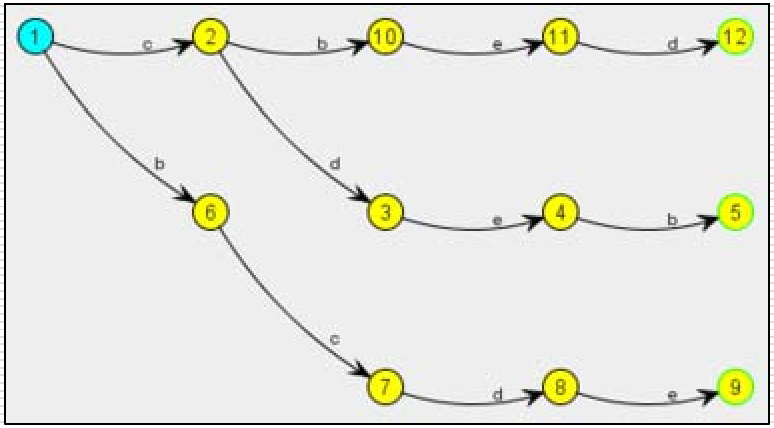
- Merging of states
  - *sk*-strings, *kh*-kontext, ...
- *SchemaBuilder*:
  - Permutation substitution
    - Identification of a candidate (sub-automaton) for unordered sequence + checking
  - Group substitution
    - Identification of a candidate for code reuse + checking
  - Checking validity of inheritance

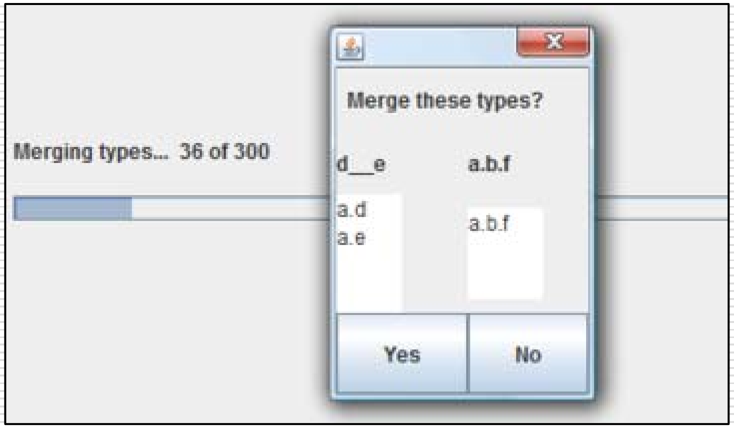
Vosta, Mlynkova, Pokorny: Even an Ant Can Create an XSD. DASFAA '08, New Delhi, India. LNCS 4947, Springer, 2008. ISBN 978-3-540-78567-5.

STEP 3: Schema Output

- Converting of the automaton to XML Schema language
- Rules:
  - Classical states → regular expression
  - Permutation state → unordered sequence
    - all construct of XML Schema
  - Inheritance state → derivation of types
    - extension or restriction construct of XML Schema
  - Group state → reuse contructs
    - element, attribute, group or attributeGroup constructs of XML Schema

Screenshots





Conclusion

- Advantages of the algorithm:
  - User interaction
    - Simple but powerful
  - Advanced XML Schema constructs
    - Cannot be inferred without UI
- Current work: implementation of a general framework (Inferrer)
- Future work:
  - Transformation of automata to regular expressions
  - Exploitation of negative examples
  - Inference of integrity constraints
  - Inference of grammars

Necasky - Mlynkova: Enhancing XML Schema Inference with Keys and Foreign Keys. SAC '09, Honolulu, Hawaii, USA. ACM Press, 2009. ISBN: 978-1-60558-166-8.

Mlynkova, Necasky: Towards Inference of More Realistic XSDs. SAC '09, Honolulu, Hawaii, USA. ACM Press, 2009. ISBN: 978-1-60558-166-8.

Thank you