# XTRACT: A System for Extracting Document Type Descriptors From XML Documents

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# XML

- A W3C standard to complement HTML
- An instance of semistructured data [Abi97]
  - Document Type Descriptor (DTD)
- Origin: SGML
- Tags describe the semantics of the data
  - HTML simply specify how the data time is to be displayed
- An element can contain a sequence of nested sub-elements
- Sub-elements may themselves be tagged elements or character data

# XML

- Standard for data representation and data exchange
- Looks like HTML but it isn't
- Collection of elements
  - Atomic (raw character data)
  - Composite (sequence of nested sub-elements)
- Example

```
<book>
  <title> A Relational Model for Large Shared Data Banks </title>
  <author>
    <name> E.F. Codd </name>
    <affiliation> IBM Research </affiliation>
  </author>
</book>
```

# Document Type Definition

- A part of XML specification
- An XML document may have a DTD
- Grammar for describing the structure of XML document
- The structure of an element is specified by a regular expression
- Terminology for XML
  - well-formed: if tags are correctly closed
  - valid: if it has a DTD and conforms to it
- For exchanges of data, validation is useful

# Document Type Definition

- Syntax
  - comma: sequence
  - |: or
  - (): grouping
  - ?, *, +: zero or one, zero or more, one or more occurrences
  - ANY: allows an arbitrary XML fragment to be nested within the element

# An Example DTD

<!ELEMENT article (title, author*)>

<!ELEMENT title (#PCDATA)>

<!ELEMENT author (name, affiliation)>

<!ELEMENT name (#PCDATA)>

<!ELEMENT affiliation (#PCDATA)>

# An Example XML Document

```
<article>
  <title> A Relational Model for Large Shared Data Banks </title>
  <author>
    <name> E. F. Codd </name>
    <affiliation> IBM Research </affiliation>
  </author>
</article>
```

# XTRACT System

- Goal:

  Infer DTDs from XML Documents

# Why are DTDs useful?

- Plays a crucial role in efficient storage of XML data
  - [Deutsch, Fernandez, Suciu '99]
  - [Shanmugasundaram et al '99]
  - DTD is exploited to generate effective relational schema
- Optimization of XML queries
  - [Goldman, Widom '97]
  - [Fernandez, Suciu '97]
  - DTD allows to restrict the search only relevant portions of the data
- Aids users to form meaningful queries over the XML database

# Why need to infer DTD?

- DTDs are not mandatory => might be missing
- XML databases that have been generated automatically
  - Relational databases
  - Flat files
  - HTML documents
  - Bibliographies

# Related Work I

- Mining DTDs from a collection of XML documents has not been addressed in the literature
- Database Community
  - Extraction of schema from semistructured data
    - [Nestrorov, Abiteboul, Motwani ‘98]
    - [Goldman, Widom ’97]
    - [Fernandez, Suciu ’97]
- Attempts to find typing for semistructured data
- In DTD, outgoing edges from a type can be described by an arbitrary regular expression
- No ordering is imposed for edges

# Related Work II

- [Gold ’67], [Gold ’78], [Angluin ‘78], [Pitt ’89]
  - Infer formal languages from examples
  - Purely theoretical and focus on investigating the computational complexity of the language inference problem
- [Kipelainen, Mannila, Ukkonen ‘95]
  - Infers a pattern language from positive examples
  - MDL principle was used
  - Assume the set of simple patterns is available
  - Cannot find general regular expressions
  - Patterns are not known apriori

# Problem Simplification

- Element types => alphabet
- Infer DTD for each element type separately
- Example sequences: instances of nested subelements
  - Only one level down in the hierarchy

# Problem Formulation

- Given a set example sequences for element *e*
- Compute a DTD for *e*

**Hard problem since DTDs can be general, complex regular expressions**

# Example

```
<book>
  <title> </title>
  <author>
    <name> </name>
    <affiliation> </affiliation>
  </author>
</book>
```

```
<book>
   <title> </title>
   <author>
      <name> </name>
      <address> </address>
   </author>
   <author>
      <name> </name>
      <address> </address>
   </author>
   <editor> </editor>
</book>
```

```
<paper>
  <title> </title>
  <author>
    <name> </name>
    <affiliation> </affiliation>
  </author>
  <conference> </conference>
  <year> </year>
</paper>
```

# Example (Ctd)

## Simplified Example Sequences

<book> :- <title><author>,
<title><author><author><editor>

<paper> :- <title><author><conference><year>

<author> :- <name><affiliation>,
<name><affiliation>,
<name><address>,
<name><address>

## Desirable Solution

<!ELEMENT book (title, author*, editor?)
<!ELEMENT paper (title, author, conference, year)>
<!ELEMENT author (name, affiliation?, address?)>

# Naive Approach I

- Factor as much as possible
  - e.g.  t, ta, taa, taaa, taaaa
    - t | t (a| a(a | a(a | aa)))
    - much more voluminous and a lot less intuitive

# Naive Approach II – DFA Minimization

- Suggestion:
  - Consider all example sequences as positive examples of a language of a DFA
  - Find the minimum DFA that accepts the language
- However:
  - Minimum DFA does not imply an intuitive simple regular expression
  - DFA minimization algorithm finds equivalent language
    - Does not generalize
  - How to infer ta* from ta, taa, taaa, taaaa?

# Desirable DTD

- It generalize to intuitively correct but previously unseen examples
- It should be concise (i.e. small in size)
  - easy to understand and succinct
- It should be precise
  - not cover too many sequences not contained in the set of examples
  - not too general and captures the structure of input sequences

Trade-off!

# Example

- p:- t, ta, taa, taaa, taaaa

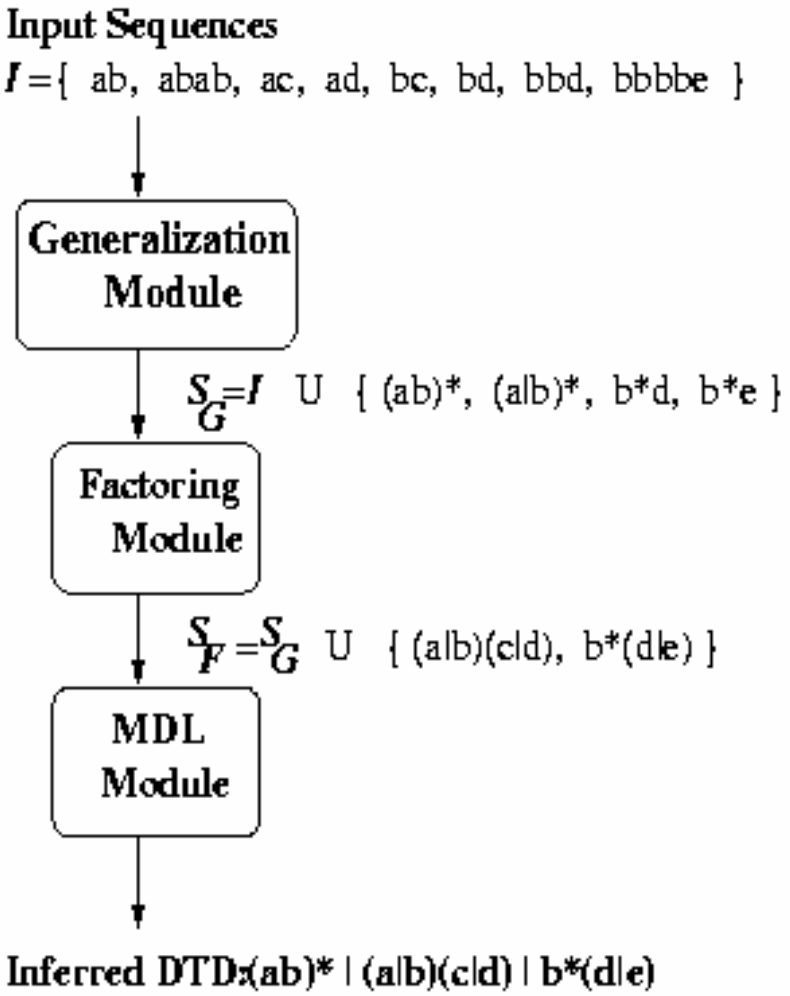
| Candidate DTD | Concise | Precise |
|---|---|---|
| t\|ta\|taa\|taaa\|taaaa | no | yes |
| (t\|a)* | yes | No |
| ta* | yes | somewhat |

# Example

I = {ab, abab, ababab}

- (a | b)*
  - a gross over-generalization of the input
  - completely fails to capture any structure inherent in input
- ab | abab | ababab,  ab | ab(ab | abab)
  - accurately reflect the structure of the input sequences but do not generalize
- (ab)*
  - succinct and generalizes the input sequence without loosing too much structure information

# Overview of XTRACT System



# XTRACT System

- Generalization
  - generalizes zero or more candidate DTDs by replacing patters in the input sequence with meta-characters like *
  - e.g. abab => (ab)*,  bbbe => b*e
- Factorization
  - factors common subexpressions from the generalized candidate DTDs
  - e.g. b*d | b*e => b* (d | e)
- Minimum Description Length (MDL) Principle
  - MDL ranks each candidate DTD and chooses the minimum cost DTD

# MDL Principle

- An information-theoretic measure for quantifying and thereby resolving the tradeoff between the conciseness and preciseness
- MDL principle has been successfully applied in a variety of situations
  - e.g. decision tree classifiers
- Roughly speaking, the best theory to infer from a set of data is the one that minimizes the sum of
  - the length of the theory, in bits (conciseness)
  - the length of the data, in bits, when encoded with the help of the theory (preciseness)

# MDL Module

- MDL Principle: minimize the sum of
  - Theory description length, plus
  - Data description length given the theory

- In order to use MDL, need to:
  - Define theory description length (candidate DTD)
  - Define data description length (input sequences) given the theory (candidate DTD)
  - Solve the resulting minimization problem

# MDL Module – Encoding Scheme

- Description Length of a DTD
  - Number of bits required to encode the DTD
  - |Size of DTD| x log (# of alphabets)
- Description Length of a sequence given a candidate DTD
  - Number of bits required to specify the sequence given DTD
  - Use a sequence of encoding indices
  - Encoding of *a* given *a* is the empty string
  - Encoding of *a* given (*a*|*b*|*c*) is the index 0
  - Encoding of *aaa* given a* is the index 3

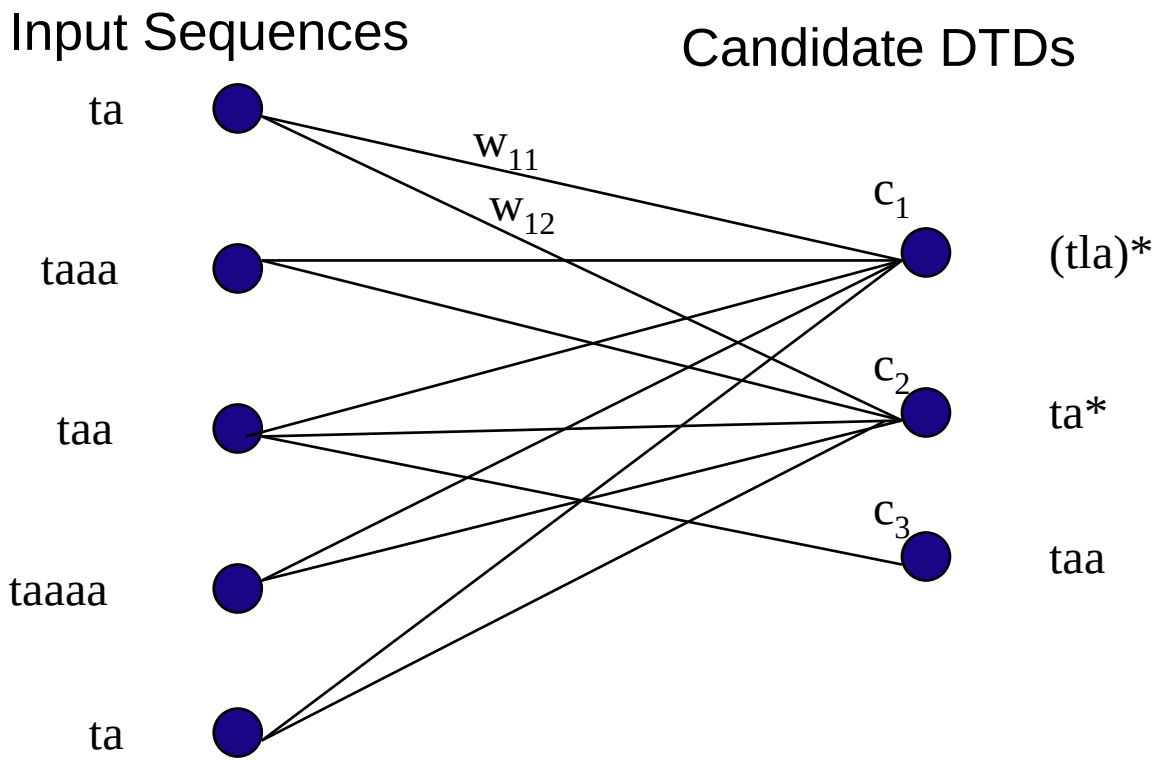
# Example

I = {ab, abab, ababab}

- (a | b)*
  - abab:  cost of 5 (the number of repetitions (4) + 4 characters to represent chosen character)
  - MDL cost = 6 (encoding DTD) + 3 + 5 + 7 = 21
- ab | abab | ababab
  - MDL cost = 14 + 3 = 17
- ab | ab(ab | abab)
  - MDL cost = 14 + 1 + 2 + 2 = 19
- (ab)*
  - MDL cost = 5 + 3 = 8

# MDL Module - Minimization

## Facility Location Problem (NP-hard)



# Computing the DTD with Minimum MDL Cost

- Facility Location Problem (FLP)
  - Let C be a set of clients and J be a set of facilities
  - c(j): cost of choosing a facility $j \in J$
  - d(j,i): cost of serving client $i \in C$ by facility $j \in J$
  - Choose a subset of facilities $F \subset J$ such that

$$\min_{F \subset J} \{ \sum_{j \in F} c(j) + \sum_{i \in C} \min_{j \in F} d(j,i) \}$$

  - NP Hard problem
  - Approximate algorithm [Charikar, Guha '99]: O(n^2logn)

# Generalization Module

- Goal:
  - Introduce metacharacters *, |
  - Produce candidate DTDs of the form
  - a*bc*, (abc)*, (a|b|c)*, ((ab)*c)*, etc.
- Combine two generalization heuristics
  - DISCOVERSEQPATTERN(s,r)
    - S=*att…ttb* => *at*b*
  - DISCOVERORPATTERN(s,d)
    - Symbol a1, a2,…am in close proximity => (a1|a2|…|am)
- Candidate DTDs are generated by calling the above functions for appropriate values of r and d

# Generalization - Example

- DISCOVERSEQPATTERN(s,r)

e.g. s = abababcabcababc, r = 2

ababababcabcababc =>

(ab)*cabcababc =>

(ab)*cabc(ab)*c => ((ab)*c)*

- DISCOVERORPATTERN(s,d)

e.g. s = abcbac, d= 2

abcbac => a(b|c)*ac

e.g. s = abcbac, d = 3

abcbac => (a|b|c)*

# Factoring Module

- Goal: Combine different candidates to derived more compact, factored DTDs forms
  - e.g. ac, ad, bc, bd => (a|b)(c|d)
- MDL modeling justification: Reduce description length of the candidate DTDs
- Intuitive justification: Capture DTDs like

  <!ELEMENT article (title, author*,

  (workshop | conference | journal),

  (computer science | physics | chemistry | … ))>
- Capture optional elements
  - ab,a => a(b | ε) => ab?

# Factoring Module

- Adaptation of the factoring algorithms for boolean expressions in logic optimization literature
- Novel heuristic algorithms for selecting subsets of candidate DTDs that give good factored forms

# Experimental Result

- Tested Algorithms
  - XTRACT
  - DDbE: IBM alphaworks DTD extraction tool (V 1.0)
    - Java component library for inferring DTD from XML data instances
    - Control parameters: default values are used

- Use both Synthetic and Real-life DTDs

- Data Sets: Generate 1000 random example sequences for each DTD

# Experimental Results

- Real-life Data Set
  - Newspaper Association of America (NAA) Classified Advertising Standard XML DTD

| No. | Original DTD | Simplified DTD |
|---|---|---|
| 1 | < !ENTITY % included-elements "audio-clip\|blind-box-reply\|graphic\|linkpi-char\|video-clip" > | $a\|b\|c\|d\|e$ |
| 2 | < !ELEMENT communications-contacts (phone\|fax\|email\|pager\|web-page)* > | $(a\|b\|c\|d\|e)^*$ |
| 3 | < !ELEMENT employment-services(employment-service.type, employment-service.location * (e.zz-generic-tag)*) > | $ab^*c^*$ |
| 4 | < !ENTITY % location"addr*, geographic-area?, city?, state-province?, postal-code?, country?" > | $a^*b?c?d?$ |
| 5 | < !ELEMENT transfer-info(transfer-number, (from-to, company-id)$^+$, contact-info)* > | $(a(bc)^+d)^*$ |
| 6 | < !ELEMENT real-estate-services(real-estate-service.type, real-estate-service.location?, r-e.response-modes*, r-e.comment?)* > | $(ab?c^*d?)^*$ |

Table 4: Real-life DTD Data Set

# Experimental Result

- Real-life Data Set
  - XTRACT is able to infer the first five correctly
  - DDbE could obtain the original DTD only the third one

| NO | Simplified DTD | DTD Obtained by XTRACT | DTD obtained by DDbE |
|---|---|---|---|
| 1 | $a\|b\|c\|d\|e$ | $a\|b\|c\|d\|e$ | $a\|b\|c\|d\|e$ |
| 2 | $(a\|b\|c\|d\|e)^*$ | $(a\|b\|c\|d\|e)^*$ | $(a\|b\|c\|d\|e)^*$ |
| 3 | $(ab^*c^*)$ | $ab^*c^*$ | $(ab^+c^*)\|(ac^*)$ |
| 4 | $a^*b?c?d?$ | $a^*b?c?d?$ | $(a^+b(c\|(c?d))?)\|((b\|a^+)?cd)\|$ $((a^+\|b)?d)\|((a^+\|b)?c)\|a^+\|b)$ |
| 5 | $(a(bc)^+d)*$ | $(a(bc)^*d)^*$ | $(a\|b\|c\|d)^+$ |
| 6 | $(ab?c^*d?)*$ | – | $(a\|b\|c\|d)+$ |

Table 6: DTDs generated by XTRACT and DDbE for Real-life Data Set

# Experimental Results

- Synthetic Data Set
  - Each DTD is randomly chosen from either
    - $A_1|A_2|\ldots|A_n$ or $A_1A_2A_3\ldots A_n$
    - n is randomly chosen between a1 and mb
    - Each $A_i$ has one of the following four forms
      - $(a_1|a_2|\ldots|a_{mi})$
      - $(a_1a_2\ldots A_{mi})$
      - $(a_1|a_2|\ldots|a_{mi})^*$
      - $(a_1a_2\ldots a_{mi})^*$
    - $m_i$ is chosen to be between 1 and ms

# Experimental Results

- Synthetic Data Set
  - abcde | efgh | ij | klm
  - (a | b | c | d | f)*gh
  - (a | b | c | d)* | e
  - (abcde)*f
  - (ab)* | cdef | (ghi)*
  - abcdef(g | h | I | j)(k | l | m | n | o)
  - (a | b | c)d*e*(fgh)*
  - (a|b)(cdefg)*hijklmnopq(r|s)*
  - (abcd)*|(e|f|g)*| h | (I j k l m)*
  - a* | (b | c | d | e | f)* | gh | (I | j | k)* | (lmn)

# Experimental Result

## Synthetic Data Set

| No. | Original DTD | DTD Inferred by XTRACT | DTD Inferred by DDbE |
|---|---|---|---|
| 1 | $abcde\|efgh\|ij\|klm$ | $abcde\|efgh\|ij\|klm$ | $abcde\|efgh\|ij\|klm$ |
| 2 | $(a\|b\|c\|d\|f)^*gh$ | $(a\|b\|c\|d\|f)^*gh$ | $gh(a\|b\|c\|d\|f)^+gh$ |
| 3 | $(a\|b\|c\|d)^*\|e$ | $(a\|b\|c\|d)^*\|e$ | $(e(a\|c\|d\|b)^+e)$ |
| 4 | $(abcde)^*f$ | $(abcde)^*f$ | $(f(a\|e\|d\|c\|b)^+f)$ |
| 5 | $(ab)^*\|cdef\|(ghi)^*$ | $(ab)^*\|cdef\|(ghi)^*$ | $cdef(a\|b\|g\|i\|h)^+cdef$ |
| 6 | $abcdef(g\|h\|i\|j)(k\|l\|m\|n\|o)$ | $abcdef(g\|h\|i\|j)(k\|l\|m\|n\|o)$ | $abcdef(j(o\|l\|m\|n\|k)\|g(o\|l\|n\|m\|k)\|$ $h(m\|l\|n\|k\|o)\|i(o\|l\|n\|m\|k))$ |
| 7 | $(a\|b\|c)d^*e^*(fgh)^*$ | $(a\|b\|c)d^*e^*(fgh)^*$ | $((c\|b\|a)d^+e^+\|ad^+\|bd^+\|c(e^+\|d^+)?\|$ $ad^*\|be^*))(f\|h\|g)^+((a\|b\|c)d^+e^+\|$ $c(e^+\|d^+)?\|a(e^+\|d^+)?\|b(e^+\|d^+)?)$ |
| 8 | $(a\|b)(cdefg)^*$ $hijklmnopq(r\|s)^*$ | $(a\|b)(cdefg)^*$ $hijklmnopq(r\|s)^*$ | $((((a\|b)hijabcdefg)\|b\|a)$ $(c\|g\|f\|e\|d\|s\|r)^+((b\|a)?hijkamnopq))$ |
| 9 | $(abcd)^*\|(e\|f\|g)^*\|h\|(ijklm)^*$ | $(abcd)^*\|(ijklm)^*\|h\|(e\|f\|g)^*$ | $h(a\|d\|c\|b\|e\|g\|f\|i\|m\|l\|k\|j)^+h$ |
| 10 | $a^*\|(b\|c\|d\|e\|f)^*\|gh\|(i\|j\|k)^*\|$ $(lmn)^*$ | $a^*\|(b\|c\|d\|e\|f)^*\|gh\|(i\|j\|k)^*\|$ $(lmn)^*$ | $(a^+\|gh)(e\|f\|d\|i\|j\|l\|n\|m\|k\|c\|b)^+$ $(a^+\|gh)$ |

Table 5: DTDs generated by XTRACT and DDbE for Synthetic Data Set

# Experimental Result

- Synthetic Data Set
  - XTRACT finds all of original DTDs
  - DDbe discovers only the first DTD accurately
  - DDbe may not cover every input sequences
    - e.g. *gh* is not covered for Dataset 2
  - Note: Dataset 4
    - *f* is appended to both the front and the back
    - symbols repeated frequently are all *or*'d together
  - Ddbe is not very good at factoring
    - e.g. Dataset 6

# Conclusions

- Inference of DTDs can be used for improving database storage and for query optimization
- Hard problem! – Naive approaches fail to produce intuitive, meaningful DTDs
- Presented the architecture of the XTRACT system for inferring a DTD for a database of XML documents
  - generalization step
  - factorization step
  - MDL cost selection step
- Demonstrated the effectiveness of XTRACT