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University of Bourgogne
Dijon - France

XML Similarity

Background, Applications and Motivations

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Overview

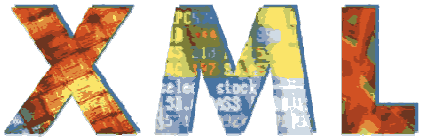
- Introduction
- Background
- Applications
- Our contributions
- Conclusion

What's XML?

Introduction and motivation

- XML (eXtensable Markup Language)
  - Structures and describes the content (and presentation)
  - Major means for efficient data representation and management

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<Academy>
  <Department >
      <Laboratory>
            <Professor>John Cramer</Professor>
              <Student>John Takagi</Student>
      </Laboratory>
   </Department>
</Academy>
```



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Why XML?

Introduction and motivation

- XML has become a *de facto* standard
  - Current applications
    - Multimedia Information description, storage and retrieval
    - Data exchange across enterprises and platforms (ontology mapping)
    - Web (services) interactions

Information destined to be shared
is henceforth represented using XML

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Introduction and motivation

How to make these two applications interoperate?

Introduction and motivation

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Emergent need

Information Retrieval and Database systems: XML documents comparison

XMLSearch

- Goal
  - Briefly introduce the XML similarity/comparison topic
    - Background
    - Applications
    - Motivations and personal contributions
    - Future research directions

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Background

- XML (eXtensable Markup Language)
  - Can be observed as an OLT
    - Node label (x.l)
    - Node depth (x.d)

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<Academy>
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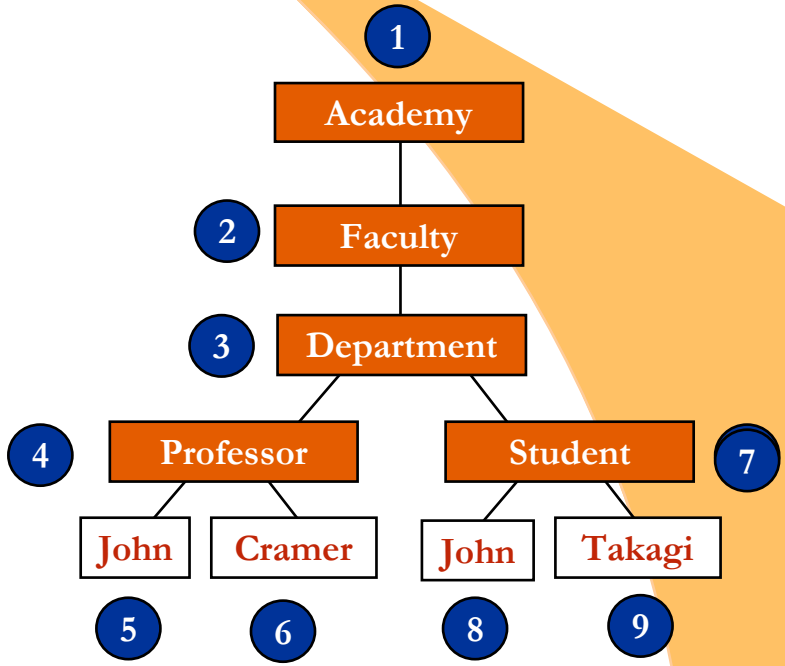
              <Professor>John Cramer</Professor>
              <Student>John Takagi</Student>
        </Laboratory>
  </Department>
</Academy>
```



Ordered Labeled Tree

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Background

- There are two different views of XML
  - *Document-centric* view
    - Involves a liberal use of free-form text that is "marked up" with elements
  - *Data-centric* view
    - More emphasis on the structure (DB like data)
    - Data-centric documents are typically easier to process with computer programs because the data is better organized
    - Typical use of XML

```
<Memo>
  Please make sure you are at the
  <Location>ninth floor</Location>by
  <MeetingTime>10:30 AM </MeetingTime>
  to<Purpose>discuss the budget</Purpose>
</Memo>
```

```
<Memo>
  <MeetingTime>10:30 AM</MeetingTime>
  <Purpose>Discuss Budget</Purpose>
  <Location>ninth floor</Location>
</Memo>
```

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Background

- A range of algorithms for comparing semi-structured data, e.g. XML documents, have been proposed:
  - Most of them exploit the *Artificial Intelligence* concept of *Edit Distance*
    - *Data-centric* view
  - Others focus on extending conventional *Information Retrieval* methods, e.g. the vector space model, so as to provide efficient XML similarity assessment
    - *Document-centric* view

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Background

- *Edit Distance*

Finding the cheapest sequence of edit operations (insert, update, delete...) that can transform one string into another

h	e	l	o	o

h	e	l	l	o

Edit distance: 1 update + 1 insert

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Background

- *Information retrieval*

Identifying important blocs

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Background

- *Information retrieval*

Identifying important blocs

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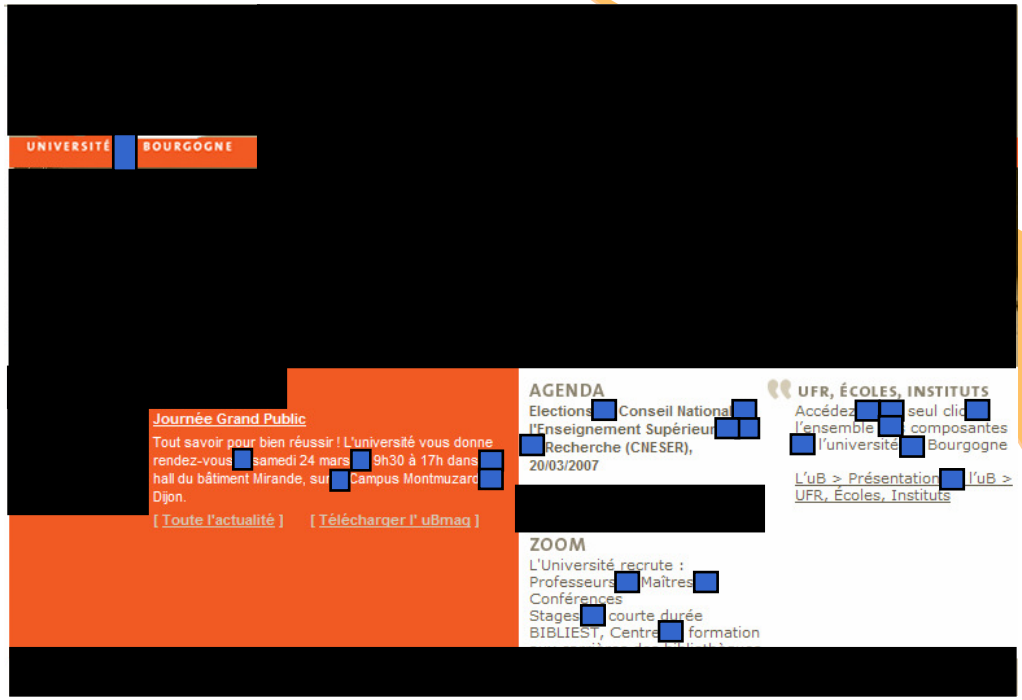
Background

- *Information retrieval*



Eliminating stop words

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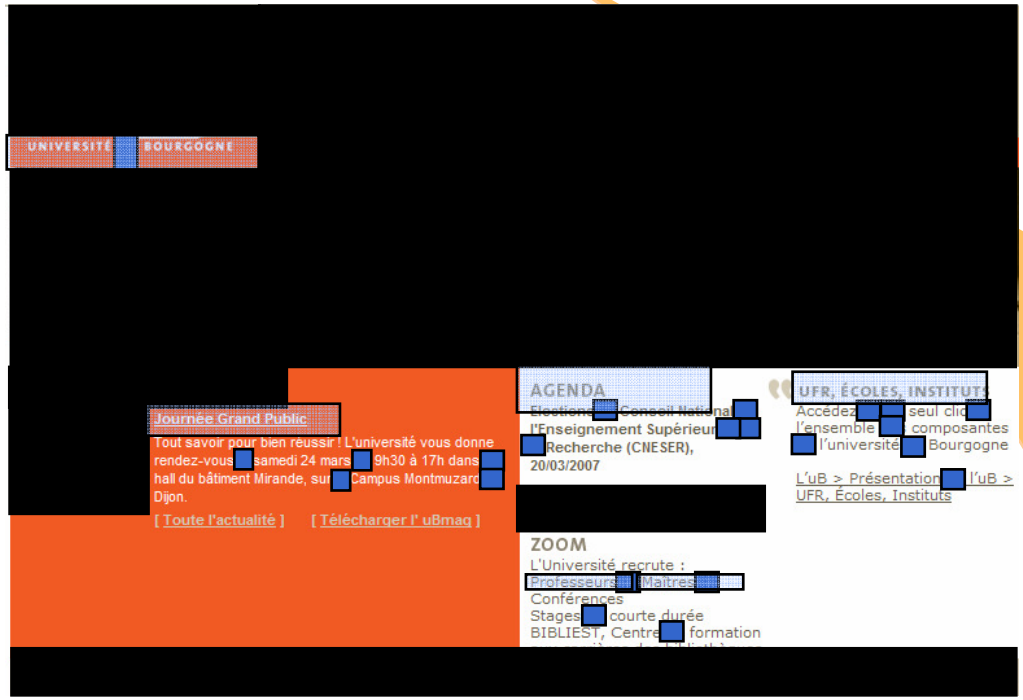
Background

- *Information retrieval*



Identifying Concepts

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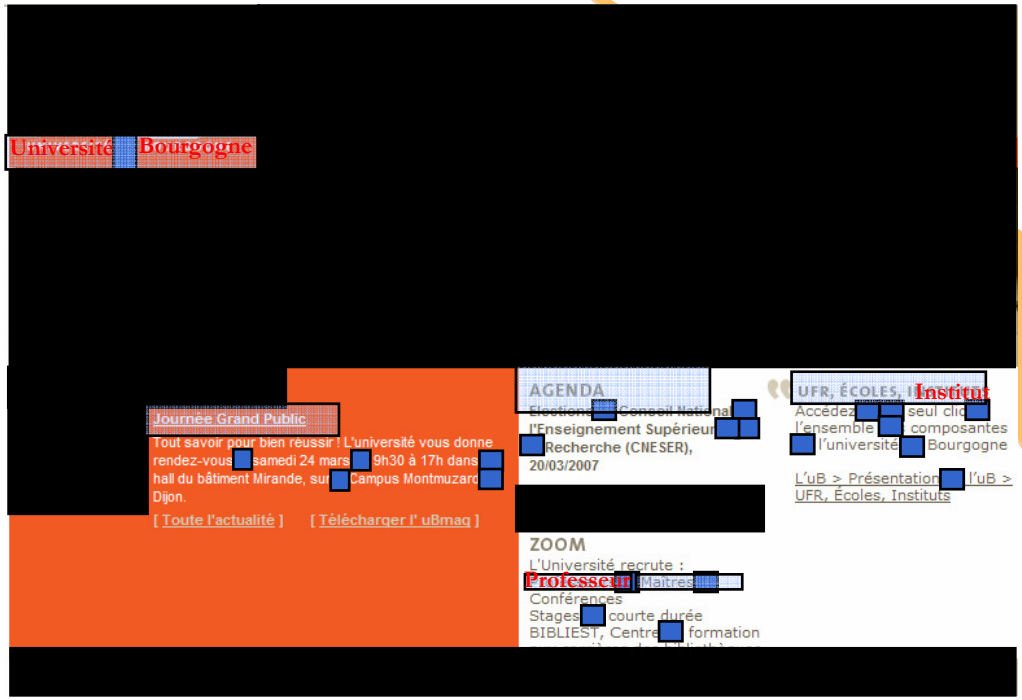
Background

- *Information retrieval*



Vector: (Université, Bourgogne, Professeur, Institut)

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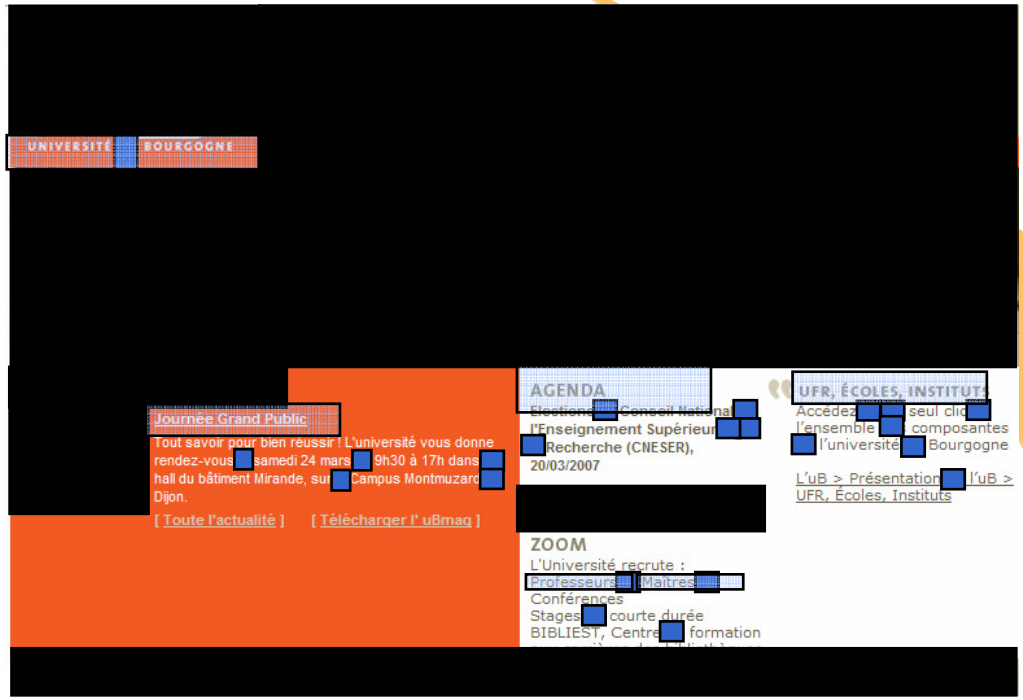
Background

- *Information retrieval*



Vector: (Université, Bourgogne, Professeur, Institut)

And each term has its importance according to its weight

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  - ED-based methods
  - IR-based methods
- Applications
- Our contributions
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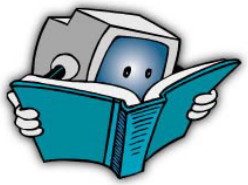
Background

ED-based methods for XML similarity

- Most algorithms proposed in the literature make use of the *AI* programming techniques for finding the *Edit Distance* between trees

Finding the cheapest sequence of edit operations that can transform one tree into another



1.[2] Nierman A. and Jagadish H. V., Evaluating structural similarity in XML documents.
2.In *Proceedings of the 5th International Workshop on the Web and Databases,* 2002.

[3] Cobéna G., Abiteboul S. and Marian A., Detecting Changes in XML Documents. In *Proc. of the IEEE Int. Conf. on Data Engineering*, 2002, 41-52.

[4] Chawathe S., Comparing Hierarchical Data in External Memory. In *VLDB ,* 1999, 90-101.

[5] Shasha D. and Zhang K., Approximate Tree Pattern Matching. In *Pattern Matching in Strings, Trees and Arrays*, chapter 14, Oxford University Press, 1995.

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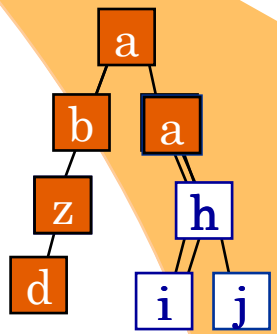
ED-based methods for XML similarity

- Algorithms can be distinguished following:
  - The set of edit operations allowed
    - *Insert node*: Insertion of inner/leaf nodes
    - *Delete node*: Deletion of inner/leaf nodes
    - U*pdate node*: Relabelling nodes
    - *Insert tree*
    - *Delete tree*
    - *Move tree*
  - The overall complexity and performance
    - $O(N^2 D^2)$
    - $O(N^2)$
    - $O(N \log(N))$ → Optimality



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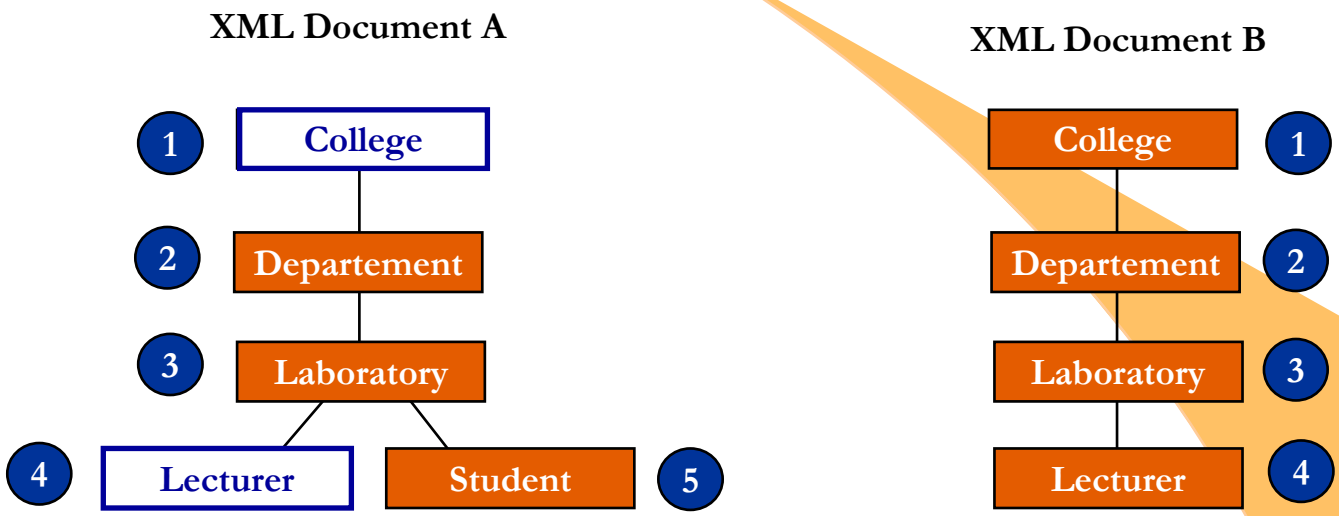
Background

- Applying Chawathe's approach [2]



Edit script = **Upd(A[1], B[1]), Upd(A[4], B[4]), Del(A[5])**

Dist(A, B) = 3

Sim = 1 / 1 + Dist

Sim(A, B) = 0.25

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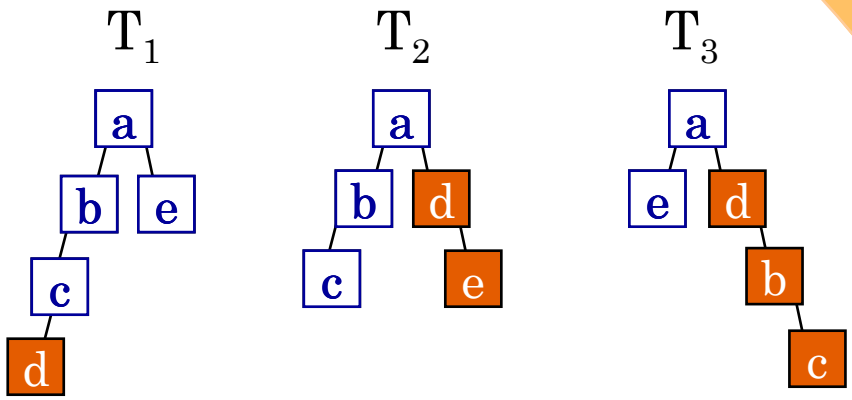
Background

- Approximations of tree *ED*
  - Tag similarity [6]
  - Path similarity [7]
  - …



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[6] Buttler D., A Short Survey of Document Structure Similarity Algorithms. In *Proceedings of the 5th International Conference on internet Computing*, Las Vegas, USA, 2004.

[7] Rafiei D., Moise D. and Sun D., Finding Syntactic Similarities between XML Documents. In *Proceedings of the 17th International Conference Database and Expert Systems Applications, 2006. DEXA '06*

[8] Flesca S., Manco G., Masciari E., Pontieri L., and Pugliese A., Detecting Structural Similarities Between XML Documents. In *Proceedings of the 5th International Workshop on The Web and Databases (WebDB 2002)*, 2002.

Overview

- Introduction
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  - ED-based methods
  - IR-based methods
- Applications
- Our contributions
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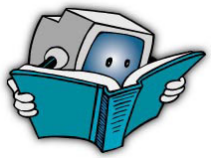
Background

IR-based methods for XML similarity

- Traditional *IR* methods are no longer adequate with semi-structured data such as XML [9]
- With XML, the content is distributed at different levels
  - Therefore, it is to be treated differently w.r.t. flat content so as to improve retrieval precision [10]



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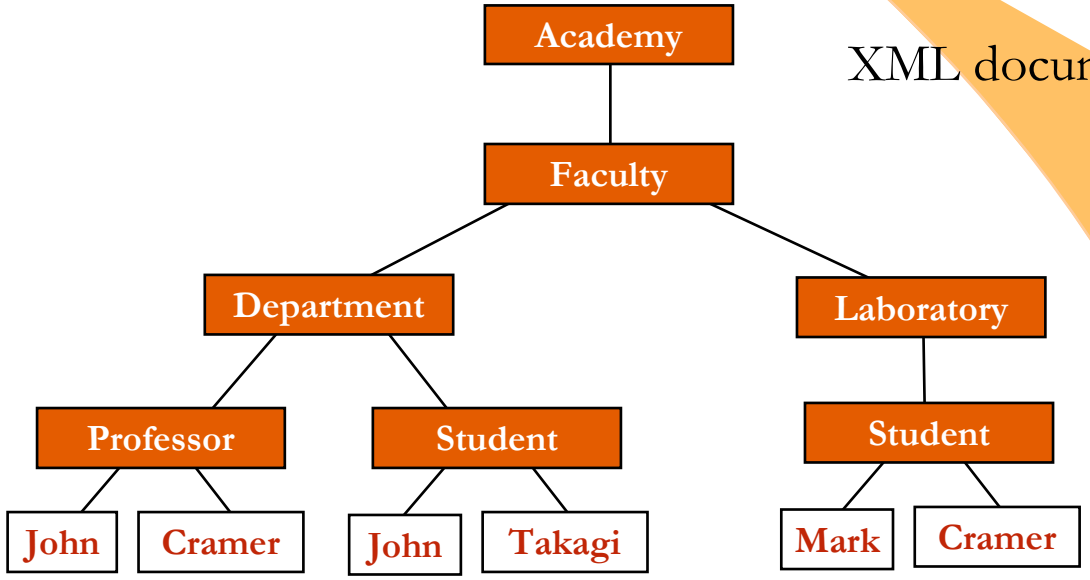
[9] Grabs T., Schek H.-J., Generating Vector Spaces On-the-fly for Flexible XML Retrieval. In *Proceedings of SIGIR'2002 Workshop on XML and information Retrieval*, p.4-13, Finland, 2002.

[10] Schlieder T. and Meuss H., Querying and Ranking XML Documents. *JASIS Spec. Top. XML/IR* 53(6):489-503, 2002.

Background

IR-based methods for XML similarity

- With traditional *IR*



XML document D_1

	John	Cramer	Takagi	Mark
$V_{D1} =$	(2 ,	2 ,	1 ,	1)

→ TF weights

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Background

IR-based methods for XML similarity

- With traditional *IR*
  - Documents and user queries usually consist of sets of keywords where **Keywords are weighted in order to reflect their relative importance**
    - A *TF-IDF* score is generally utilized

$$Document = ("t_1,w_1", \ldots, "t_i,w_i", \ldots\ldots, "t_n,w_n")$$

$$Query = ("q_1,k_1", \ldots, "q_i,k_i", \ldots\ldots, "q_n,k_n")$$

How to calculate the similarity between them?

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IR-based methods for XML similarity

- With traditional *IR*
  - Documents and user queries usually consist of sets of keywords where **Keywords are weighted in order to reflect their relative importance**
    - A *TF-IDF* score is generally utilized

$$Document = ("t_1,w_1", \ldots, "t_i,w_i", \ldots\ldots, "t_n,w_n")$$

$$Query = ("t_1,k_1", \ldots, "t_i,k_i", \ldots\ldots, "t_n,k_n")$$

By using the same semantic space

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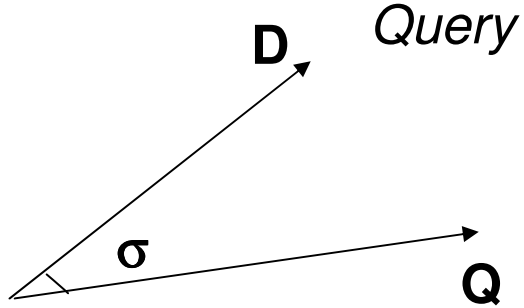
Background

IR-based methods for XML similarity

- With traditional *IR*
  - Documents and user queries usually consist of sets of keywords where **Keywords are weighted in order to reflect their relative importance**
    - A *TF-IDF* score is generally utilized

$$Document = ("w_1", \ldots, "w_i", \ldots\ldots, "w_n")$$

$$Query = ("k_1", \ldots, "k_i", \ldots\ldots, "k_n")$$



$$Similarity(D, Q) = \frac{\sum_{i=1}^{n}(w_i \times k_i)}{\sqrt{\sum_{i=1}^{n} w_i^2 \times \sum_{i=1}^{n} k_i^2}}$$

Following the *vector space model*, documents/queries become weight vectors

Similarity measures between vectors are put to use:

Cosine, Jaccard, Dice, …

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IR-based methods for XML similarity

- With traditional *IR*
  - Identifying similar documents to a query comes down to:
    - Ranking the documents according to their similarity scores with the query (selection via a similarity threshold)

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IR-based methods for XML similarity

- Extending traditional *IR* [9, 11]
  - Defining indexing nodes
  - Down-weighting the statistics (*TF-IDF* values) when the terms are propagated upwards in the document tree (*nested retrieval*)
  - Introducing the notion of *category* (*flexible retrieval*)
    - The users can dynamically – at query time – define the scope of their queries

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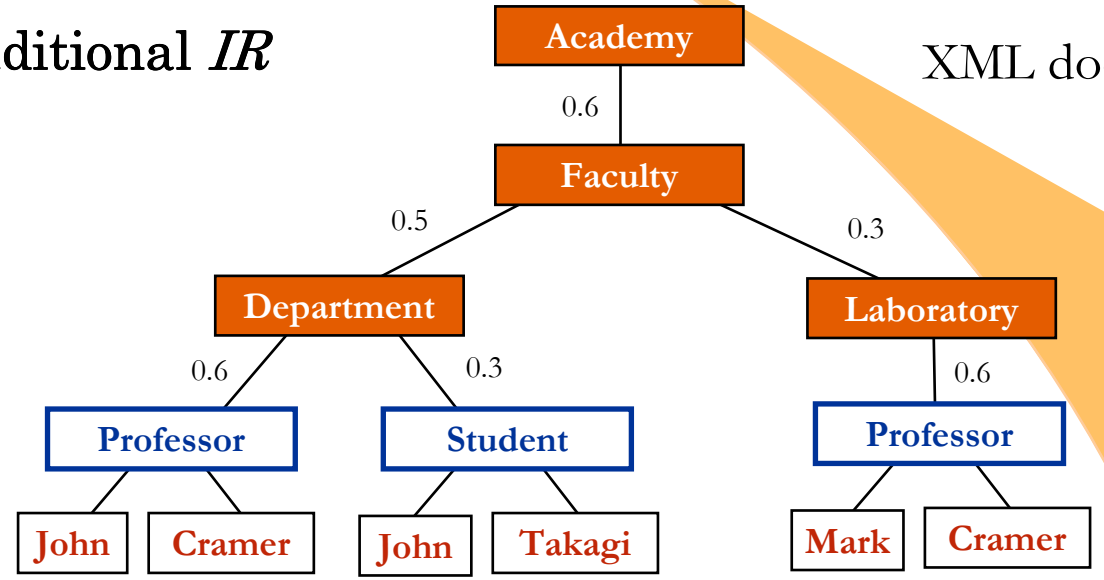
1.[9] Grabs T., Schek H.-J., Generating Vector Spaces On-the-fly for Flexible XML Retrieval.
2.In *Proceedings of SIGIR'2002 Workshop on XML and information Retrieval*, p.4-13, Finland, 2002.
[11] Fuhr N. and Großjohann K., XIRQL: A Query Language for Information Retrieval.
In *Proceedings of ACM-SIGIR*, New Orleans, 2001, pp. 172-180.

Background

IR-based methods for XML similarity

- With traditional *IR*



XML document D_1

	John	Cramer	Takagi	Mark
$V_{Professor}$ =	(1 ,	1 ,	0 ,	1)
$V_{Student}$ =	(1 ,	0 ,	1 ,	0)
$V_{Department}$ =	(0.9 ,	0.6 ,	0.3 ,	0)
$V_{Faculty}$ =	(0.45 ,	0.48 ,	0.15 ,	0.18)

→ TF/IDF scores

} Down-weighted TF scores

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IR-based methods for XML similarity

- **Extending traditional *IR*:**
  - Indexing terms w.r.t. their context [12]
    - *(ti, ci)* where each term *ti* is qualified by the context in which it appears.
    - *ci* is the path from the root to *ti*
    - Similarity between contexts (*LCS* algorithm)
  - …
  - Representing XML as matrixes [14]
    - A term is expressed by a vector $w_D(ti)_{1...k}$ reflecting the distribution of the term *ti* in the XML structure of the document collection, w.r.t. to each path *k* occurring in the collection
    - The similarity between a query and a document is evaluated as the correlation between two matrixes

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In which applications, XML Similarity is useful?

Applications

- Four main areas:
  - XML data warehousing
  - XML data integration
  - XML classification and clustering
  - XML querying

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Applications

XML data warehousing

- The need of fine-grained method is mandatory in this field
  - Deltas, i.e. *edit scripts*: means of change detection and management

- Various uses:
  - Version control and change management
  - Querying the past
  - Learning about changes
  - Monitoring changes
  - Archiving
  - Mirroring

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Applications

XML data integration

- Integrating two XML data sources, comes down to performing an *approximate join* between these sources
  - Using a predefined XML similarity measure (most likely a tree edit distance based measure)

- Output of the *approximate join* between two data sources *S1* and *S2*:
  - All pairs of documents (*d1, d2*) of *S1* and *S2* such that $Sim(d1, d2) \geq s$ [15]
  - Subsequently, the identified pairs of documents are integrated to form unified views of the data.

[15] Guha S., Jagadish H.V., Koudas N., Srivastava D. and Yu T., Approximate XML Joins. In *Proceedings of ACM SIGMOD 2002*, pp. 287-298 (2002).

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Applications

XML classification and clustering

- Classification of XML documents gathered from the web against a set of DTDs declared in an XML database [16]
  - It can be undertaking using
    - An XML/DTD comparison method
    - Or an XML/XML comparison method (e.g. tree edit distance methods)
- XML clustering: Grouping similar XML documents together
  - Improves storage indexing [17], thus positively affecting the retrieval process
  - Plays a major role in effective DTD extraction [2]
  - Has a major impact on information extraction [6]

[16] Bertino E., Guerrini G., Mesiti M., A Matching Algorithm for Measuring the Structural Similarity between an XML Documents and a DTD and its Applications, *Elsevier Computer Science, 29*, 2004, 23-46.

[17] Schöning H., Tamoni – A DBMS Designed for XML. In *Proceedings of the ICDE Conference*, p. 149-154, 2001.

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Applications

XML query and search systems

- Retrieval of XML documents from an XML data collection
- The database community has proposed several languages for querying XML, such as XML-QL [18], XQL [19], XQuery [20], …
  - These languages are based on exact matching and do not support ranked queries
- Several attempts to extend these languages
  - Most of these are IR-based methods for XML similarity
  - Examples: ELIXIR [21], XIRQL [22], approXQL [23], XQuery/IR [24], …

Hiroshi Ishikawa, Kazumi Kubota, Yasuhiko Kanemasa, Yasuo Noguchi: The Design of a Query Language for XML Data. DEXA Workshop 1999: 919-922

Hiroshi Ishikawa, Shohei Yokoyama, Manabu Ohta, Kaoru Katayama: On Mining XML Structures Based on Statistics. KES (1) 2005: 379-390

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Overview

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  - Integrating semantics in XML similarity
  - Enhancing XML structural similarity
- Conclusion

Contributions

Integrating semantics in XML similarity

- Most algorithms for comparing semi-structured data, e.g. XML documents:
  - Focus on the structure of XML documents
  - Ignore the semantics involved

However, in the field of information retrieval (IR), estimating semantic similarity between documents is of key importance to improving search results [25]

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[25] Maguitman A. G., Menczer F., Roinestad H. and Vespignani A., Algorithmic Detection of Semantic Similarity. In *Proceedings of the 14th International World Wide Web Conference*, 107-116, Chiba, Japan, 2005

Contributions

- Example :

```
<Academy>
  <Department >
    <Laboratory>
      <Professor></Professor>
      <Student></Student>
    </Laboratory>
  </Department>
</Academy>
```

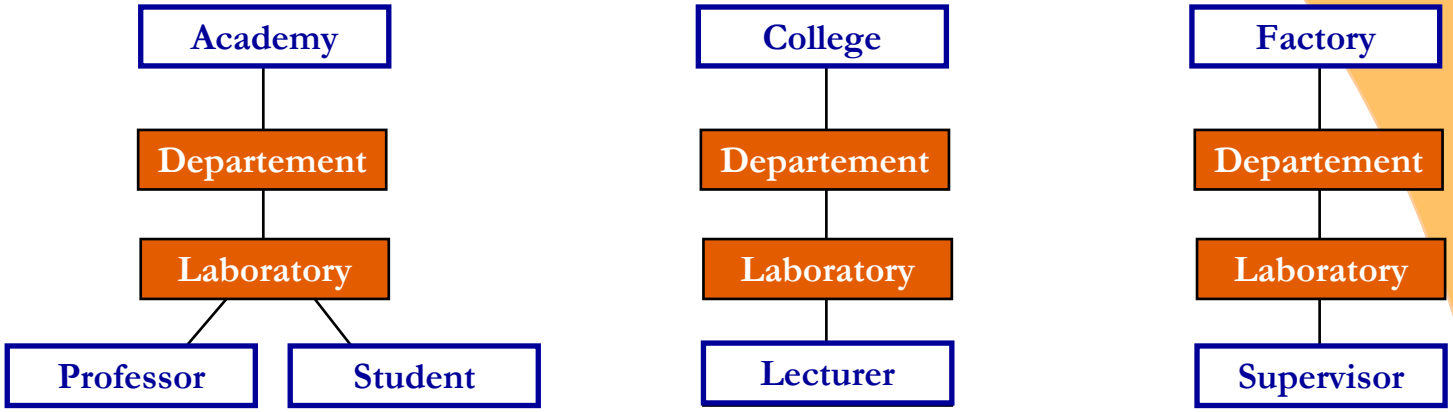
XML Document A

```
<College>
 <Department >
   <Laboratory>
     <Lecturer></Lecturer>
   </Laboratory>
 </Department>
</College>
```

XML Document B

```
<Factory>
 <Department >
   <Laboratory>
     <Supervisor></Supervisor>
   </Laboratory>
 </Department>
</Factory>
```

XML Document C



$$\mathrm{Sim}(A, B) \overset{?}{=} \mathrm{Sim}(A, C)$$

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Integrating semantics in XML similarity

Motivation

How to amend existing XML comparison approaches in order to take into consideration both structural and semantic characteristics of XML documents ?

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Integrating semantics in XML similarity

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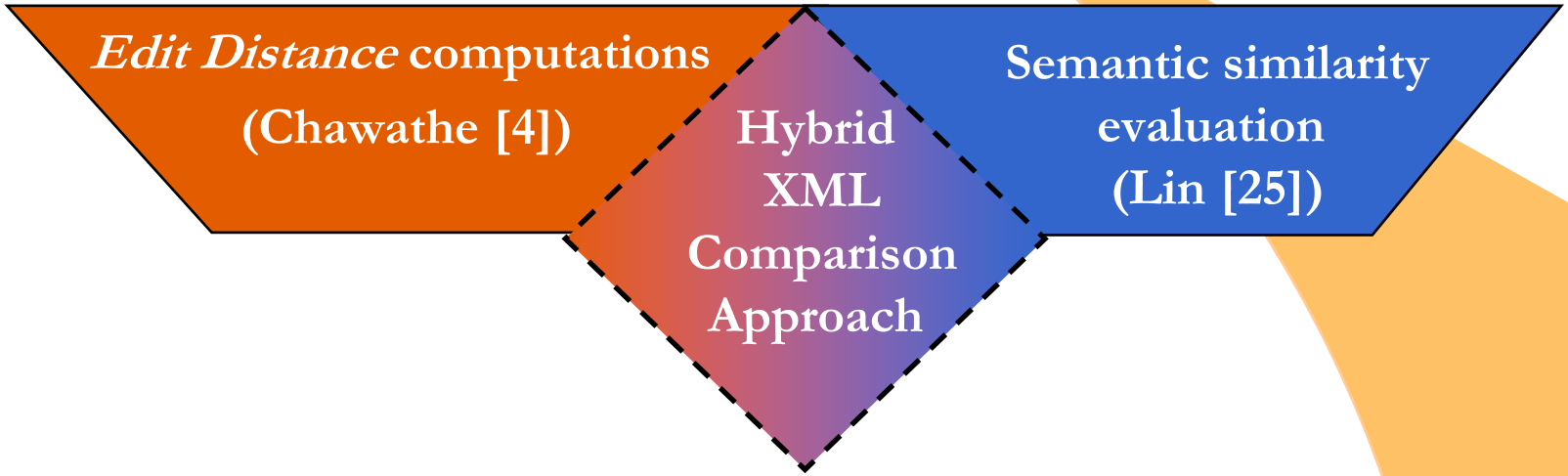
Proposal



[4] Chawathe S., Comparing Hierarchical Data in Extended Memory. In *Proceedings of the Twenty-fifth International Conference on Very Large Data Bases. Edinburgh, Scotland, U.K.,* p. 90-101, 1999

[25] Lin D., Am Information-Theoretic Definition of Similarity. *In Proceedings of the 15th International Conference on Machine Learning*, 296-304, Morgan Kaufmann Publishers Inc., 1998

Contributions

A central question in most edit distance approaches:

How to assign edit operations costs?

- Intuitive cost model:
  - $Cost_{Ins} = 1$
  - $Cost_{Del} = 1$
  - $Cost_{Upd} = 1$ when $x.l \neq y.l$ otherwise $Cost_{Upd} = 0$

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Contributions

Integrating semantics in XML similarity

- Edit operations:
  - $Cost_{Sem_Upd}(x, y) = 1 - Sim_{Sem}(x.l, y.l)$
  - $Cost_{Sem_Ins}(x, i, p, \lambda(x)) = 1 - Sim_{Sem}(\lambda(x), p.l)$
  - $Cost_{Sem_Del}(x, p) = 1 - Sim_{Sem}(x.l, p.l)$

$Cost_{Sem_Op} \nearrow$ when $Sim_{Sem} \searrow$

$Cost_{Sem_Op} \searrow$ when $Sim_{Sem} \nearrow$

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Contributions

Integrating semantics in XML similarity

- Semantic similarity measure adopted: *Lin* [25]
- $Sim_{Sem}(C_1, C_2) = \dfrac{2 \log P(C)}{\log P(C_1) + \log P(C_2)} \in [0, 1]$

with C is the lowest common ancestor of C1 and C2 (maximizing their pair wise similarity value)

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[25] Lin D., Am Information-Theoretic Definition of Similarity. *In Proceedings of the 15th International Conference on Machine Learning*, 296-304, Morgan Kaufmann Publishers Inc., 1998

Contributions

Integrating semantics in XML similarity

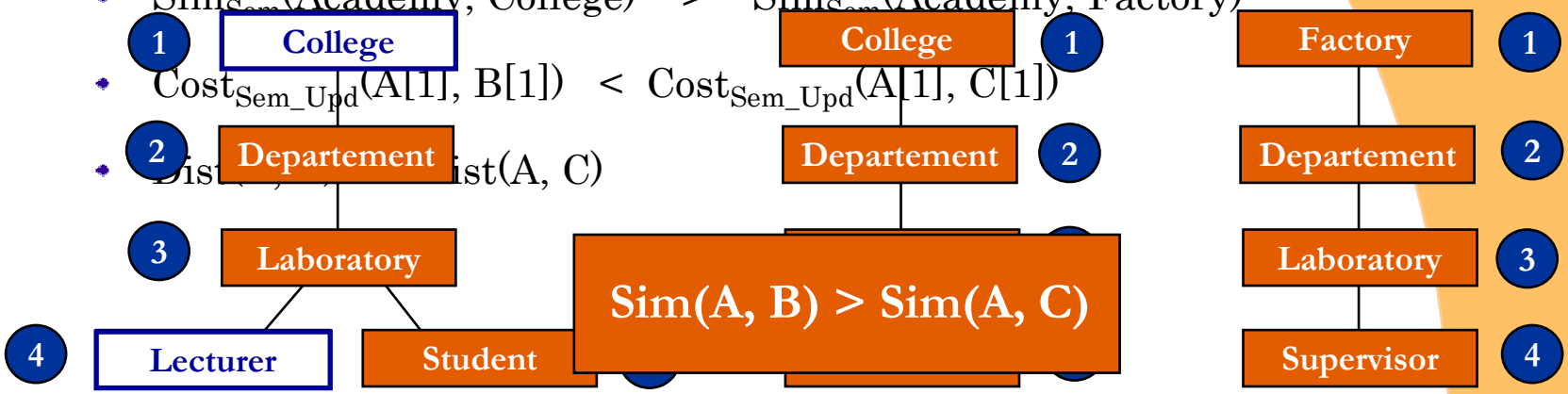
T2

- Example
  - $Cost_{Sem_Upd}(A[1], B[1]) = 1 - Sim_{Sem}(Academy, College)$
  - $Cost_{Sem_Upd}(A[1], C[1]) = 1 - Sim_{Sem}(Academy, Factory)$

Edit script = **Upd(A[1], B[1]), Upd(A[4], B[4]), Del(A[5], A[3])**

XML Document A **XML Document B** **XML Document C**

- $Sim_{Sem}(Academy, College) > Sim_{Sem}(Academy, Factory)$
- $Cost_{Sem_Upd}(A[1], B[1]) < Cost_{Sem_Upd}(A[1], C[1])$
- $Dist(A, B) < Dist(A, C)$



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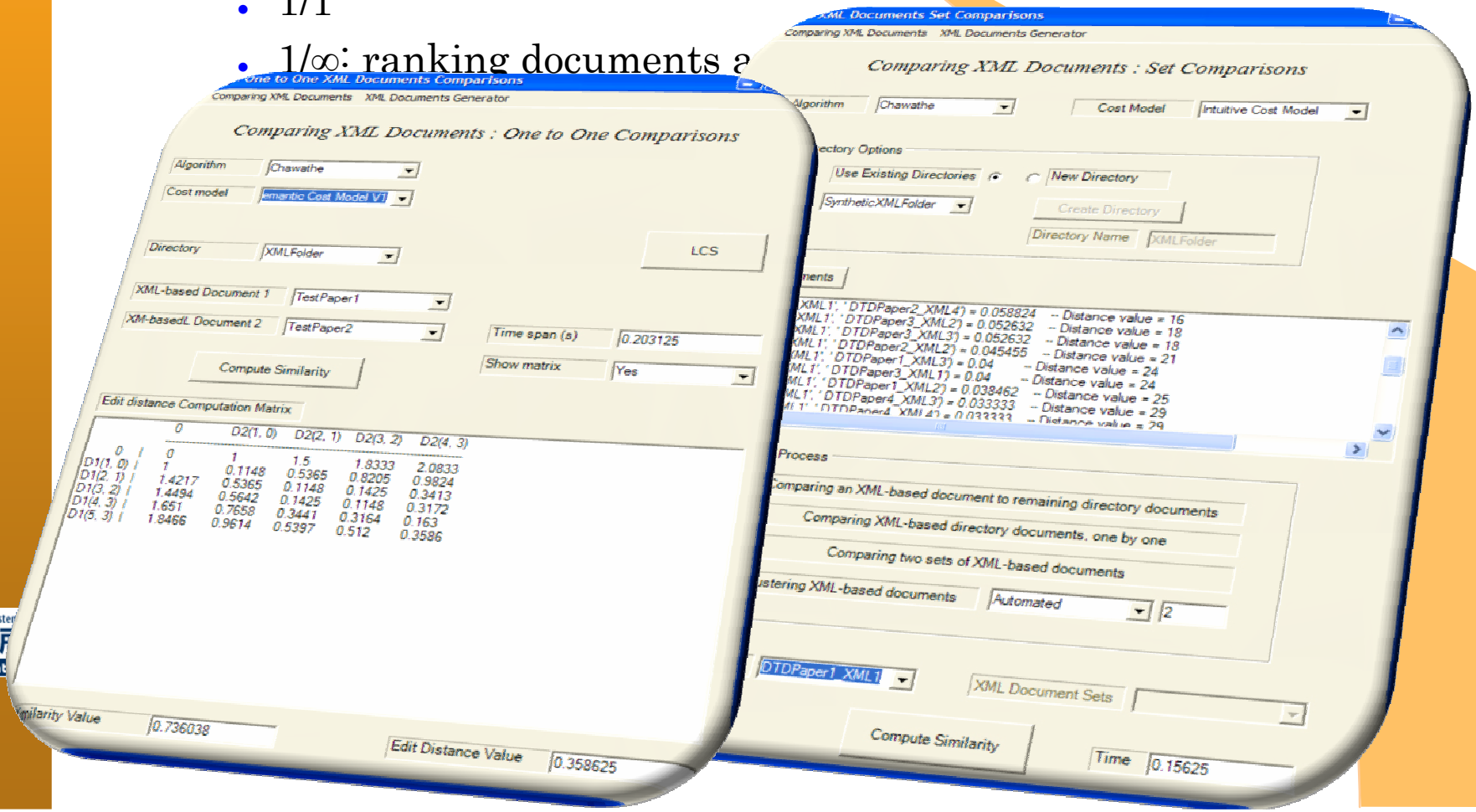
T2

Tekli, 2006/06/06

Contributions

- Prototype *XS³* *(XML Structure and Semantic Similarity)*
  - XML documents comparison
    - 1/1
    - 1/∞: ranking documents a



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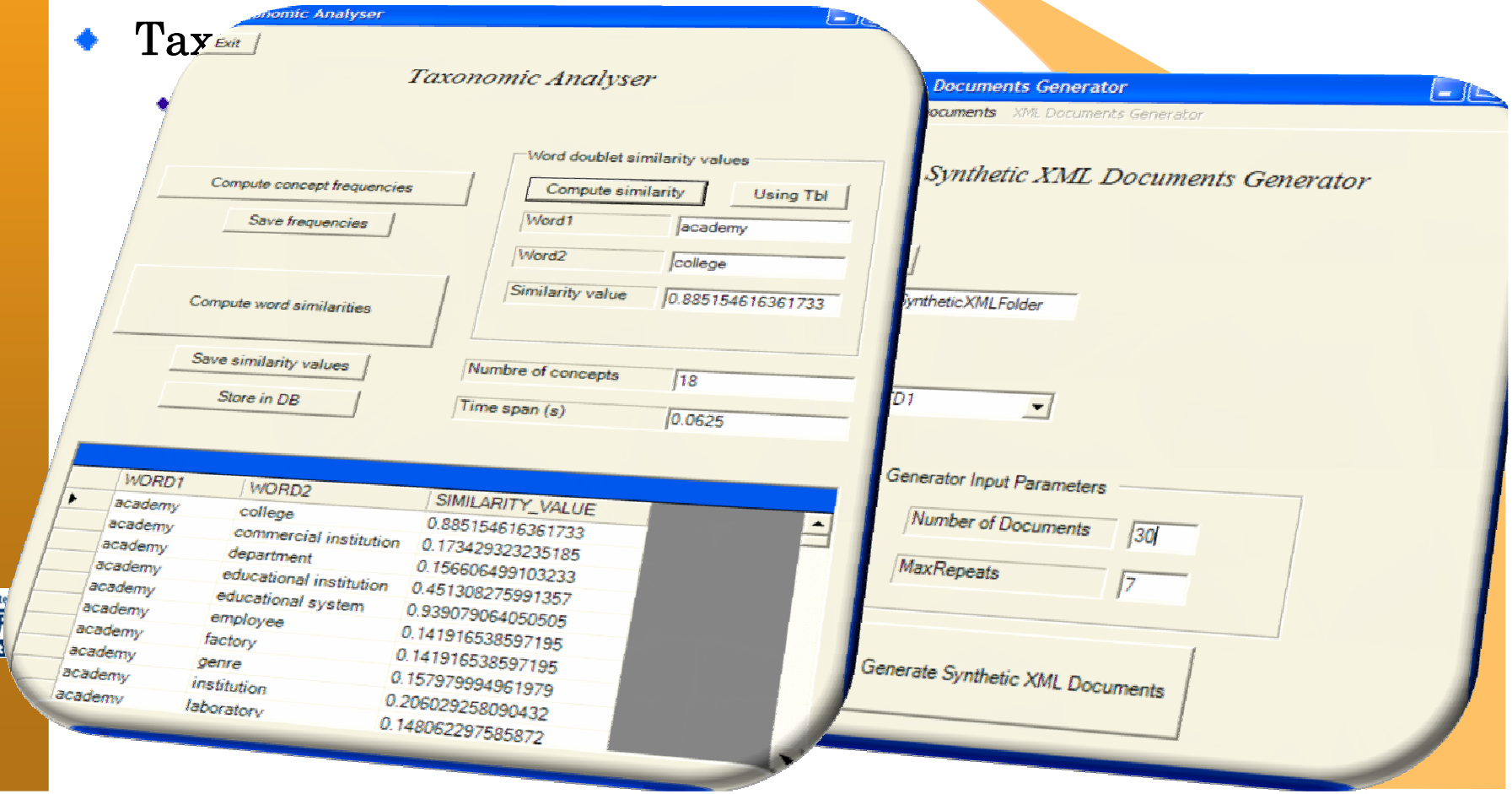
Contributions

- Synthetic XML documents generator
  - Producing sets of XML documents based on given DTDs
- Tax



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Contributions

- Experimental results
  - Higher average similarity values, underlining similarities (of semantic nature) that were previously undetected
  - Straight distinction between documents corresponding to different DTDs
  - Capturing semantic affinities between document sets

```
<!DOCTYPE DTD1 [
<!ELEMENT Academy (Administrative unit+)>
    <!ELEMENT Administrative unit (Branch?)>
        <!ELEMENT Branch (Educator?, Student+)>
            <!ELEMENT Educator (#PCDATA)>
            <!ELEMENT Student (#PCDATA)>   ]>
```

```
<!DOCTYPE DTD2 [
<!ELEMENT School (Administrative unit+)>
    <!ELEMENT Administrative unit (Section?)>
        <!ELEMENT Section (Educator?, Scholar*)>
            <!ELEMENT Educator (#PCDATA)>
            <!ELEMENT Scholar (#PCDATA)>  ]>
```

```
<!DOCTYPE DTD3 [
<!ELEMENT Government (Administrative unit+)>
    <!ELEMENT Administrative unit (Section?)>
        <!ELEMENT Section (Professional?, Worker+)>
            <!ELEMENT Professional (#PCDATA)>
            <!ELEMENT Worker (#PCDATA)>   ]>
```

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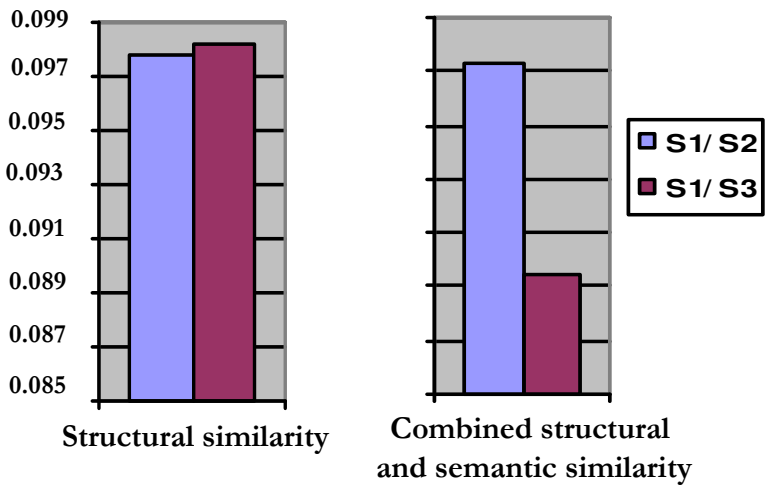
Contributions

- Experimental results
  - Higher average similarity values, underlining similarities (of semantic nature) that were previously undetected
  - Straight distinction between documents corresponding to different DTDs
  - Capturing semantic affinities between document sets



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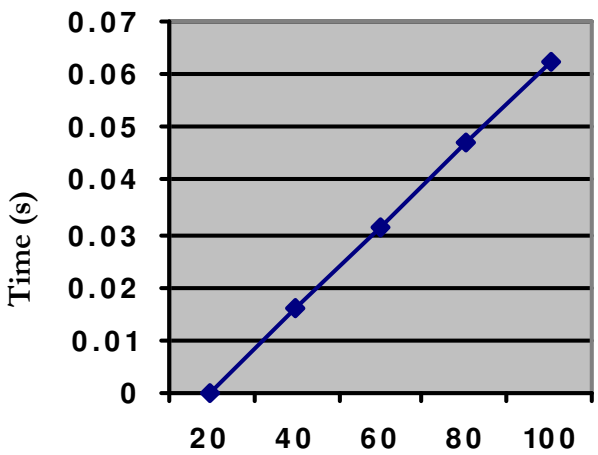
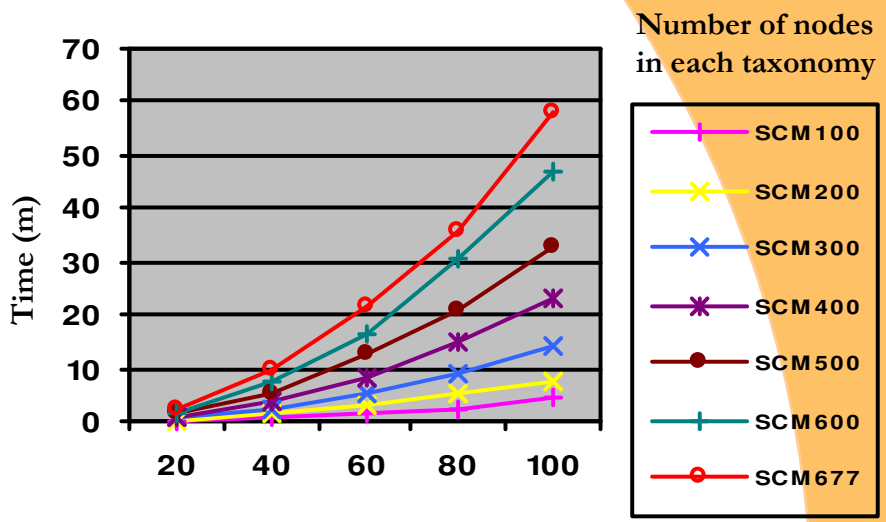
Contributions

- Experimental results

Our approach is of polynomial complexity

- Chawathe's classical *Edit Distance* process [4] being linear in the number of nodes of each tree $O(|A|\ |B|)$





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Contributions

Integrating semantics in XML similarity

- This is the first attempt to combine *Edit Distance* structural similarity computations with IR semantic similarity assessment, in an XML context
- Publications:
  - SOFSEM 2007
    - Tekli J., Chbeir R., Yetongnon K., **A Hybrid Approach for XML Similarity**. In *Proc. of the 33rd International Conference on Current Trends in Theory and Practice of Computer Science*, Springer LNCS, Czech Republic, 2007.
  - COMAD 2006
    - Tekli J., Chbeir R., Yetongnon K., **Semantic and Structure based XML Similarity: An Integrated Approach**. In *Proc. of the 13th International Conference on Management of Data (COMAD)*, New Delhi, India, 2006.

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Overview

- Introduction
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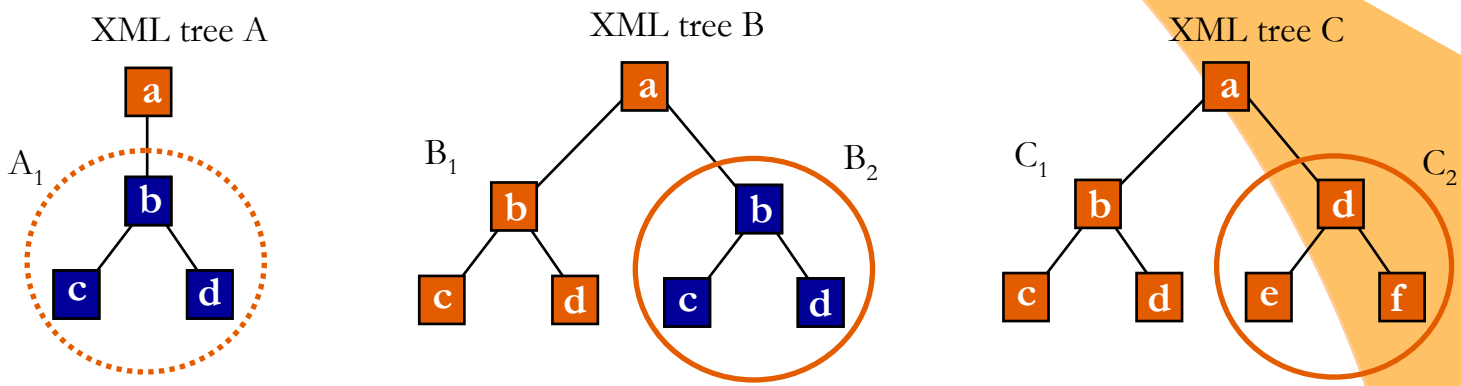
- Applications
- Our contributions
  - Integrating semantics in XML similarity
  - Enhancing XML structural similarity
- Conclusion

Contributions

Enhancing XML structural similarity

- We identified certain cases where existing edit distance approaches yield inaccurate similarity results:
  - Similarity between sub-trees A_1 and B_1



Following Chawathe [4], Dist(A, B) = Dist(A, C) = 3

An extension of Chawathe [4], provided by Nierman and Jagadish [2], is able to detect such sub-tree similarities, i.e. only when the *containment* relation is fulfilled

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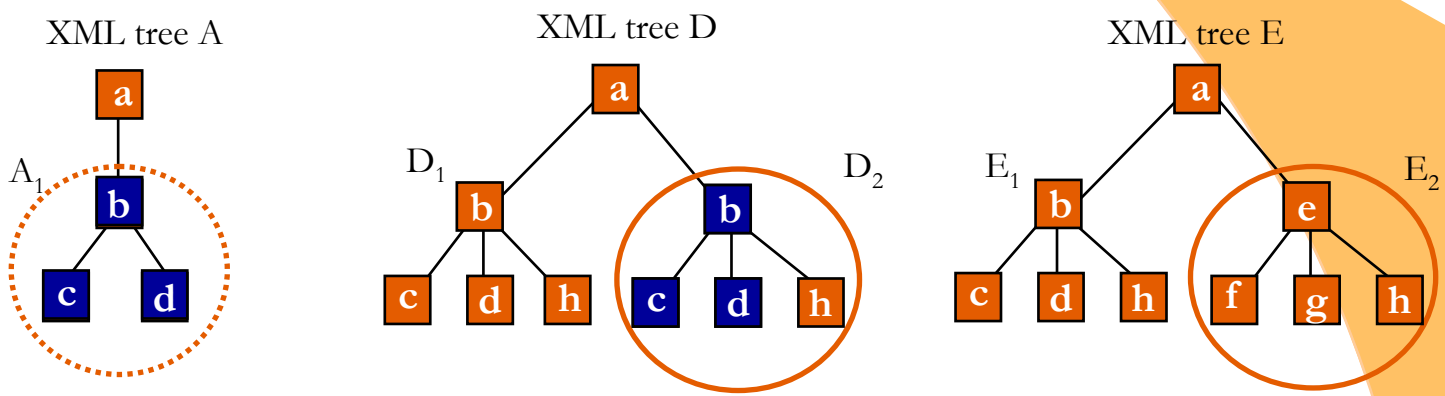
Contributions

Enhancing XML structural similarity

- We identified certain cases where the existing edit distance approaches yield inaccurate similarity results:
  - Similarity between XML trees A/D (sub trees A_1 and D_2) w.r.t. A/E



Following Chawathe [4], Dist(A, D) = Dist(A, E) = 5

The containment relation is not fulfilled

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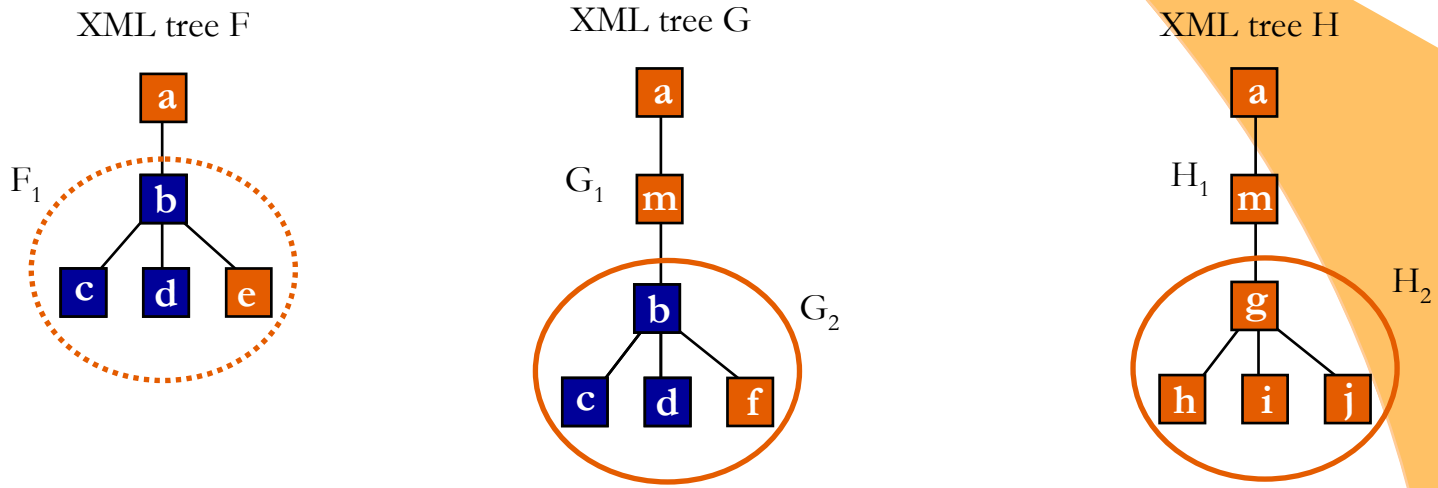
Enhancing XML structural similarity

- We identified certain cases where the existing edit distance approaches yield inaccurate similarity results:
  - Similarity between XML trees F and G (sub-trees F_1 and G_2) w.r.t. F and H



Following Chawathe [4], Dist(F, G) = Dist(F, H) = 7

The containment relation is not fulfilled and the sub-trees sharing structural similarities occur and different depths

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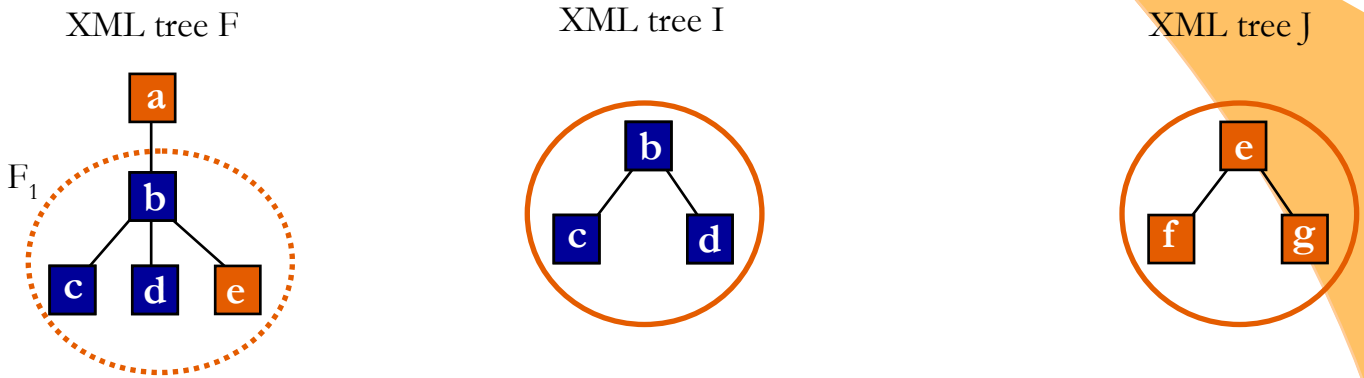
Enhancing XML structural similarity

- We identified certain cases where the existing edit distance approaches yield inaccurate similarity results:
  - Similarity between XML trees F and I (sub-tree F_1 and tree I) w.r.t. F and J



Following Chawathe [4], Dist(F, I) = Dist(F, J) = 6

The containment relation is not fulfilled and structural similarities occur, not only among sub-trees, but also at the sub-tree/tree level

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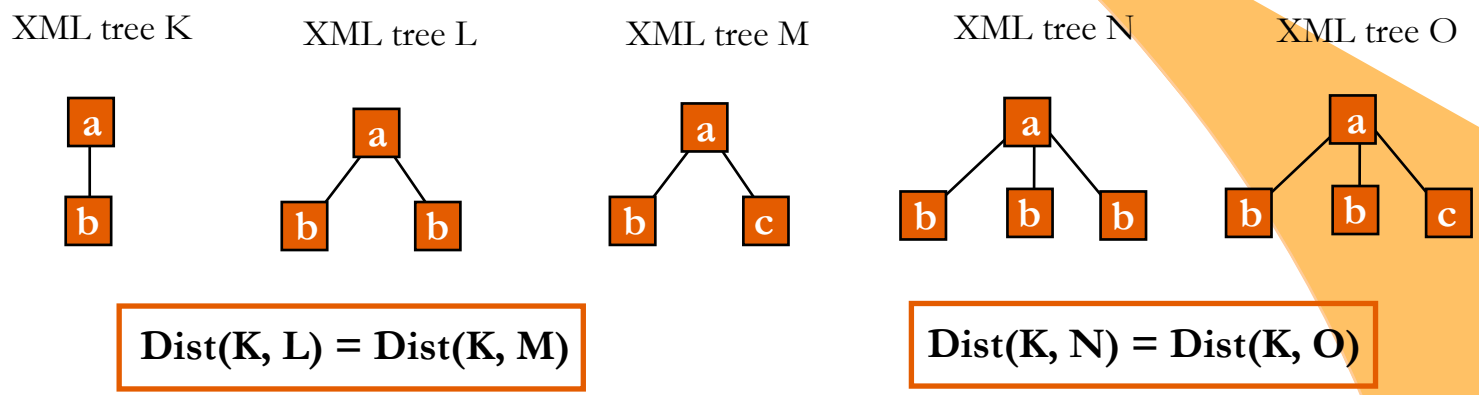
Enhancing XML structural similarity

- In addition, current XML structural similarity approaches overlook the special case of leaf node repetitions:



- We explicitly mention the case of leaf node since:
  - Leaf nodes are a special kind of sub trees: *single node sub-trees*
  - Leaf node repetitions are as frequent as substructure repetitions in XML documents
  - Detecting leaf node repetitions is spontaneous in the XML context, and would help increase the discriminative power of XML comparison methods

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- Our approach
  - is able to provide an improved method for comparing heterogeneous XML documents
  - takes into account sub-tree structural commonalities while comparing XML trees

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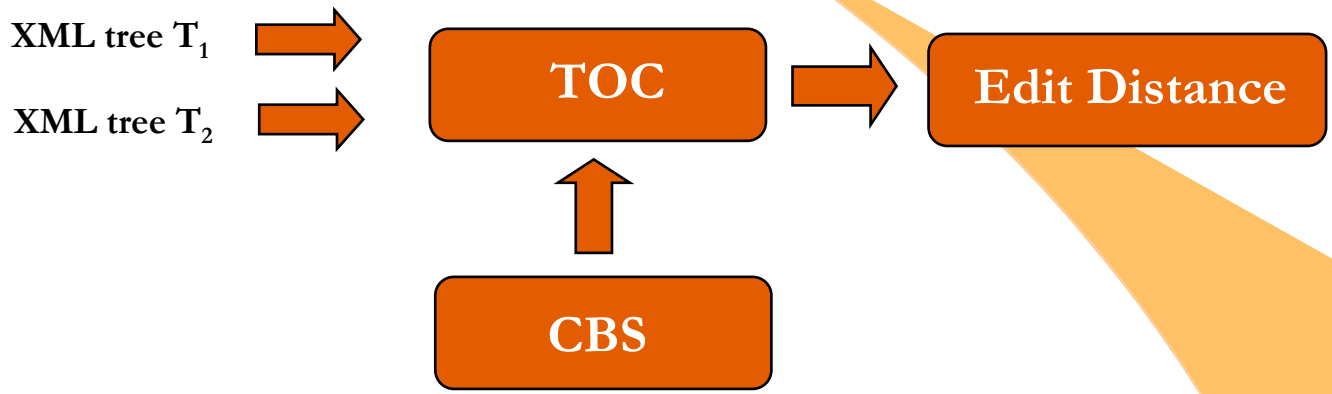
- Overview of our structural similarity approach:



- *CBS*
  - an algorithm for identifying the *Commonality Between Sub-trees*

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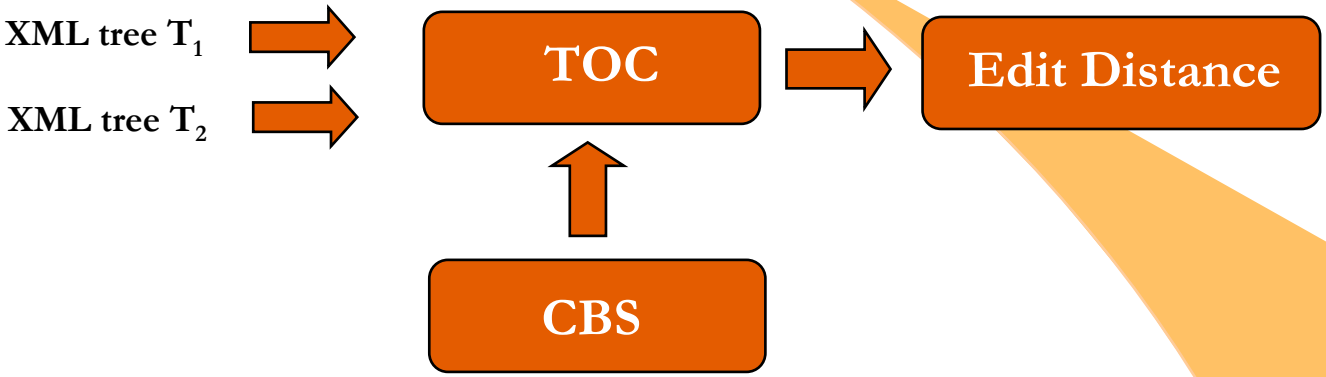
- Overview of our structural similarity approach:



- *TOC*
  - an algorithm for computing the *Tree edit distance Operations Costs*
  - makes use of *CBS*, its results being exploited via [2]'s main edit distance algorithm (Nierman and Jagadish), so as to identify the structural similarity between two XML documents

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Commonality Between Sub-trees (*CBS*)

- Given two sub-trees $A = (a_1, \ldots, a_m)$ and $B = (b_1, \ldots, b_n)$, the structural commonality between A and B, designated by $ComSubTree(A, B)$, is a set of nodes $N = \{n_1, \ldots, n_p\}$ such that $ni \in N$, ni occurs in A and B with the same label, depth and relative node order (in preorder traversal ranking) as in A and B.
- **Formal definition** : For $1 \leq i \leq p$; $1 \leq r \leq m$; $1 \leq u \leq n$:
  - $n_i.l = a_r.l = b_u.l$
  - $n_i.d = a_r.d = b_u.d$
  - For any $n_j \in N / i \leq j$, $as \in A$ and $bv \in B$ such as:
    - $n_j.l = a_s.l = b_v.l$
    - $n_j.d = a_s.d = b_v.d$
    - $r \leq s$, $u \leq v$
  - There is no set of nodes N' that satisfies conditions *1*, *2* and *3* and is of larger cardinality than N.

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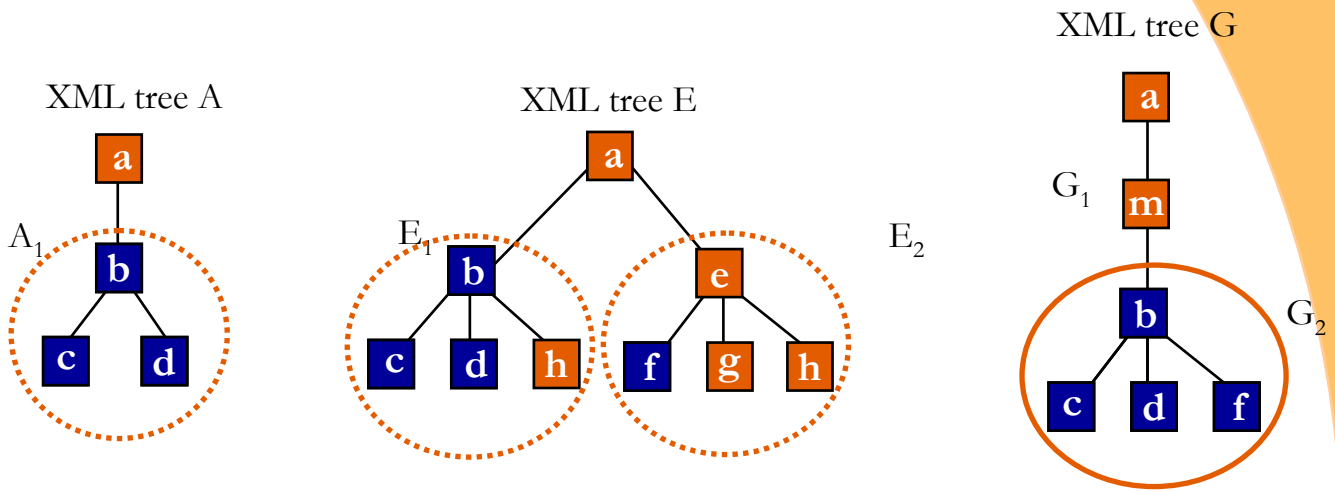
Commonality Between Sub-trees (*CBS*)

- In other words, the problem of finding the structural commonality between two sub-trees T_i and T_j is equivalent to finding the maximum number of matching nodes in T_i and T_j

- For example:
  - *ComSubTree*(A_1, E_1) = 3 (3 structurally matching nodes), *ComSubTree*(A_1, E_2) = 0
  - *ComSubTree*(E_1, G_2) = 3 , *ComSubTree*(E_2, G_2) = 1
  - …



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Commonality Between Sub-trees (*CBS*)

- In other words, the problem of finding the structural commonality between two sub-trees T_i and T_j is equivalent to finding the maximum number of matching nodes in T_i and T_j
  - On the other hand, the problem of finding the shortest edit distance between T_i and T_j comes down to identifying the minimal number of edit operations that can transform T_i to T_j.
  - Those are dual problems since identifying the shortest edit distance between two sub-trees (trees) underscores, in a roundabout way, their maximum number of matching nodes.

- Therefore, our algorithm (*CBS*), for identifying the structural commonality between sub-trees, is based on the edit distance concept

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Commonality Between Sub-trees (*CBS*)

```
Algorithm CBS()
Input: Sub-trees SbT_i and SbT_j (in Id-pair representations)
Output: |ComSubTree(SbT_i, SbT_j)|

Begin
  Dist [][] = new [0...|SbT_i|][0...|SbT_j|]
  Dist[0][0] = 0

  For (n = 1 ; n ≤ |SbT_i| ; n++)
      { Dist[n][0] = Dist[n-1][0] + Cost_Del(SbT_i[n]) }
  For (m = 1 ; m ≤ |SbT_j| ; m++)
      { Dist[0][m] = Dist[0][m-1] + Cost_Ins(SbT_j[m]) }

  For (n = 1 ; n ≤ |SbT_i| ; n++)
  {
     For (m = 1 ; m ≤ |SbT_j| ; m++)
     {
        Dist[n][m] = min{
              If (SbT_i[n].d = SbT_j[m].d & SbT_i[n].l = SbT_j[m].l)
                  { Dist[n-1][m-1] },
              Dist[n-1][m] + Cost_Del(SbT_i[n]),        // simplified node
              Dist[n][m-1] + Cost_Ins(SbT_j[m])         // operations syntaxes.
                        }
     }
  }

  Return (|SbT_i|+|SbT_j| - Dist[|SbT_i|][|SbT_j|]) / 2        // |ComSubTree(SbT_i, SbT_j)|
End
```

CBS can be equally applied on whole trees. Nonetheless, in our approach, its use is couples with sub-trees

Returns the number of structurally matching nodes between two sub-trees

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Commonality Between Sub-trees (*CBS*)

- $|ComSubTree(SbT_i, SbT_j)|$, is identified w.r.t. the minimum edit distance:
  - Total number of deletions - we delete all nodes of SbT_i except those having matching nodes in SbT_j:
    - $|SbT_i| - |ComSubTree(SbT_i, SbT_j)|$
  - Total number of insertions - we insert into SbT_i all nodes of SbT_j except those having matching nodes in $SbTi$:
    - $|SbT_j| - |ComSubTree(SbT_i, SbT_j)|$

- Following *CBS*, the edit distance between sub-trees SbT_i and SbT_j becomes as follows:
  - $Dist[|SbT_i|][|SbT_j|] = \Sigma_{Deletions} \times 1 + \Sigma_{Insertions} \times 1$
    $= |SbT_i| + |SbT_j| - 2\ |ComSubTree(SbT_i, SbT_j)|$

$$|ComSubTree(SbT_i, SbT_j)| = \frac{|SbT_i| + |SbT_j| - Dist[|SbT_i|][|SbT_j|]}{2}$$

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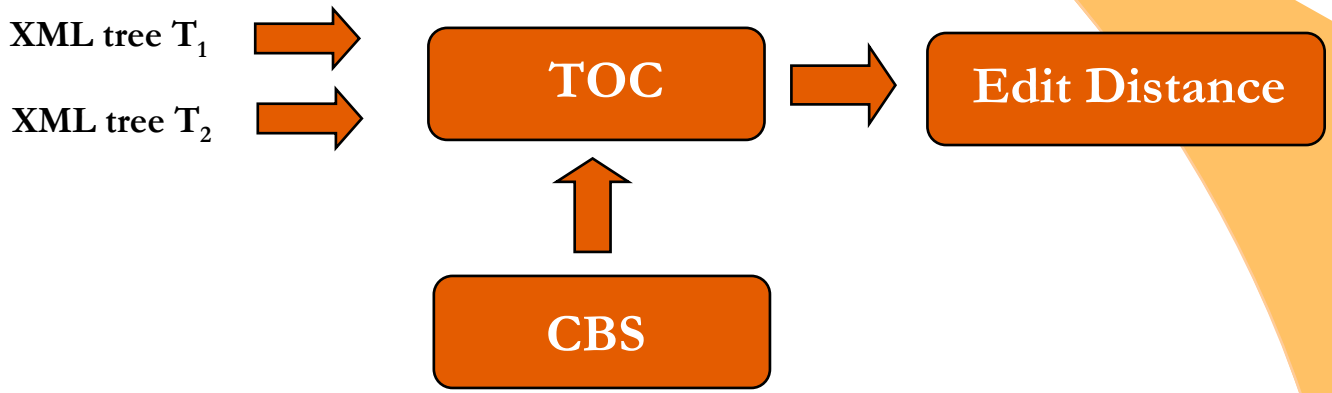
Contributions

Tree edit distance Operations Costs (*TOC*)

- The *CBS* algorithm, for the identification of the *commonality* between sub-trees, is to be utilized in *TOC*: an algorithm dedicated to computing the tree edit distance operations costs



- Consequently, those costs will be exploited via [2]'s main edit distance approach (Nierman and Jagadish) providing an improved and more accurate XML structural similarity measure

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Tree edit distance Operations Costs (*TOC*)

- Using *CBS*, *TOC* identifies the structural *commonality* between each and every pair of sub-trees (SbT_i, SbT_j) in the two trees *A* and *B* being compared, as well as their commonalities with the whole trees A and B.
- Consequently, those values are normalized via corresponding tree/sub-tree cardinalities $Max(|SbT_i|, |SbT_j|)$, to be comprised between 0 and 1 :
  - $$\frac{CBS(SBT_i, SBT_j)}{Max(|SBT_i|, |SBT_j|)} = 0$$ when there's no commonality between SBT_i and SBT_j : $CBS(SBT_i, SBT_j) = 0$
  - $$\frac{CBS(SBT_i, SBT_j)}{Max(|SBT_i|, |SBT_j|)} = 1$$ when SBT_i and SBT_j are identical $CBS(SBT_i, SBT_j) = |SBT_i| = |SBT_j|$

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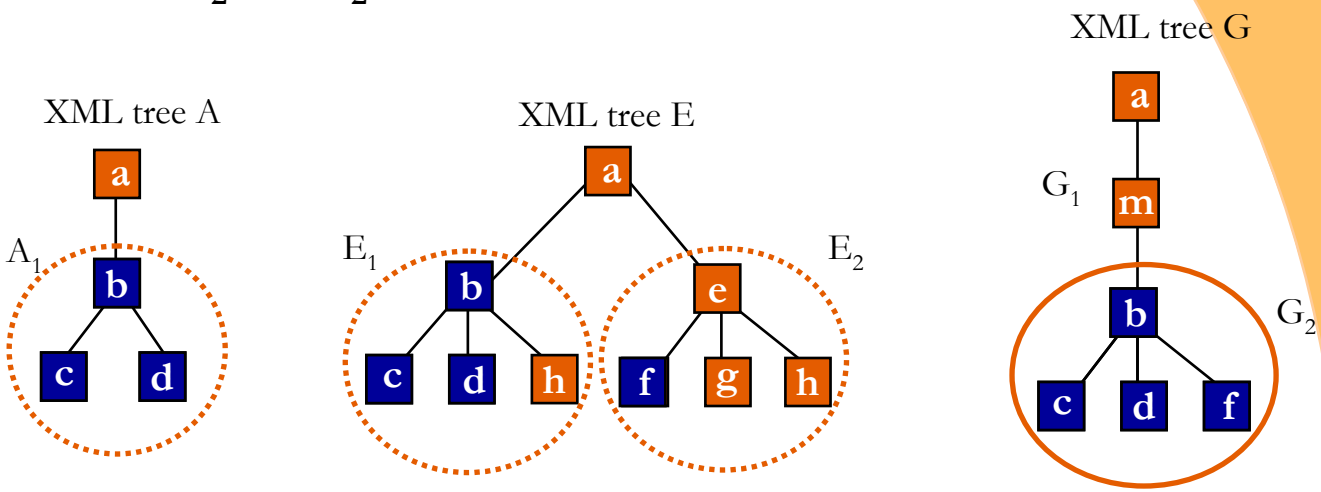
Tree edit distance Operations Costs (*TOC*)

- For example:
  - $$\frac{CBS(A_1, E_1)}{Max(|A_1|, |E_1|)} = \frac{3}{4} = 0.75$$
  - $$\frac{CBS(E_2, G_2)}{Max(|E_2|, |G_2|)} = \frac{1}{4} = 0.25$$



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Tree edit distance Operations Costs (*TOC*)

- Consequently, tree insert/delete operations cos
normalized commonality between the concerne

Algorithm TOC()

Input: Trees T_1 and T_2

Output: insert tree and delete tree operations costs

Begin

For each sub-tree SbT_i in T_1 // Going through // all sub-trees in T_1.

{

$$Cost_{DelTree}(SbT_i) = \sum_{\text{All nodes } x \text{ of } SbT_i} Cost_{Del}(x)$$

For each sub-tree SbT_j in T_2 // Going through // all sub-trees in T_2.

{

$$Cost_{InsTree}(SbT_j) = \sum_{\text{All nodes } x \text{ of } SbT_j} Cost_{Ins}(x)$$

$$Cost_{DelTree}(SbT_i) = \text{Min}\{ Cost_{DelTree}(SbT_i), \sum_{\text{All nodes } x \text{ of } SbT_i} Cost_{Del}(x) \times \frac{1}{1 + \frac{CBS(SbT_i, SbT_j)}{\text{Max}(|SbT_i|, |SbT_j|)}} \}$$

$$Cost_{InsTree}(SbT_j) = \text{Min}\{ Cost_{InsTree}(SbT_j), \sum_{\text{All nodes } x \text{ of } SbT_j} Cost_{Ins}(x) \times \frac{1}{1 + \frac{CBS(SbT_i, SbT_j)}{\text{Max}(|SbT_i|, |SbT_j|)}} \}$$

}

}

Usually, the cost of deleting a tree is equal to the sum of the costs of deleting its nodes

Tree operations costs vary w.r.t. the normalized commonality between the sub-trees in the XML trees being compared

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Contributions

Tree edit distance Operations Costs (*TOC*)

- Tree operations costs vary as follows:
  - **Max Cost:** $Cost_{InsTree/DelTree}(SbT_i) = \sum Cost_{Ins/Del}(x) \times \frac{1}{1+0}$
    - Sum of the costs of inserting/deleting the sub-tree nodes

Minimum normalized commonality

  - **Min Cost:** $Cost_{InsTree/DelTree}(SbT_i) = \sum Cost_{Ins/Del}(x) \times \frac{1}{1+1}$
    - Half its maximum cost

Maximum normalized commonality

We assign tree operation costs in such a way so as to guaranty that the cost of inserting/deleting a non-leaf node sub-tree will never be less than the cost of inserting/deleting a single node.

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Tree edit distance Operations Costs (*TOC*)

- In fact, *TOC* is based on the intuition that tree operations are more costly than node operations.

- *Proof:*
  - *The smallest non-leaf node sub-tree that can be treated via a tree operation is a sub-tree consisting of two nodes.*
  - *For such a tree, the maximum tree operation cost is equal to 2*
  - *The minimum tree operation cost is equal to 1:*
    - *Equivalent to the cost of inserting/deleting a single node,*
    - ***That is the lowest tree operation cost attainable, for a non-leaf node sub-tree following TOC.***

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Tree edit distance Operations Costs (*TOC*)

The special case of leaf node sub-trees:

- The maximum cost for inserting/deleting a single node sub-tree is 1
  - The cost of inserting/deleting the single node at hand
    - $Cost_{InsTree/DelTree}(SbT_i) = Cost_{Ins/Del}(x) \times 1 = 1$

- The minimum cost for deleting a single node sub-tree is equal to $\frac{1}{2}$
  - Half its maximum insert/delete cost
    - $Cost_{InsTree/DelTree}(SbT_i) = Cost_{Ins/Del}(x) \times \frac{1}{2} = \frac{1}{2}$

Following the intuition that tree operations are more costly than node operations.

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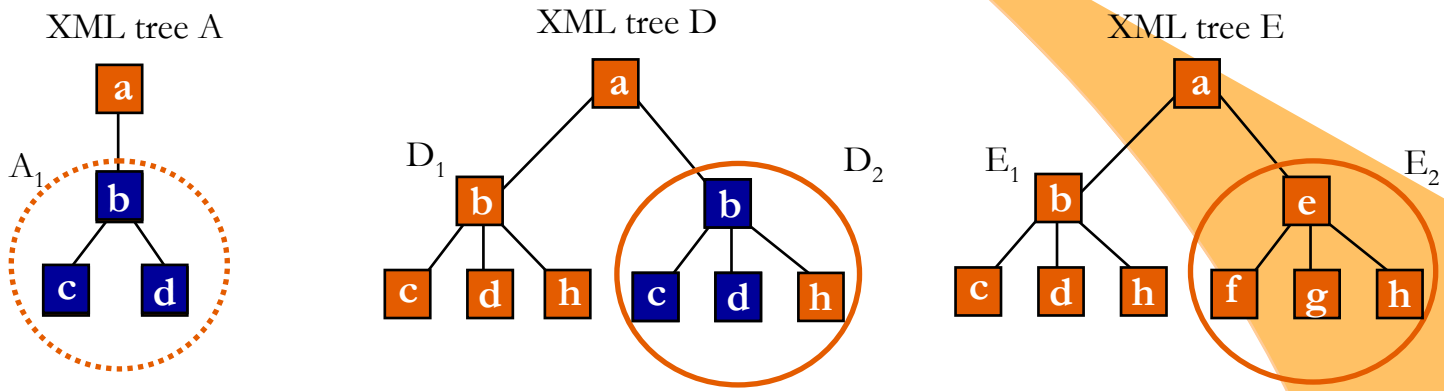
Tree edit distance Operations Costs (*TOC*)

- Computation examples: None leaf-node sub-trees



Following Chawathe [4], Dist(A, D) = Dist(A, E) = 5

- Cost $_{InsTree}(D_2) = 4 \times \dfrac{1}{1 + \dfrac{3}{4}} = 2.2856$

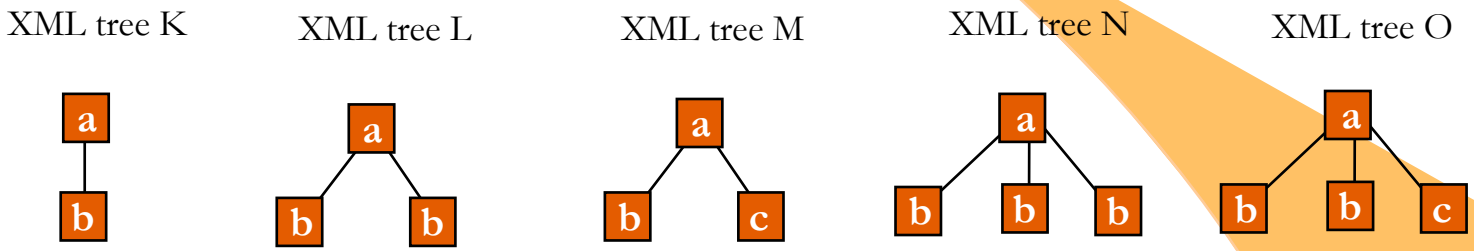
Insertion of node *h*

- Following our approach, **Dist(A, D) = 1 + 2.2856 = 3.2856** $\neq$ Dist(A, E)=5

Contributions

Tree edit distance Operations Costs (*TOC*)

- Computation examples: Leaf node sub-trees



Dist(K, L) = Dist(K, M) = 1

Dist(K, N) = Dist(K, O) = 2

- $\text{Cost}_{\text{InsTree}}(b) = 1 \times \dfrac{1}{1 + \dfrac{1}{1}} = 0.5$
- Following our approach, **Dist(K, L) = 0.5** $\neq$ Dist(K, M) =1
- Following our approach, **Dist(K, N) = 0.5 + 0.5 = 1** $\neq$ Dist(K, O) =2

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Tree edit distance Operations Costs (*TOC*)

- Computation examples: Comparing results with current approaches

	Our Approach		N. & J. [13]	Dalamagas *et al.* [6]	Chawathe [4]
	Distance	*Similarity*			
A/B	1.5	0.4	*Detected*	*Not detected*	*Not detected*
A/C	3	0.25			
A/D	3.2856	0.2333	*Not detected*	*Not detected*	*Not detected*
A/E	5	0.1667			
F/G	5.4106	0.1560	*Not detected*	*Not detected*	*Not detected*
F/H	7	0.125			
F/I	4.2857	0.1892	*Not detected*	*Not detected*	*Not detected*
F/J	6	0.1429			
K/L	0.5	0.6667	*Not detected*	*Not detected*	*Not detected*
K/M	1	0.5			
K/N	1	0.5	*Not detected*	*Not detected*	*Not detected*
K/O	1.5	0.4			

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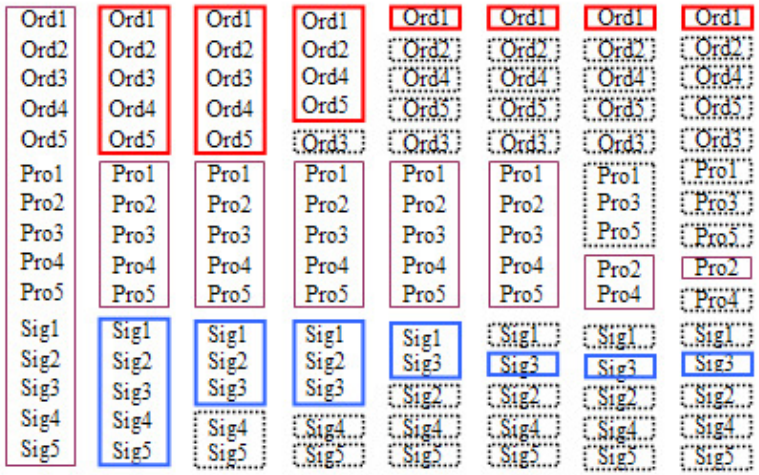
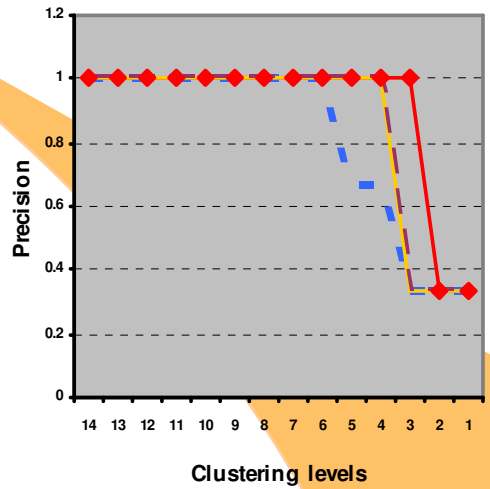
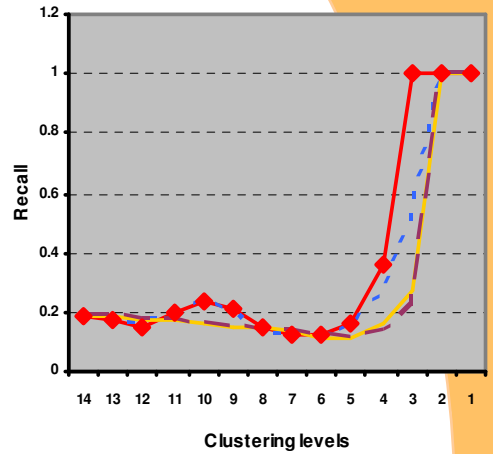
Contributions

- Experiments are based on structural clustering



Level:	1 & 2	3 & 4	5	6 & 7	8	9	10	…, 14
∑a =	5	15	13	12	8	7	4	3
∑b =	10	0	0	0	0	0	0	0
∑c =	0	0	2	3	7	8	11	12
PR =	0.3333	1	1	1	1	1	1	1
R =	1	1	0.8667	0.8	0.5333	0.4667	0.2667	0.2





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Contributions

An improved XML structural similarity approach

- Experiments are based on structural clustering
  - Evaluation on a real data set:
    - Sigmod Record
      - OrdinaryIssuePage.dtd
      - ProceedingsPage.dtd
      - SigmodRecord.dtd
  - Evaluation on a synthetic data set:
    - Two sets of 600 documents each based on real word and synthetic DTDs
      - From http://www.xmlfiles.com and http://www.w3schools.com
    - The first set was created with *MaxRepeats = 5*
    - The second with *MaxRepeats = 10*, the latter set underlining XML documents with greater size and variability w.r.t. the former

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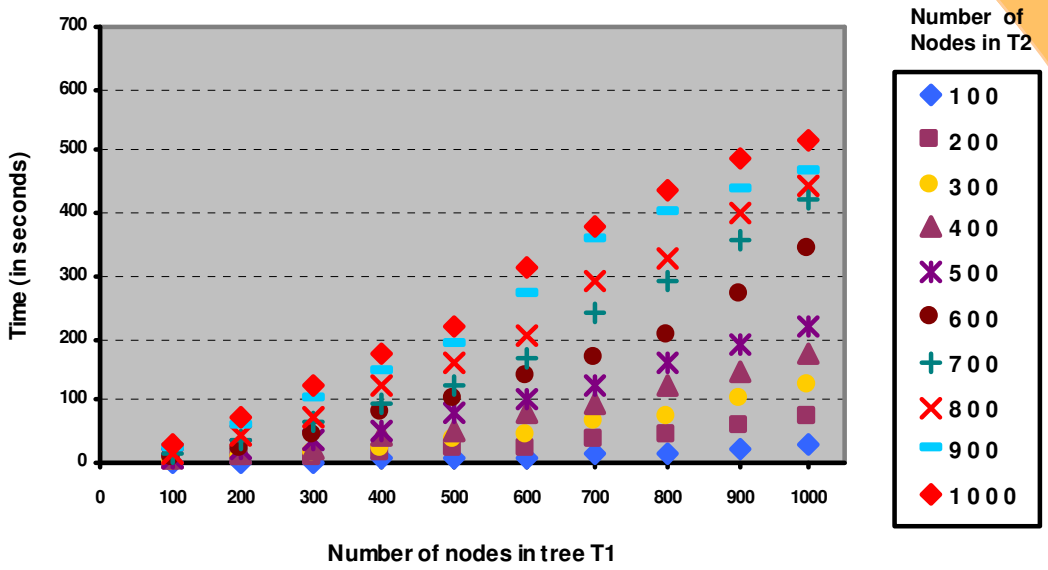
Contributions

An improved XML structural similarity approach

- Timing analysis
  - Our approach is linear in the number of nodes of each tree $\mathcal{O}(|A|\ |B|)$



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Conclusion

- In the past few years, XML has been established as the *de facto* standard format for web publishing [26]
  - Attracting growing attention in information retrieval, database as well as multimedia related research

- As a result, XML similarity becomes a central issue, especially in:
  - Data warehousing
  - Data integration
  - Classification and clustering
  - Information search and retrieval

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Conclusion

- Future work
  - Exploiting semantic similarity to compare, not only the structure of XML documents, but also their information content (values)

```
<Factory>
        <Department>
            <Laboratory>
                <Product> BMW Z3 </Product>
                <Product> BMW X5 </Product>
            </Laboratory>
        </Department>
</Factory>
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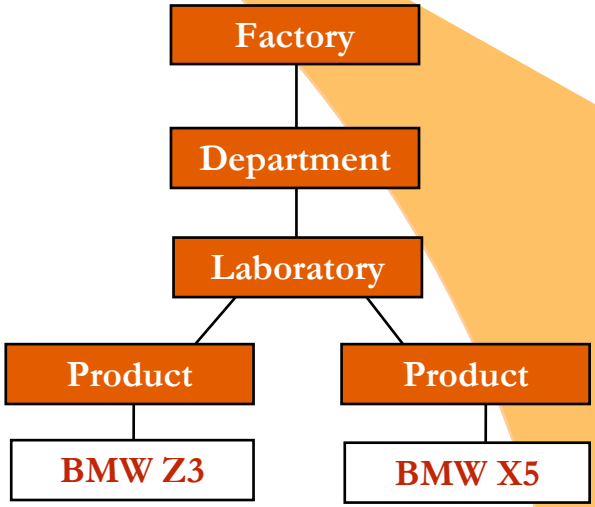

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ありがとう

質問 …

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