Overview

1. Introduction
2. Basic XML concepts
3. Challenges in XML IR
4. Vector space model for XML IR
5. Evaluation of XML IR
Outline

1. Introduction

2. Basic XML concepts

3. Challenges in XML IR

4. Vector space model for XML IR

5. Evaluation of XML IR
IR and relational databases

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- RDB systems are used for querying *relational data*: sets of records that have values for predefined attributes such as employee number, title and salary.
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Some structured data sources containing text are best modeled as structured documents rather than relational data (*Structured retrieval*).
Structured retrieval

Basic setting: queries are structured or unstructured; documents are structured.
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Applications of structured retrieval

Digital libraries, patent databases, blogs, tagged text with entities like persons and locations (named entity tagging).
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Example

- Digital libraries: give me a full-length article on fast fourier transforms
- Patents: give me patents whose claims mention RSA public key encryption and that cite US patent 4,405,829
- Entity-tagged text: give me articles about sightseeing tours of the Vatican and the Coliseum
Why RDB is not suitable in this case

Three main problems
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Solution: adapt ranked retrieval to structured documents to address these problems.
# Structured Retrieval

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### Structured Retrieval

#### RDB search, Unstructured IR, Structured IR

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Standard for encoding structured documents: **Extensible Markup Language (XML)**
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Standard for encoding structured documents: **Extensible Markup Language (XML)**

- structured IR → XML IR
- also applicable to other types of markup (HTML, SGML, ...)

Schütze, Lioma: XML retrieval
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XML document

- Ordered, labeled tree
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- An element can have one or more XML attributes (e.g. `number`)  
- Attributes can have values (e.g. `vii`)  

```xml
<play>
  <author>Shakespeare</author>
  <title>Macbeth</title>
  <act number="I">  
    <scene number="vii">  
      <title>Macbeth’s castle</title>
      <verse>Will I with wine ...
    </verse>
  </scene>
  <act>
  </act>
</play>
```
Ordered, labeled tree

Each node of the tree is an XML element, written with an opening and closing XML tag (e.g. `<title...>`, `</title...>`)  

An element can have one or more XML attributes (e.g. `number`)  

Attributes can have values (e.g. `vii`)  

Attributes can have child elements (e.g. `title, verse`)  

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    </scene>  
  </act>
</play>
```
XML document

- **root element**: play
  - **element**: author
    - text: Shakespeare
  - **element**: act
  - **element**: title
    - text: Macbeth
  - **attribute**: number="I"
  - **element**: scene
    - **attribute**: number="vii"
      - **element**: verse
        - text: Will I with... 
      - **element**: title
        - text: Macbeth's castle
The leaf nodes consist of text.
The *internal nodes* encode **document structure** or **metadata** functions

- **root element**: `play`
  - `author`
    - text: *Shakespeare*
    - attribute: `number="I"`
    - attribute: `number="vii"`
  - `act`
    - `scene`
    - `verse`
    - `title`
  - `title`
    - text: *Macbeth’s castle*
  - `text`: *Will I with ... Macbeth’s castle*
XML basics

- **XML Document Object Model (XML DOM):** standard for accessing and processing XML documents
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- **Schema:** puts constraints on the structure of allowable XML documents. E.g. a schema for Shakespeare’s plays: scenes can only occur as children of acts.
  - Two standards for schemas for XML documents are: XML DTD (document type definition) and XML Schema.
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First challenge: document parts to retrieve

Structured or XML retrieval: users want us to return parts of documents (i.e., XML elements), not entire documents as IR systems usually do in unstructured retrieval.
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Example
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- In this case, the user is probably looking for the scene.
- However, an otherwise unspecified search for *Macbeth* should return the play of this name, not a subunit.
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Solution: structured document retrieval principle
Structured document retrieval principle

One criterion for selecting the most appropriate part of a document:

A system should always retrieve the most specific part of a document answering the query.
Structured document retrieval principle

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- Motivates a retrieval strategy that returns the *smallest unit* that contains the information sought, but does not go below this level.
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- Hard to implement this principle algorithmically. E.g. query: title:Macbeth can match both the title of the tragedy, Macbeth, and the title of Act I, Scene vii, Macbeth’s castle.
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- Hard to implement this principle algorithmically. E.g. query: title:Macbeth can match both the title of the tragedy, Macbeth, and the title of Act I, Scene vii, Macbeth’s castle.
  - But in this case, the title of the tragedy (higher node) is preferred.
  - Difficult to decide which level of the tree satisfies the query.
Second challenge: document parts to index

Central notion for indexing and ranking in IR: document unit or indexing unit.
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Central notion for indexing and ranking in IR: document unit or **indexing unit**.

- In unstructured retrieval, usually straightforward: files on your desktop, email messages, web pages on the web etc.
- In structured retrieval, there are four main different approaches to defining the indexing unit:
  1. non-overlapping pseudodocuments
  2. top down
  3. bottom up
  4. all
XML indexing unit: approach 1

Group nodes into non-overlapping pseudodocuments.
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Group nodes into non-overlapping pseudodocuments.

Indexing units: books, chapters, sections, but \textcolor{red}{without overlap}.
Disadvantage: pseudodocuments may not make sense to the user because they are not coherent units.
XML indexing unit: approach 2

Top down (2-stage process):
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1. start with one of the largest elements as the indexing unit, e.g. the *book* element in a collection of books

2. then, postprocess search results to find for each book the subelement that is the best hit.
XML indexing unit: approach 2

Top down (2-stage process):

1. start with one of the largest elements as the indexing unit, e.g. the *book* element in a collection of books
2. then, postprocess search results to find for each book the subelement that is the best hit.

This two-stage retrieval process often fails to return the best subelement because the relevance of a whole book is often not a good predictor of the relevance of small subelements within it.
XML indexing unit: approach 3

Bottom up:
Instead of retrieving large units and identifying subelements (top down), we can search all leaves, select the most relevant ones and then extend them to larger units in postprocessing.
XML indexing unit: approach 3

Bottom up:
Instead of retrieving large units and identifying subelements (top down), we can search all leaves, select the most relevant ones and then extend them to larger units in postprocessing.
Similar problem as top down: the relevance of a leaf element is often not a good predictor of the relevance of elements it is contained in.
XML indexing unit: approach 4

Index all elements: the least restrictive approach.
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Index all elements: the least restrictive approach.

Also problematic:

- many XML elements are not meaningful search results, e.g., an ISBN number.
- indexing all elements means that search results will be highly redundant.
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Example

For the query *Macbeth’s castle* we would return all of the *play*, *act*, *scene* and *title* elements on the path between the root node and *Macbeth’s castle*. The leaf node would then occur 4 times in the result set: 1 directly and 3 as part of other elements.
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We call elements that are contained within each other **nested elements**. Returning redundant nested elements in a list of returned hits is not very user-friendly.
Third challenge: nested elements

Because of the redundancy caused by nested elements it is common to restrict the set of elements eligible for retrieval.
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In most of these approaches, result sets will still contain nested elements.
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**Highlighting**

- **Gain 1**: enables users to scan medium-sized elements (e.g., a section); thus, if the section and the paragraph both occur in the results list, it is sufficient to show the section.
- **Gain 2**: paragraphs are presented in-context (i.e., their embedding section). This context may be helpful in interpreting the paragraph.
Nested elements and term statistics

Further challenge related to nesting: we may need to distinguish different contexts of a term when we compute term statistics for ranking, in particular inverse document frequency (idf).
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Example

The term *Gates* under the node *author* is unrelated to an occurrence under a content node like *section* if used to refer to the plural of *gate*. It makes little sense to compute a single document frequency for *Gates* in this example.
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Solution: compute idf for XML-context term pairs.

- sparse data problems (many XML-context pairs occur too rarely to reliably estimate df)
- compromise: consider the parent node $x$ of the term and not the rest of the path from the root to $x$ to distinguish contexts.
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Main idea: lexicalised subtrees

Aim: to have each dimension of the vector space encode a word together with its position within the XML tree.
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How: Map XML documents to lexicalised subtrees.
Main idea: lexicalised subtrees
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Take each text node (leaf) and break it into multiple nodes, one for each word. E.g. split *Bill Gates* into *Bill* and *Gates*. 
Main idea: lexicalised subtrees

1. Take each text node (leaf) and break it into multiple nodes, one for each word. E.g. split *Bill Gates* into *Bill* and *Gates*.

2. Define the dimensions of the vector space to be lexicalized subtrees of documents – subtrees that contain at least one vocabulary term.
Lexicalised subtrees

We can now represent queries and documents as vectors in this space of lexicalized subtrees and compute matches between them, e.g. using the vector space formalism.
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**Vector space formalism in unstructured VS. structured IR**

The main difference is that the dimensions of vector space in unstructured retrieval are vocabulary terms whereas they are lexicalized subtrees in XML retrieval.
There is a tradeoff between the dimensionality of the space and accuracy of query results.
Structural term

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- If we restrict dimensions to vocabulary terms, then we have a standard vector space retrieval system that will retrieve many documents that do not match the structure of the query (e.g., Gates in the title as opposed to the author element).

- If we create a separate dimension for each lexicalized subtree occurring in the collection, the dimensionality of the space becomes too large.
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- If we restrict dimensions to vocabulary terms, then we have a standard vector space retrieval system that will retrieve many documents that do not match the structure of the query (e.g., Gates in the title as opposed to the author element).
- If we create a separate dimension for each lexicalized subtree occurring in the collection, the dimensionality of the space becomes too large.

**Compromise:** index all paths that end in a single vocabulary term, in other words, all XML-context term pairs. We call such an XML-context term pair a **structural term** and denote it by $\langle c, t \rangle$: a pair of XML-context $c$ and vocabulary term $t$. 
Context resemblance

A simple measure of the similarity of a path $c_q$ in a query and a path $c_d$ in a document is the following context resemblance function $CR$:

$$CR(c_q, c_d) = \begin{cases} \frac{1+|c_q|}{1+|c_d|} & \text{if } c_q \text{ matches } c_d \\ 0 & \text{if } c_q \text{ does not match } c_d \end{cases}$$

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$|c_q|$ and $|c_d|$ are the number of nodes in the query path and document path, resp.
$c_q$ matches $c_d$ iff we can transform $c_q$ into $c_d$ by inserting additional nodes.
Context resemblance example

\[ q_3 \]

\[ q_4 \]

\[ d_2 \]

\[ d_3 \]
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CR(c_{q4}, c_{d2}) = \frac{3}{4} = 0.75.
\]
Context resemblance example

\[
CR(c_q, c_d) = \begin{cases} 
\frac{1+|c_q|}{1+|c_d|} & \text{if } c_q \text{ matches } c_d \\
0 & \text{if } c_q \text{ does not match } c_d
\end{cases}
\]

\[CR(c_{q4}, c_{d2}) = \frac{3}{4} = 0.75. \text{ The value of } CR(c_q, c_d) \text{ is } 1.0 \text{ if } q \text{ and } d \text{ are identical.}\]
Context resemblance exercise

\[ CR(c_q, c_d) = \begin{cases} 
\frac{1 + |c_q|}{1 + |c_d|} & \text{if } c_q \text{ matches } c_d \\
0 & \text{if } c_q \text{ does not match } c_d 
\end{cases} \]

\[ CR(c_{q4}, c_{d3}) = ? \]
Context resemblance exercise

\[
\text{CR}(c_q, c_d) = \begin{cases} 
\frac{1 + |c_q|}{1 + |c_d|} & \text{if } c_q \text{ matches } c_d \\
0 & \text{if } c_q \text{ does not match } c_d 
\end{cases}
\]

\[
\text{CR}(c_{q_3}, c_{d_3}) = \frac{3}{5} = 0.6.
\]
Document similarity measure

The final score for a document is computed as a variant of the cosine measure, which we call $\text{SimNoMerge}$. 

$$\text{SimNoMerge}(q, d) = \frac{\sum_{c_k \in B} \sum_{c_l \in B} C_R(c_k, c_l) \sum_{t \in V} \text{weight}(q, t, c_k) \text{weight}(d, t, c_l)}{\sqrt{\sum_{c \in B, t \in V} \text{weight}^2(d, t, c)}}$$

- $V$ is the vocabulary of non-structural terms.
- $B$ is the set of all XML contexts.
- $\text{weight}(q, t, c)$, $\text{weight}(d, t, c)$ are the weights of term $t$ in XML context $c$ in query $q$ and document $d$, resp. (standard weighting e.g. $\text{idf}_t \cdot \text{wf}_{t,d}$, where $\text{idf}_t$ depends on which elements we use to compute $\text{df}_t$.)

$\text{SimNoMerge}(q, d)$ is not a true cosine measure since its value can be larger than 1.0.
SimNoMerge algorithm

ScoreDocumentsWithSimNoMerge(q, B, V, N, normalizer)

1. for n ← 1 to N
2. do score[n] ← 0
3. for each ⟨cq, t⟩ ∈ q
4. do wq ← WEIGHT(q, t, cq)
5. for each c ∈ B
6. do if CR(cq, c) > 0
7. then postings ← GetPostings(⟨c, t⟩)
8. for each posting ∈ postings
9. do x ← CR(cq, c) * wq * weight(posting)
10. score[docID(posting)]+ = x
11. for n ← 1 to N
12. do score[n] ← score[n] / normalizer[n]
13. return score
Initiative for the Evaluation of XML Retrieval (INEX)

INEX: standard benchmark evaluation (yearly) that has produced test collections (documents, sets of queries, and relevance judgments).
Based on IEEE journal collection (since 2006 INEX uses the much larger English Wikipedia as a test collection).
The relevance of documents is judged by human assessors.
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**INEX 2002 collection statistics**

| 12,107   | number of documents |
| 494 MB   | size                |
| 1995–2002| time of publication of articles |
| 1,532    | average number of XML nodes per document |
| 6.9      | average depth of a node |
| 30       | number of CAS topics |
| 30       | number of CO topics  |
INEX topics

Two types:

1. content-only or **CO topics**: regular keyword queries as in unstructured information retrieval

2. content-and-structure or **CAS topics**: have structural constraints in addition to keywords
INEX topics

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1. content-only or **CO topics**: regular keyword queries as in unstructured information retrieval

2. content-and-structure or **CAS topics**: have structural constraints in addition to keywords

Since CAS queries have both structural and content criteria, relevance assessments are more complicated than in unstructured retrieval.
INEX relevance assessments

INEX 2002 defined component coverage and topical relevance as orthogonal dimensions of relevance.
INEX relevance assessments

INEX 2002 defined **component coverage** and **topical relevance** as orthogonal dimensions of relevance.

**Component coverage**

Evaluates whether the element retrieved is “structurally” correct, i.e., neither too low nor too high in the tree.
INEX relevance assessments

INEX 2002 defined component coverage and topical relevance as orthogonal dimensions of relevance.

Component coverage

Evaluates whether the element retrieved is “structurally” correct, i.e., neither too low nor too high in the tree.

We distinguish four cases:

1. Exact coverage (E): The information sought is the main topic of the component and the component is a meaningful unit of information.
2. Too small (S): The information sought is the main topic of the component, but the component is not a meaningful (self-contained) unit of information.
3. Too large (L): The information sought is present in the component, but is not the main topic.
4. No coverage (N): The information sought is not a topic of the component.
The **topical relevance** dimension also has four levels: highly relevant (3), fairly relevant (2), marginally relevant (1) and nonrelevant (0).
INEX relevance assessments

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**Combining the relevance dimensions**

Components are judged on both dimensions and the judgments are then combined into a digit-letter code, e.g. 2S is a fairly relevant component that is too small. In theory, there are 16 combinations of coverage and relevance, but many cannot occur. For example, a nonrelevant component cannot have exact coverage, so the combination 3N is not possible.
The relevance-coverage combinations are quantized as follows:

\[
Q(\text{rel}, \text{cov}) = \begin{cases} 
1.00 & \text{if } (\text{rel}, \text{cov}) = 3E \\
0.75 & \text{if } (\text{rel}, \text{cov}) \in \{2E, 3L\} \\
0.50 & \text{if } (\text{rel}, \text{cov}) \in \{1E, 2L, 2S\} \\
0.25 & \text{if } (\text{rel}, \text{cov}) \in \{1S, 1L\} \\
0.00 & \text{if } (\text{rel}, \text{cov}) = 0N 
\end{cases}
\]

This evaluation scheme takes account of the fact that binary relevance judgments, which are standard in unstructured IR, are not appropriate for XML retrieval. The quantization function \( Q \) does not impose a binary choice relevant/nonrelevant and instead allows us to grade the component as partially relevant.
INEX relevance assessments

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This evaluation scheme takes account of the fact that binary relevance judgments, which are standard in unstructured IR, are not appropriate for XML retrieval. The quantization function \(Q\) does not impose a binary choice relevant/nonrelevant and instead allows us to grade the component as partially relevant. The number of relevant components in a retrieved set \(A\) of components can then be computed as:

\[
\#(\text{relevant items retrieved}) = \sum_{c \in A} Q(\text{rel}(c), \text{cov}(c))
\]
INEX evaluation measures

As an approximation, the standard definitions of precision and recall can be applied to this modified definition of relevant items retrieved, with some subtleties because we sum graded as opposed to binary relevance assessments.
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**Drawback**

Overlap is not accounted for. Accentuated by the problem of multiple nested elements occurring in a search result.
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**Drawback**

Overlap is not accounted for. Accentuated by the problem of multiple nested elements occurring in a search result.

Recent INEX focus: develop algorithms and evaluation measures that return non-redundant results lists and evaluate them properly.
Recap

- Structured or XML IR: effort to port unstructured (standard) IR know-how onto a scenario that uses structured (DB-like) data
- Specialised applications (e.g. patents, digital libraries)
- A decade old, unsolved problem
- [http://inex.is.informatik.uni-duisburg.de/](http://inex.is.informatik.uni-duisburg.de/)