XML Indexing and Search

Native XML Database

- Uses XML document as logical unit
- Should support
  - Elements
  - Attributes
- Contrast with
  - DB modified for XML
  - Generic IR system modified for XML

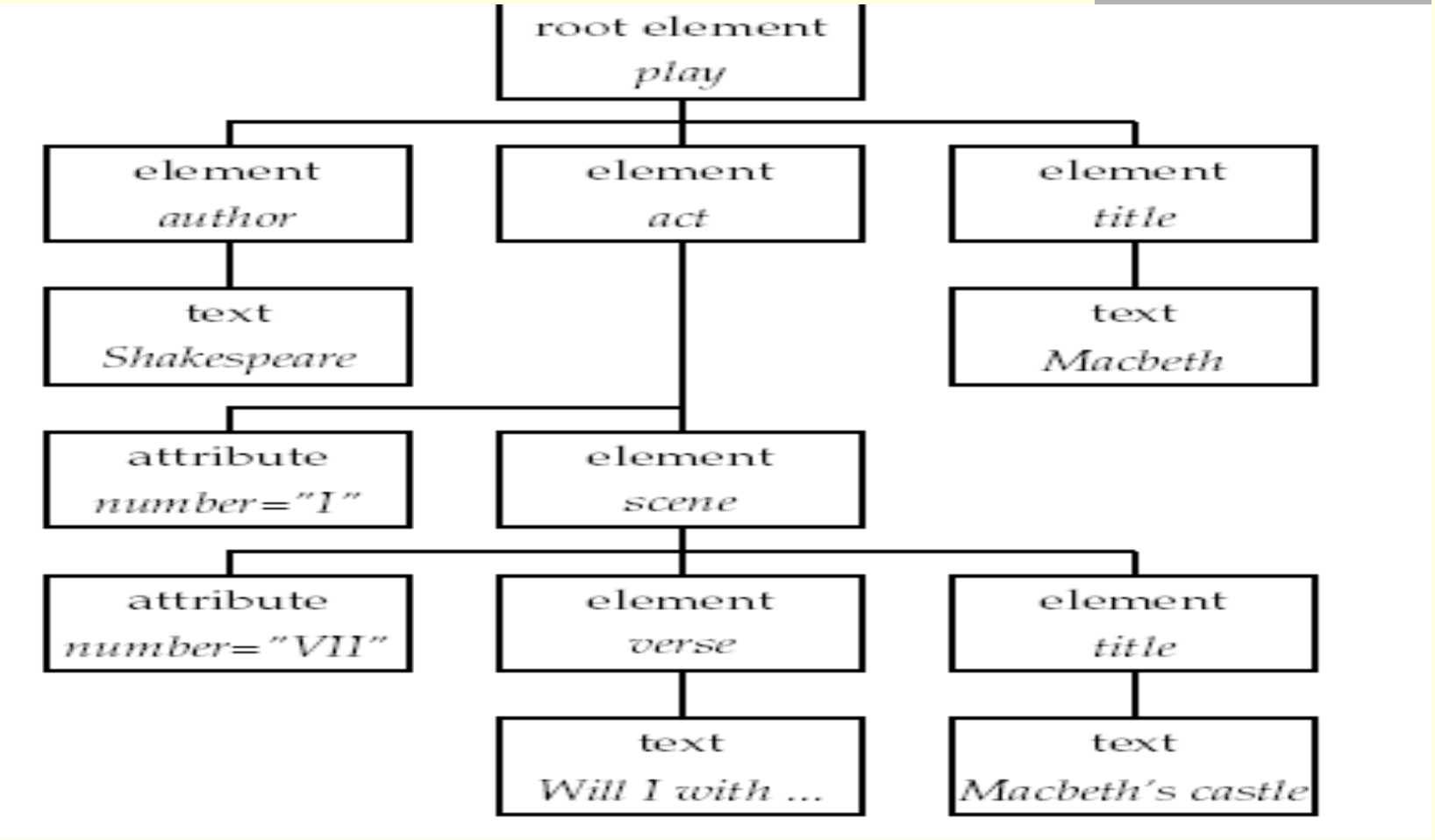
Semi structured Retrieval

XML documents are semi structured.

Can be viewed as an ordered, labeled tree:

- *leaf nodes* containing text
- *internal nodes* define the roles of the leaf nodes in the document.
- the labeled internal nodes encode either the structure of the document (*title*, *act*, and *scene*) or metadata functions (*author*).

```
<play>
  <author>Shakespeare</author>
  <title>Macbeth</title>
  <act number="I">
    <scene number="VII">
      <title>Macbeth's castle</title>
      <verse>Will I with wine and wassail ...</verse>
    </scene>
  </act>
</play>
```


root element
play
element
author
element
act
element
title
text
Shakespeare
text
Macbeth
attribute
number="I"
element
scene
attribute
number="VII"
element
verse
element
title
text
Will I with ...
text
Macbeth's castle

- The nodes of the tree are *XML elements* and are written with an opening and closing *tag*.
- An element can have one or more *XML attributes*.
- XML documents are processed and accessed through XML Document Object Model or *DOM*.
- DOM represents elements, attributes and text within elements as nodes in a tree.

- *XPath* is the standard for paths in XML (referred as Context)
- Ex:

act/scene -selects all *scene* elements whose parent is an *act* element.

- play//scene selects all *scene* elements occurring in a *play* element.
- /play/title
- /play//title
- /scene/title selects no elements.

XML Indexing and Search

- Most native XML databases have taken a DB approach
  - Exact match
  - Evaluate path expressions
  - No IR type relevance ranking
- Only a few that focus on relevance ranking

Data vs. Text-centric XML

- Data-centric XML: used for messaging between enterprise applications
  - Mainly a recasting of relational data
- Content-centric XML: used for annotating content
  - Rich in text
  - Demands good integration of text retrieval functionality
  - E.g., find me the ISBN #s of Books with at least three Chapters discussing cocoa production, ranked by Price

IR XML Challenge 1: Term Statistics

- There is no document unit in XML
- How do we compute tf and idf?
- Global tf/idf over all text context is useless
- Indexing granularity

IR XML Challenge 2: Fragments

- IR systems don't store content (only index)
- Need to go to document for retrieving/ displaying fragment
  - E.g., give me the Abstracts of Papers on existentialism
  - Where do you retrieve the Abstract from?
- Easier in DB framework

IR XML Challenges 3: Schemas

- Ideally:
  - There is one schema
  - User understands schema
- In practice: rare
  - Many schemas
  - Schemas not known in advance
  - Schemas change
  - Users don’t understand schemas
- Need to identify similar elements in different schemas
  - Example: employee

IR XML Challenges 4: UI

- Help user find relevant nodes in schema
  - Author, editor, contributor, “from:”/sender
- What is the query language you expose to the user?
  - Specific XML query language? No.
  - Forms? Parametric search?
  - A textbox?
- In general: design layer between XML and user

IR XML Challenges 5: using a DB

- Why you don’t want to use a DB
  - Spelling correction
  - Mid-word wildcards
  - Contains vs “is about”
  - DB has no notion of ordering
  - Relevance ranking

XIRQL

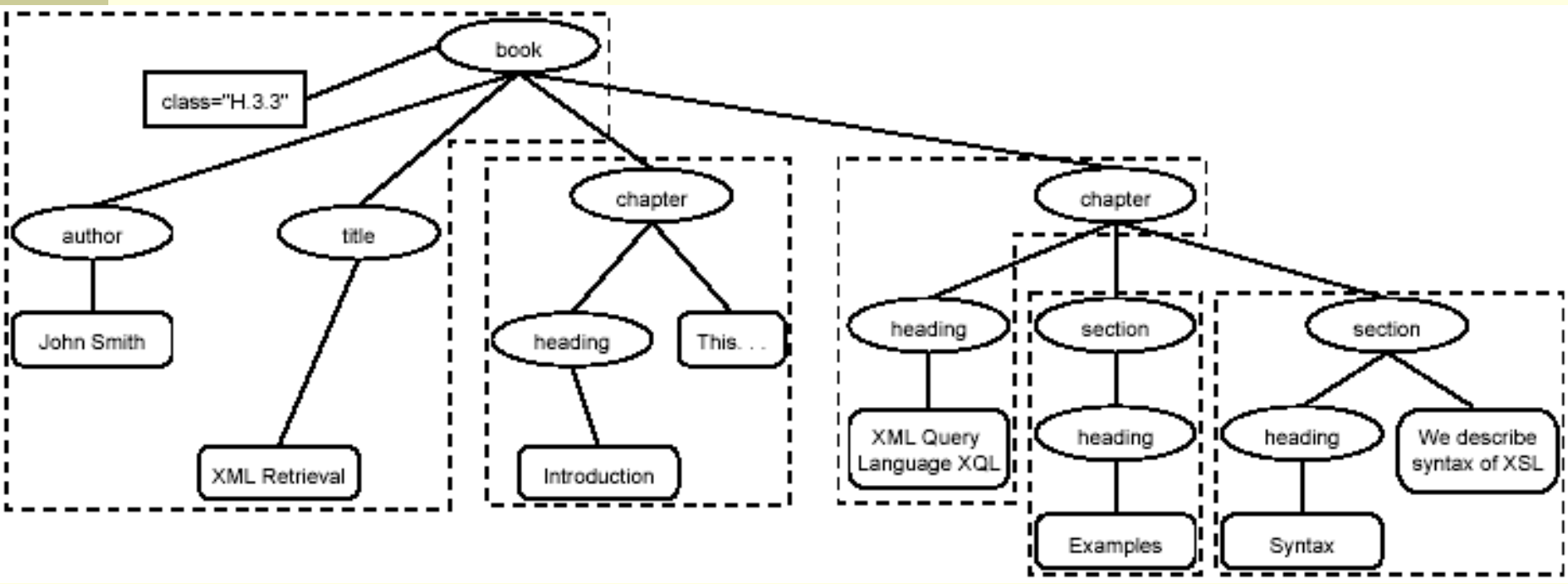
XIRQL

- University of Dortmund
  - Goal: open source XML search engine
- Motivation
  - “Returnable” fragments are special
    - E.g., don’t return a <bold> some text </bold> fragment
  - Structured Document Retrieval Principle
  - Empower users who don’t know the schema
    - Enable search for any person no matter how schema encodes the data
    - Don’t worry about attribute/element

Atomic Units

- Specified in schema
- Only atomic units can be returned as result of search (unless unit specified)
- Tf.idf weighting is applied to atomic units

XIRQL Indexing



Structured Document Retrieval Principle

- A system should always retrieve the most specific part of a document answering a query.
- Example query: xql
- Document:
  <chapter> 0.3 XQL
  <section> 0.5 example </section>
  <section> 0.8 XQL 0.7 syntax </section>
  </chapter>
- Return section, not chapter

- motivates a retrieval strategy that returns the smallest unit that contains the information
- hard to implement this principle algorithmically.

Text-Centric XML Retrieval

Text-centric XML retrieval

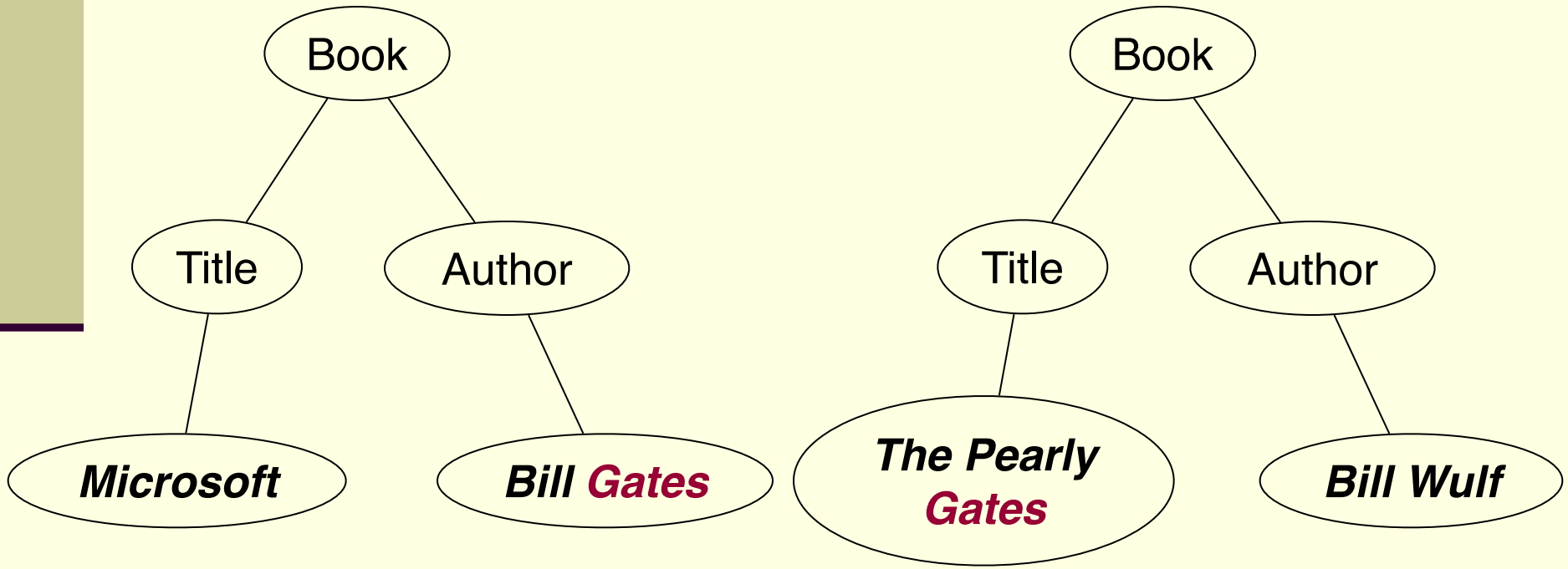
- Documents marked up as XML
  - E.g., assembly manuals, journal issues …
- Queries are user information needs
  - E.g., give me the Section (element) of the document that tells me how to change a brake light
- Different from well-structured XML queries where you tightly specify what you're looking for.

Vector spaces and XML

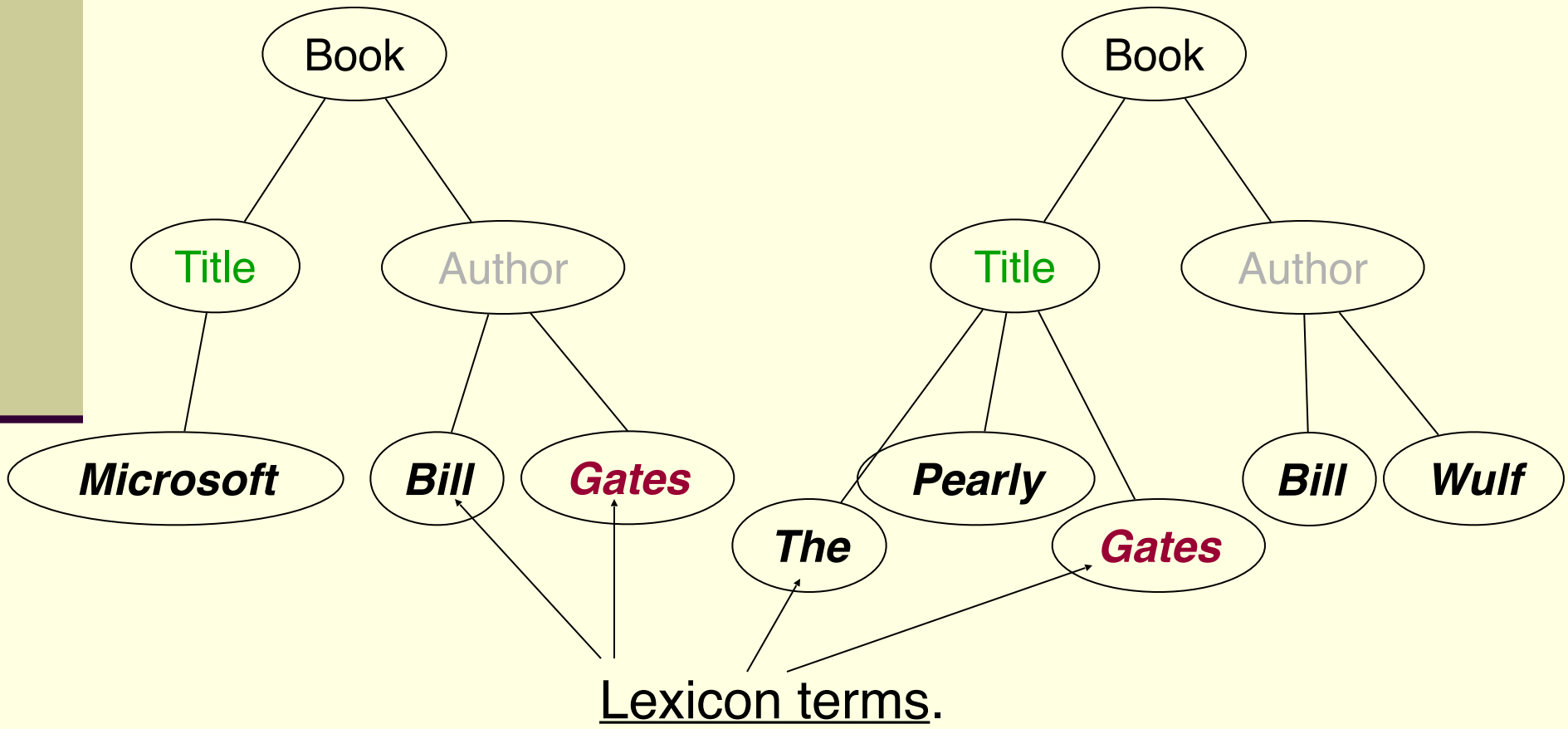
- Vector spaces – tried+tested framework for keyword retrieval
  - Other “bag of words” applications in text: classification, clustering …
- For text-centric XML retrieval, can we make use of vector space ideas?
- Challenge: capture the structure of an XML document in the vector space.

Vector spaces and XML

- For instance, distinguish between the following two cases



Content-rich XML: representation

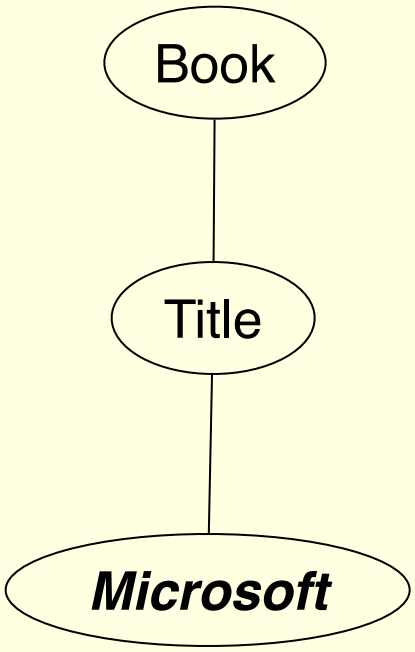


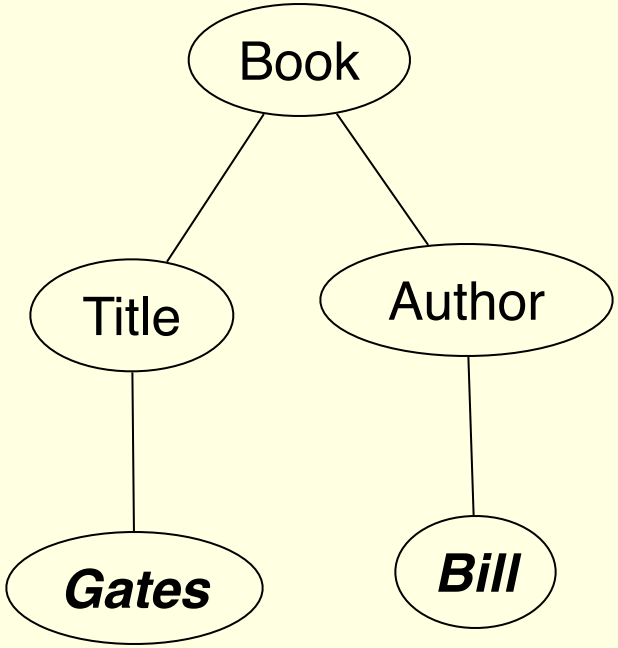
Encoding the Gates differently

- What are the axes of the vector space?
- In text retrieval, there would be a single axis for Gates
- Here we must separate out the two occurrences, under Author and Title
- Thus, axes must represent not only terms, but something about their position in an XML tree

Queries

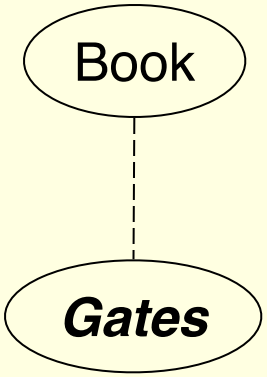
- Before addressing this, let us consider the kinds of queries we want to handle





Query types

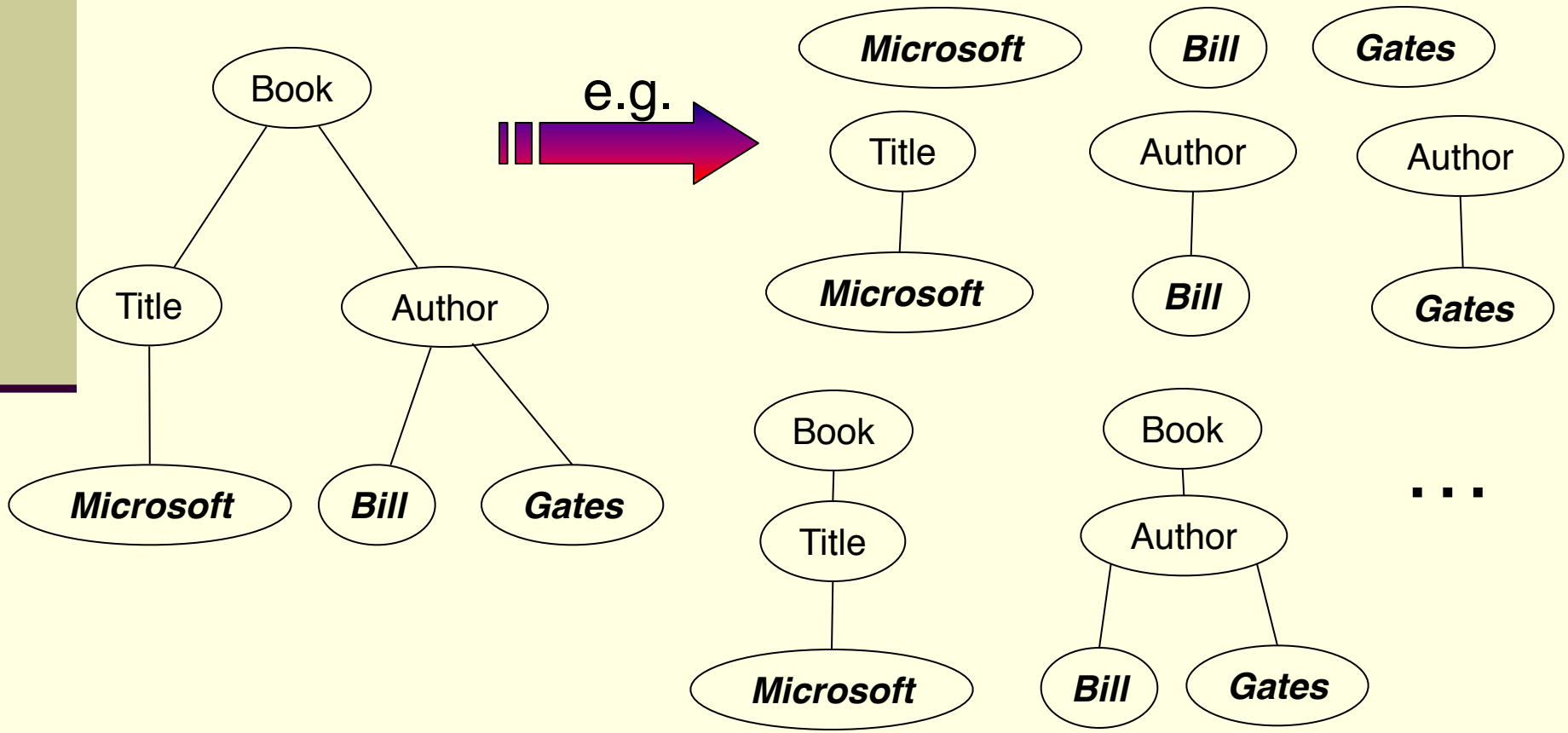
- The preceding examples can be viewed as sub-trees of the document
- But what about?



- (***Gates*** <u>somewhere</u> underneath Book)

Subtrees and structure

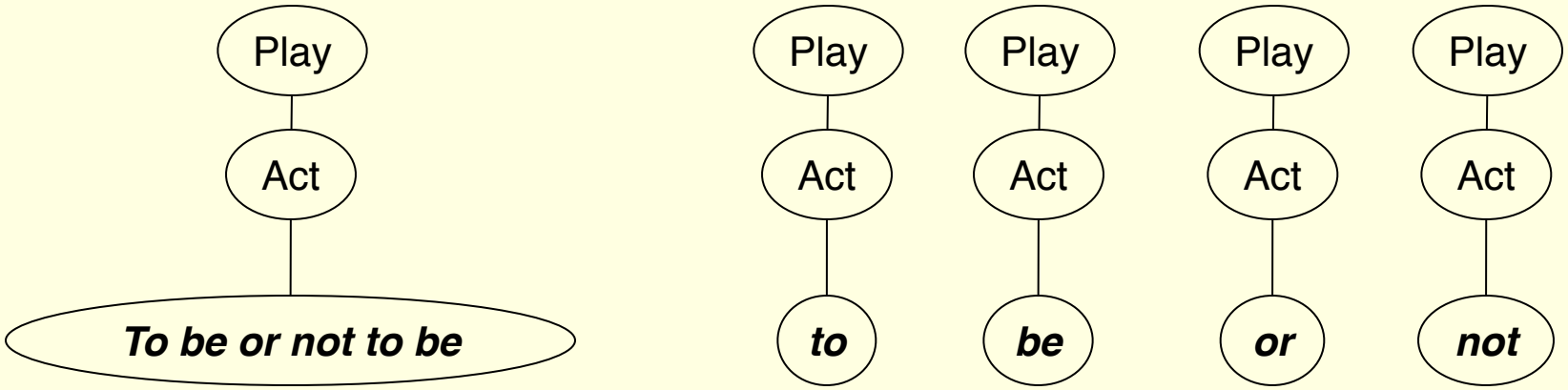
- Consider all subtrees of the document that include at least one lexicon term:



Structural terms

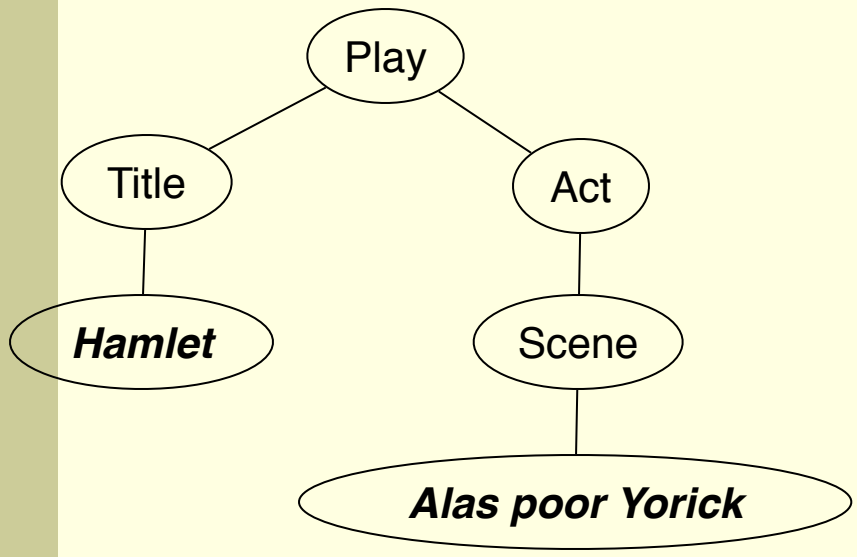
- Call each of the resulting subtrees a *structural term*
- Note that structural terms might occur multiple times in a document
- Create one axis in the vector space for each distinct structural term
- Weights based on frequencies for number of occurrences (just as we had *tf)*
- All the usual issues with terms (stemming? Case folding?) remain

Example of *tf* weighting



- Here the structural terms containing ***to*** or ***be*** would have more weight than those that don't

Down-weighting



- For the doc on the left: in a structural term rooted at the node Play, shouldn't ***Hamlet*** have a higher *tf* weight than ***Yorick***?
- Idea: multiply *tf* contribution of a term to a node *k* levels up by γ^k, for some $\gamma < 1$.

Down-weighting example, γ=0.8

- For the doc on the previous slide, the *tf* of
  - ***Hamlet*** is multiplied by 0.8
  - ***Yorick*** is multiplied by 0.64

in any structural term rooted at Play.

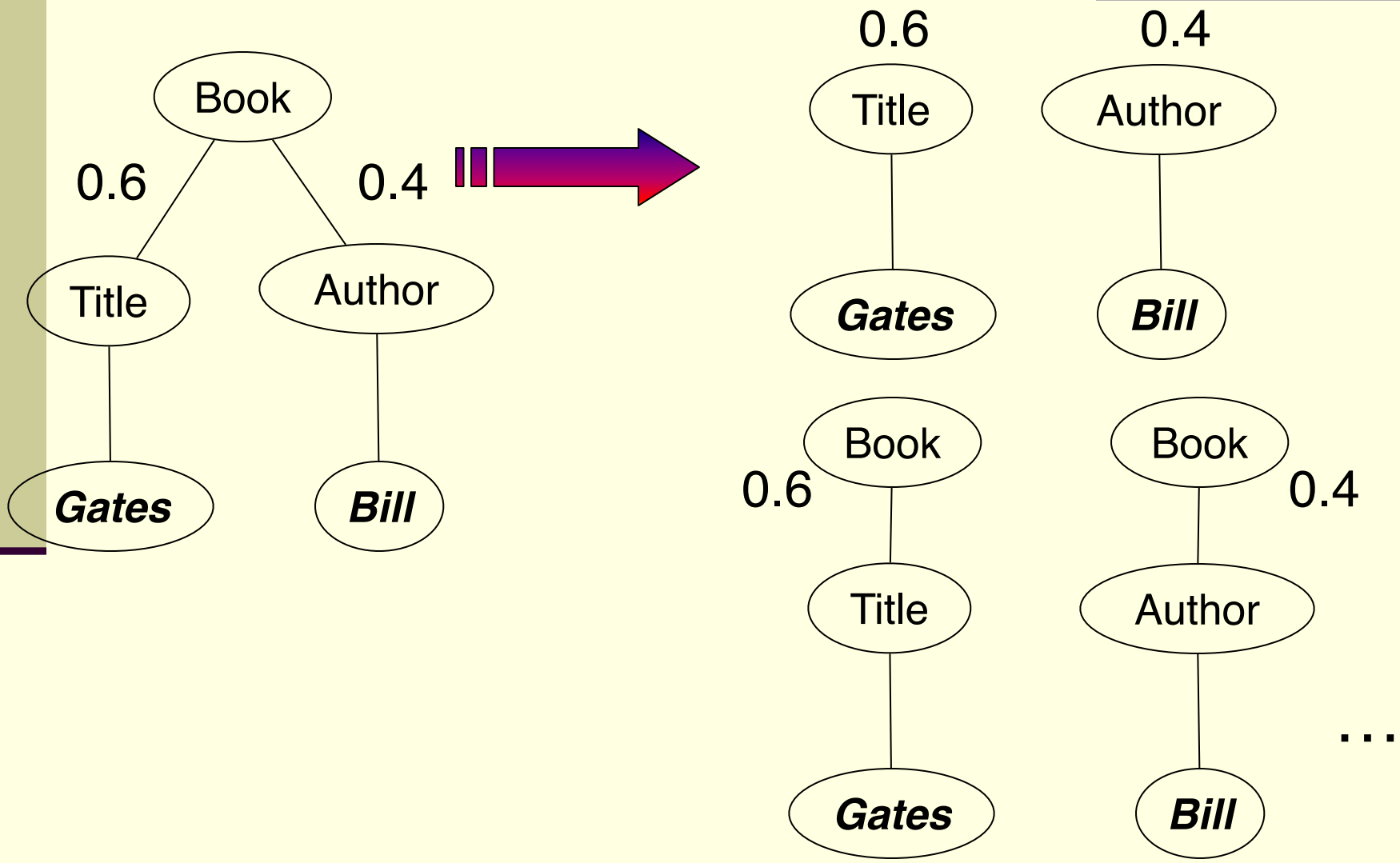
The number of structural terms

- Can be huge!
- Impractical to build a vector space index with so many dimensions

Structural terms: docs+queries

- The notion of structural terms is independent of any schema/DTD for the XML documents
- Well-suited to a heterogeneous collection of XML documents
- Each document becomes a vector in the space of structural terms
- A query tree can likewise be factored into structural terms
  - And represented as a vector
  - Allows weighting portions of the query

Example query



Weight propagation

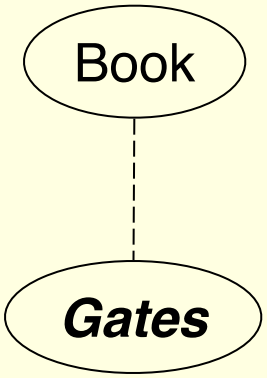
- The assignment of the weights 0.6 and 0.4 in the previous example to subtrees was simplistic
  - Can be more sophisticated
  - Think of it as generated by an application, not necessarily an end-user
- Queries, documents become normalized vectors
- Retrieval score computation “just” a matter of cosine similarity computation

Restrict structural terms?

- Depending on the application, we may restrict the structural terms
- E.g., may never want to return a Title node, only Book or Play nodes
- So don't enumerate/index/retrieve/score structural terms rooted at some nodes

The catch remains

- This is all very promising, but …
- How big is this vector space?
- Can be exponentially large in the size of the document
- Cannot hope to build such an index
- And in any case, still fails to answer queries like



(somewhere underneath)

Two solutions

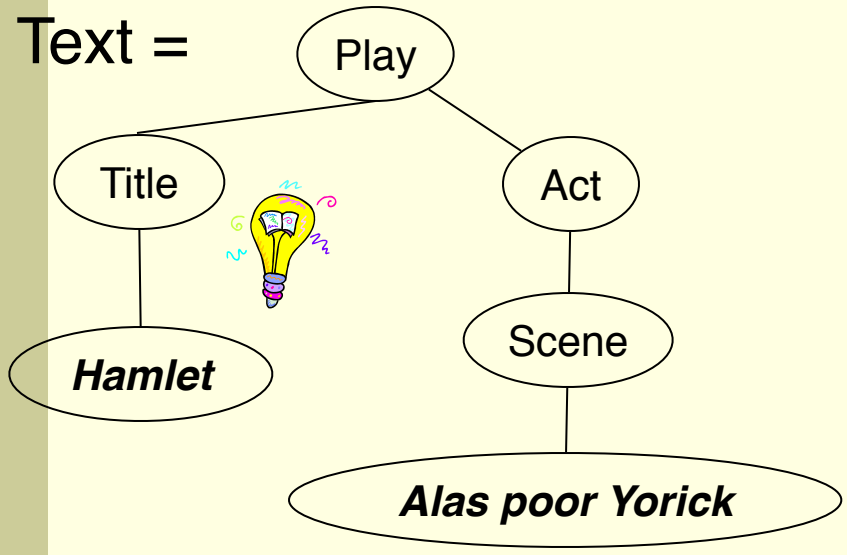
- Query-time materialization of axes
- Restrict the kinds of subtrees to a manageable set

Query-time materialization

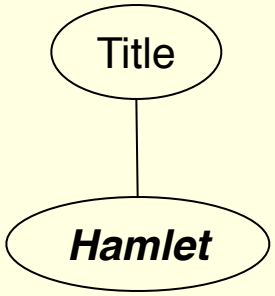
- Instead of enumerating all structural terms of all docs (and the query), enumerate only for the query
  - The latter is hopefully a small set
- Now, we're reduced to checking which structural term(s) from the query match a subtree of any document
- This is tree pattern matching: given a *text tree* and a *pattern tree*, find matches
  - Except we have many text trees
  - Our trees are labeled and weighted

Example

Text =



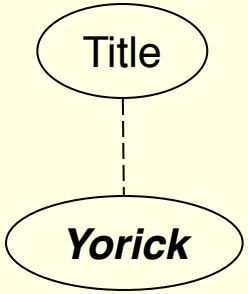
Query =



- Here we seek a doc with ***Hamlet*** in the title
- On finding the match we compute the cosine similarity score
- After all matches are found, rank by sorting

(Still infeasible)

- A doc with ***Yorick*** somewhere in it:
- Query =

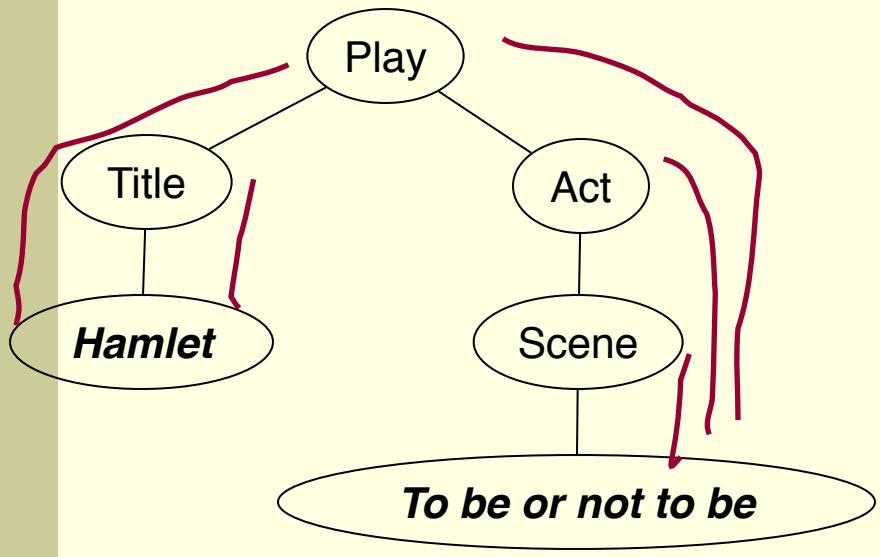


- Will get to it …

Restricting the subtrees

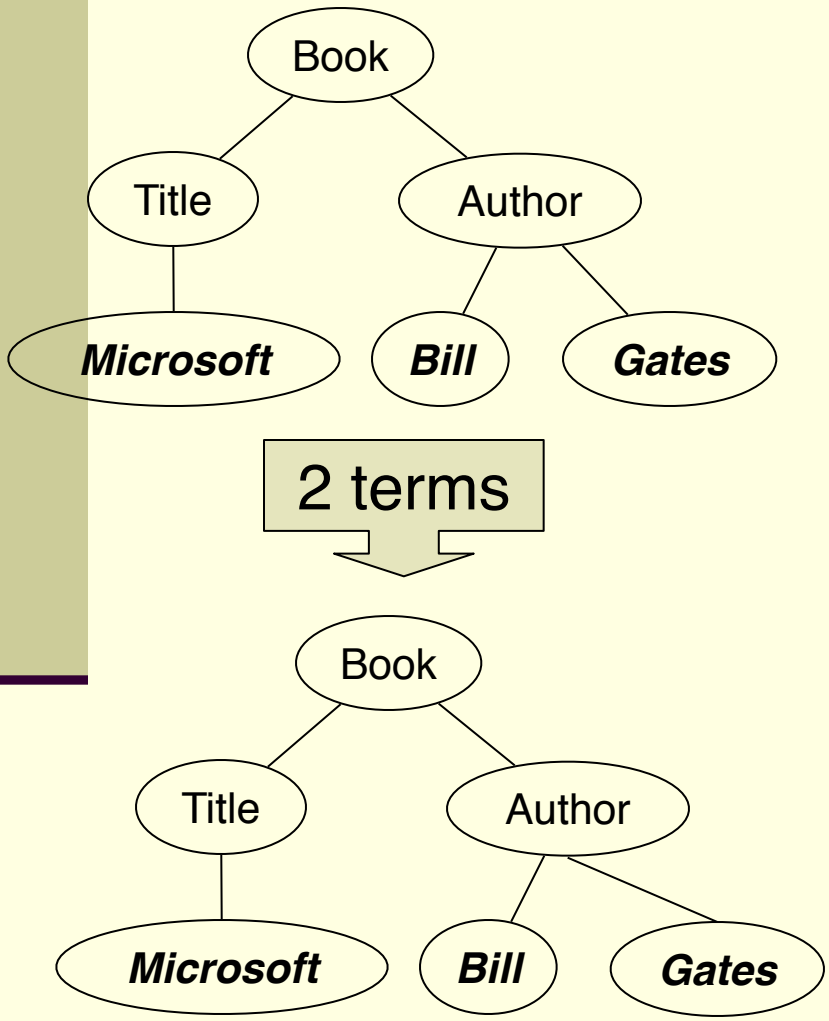
- Enumerating all structural terms (subtrees) is prohibitive, for indexing
  - Most subtrees may never be used in processing any query
- Can we get away with indexing a restricted class of subtrees
  - Ideally – focus on subtrees likely to arise in queries

JuruXML (IBM Haifa)



- Only paths including a lexicon term
- In this example there are only 14 (why?) such paths
- Thus we have 14 structural terms in the index

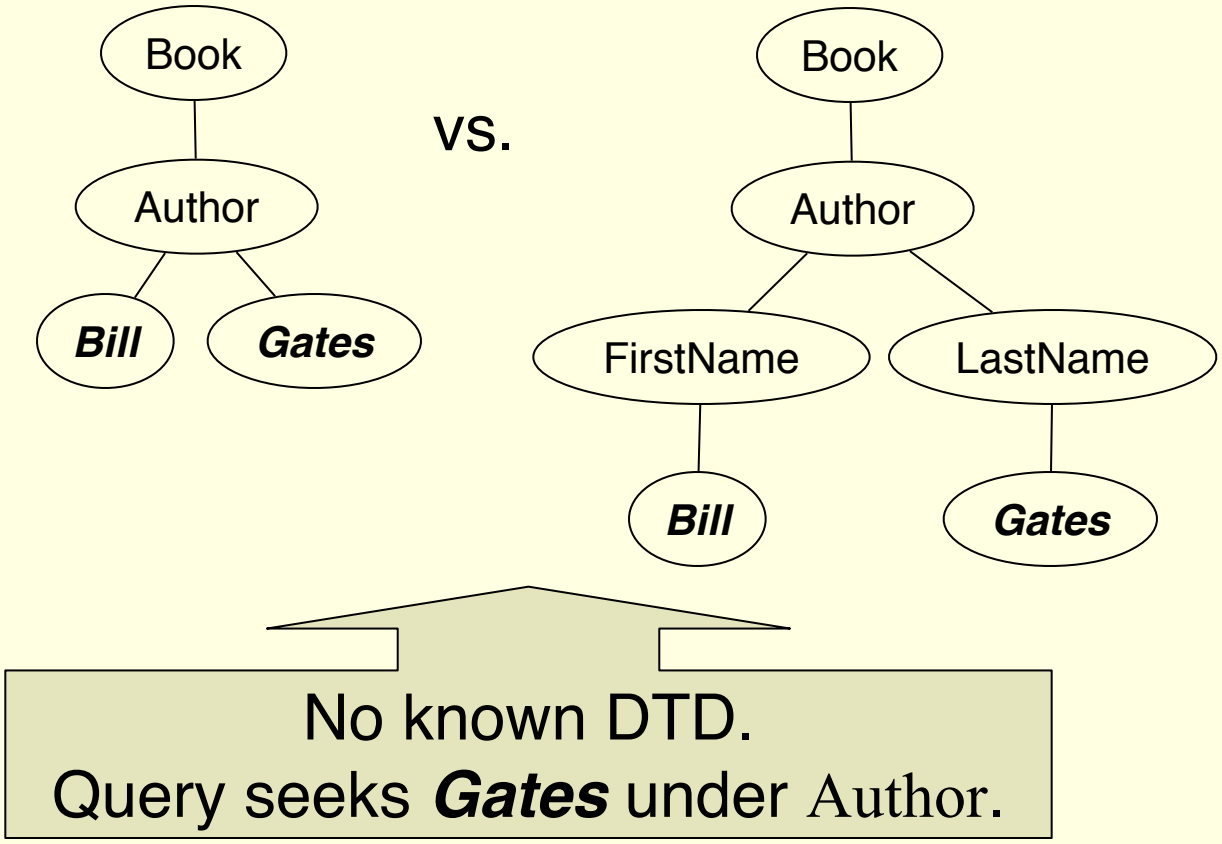
Variations



- Could have used other subtrees – e.g., all subtrees with two siblings under a node
- Which subtrees get used: depends on the likely queries in the application
- Could be specified at index time – area with little research so far

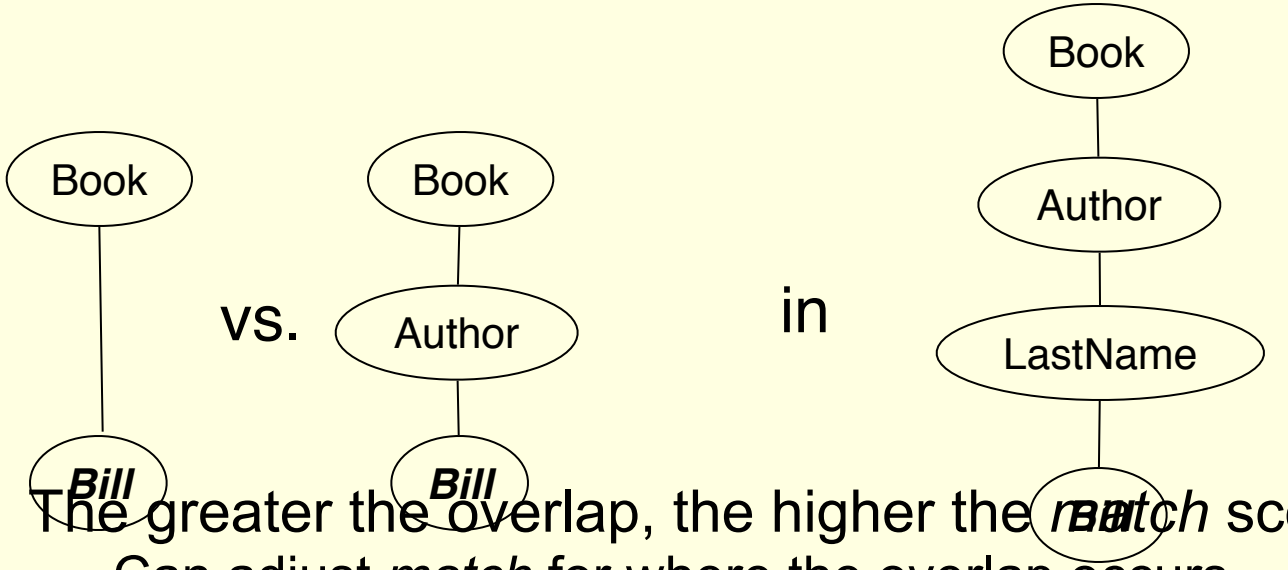
Descendants

- Return to the descendant examples:



Handling descendants in the vector space

- Devise a *match* function that yields a score in [0,1] between structural terms
- E.g., when the structural terms are paths, measure overlap



- The greater the overlap, the higher the *match* score
  - Can adjust *match* for where the overlap occurs

How do we use this in retrieval?

- First enumerate structural terms in the query
- Measure each for *match* against the dictionary of structural terms
  - Just like a postings lookup, except not Boolean (does the term exist)
  - Instead, produce a score that says “80% close to this structural term”, etc.
- Then, retrieve docs with that structural term, compute cosine similarities, etc.

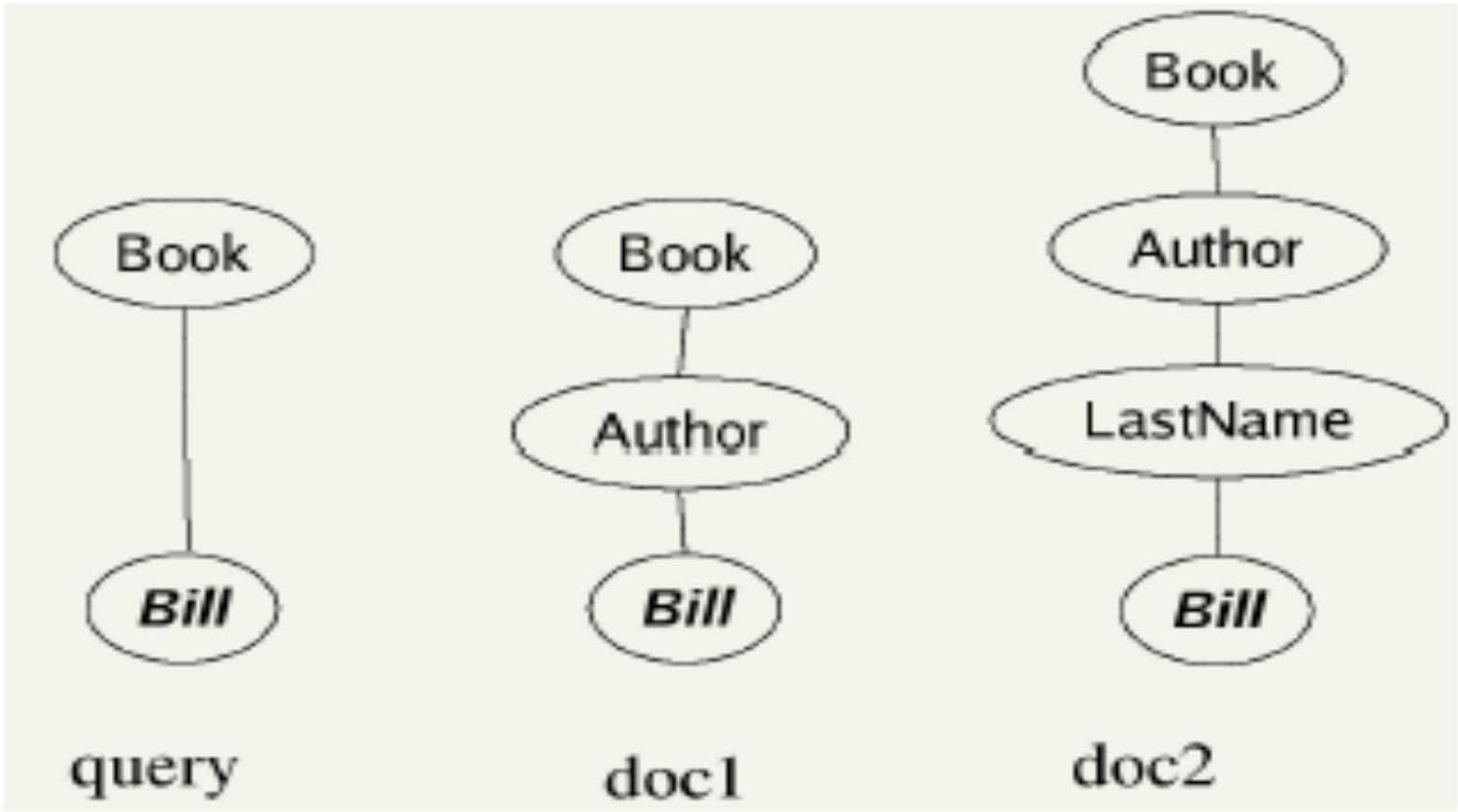


Figure cr(q, $d1$) = 3/4 = 0.75 and cr(q, $d2$) = 3/5 = 0.6.

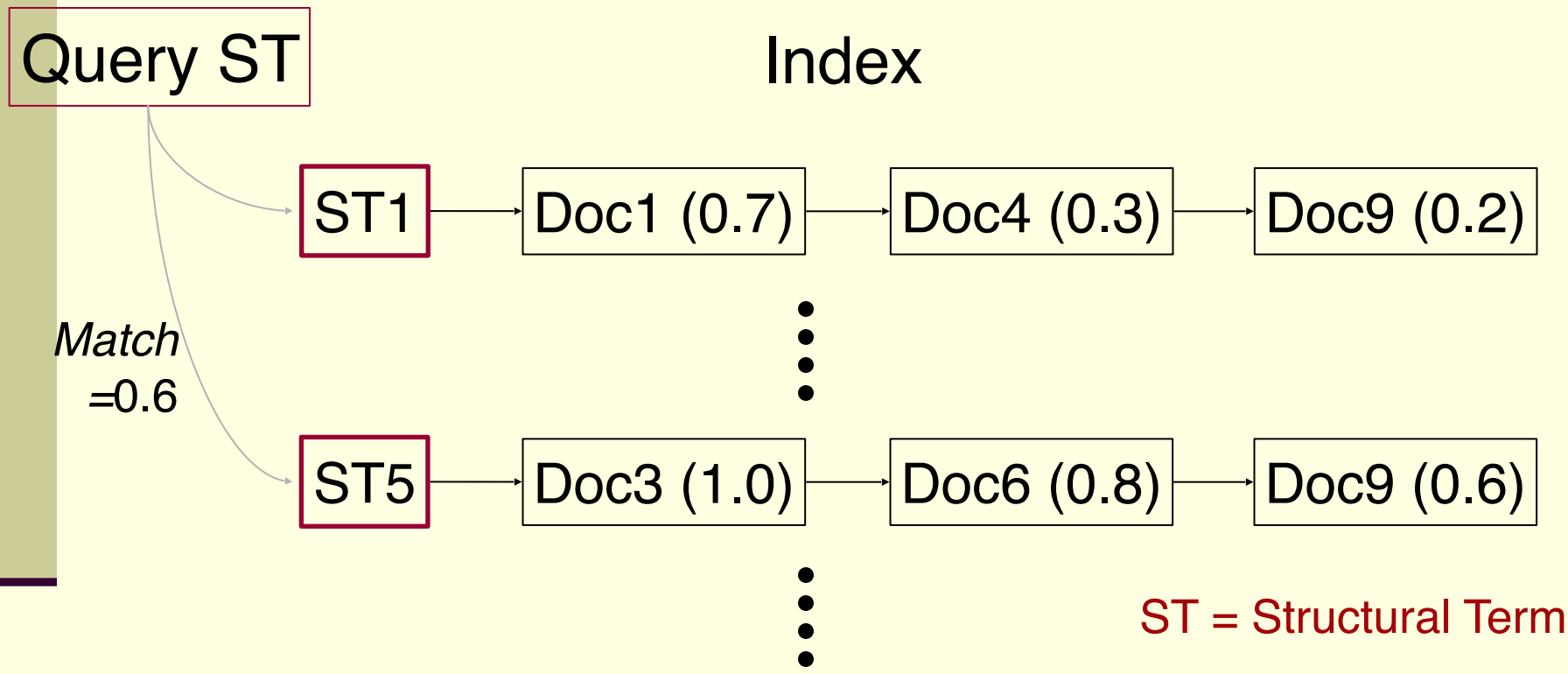
$$\mathrm{cr}(q, d) = \frac{1 + |q|}{1 + |d|}$$

context resemblance similarity

$$\text{sim-cr}(q,d) = \frac{\sum_{t \in V} \sum_{c_k \in C} \sum_{c_l \in C} \text{weight}(q,t,c_k)\,\text{weight}(d,t,c_l)\,\text{cr}(c_k,c_l)}{|\vec{q}||\vec{d}|}$$

V is the vocabulary of (non-structural) terms;
C is the set of all contexts (paths) occurring in the collection and the queries;
and weight(*d*, *t*, *ck*) is the weight of term *t* in context *ck* in document *d*.

Example of a retrieval step



Now rank the Doc's by cosine similarity;
e.g., Doc9 scores 0.578.

- ST in the query occurs as ST1 in the index and has a match coefficient of 0.6 with a second term ST5 in the index.
- highest ranking document is Doc9 with a similarity of 1.0× 0.2+0.6×0.6 = 0.56.
- Query weights are assumed to be 1.0.

Indexing and search in JuruXML.

Indexing

For each indexing unit *i*:

Compute structural terms for *i*

Construct index

Search

Compute structural terms for query

For each structural term *t*:

Find matching structural terms in dictionary

For each matching structural term *t′*:

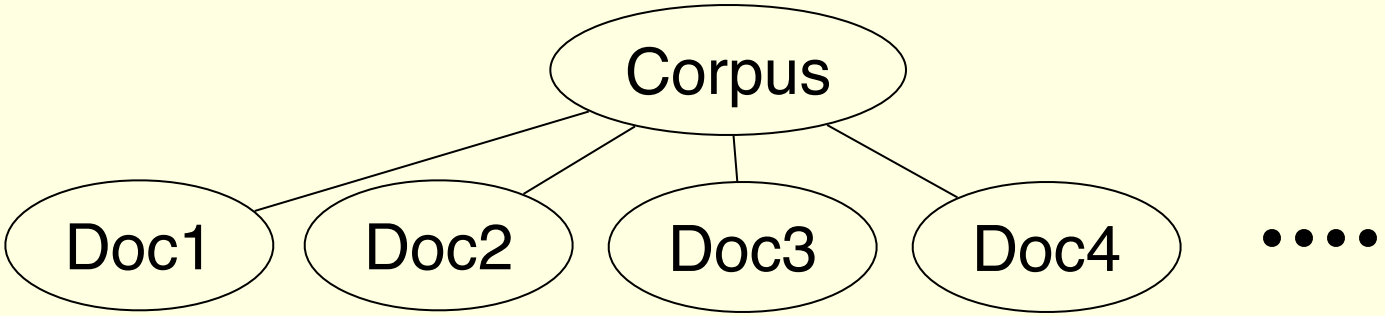
Compute matching weight cr(*t*, *t′*)

Search inverted index with computed terms and weights

Return ranked list

Closing technicalities

- But what exactly is a Doc?
- In a sense, an entire corpus can be viewed as an XML document



What are the Doc's in the index?

- Anything we are prepared to return as an answer
- Could be nodes, some of their children …

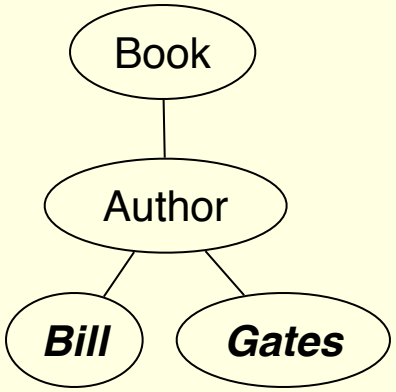
What are queries we can't handle using vector spaces?

- Find figures that describe the Corba architecture and the paragraphs that refer to those figures
  - Requires JOIN between 2 tables
- Retrieve the titles of articles published in the Special Feature section of the journal *IEEE Micro*
  - Depends on order of sibling nodes.

Can we do IDF?

- Yes, but doesn't make sense to do it corpus-wide
- Can do it, for instance, within all text under a certain element name say Chapter
- Yields a *tf-idf* weight for each lexicon term under an element
- Issues: how do we propagate contributions to higher level nodes.

Example



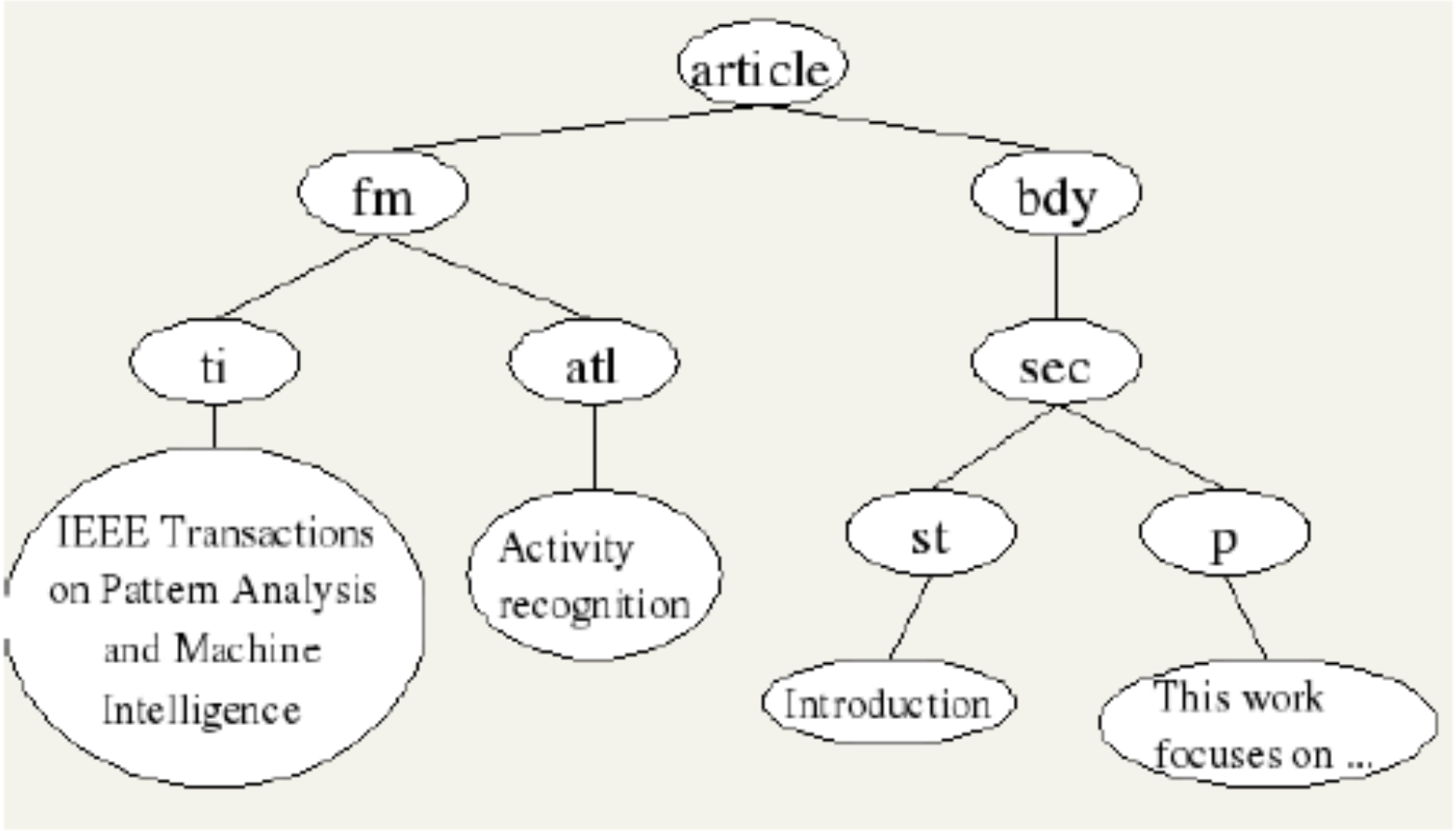
- Say ***Gates*** has high IDF under the Author element
- How should it be *tf-idf* weighted for the Book element?
- Should we use the *idf* for ***Gates*** in Author or that in Book?

INEX: a benchmark for text-centric XML retrieval

INEX(**IN***itiative for the* **E***valuation of* **X***ML retrieval*)

- Benchmark for the evaluation of XML retrieval
  - Analog of TREC (recall CS276A)
- Consists of:
  - Set of XML documents
  - Collection of retrieval tasks

Schema of INEX Document



Fm – front matter, ti – title, atl- article title,

- There are two types of queries, called *topics*, in INEX:
- content-only or CO topics and
- content-and-structure or CAS topics.

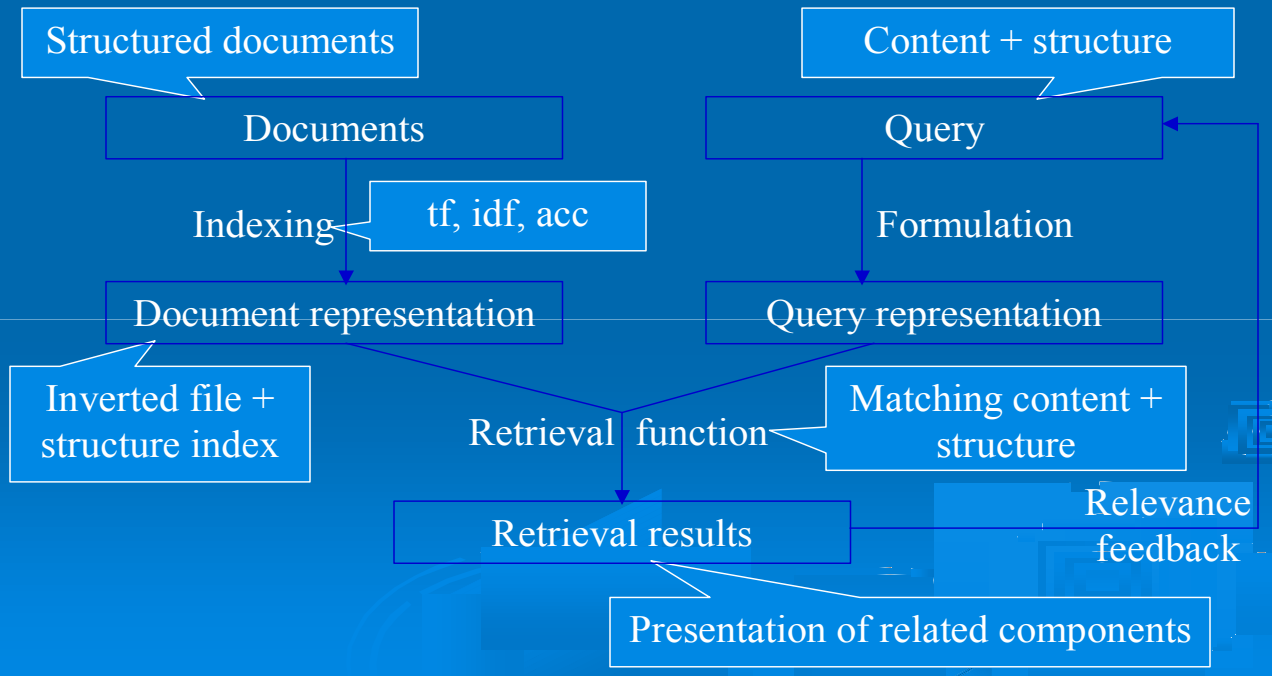
Content only queries

- Standard IR queries but we retrieve document component

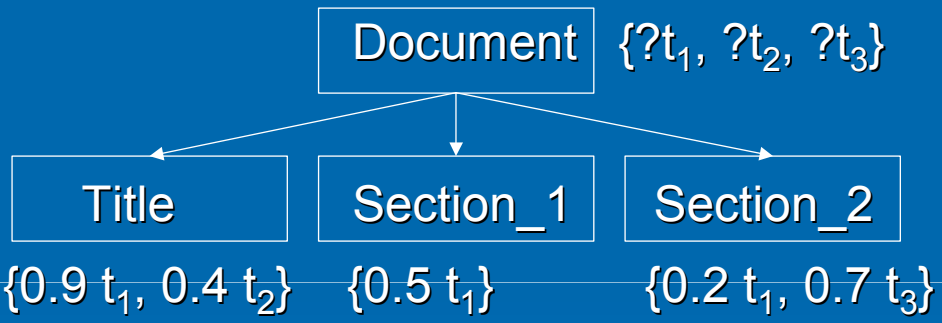
Content and Structure (CAS) Queries

- Put on constraints on which type of components are retrieved
- e.g. “sections of an article in … about ….”

Conceptual model for XML retrieval



Example of XML approaches



? = Aggregated weight of t_i in Document based on the instances of t_i in the sub-elements (Title, Section_1 and Section_2)

INEX

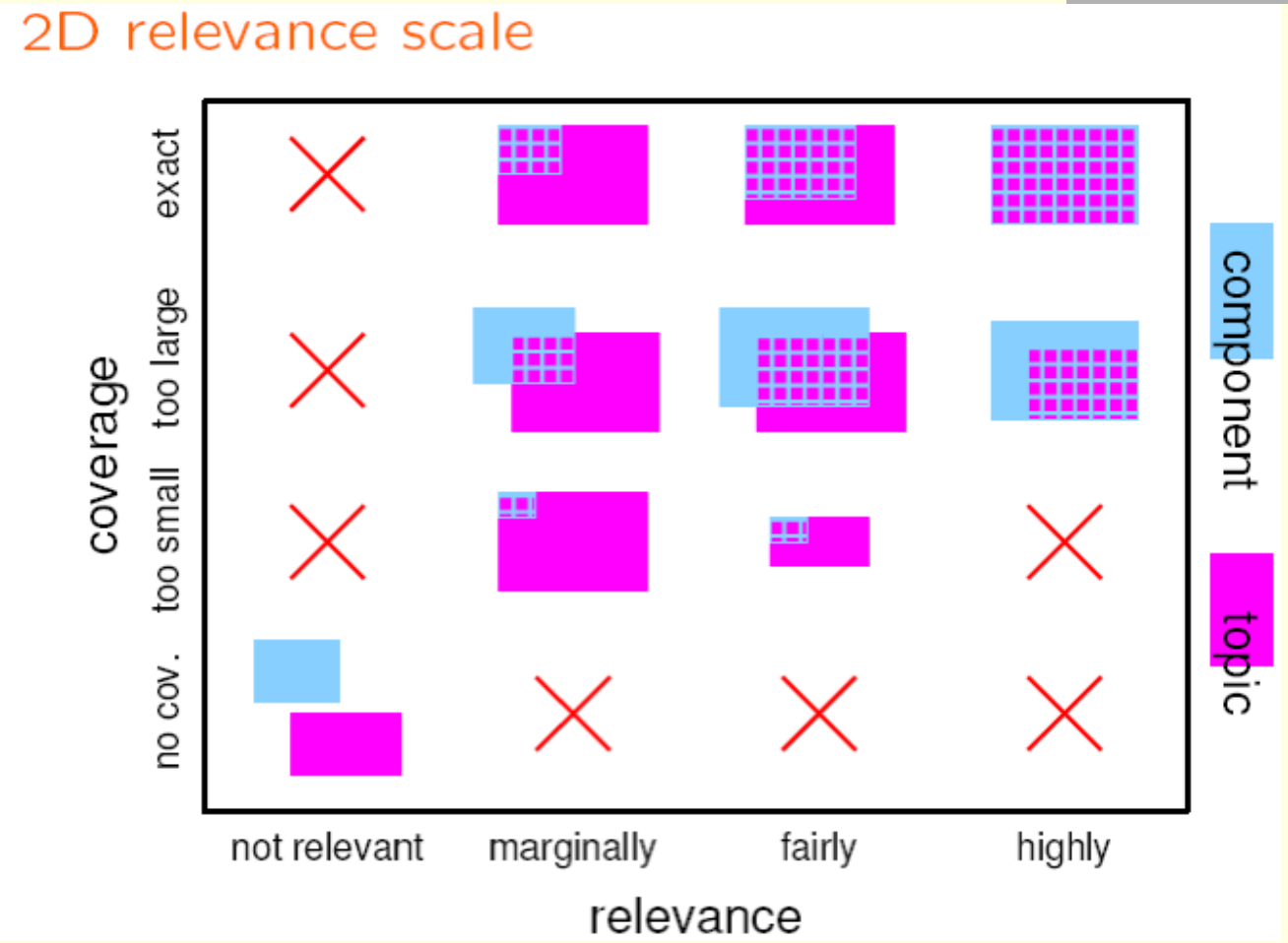
- Each engine indexes docs
- Engine team converts retrieval tasks into queries
  - In XML query language understood by engine
- In response, the engine retrieves not docs, but elements within docs
  - Engine ranks retrieved elements

INEX assessment

- For each query, each retrieved element is human-assessed on two measures:
  - Topical Relevance – how relevant is the retrieved element
  - Component Coverage – is the retrieved element too specific, too general, or just right
    - E.g., if the query seeks a definition of the Fast Fourier Transform, do I get the equation (too specific), the chapter containing the definition (too general) or the definition itself
- These assessments are turned into composite precision/recall measures

- The component coverage dimension evaluates whether the element retrieved is “structurally” correct, i.e., neither too low nor too high in the tree.
- The topical relevance dimension also has four levels: highly relevant (3)fairly relevant (2) marginally relevant (1) and irrelevant (0).

2D relevance scale



INEX corpus

- 12,107 articles from IEEE Computer Society publications
- 494 Megabytes
- Average article:1,532 XML nodes
  - Average node depth = 6.9

INEX topics

- Each topic is an information need, one of two kinds:
  - Content Only (CO) – free text queries
  - Content and Structure (CAS) – explicit structural constraints, e.g., containment conditions.

Sample INEX CO topic

<Title> computational biology </Title>

<Keywords> computational biology, bioinformatics, genome, genomics, proteomics, sequencing, protein folding </ Keywords>

<Description> Challenges that arise, and approaches being explored, in the interdisciplinary field of computational biology</Description>

<Narrative> To be relevant, a document/component must either talk in general terms about the opportunities at the intersection of computer science and biology, or describe a particular problem and the ways it is being attacked. </ Narrative>

INEX assessment

- Each engine formulates the topic as a query
  - E.g., use the keywords listed in the topic.
- Engine retrieves one or more elements and ranks them.
- Human evaluators assign to each retrieved element relevance and coverage scores.

Assessments

- Relevance assessed on a scale from Irrelevant (scoring 0) to Highly Relevant (scoring 3)
- Coverage assessed on a scale with four levels:
  - No Coverage (N: the query topic does not match anything in the element
  - Too Large (The topic is only a minor theme of the element retrieved)
  - Too Small (S: the element is too small to provide the information required)
  - Exact (E).
- So every element returned by each engine has ratings from {0,1,2,3} × {N,S,L,E}

Combining the assessments

- Define scores:

$$f_{strict}(rel, cov) = \begin{cases} 1 & \text{if } rel, cov = 3E \\ 0 & \text{otherwise} \end{cases}$$

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

The *f*-values

- Scalar measure of goodness of a retrieved elements
- Can compute *f*-values for varying numbers of retrieved elements 10, 20 … etc.
  - Means for comparing engines.

From raw *f*-values to … ?

- INEX provides a method for turning these into precision-recall curves
- “Standard” issue: only elements returned by some participant engine are assessed