XML Full-Text Search and Scoring

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AT&T Labs

- 5,500 scientists and engineers
- AT&T's patent portfolio includes 1,580 granted patents
- Over 80% of our scientists & technologists hold a PhD or other advanced degree
- Currently involved with approximately 90 U.S. & international universities

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Research Priorities for 2005

- Speech
- Access
- Security
- Information Management
  - Network Management
  - Information Systems
- Enabling Infrastructure
  - Network
  - Software

Internet and Network Systems Research

- **Optical Systems**
- **Access and Metro Network**
- **Access Technology and Applications**
- **Network Analysis and Optimization**
- **Network Theory**
- **Network Measurement, Monitoring, and Management**
- **IP Managed Services**
- **Network Security**
- **Internet and Network Incubation**

Information & Software Systems

- **Statistics**
- **Information Mining**
- **Customer Information**
- **Information Visualization**
- **Data Management**
- **Communication Software – Artificial Intelligence**
- **Dependable, Distributed Computing and Communication**
- **Software Systems - Scale**
- **Information Mining & Software Systems Incubation**
- **Information Mining Services**

Voice & IP Services

- **Speech Algorithms & Engines**
- **Natural Language Understanding & Dialog**
- **Knowledge Discovery from Speech & Data**
- **Multimedia Services**
- **IP Services**
- **Speech Services**

Database Research at AT&T

- Researchers
  - Sihem Amer-Yahia, Mary Fernandez, Rick Greer, Ted Johnson , Flip Korn, Yannis Kotidis, Misha Rabinovich, Divesh Srivastava, Yannis Velegrakis
- Research
  - Large Scale Storage Systems
  - XML Query Processing
  - Data Stream Processing
  - Network Monitoring
  - Information Hosting
  - Data Integration
- Systems
  - Daytona, Silkroute, Galax, ShreX, GalaTex, Gigascope, Spider, Bellman, RaDar.

Motivation

- XML is able to represent a mix of structured and unstructured (text) information.
- Examples of XML repositories are: IEEE INEX data collection, Shakespeare's plays, DBLP, the Library of Congress collection.
- Existing query languages for XML (XPath and XQuery) are very limited when querying text.
- Two main activities: W3C, INEX (TREC for XML).

Outline

- Extending XPath/XQuery to support full-text search
  - *syntax, data model and semantics*.
- Scoring on both content and structure
  - *approximate matching on structure*.
- Open Issues.

Extending XPath/XQuery

- Full-text Search in XML
  - definition and requirements.
- TeXQuery and XQuery Full-Text
  - syntax, data model and semantics.
- GalaTex
  - architecture and implementation.

Joint work with Chavdar Botev and Jayavel Shanmugasundaram *(Cornell U.), Emiran Curtmola (UC San Diego)*

FT Search Queries

```
<book id="1000">
   <author>Elina Rose</author>
   <content>
      <p> The usability of software measures how
            well the software provides support for
            quickly achieving specified goals.
      </p>
      <p> The users must be and feel well-served. </p>
   </content>
</book>
```

- *return book paragraphs containing the keyword “software” and stemmed forms of “usability” and do not contain “Rose”*
- *return elements containing "usability" and ("software" or "goals") within 12 words*
- *return ranked results*

FT Search Definition

- ***Context expression***: XML nodes where the search occurs: ***e.g., book chapters.***
  - ***Use XPath and XQuery to identify nodes in the search context***

- ***Return expression***: document fragments that are returned to users: ***e.g., book title and authors.***
  - ***Use XPath and XQuery to build returned answers***

- ***Search expression***: FT search conditions: ***e.g., Boolean, proximity, stemming*****.**
  - ***Need for new language primitives***

- ***Score expression***: a scoring function for threshold or top-K queries.
  - ***Need for scoring framework***

FT Search Requirements

- Composable FT search conditions
  - *keyword, proximity order, times, stemming, stop words, thesaurus, wildcards*, …
- Integrate FT search with XPath/*XQuery*.
  - Non-trivial since structured XML queries operate on XML nodes, while FT queries operate on keywords and their positions *within* XML nodes.
- *No extension to XPath/XQuery data model.*
- Enable *answer scoring* and top-K queries.

Prior Work

- *SQL/MM* extends SQL with primitives on text, images and spatial data.
- *Keyword similarity*: Elixir, XXL, XIRQL.
- *Proximity distance*: InQuery, SQL/MM.
- *Relevance ranking*: XQueryIR, XIRQL, XXL, JuruXML.
- *Dynamic context*: XRank, TIX, XSearch.
- All explore only a few FT search primitives at a time and none of them develops a fully compositional model for FT search.

Prior Work

- Current XML query languages provide very rudimentary text/IR support:
  - *Composability* and *extensibility* not supported.
  - Data Model not formalized.
  - Hard to optimize across structured and unstructured queries.
- Sophisticated scoring and ranking algorithms interleaved with query processing.

XQuery in a Nutshell

- Functional language. Compositional.
- Input/Output: *sequence of items*
  - *atomic types, elements, attributes, processing instructions, comments,...*
- XPath core navigation language.
- Variable binding.
- Element construction.

XQuery FLWOR Expression

- *Find books on usability sorted on price:*

```
for $item in //books/book
let $pval := $item/metadata/price
where fn:contains($item//content,"usability")
order by $pval ascending
return <result>
           {$item/title}
           <price> {$pval} </price>
       </result>
```

- Limited sub-string operations: *fn:start-with(), fn:end-with()*
- *No scoring or ranking*

Alternative XQuery Extensions

- One *function* per FT primitive:

  distance(
  contains ($n, "usability"),
  contains ($n, "software") or contains ($n, "analysis), 10)

  returned type not sufficient to compute keyword distance.

- Sublanguage:

  contains($n, "usability and (software or analysis) distance 10")

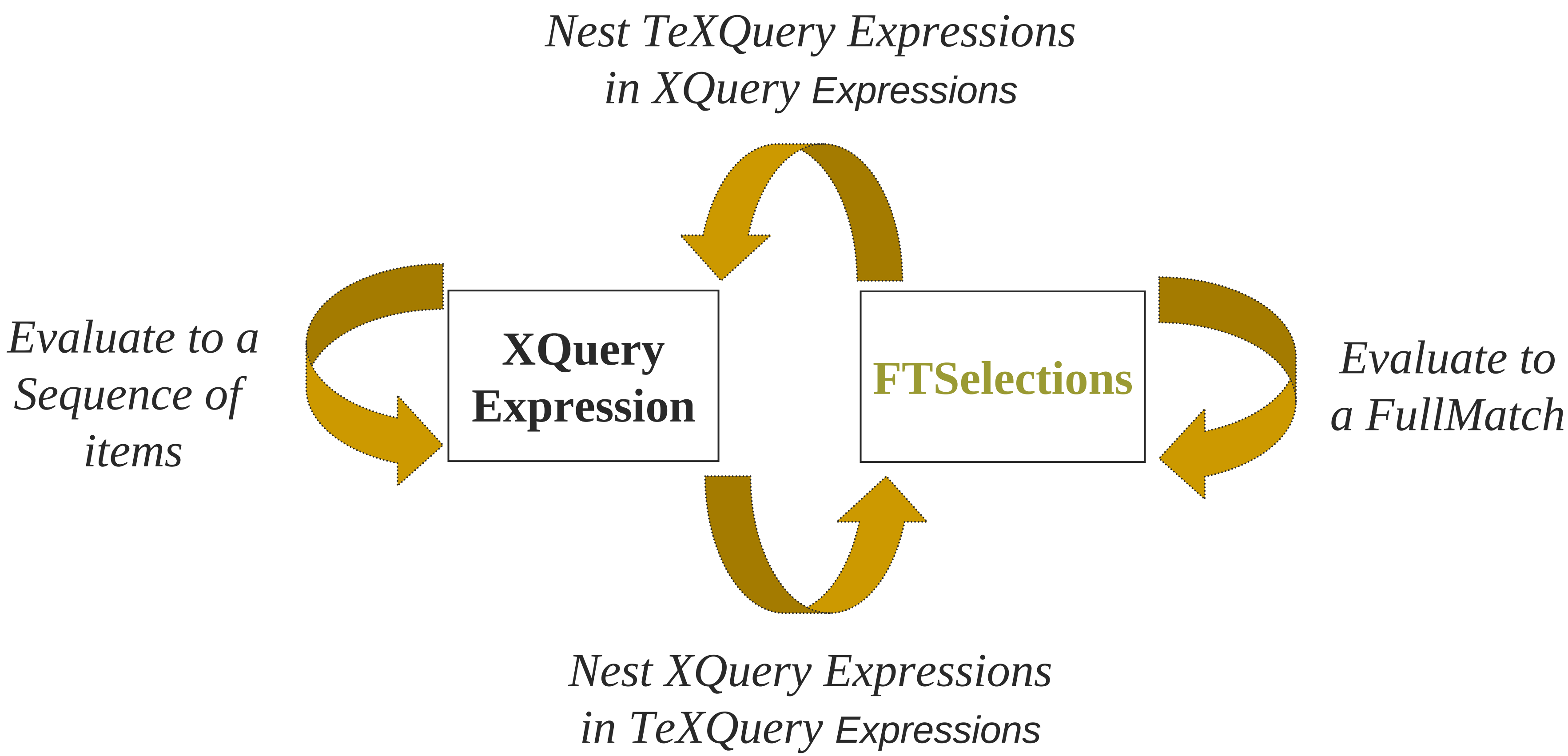
  FT search specified in an uninterpreted string that is opaque to the rest of the XQuery language.

TeXQuery

*[*Amer-Yahia, Botev, Shanmugasundaram WWW'04]

- Fully composable FT search primitives called **FTSelections**.
- *Composable* with XPath/XQuery.
- *Formal data model* called FullMatch.
- *Scoring* and ranking.
- Basis for XQuery Full-Text.

XQuery/TeXQuery Composability



XQuery Full-Text

- Full-Text Task Force (FTTF) started in Fall 2002 to extend XQuery with full-text search capabilities.
- Members:
  - AT&T, IBM, Microsoft, Oracle, the US Library of Congress.
- Adopted TeXQuery in June 2004.
- FTTF documents (public comments are welcome!):
  - *http://www.w3.org/TR/xmlquery-full-text-use-cases/*
  - *http://www.w3.org/TR/xmlquery-full-text-requirements/*
  - *http://www.w3.org/TR/xquery-full-text/*

XQuery Full-Text Syntax

- *FTContainsExpr ::= RangeExpr ("ftcontains" FTSelection FTIgnoreOption?)?*

  returns true if at least one node in ContextExpr satisfies FTSelection.

- *FTScoreClause* ::= "score" "$" *VarName* "as" *Expr*

  provides access to fine-grained ranking (e.g., threshold and top-k.)

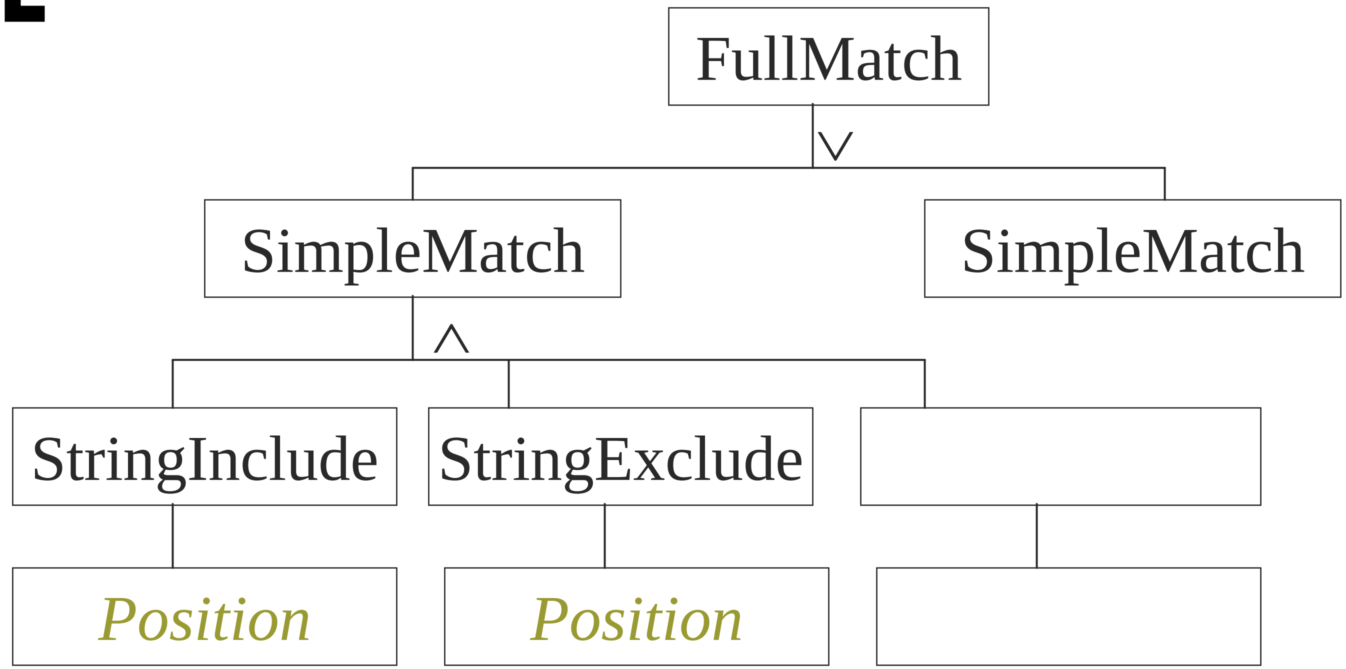
FT Search: FTSelections

- FTWord | FTAnd | FTOr | FTNot | FTMildNot | FTOrder | FTWindow | FTDistance | FTScope | FTTimes | FTSelection (FTMatchOptions)*
  - ***books//title [. ftcontains “usability”]***
  - ***books//abstract [. ftcontains (“usability” || “web-testing”)]***
  - ***books//content [. ftcontains (“usability” && “software”) ordered window at most 3]***
  - ***books//abstract [. ftcontains (“usability” && “web”) same sentence]***
  - ***books//title [. ftcontains “usability” 4 occurrences]***
  - ***books//book/section [. ftcontains books/book/title]***

FT Search: FTMatchoptions

- **FTCaseOption | FTDiacriticsOption| FTStemOption | FTThesaurusOption | FTStopwordOption | FTLanguageOption | FTWildCardOption**
  - ***books//title [. ftcontains ("usability") case sensitive with thesaurus "synonyms"]***
  - ***books//content [. ftcontains ("usability" && "software") with stopwords window at most 3]***
  - ***books//title ftcontains ("Utilisation" language "French" with stemming && ".?site" with wildcards)***
  - ***books//abstract [. ftcontains "usability" || "web-testing" with special characters]***

XQuery Full-Text Semantics



Propositional formula over word positions in DNF

FullMatch (AllMatch) Data Model

- FullMatch has a hierarchical structure represented as XML.
- Semantics of FTSelections specified as transformation of input FullMatches to an output XML FullMatch.
- Semantics of FTSelections specified in XQuery itself!
- FT search and structural search represented in same framework:
  - Enables joint optimization

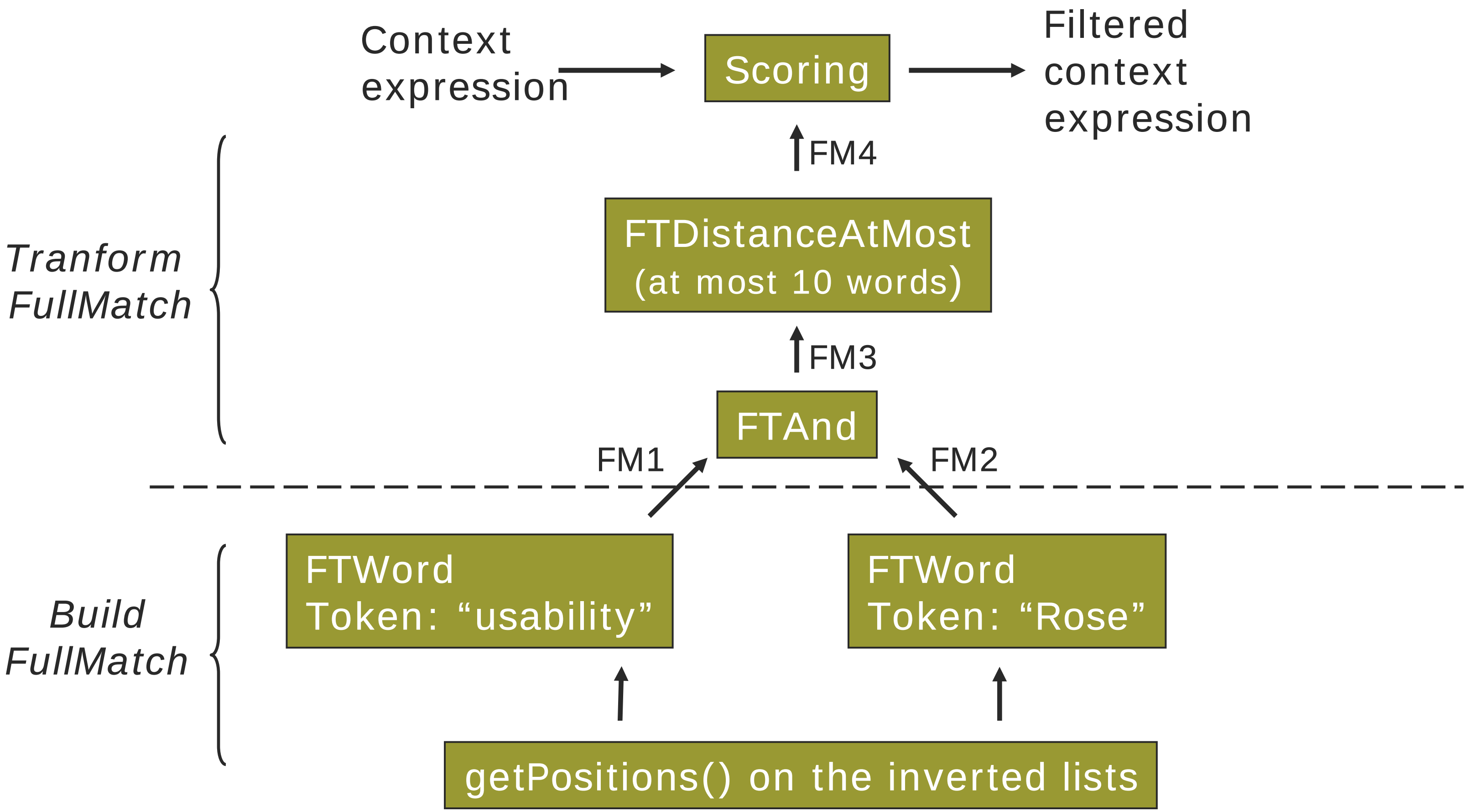
Sample Document and Query

```
<book(1) id(2)=``1000(3)''>
    <author(4)>Elina(5) Rose(6)</author(7)>
    <content(8)>
        <p(9)> The(10) usability(11) of(12) software(13)
               measures(14) how(15) well(16) the(17)
               software(18) provides(19) support(20) for(21)
               quickly(22) achieving(23) specified(24)
               goals(25). </p(26)>
        <p(27)>The(28) users(29) must(30) not(31) only(32)
               be(33) well-served(34), but(35) must(36)
               feel(37) well-served(38).</p(39)>
    </content(40)>
</book(41)>
```

books//book ftcontains

(“usability” with stemming && “Rose”) window at most 10

Query Evaluation Plan



Positions of “usability” with stemming , “Rose”

```
<book(1) id(2)=``1000(3)''>
    <author (4)>Elina(5) Rose(6)</author(7)>
    <content(8)>
        <p(9)> The(10) usability(11) of(12) software(13)
                measures(14) how(15) well(16) the(17)
                software(18) provides(19) support(20) for(21)
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                be(33) well-served(34), but(35) must(36)
                feel(37) well-served(38).</p(39)>
    </content(40)>
</book(41)>
```
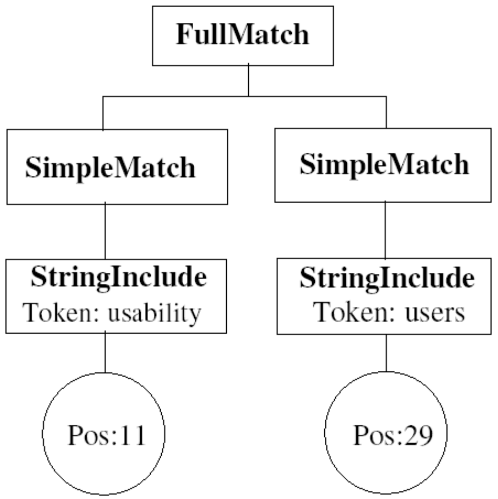
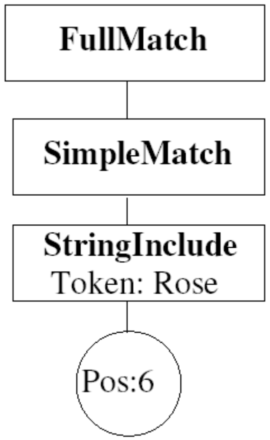

“usability” with stemming , “Rose”



“usability” with stemming

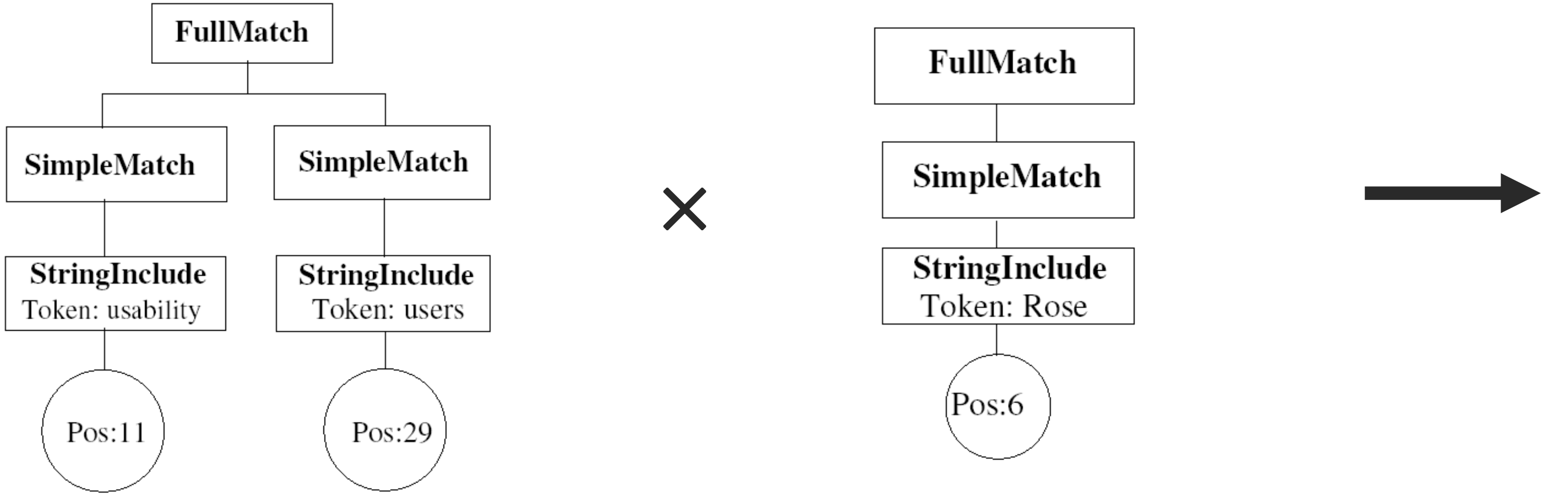


“Rose”

FTWord Semantics

```
declare function fts:FTSingleSearchToken(
                    $evalCtx as element()*,
                    $searchToken as schema-element(fts:TokenInfo),
                    $matchOptions as xs:string,
                    $queryPos as xs:string )  as schema-element (fts:FullMatch)
{  validate
  { <fts:FullMatch>
    {  for $position in fts:getPositions($evalCtx, $searchToken, "")
       return
         <fts:SimpleMatch>
           <fts:StringInclude queryString="{$searchToken/@word}“
                                queryPos="{$queryPos}">
                { $position }
           </fts:StringInclude>
         </fts:SimpleMatch>
     }
     </fts:fullMatches>
  }
};
```

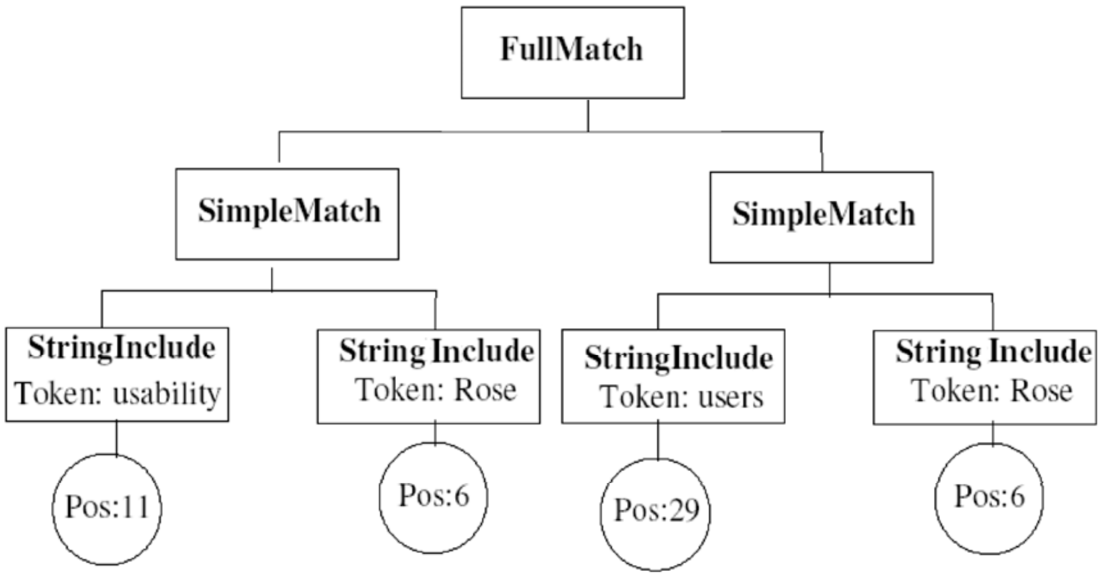
“usability” with stemming && “Rose”



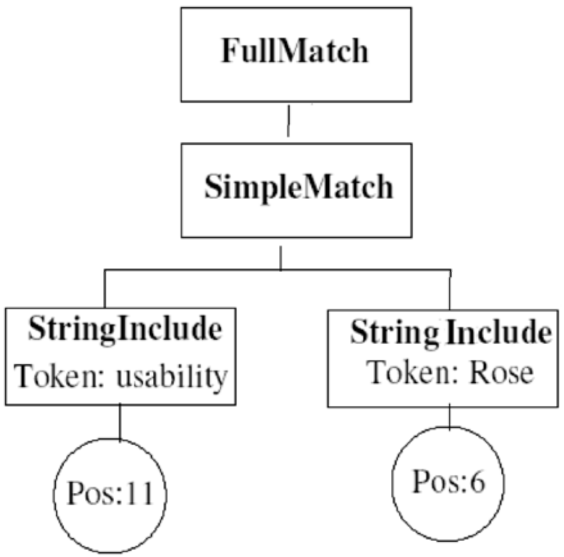
“usability” with stemming **“Rose”**

```
function fts:FTAnd ($fullMatch1 as element(fullMatch, fts:FullMatch),
                    $fullMatch2 as element(fullMatch, fts:FullMatch))
        as element(fullMatch, fts:FullMatch)
     {<fullMatch> {for $sm1 in $fullMatch1/simpleMatch
                   for $sm2 in $fullMatch2/simpleMatch
                   return <simpleMatch> {$sm1/* $sm2/*} <simpleMatch>
      </fullMatch>}
```

“usability” with stemming && “Rose”



“usability” with stemming && “Rose” window at most 10



Scoring Requirements

- Ranking answers on their relevance to FT query is an inherent part of FT search.
- Score value should reflect relevance of answer to FT expression.
- Score value depends on scoring algorithm but must satisfy:
  - Score is of type xs:float in the range [0, 1].
  - For score values greater than 0, a higher score must imply a higher degree of relevance.
  - If the Boolean evaluation of the FT expression is false then score value must be 0.

Scoring Examples

- ***Query returning scores:***
  for $b in /books/book
  score $s as $b/content ftcontains "web site" && "usability" and
  $b//chapter/title ftcontains "testing"
  return $s
- ***Top-K query example:***
  for $result at $pos in
  for $p in //books/book/paragraph
  score $s as $p ftcontains “users“ && “software“ with
  distance at most 13 words
  order by $s
  return $p
  where $pos <= 10
  return $result

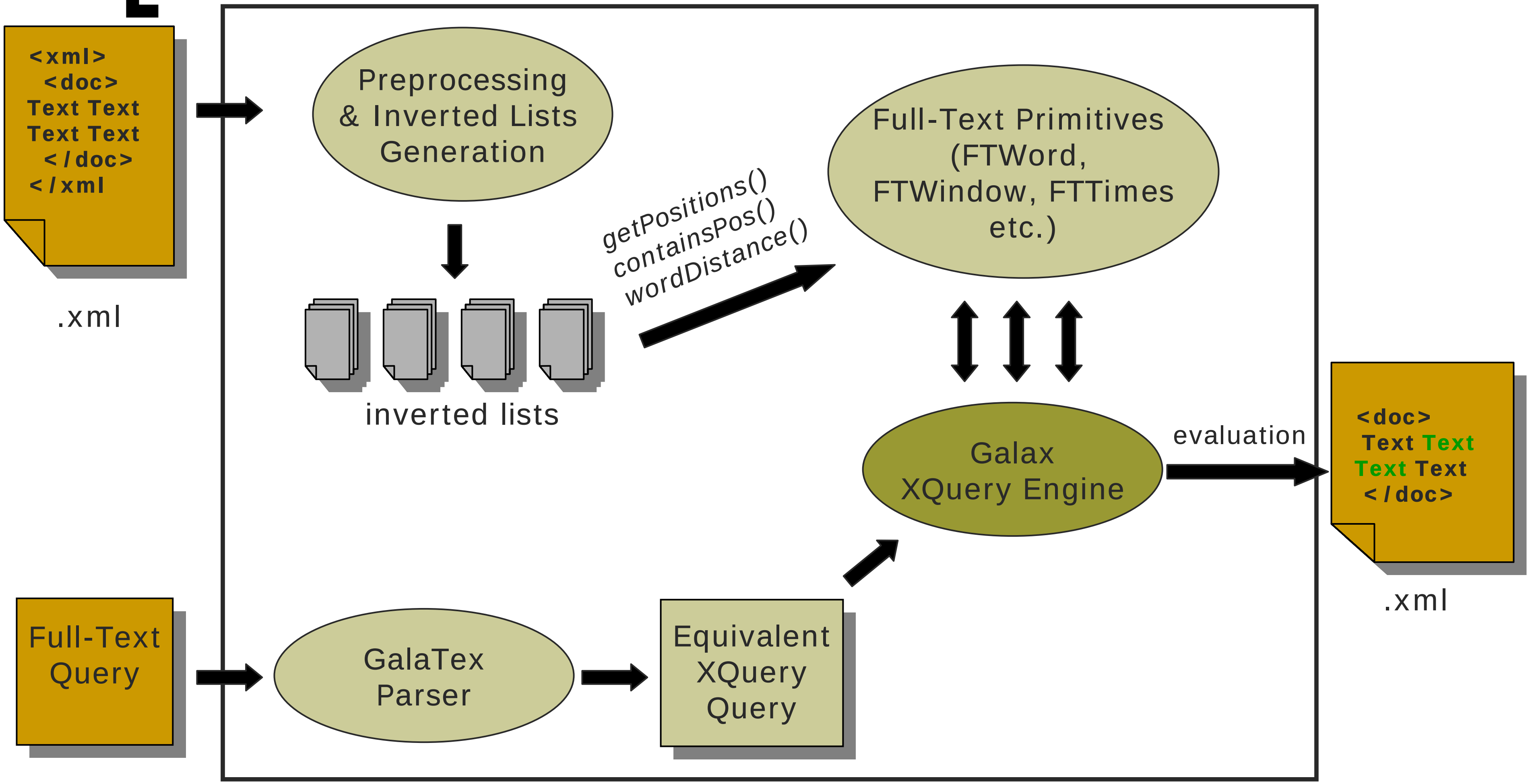
New Scoring Desiderata

- FT expression true implies score > 0.
- score = 0 implies ftcontains false.
- FT expression false should not imply anything for score.
- Answers satisfying query *approximately may* be returned.
- *Scoring answers needs to consider scoring FT, scalar and structural predicates.*

GalaTex overview

- First complete conformant implementation of W3C XQuery Full-Text language.
- Web demo includes W3C XQuery Full-Text Use Cases: ***http://www.galaxquery.com/galatex***
- Poster presentation at WWW'05.
- Built on top of the Galax XQuery engine.
- Soon (in a few weeks) available as open source non-commercial software.

GalaTex Architecture



GalaTex Demo Snapshot

GalaTex Use Cases:

W3C XQuery Full-Text Usecases

My Examples

with Match Options

XQuery Full-Text query is:

```
(: Q2: 2.2.2 Find all book subjects containing the phrase "usability testing" :)
<results>
{
  $xmlfile/books/book/metadata/subjects/subject[ . ftcontains "Usability testing" ]
}
</results>
```

Generated XQuery query is:

```
<results>
{ $xmlfile/books/book/metadata/subjects/subject[
( let $ec_1 := ( . ) return
  fts:FTContains( $ec_1,
   fts:FTWordsSelectionAny( $ec_1, "Usability testing", validate
       {<fts:FTMatchOptions/>}, "1")))]
} </results>
```

Dynamic Evaluation:

```
<results xmlns:fts="http://www.w3.org/xquery-fulltext">
        <subject >Usability testing</subject>
        <subject >Usability testing</subject>
        <subject >Usability testing</subject>
</results>
```

Scoring XML

Joint work with **Nick Koudas, (U. of Toronto) , Amélie Marian (Columbia University), Divesh Srivastava (AT&T Labs Research), David Toman (University of Waterloo)**

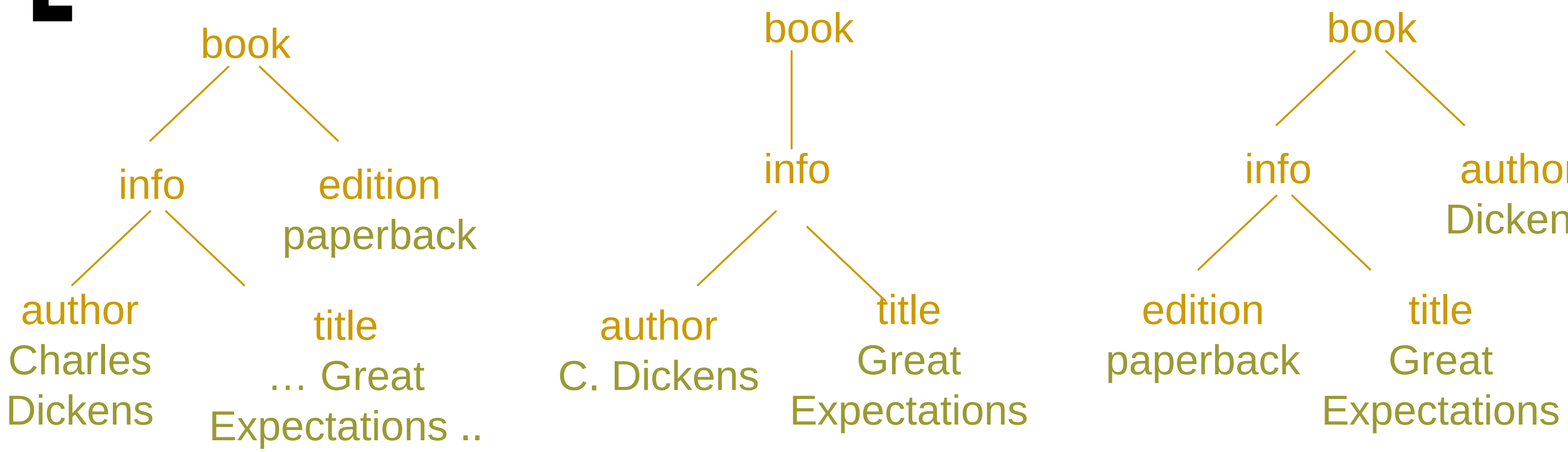
Motivation

- Queries on XML data combine conditions on structure with conditions on values.
- Computing the relevance of an answer to a query should rely on:
  - Evaluating conditions on values and on structure approximately.
  - Combining scores.
- Only a few recent contributions to approximate XML queries on structure [Schlieder'02, Delobel and Rousset'02, Amer-Yahia et al'02].
- **Goal**: Study query approximation on structure in XML and define a family of scoring methods.

Outline

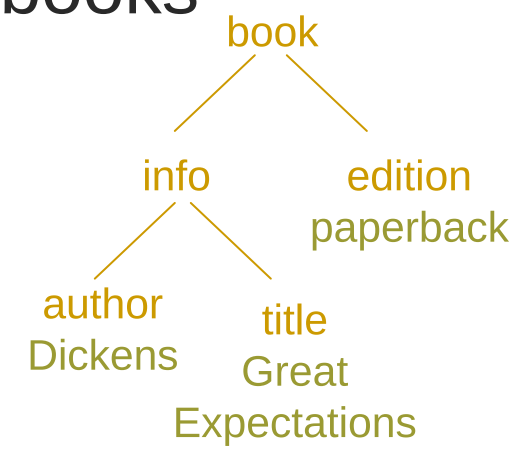
- Examples of Query Approximation on Structure.
- XML Query Relaxation.
- Scoring Functions for XML.

Query and Data Examples



- Heterogeneous XML Data about books
- Query:

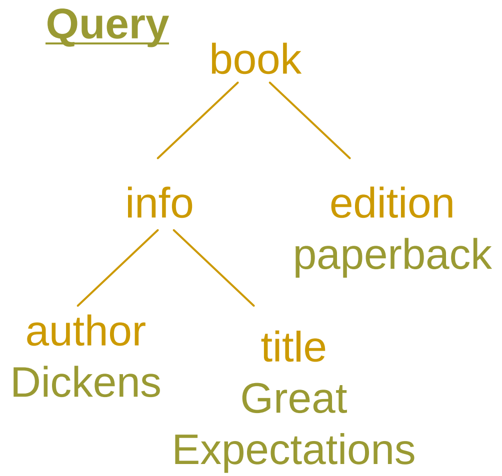
book [./info/author ftcontains "Dickens"] and [./info/title ftcontains "Expectations"] and [./edition ftcontains "paperback"]

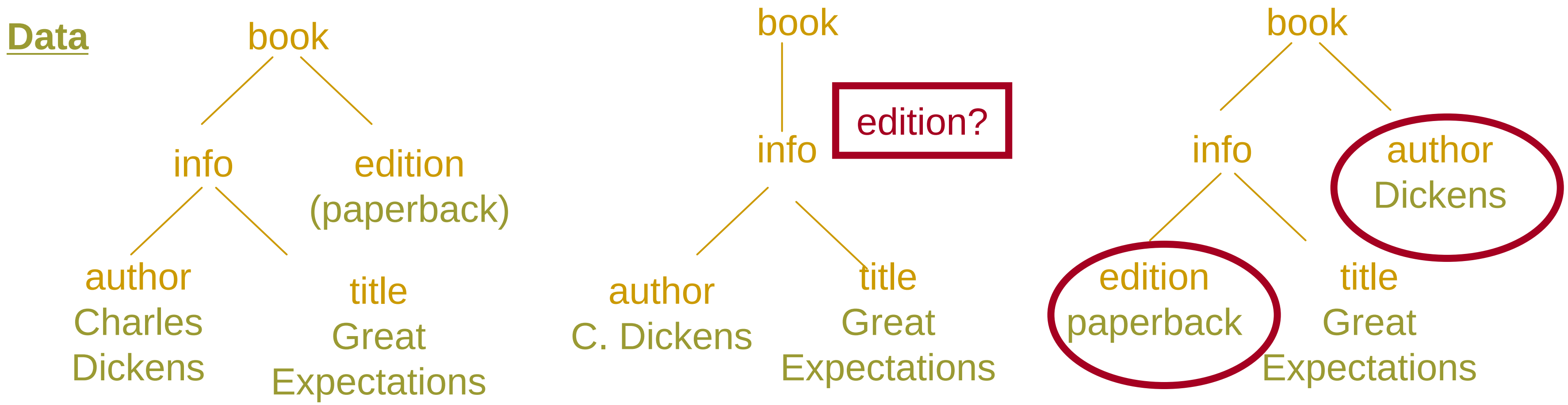


XML Query Relaxation

[Amer-Yahia, Cho and Srivastava EDBT'02]
[Amer-Yahia, Lakshmanan and Pandit SIGMOD'04]

- Tree pattern relaxations:
  - Leaf node deletion
  - Edge generalization
  - Subtree promotion

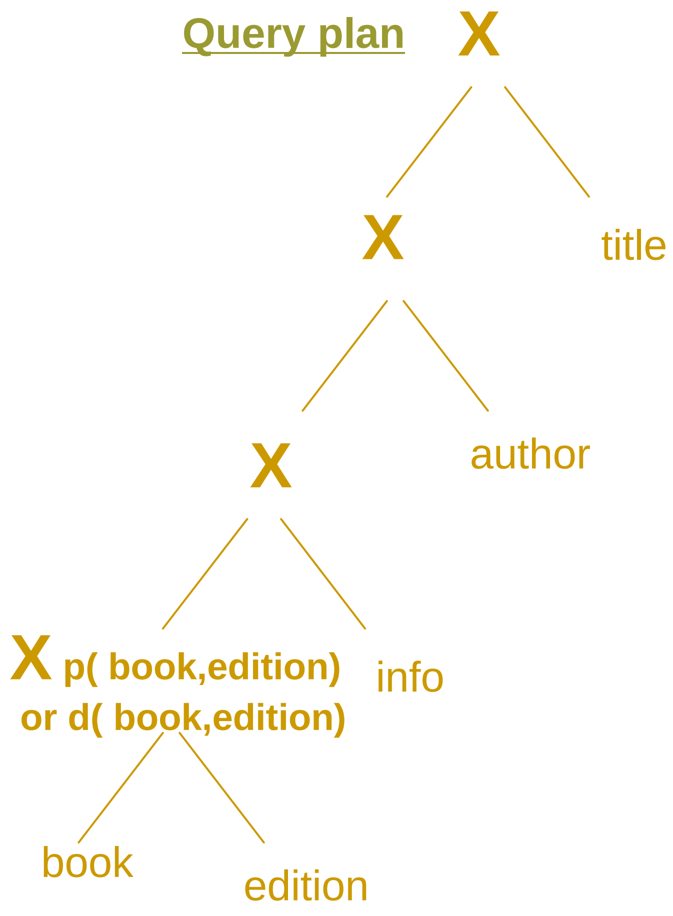




XML Query Relaxation

[Amer-Yahia, Cho, Srivastava EDBT'02]

- Encode relaxations in a single join plan:
  - More efficient than rewriting-based techniques.
  - Static threshold for top-K pruning.
  - Batch mode processing.
- Challenge: Maximize answer scores to enable early pruning
- Traditional join ordering not applicable



Scoring Functions Critical for Top-*k* Query Processing

- Top-*k* answer quality depends on scoring function.
- Efficient top-*k* query processing requires scoring function:
  - Monotonic.
  - Fast to compute.
- Little attention given to scoring functions for structured and semi-structured data
  - Extensively studied over text data (e.g., *tf.idf*)
  - → Proposed scoring function inspired by *tf.idf* for XML data

Adaptation of *tf.idf* to XML

[Marian, Amer-Yahia, Koudas, Srivastava ICDE'05]

Document Collection (Information Retrieval)	XML Document
Document	XML Node (result is a subtree rooted at a distinguished node, i.e., a node with a given label and structural properties)
Keyword(s)	Query Pattern
idf (inverse document frequency) is a function of the fraction of documents that contain the keyword(s)	*idf* is a function of the fraction of distinguished nodes that match the query pattern
tf (term frequency) is a function of the number of occurrences of the keyword in the document	*tf* is a function of the number of ways the query pattern matches the distinguished node

Scoring Function for XML Approximate Matches

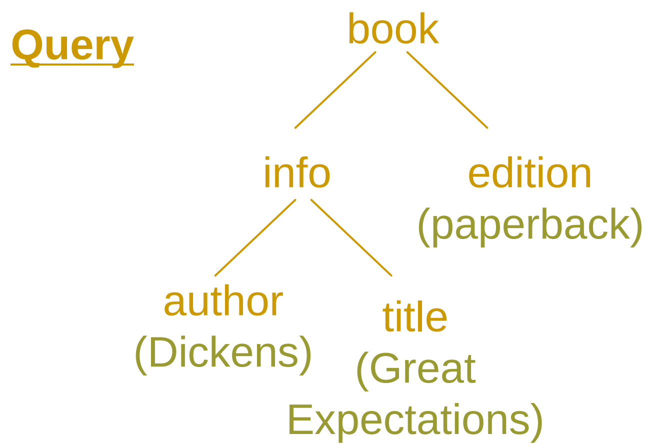
- Required properties:
  - Exact matches should be scored higher than relaxed matches (*idf*)
  - Returned elements with several matches should be ranked higher than those with fewer matches (*tf*)
- How to combine *tf* and *idf*?
  - *tf.idf*, as used by IR, violates above properties
  - Ranking based on *idf*, then breaking ties using *tf* satisfies the properties

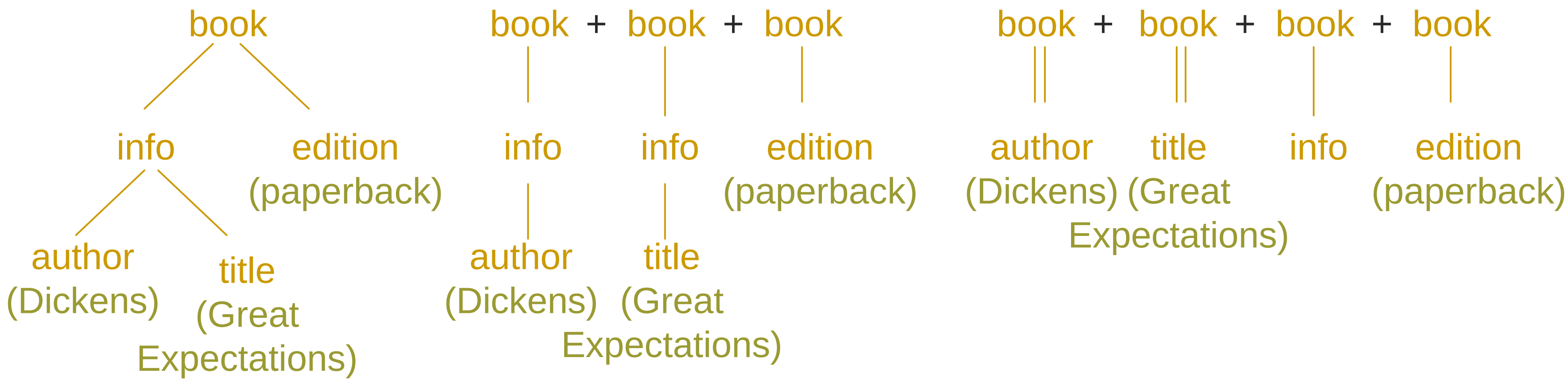
(a) (b)

score(a) ≷= score(b)

A Family of Scoring Methods for XML Path Queries

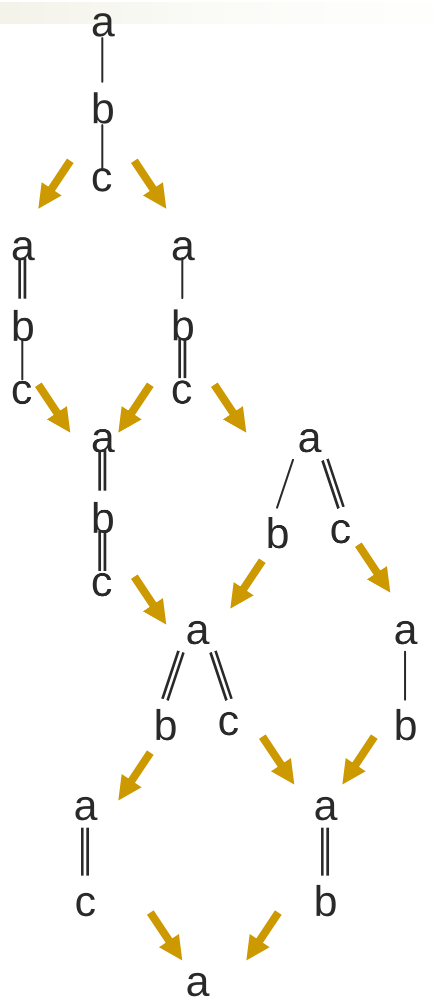
- Twig predicate
  - High quality
  - Expensive computation
- Path predicates
- Binary predicates
  - Low quality
  - Fast computation





Representing Relaxed Query Patterns: DAG Structure

- Each child is more relaxed (has more matches) than its parents
- *idf* of a child is lower than the *idf* of its parents
- *idf* scores are accessible in constant time for any match (complete or partial) using hash function



Exhaustive algorithm to build the DAG

Query Processing using the DAG

- Benefits:
  - Score computation done in a preprocessing phase (using exact or approximate information)
  - Score access during query processing done in constant time
  - Additional information needed for query processing precomputed and accessed in constant time (e.g., score upper bound)
- *tf* estimated at runtime based on available information

Summary of Contributions

- A family of scoring methods for XML queries
  - Structure and content
  - Structural relaxations
- Evaluation of the scoring methods tradeoffs.
- Efficient data structures to compute and access scores during top-k query processing.

Open Issues

- Extensive experimental evaluation of scoring functions and ranking algorithms for XML:
  - INEX topics and datasets.
  - In collaboration with K. Hatano (NAIST).
- Define a score-aware algebra for XQuery Full-Text for the joint optimizations of queries on both structure and text:
  - Consistent scoring: equivalent query expressions should result in same scores.
  - Consistent ranking: equivalent query expressions should result in the same topK results for any given document fragment.
  - Optimize individual FTSelections: e.g. FTAnd.
  - In collaboration with E. Curtmola and A. Deutsch (UCSD).
- Refine XQuery Full-Text language syntax and semantics:
  - A syntax for specifying structural relaxations?
  - Semantics of structural relaxations when combined with query approximation on content?