Phrase Matching in XML

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Motivation

- **Phrase matching is common in information retrieval**
  - **complements keyword matching**
  - **example: “To be or not to be”**
  - **word matches: contiguity or proximity**
- **XML used for document markup**
  - **XML tagging destroys contiguity of words**
  - **heavy tagging (e.g., Treebank) upsets proximity**
- **Goal: Understand phrase matching in XML documents**

Motivation: Various XML Examples

- Jon Bosak's Shakespeare's plays in XML
  - identifies play elements: scenes, speeches
- The U Penn Treebank
  - identifies grammatical elements: nouns, verbs
- Library of Congress legislative bills
  - identifies bill elements: sponsor, committee-name

Motivation: Example

- **Annotated Shakespeare**
  - **problem: text interleaves with arbitrary XML markup**

```
<SPEECH>
   <SPEAKER>HAMLET</SPEAKER>
   <LINE>To be, or not to be:
      <COMMENT> The line <QUOTE> To be, or not to be:
      that is the question</QUOTE> is one of the most
      quoted phrases in the English language.</COMMENT>
   that is the question:</LINE>
</SPEECH>
```

- **Solution: specify tags, entire XML annotations to ignore**
  - **identify structural, semantic markup, commentaries on original text**
  - **dynamic specification permits flexibility**

Problem Statement

- **Given (pre-processed) XML database, and**
- **Proximity query specified by:**
  - **context node tags** C
  - **list of phrase words** $W = [w_1, \ldots, w_q]$
  - **ignore-tag tags** T
  - **ignore-annot tags** A
  - **proximity threshold** K
- **Identify all (context node, witness list) pairs in DB**

Overview

- Motivation
- Problem statement
- Exact phrase matching
- Proximity phrase matching
- Experimental Results
- Related Work
- Open Problems

Exact Phrase Matching: Interval Encoding

- **(Start, End) numbering of XML elements and text**

<SPEECH$_{(1,44)}$>
<SPEAKER$_{(2,4)}$> HAMLET$_{3}$</SPEAKER>
<LINE$_{(5,43)}$> To$_{6}$ be$_{7}$, or$_{8}$ not$_{9}$ to$_{10}$ be$_{11}$:
<COMMENT$_{(12,38)}$> The$_{13}$ line$_{14}$ <QUOTE$_{(15,26)}$> To$_{16}$ be$_{17}$, or$_{18}$ not$_{19}$ to$_{20}$ be$_{21}$:
that$_{22}$ is$_{23}$ the$_{24}$ question$_{25}$</QUOTE> is$_{27}$ one$_{28}$ of$_{29}$ the$_{30}$ most$_{31}$
quoted$_{32}$ phrases$_{33}$ in$_{34}$ the$_{35}$ English$_{36}$ language$_{37}$.</COMMENT>
that$_{39}$ is$_{40}$ the$_{41}$ question$_{42}$:</LINE>
</SPEECH>

- **Properties**
  - **(anc, desc) $\equiv$ interval containment**
  - **word adjacency $\equiv$ interval contiguity**

Exact Phrase Matching: Inverted Indexes

- {(Tag/word, list of intervals)} in Start order

<SPEECH$_{(1,44)}$>
<SPEAKER$_{(2,4)}$> HAMLET$_{3}$</SPEAKER>
<LINE$_{(5,43)}$> To$_{6}$ be$_{7}$, or$_{8}$ not$_{9}$ to$_{10}$ be$_{11}$:
<COMMENT$_{(12,38)}$> The$_{13}$ line$_{14}$ <QUOTE$_{(15,26)}$> To$_{16}$ be$_{17}$, or$_{18}$ not$_{19}$ to$_{20}$ be$_{21}$:
that$_{22}$ is$_{23}$ the$_{24}$ question$_{25}$</QUOTE> is$_{27}$ one$_{28}$ of$_{29}$ the$_{30}$ most$_{31}$
quoted$_{32}$ phrases$_{33}$ in$_{34}$ the$_{35}$ English$_{36}$ language$_{37}$.</COMMENT>
that$_{39}$ is$_{40}$ the$_{41}$ question$_{42}$:</LINE>
</SPEECH>

$L_{\texttt{SPEECH}}$	$L_{\texttt{LINE}}$	$L_{\texttt{COMMENT}}$	$L_{\texttt{to}}$	$L_{\texttt{be}}$	...	$L_{question}$
(1,44)	(5,43)	(12,38)	(6,6)	(7,7)		(25,25)
			(10, 10)	(11,11)		(42,42)
			(16, 16)	(17,17)		
			(20, 20)	(21,21)		

- Build B-tree on Start and End positions for probing

Exact Phrase Matching: Output

- **(context node, witness list) pairs in DB**

<SPEECH$_{(1,44)}$>
    <SPEAKER$_{(2,4)}$> HAMLET$_{3}$</SPEAKER>
    <LINE$_{(5,43)}$> To$_{6}$ be$_{7}$, or$_{8}$ not$_{9}$ to$_{10}$ be$_{11}$:
        <COMMENT$_{(12,38)}$> The$_{13}$ line$_{14}$ <QUOTE$_{(15,26)}$> To$_{16}$ be$_{17}$, or$_{18}$ not$_{19}$ to$_{20}$ be$_{21}$:
        that$_{22}$ is$_{23}$ the$_{24}$ question$_{25}$</QUOTE> is$_{27}$ one$_{28}$ of$_{29}$ the$_{30}$ most$_{31}$
        quoted$_{32}$ phrases$_{33}$ in$_{34}$ the$_{35}$ English$_{36}$ language$_{37}$.</COMMENT>
    that$_{39}$ is$_{40}$ the$_{41}$ question$_{42}$:</LINE>
</SPEECH>

{(1,44),
{ [6, 7, 8, 9, 10, 11, (12, 38), 39, 40, 41, 42],
[16, 17, 18, 19, 20, 21, 22, 23, 24, 25] } }

- **Each witness can be compacted to a single interval**

Exact Phrase Matching: Notation

- L_C: **index of all intervals of context nodes**
- L_{w_j}: **index of all intervals of word** w_j
- L_M: **index of all intervals of ignored markup**
  - L_{a_j}: **index of all ignore-annot intervals**
  - LE_{t_j}: $\{(s, s), (e, e) \mid (s, e)$ **in ignore-tag index** $L_{t_j}\}$

Exact Phrase Matching: Indexed Nested Loops

- **Generalizes relational indexed nested loops**

for each context interval i_c in L_C $\{$
witnessSet = $\{\ \}$;
index probe L_{W_1} to find first interval i_1 such that descendant(i_1, i_c);
repeat $\{$
matchPos = 1; m = [i_1];
repeat $\{$
probe ($L_{W_{(matchPos+1)}} \cup L_M$) to find i_2 with i_2.start = last(m).end+1;
if (no match found) break;
if ($i_2 \in L_{W_{(matchPos+1)}}$) matchPos++; m = append(m, i_2);
$\}$ until (matchPos = q)
if (matchPos = q) witnessSet = witnessSet $\cup$ $\{$ m $\}$; /* complete witness */
i_1 = next(L_{W_1})
$\}$ until not(descendant(i_1, i_c))
output (i_c, witnessSet) $\}$

  - **nested context nodes: repeated computation**
  - **arbitrarily many probes of L_M**

Exact Phrase Matching: PIX

```
while (not(empty(L))) {
    i = remove-first(L);
    if (i ∈ L_C) { /* i is context interval */
        if (not(empty(S)) && not(descendant(i,top(S).interval)))
            output-and-clean(i);
        new-interval(i);
    } else { /* i is word or ignored markup */
        if (empty(S)) break;
        if (not(descendant(i, top(S).interval))) output-and-clean(i);
        if (i ∈ L_M) {
            extend-with-markup(i);
            if (i ∈ L_{a_j}) /* i is nested annotation */
                new-interval(i);
        } else if (i ∈ L_{W_pos}) extend-with-word(i, pos);
} }
if (not(empty(S))) output-and-clean((0,0));

output-and-clean(i) {
    repeat {
        c = pop(S);
        if (c.interval ∈ L_C) /* context interval */
            output(c.interval,c.witnessSet);
        /* Propagate nested witnesses up stack */
        top(S).witnessSet ∪ = c.witnessSet;
    } until (empty(S) or descendant(i,top(S).interval));
}
```

```
extend-with-markup(i) {
    for each m ∈ top(S).matchSet {
        if (i.start = last(m.partialWitness).end + 1)
            m.partialWitness = append(m.partialWitness, i);
        else
            discard-partial-match(m)
    }
}

extend-with-word(i, pos) {
    if (pos = 1) {
        top(S).matchSet = top(S).matchSet ∪ ([ i ], 1);
    } else {
        for each m ∈ top(S).matchSet {
            if (m.matchPos + 1 = pos and i.start =
                    last(m.partialWitness).end + 1) {
                m.partialWitness = append(m.partialWitness, i);
                m.matchPos++;
                /* Once matched complete phrase */
                if (m.matchPos = q) {
                    top(S).witnessSet ∪ = { m.partialWitness };
                    discard-partial-match(m)
                }
            } else discard-partial-match(m)
} } }
```

Exact Phrase Matching: PIX Analysis

- Generalizes stack-based structural join algorithm
  - stack to identify (anc, desc) pairs
  - key reliance on interval numbering with contiguity
  - take order of phrase words into account
  - use markup intervals between phrase words
- Analysis
  - traverse each interval list once
  - bounded-size in-memory stack
- Asymptotically optimal (linear) I/O complexity

Proximity Phrase Matching: Key Ideas

- **Only modify extend-with-word()**
  - **keep track of positions skipped, up to K**
- **Permits skipping over unknown words and tags**
  - **in addition to ignore-tags, ignore-annots**
- **Can also generalize INL using B-tree indexes**

Experimental Results: INL vs PIX

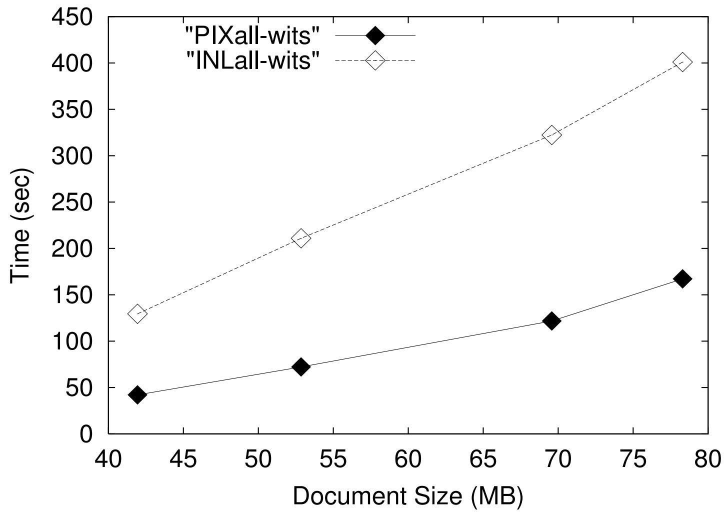
- **Implementation**
  - in Java, uses Berkeley DB package for indexes
- **Data Sets**
  - real data from Treebank linguistic corpus (WSJ, Brown corpus)
  - synthetic XMach data modified for text

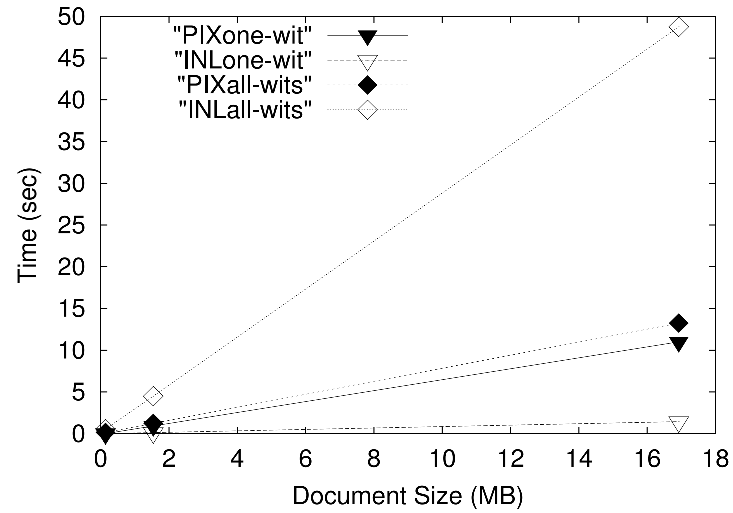
Experiments: Applicability of Known Results

- **No context nesting, no ignored markup**
  - **akin to relational joins**
- $| L_{w_1} | \ll | L_{w_2} |$
  - **INL is substantially better**
- $| L_{w_1} | \sim | L_{w_2} |$
  - **PIX is superior**

Experiments: Exploring Variability

- Vary number of witnesses and context nodes

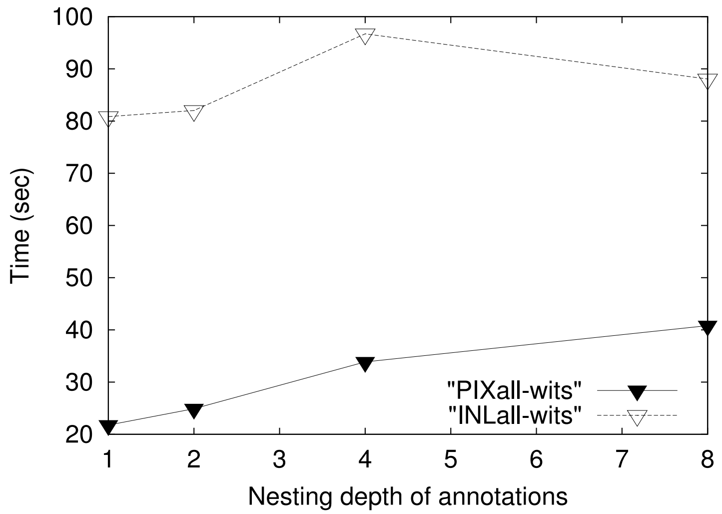


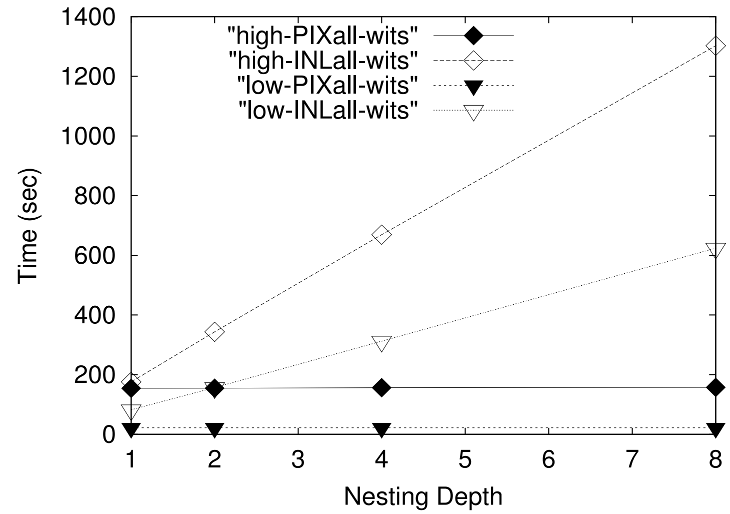


- PIX is about four times faster than INL for all witnesses
  - repeated index probing for markup is expensive

Experiments: Exploring Variability

- Vary nesting of context nodes and annotations





- PIX is independent of nesting depth, INL increases linearly
  - repeated index probing for nested context nodes

Experiments: Real Data

- Treebank data, no control on dataset

	Witnesses reported: One	Witnesses reported: All
INL	0.06s	0.06s
PIX	25.21s	27.10s

		Witnesses reported: One	Witnesses reported: All
WSJprd	INL	3.91s	4.03s
	PIX	0.45s	0.95s
Brown	INL	16.12s	16.12s
	PIX	15.12s	15.13s

- Real data supports observed behavior on synthetic data
  - synthetic data was reasonably realistic

Experiments: Summary

- No context nesting, no ignored markup
  - INL/PIX tradeoffs $\sim$ relational joins
- Vary number of witnesses and context nodes
  - INL and PIX grow linearly, PIX is faster for all witnesses
- Vary nesting of context nodes and annotations
  - PIX is independent, INL increases linearly
- Real data supports observed behavior on synthetic data

Related Work

- IR search engines ignore HTML tags for phrase matching
  - no prior work on XML and phrase matching
- Structural join algorithms [AJK+02]
  - use of stack, asymptotic optimal I/O
- Keyword matching in XML
  - dynamic context ([SKW01], XRank [GSB+03], TIX [AYJ03])
  - word approximation (XXL [TW02], XIRQL [FG01])

Open Problems: Cost-based PPM

- A hybrid of INL and PIX is likely to be best
  - which inverted lists to scan
  - which inverted lists to index probe
  - which query plan
- Analogy with relational join expression evaluation
  - need a cost model
  - need cardinality estimates

Open Problems: Scoring and Ranking

- Not all witnesses are equal
  - different numbers of ignore-tags
  - different numbers and sizes of ignore-annots
- Not all context nodes are equal
  - different types of witnesses
- Generalize TF*IDF measure from IR
  - some preliminary ideas in paper

Open Problems: Top-K Answers

- **Partial proximity phrase matching**
  - what if not all phrase words match?
  - what if proximity threshold exceeded?
  - how to assign scores?
- **Dynamic context determination**
  - is specific partial match better than general match?
  - how does one get top-K context nodes?

Conclusions

- Core contributions: XML phrase matching
  - proposed useful query primitives
  - developed efficient algorithms
  - performed experimental validation
  - built PIX prototype on top of GALAX
- Easily extended for phrase matching on streaming XML
  - no indices, track element nesting
- XML structure+text research
  - wealth of challenging problems

Motivation: PIX

- **Problem: XML tagging destroys words contiguity**
  - **heavy tagging (e.g., Treebank) upsets proximity**
- **Approach 1: Ignore all XML tags**
  - **used by IR search engines on HTML**
- **Why is this not enough?**

```
<LINE>To be, or not to be:
   <COMMENT> ...one of the most quoted phrases ...</COMMENT>
that is the question:</LINE>
```

- **Lesson: Need to ignore entire XML annotations**

Motivation: PIX

- Approach 2: Specify ignore-annots, ignore other tags
  - identify commentaries on original text
  - identify parenthetical phrases
- Why is this not enough?

```
   <LINE>Be all my sins remember'd</LINE>
</SPEECH>
<SPEECH>
   <SPEAKER>OPHELIA</SPEAKER>
```

- Lesson: Use XML markup to identify boundaries

Motivation: PIX

- Approach 3: Specify ignore-annots, ignore-tags
  - data-driven or query-specified?
- Argument for dynamic (query-time) specification

```
<LINE>The harlot's cheek
   <PP>beautied with plastering art</PP></LINE>
<LINE>Is not more ugly to the thing that helps it</LINE>
```

- Lesson: Dynamic specification permits flexibility (usability?)