

TASM: Top- k Approximate Subtree Matching

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Outline

- 1 Motivation and Problem Definition
- 2 TASM-Postorder
 - Upper Bound on Subtree Size
 - Prefix Ring Buffer Pruning
- 3 Experiments
- 4 Conclusion and Future Work

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1 Motivation and Problem Definition

2 TASM-Postorder

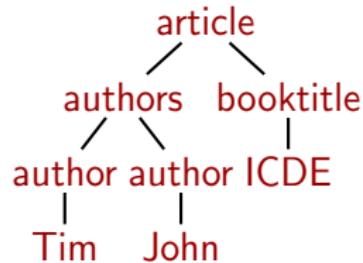
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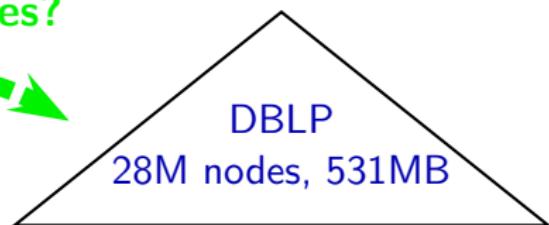
Query (XML fragment)



top- k matches?



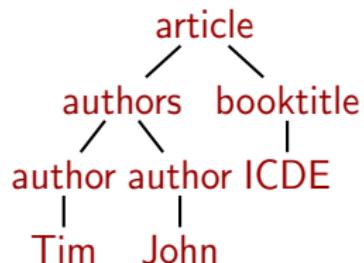
Document (very large XML)



Rank the top- k matches for the article query in the DBLP document!

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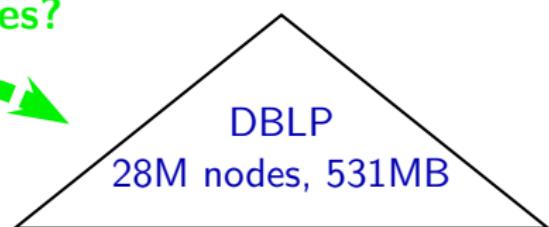
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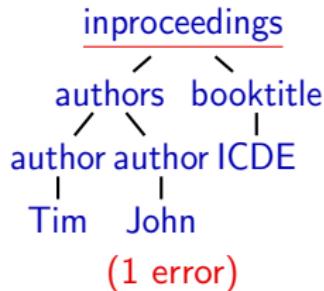


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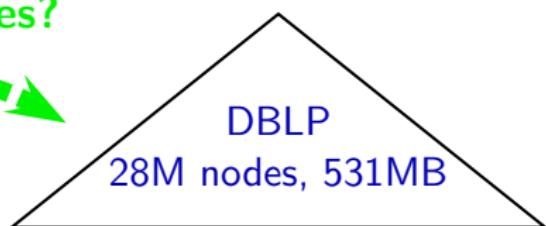
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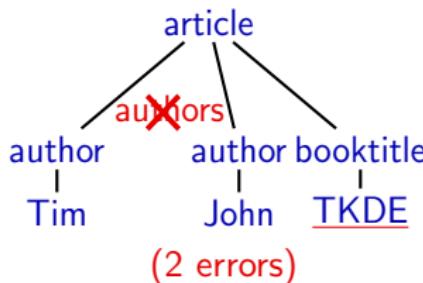
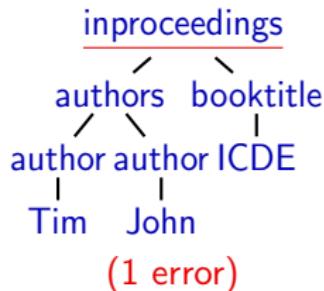


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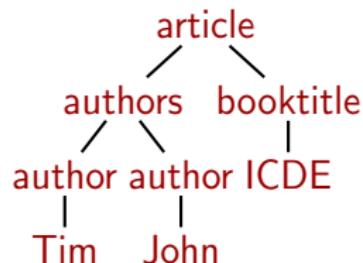
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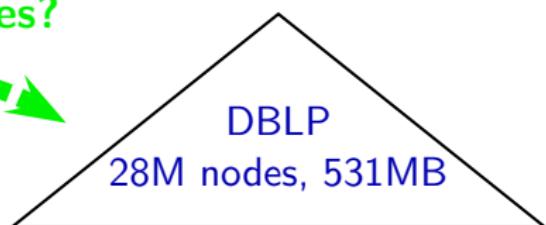
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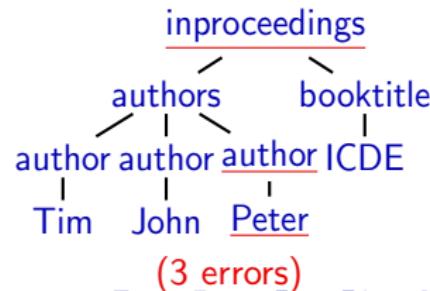
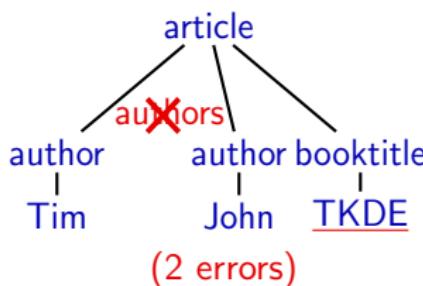
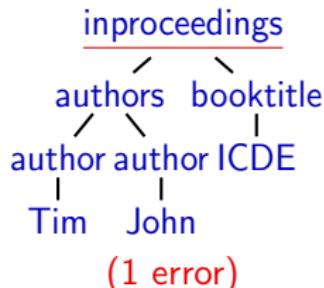


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Given: query tree Q , document tree T , size k of ranking

Goal: Compute a

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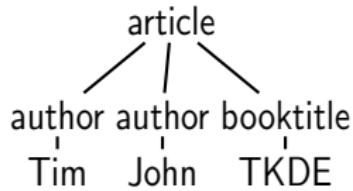
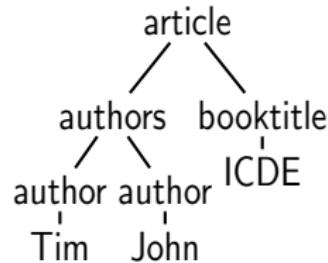
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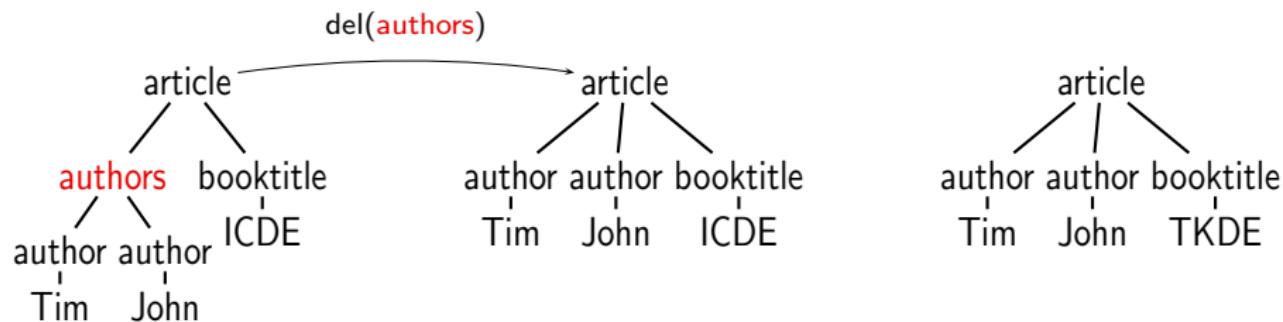
- Subtree T_i :
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- top- k ranking $R = (T_1, T_i, \dots, T_k)$
 - subtrees sorted by distance to query
 - best k subtrees: $T_i \notin R \Rightarrow ted(Q, T_k) \leq ted(Q, T_i)$

Ranking Function: Tree Edit Distance (TED)



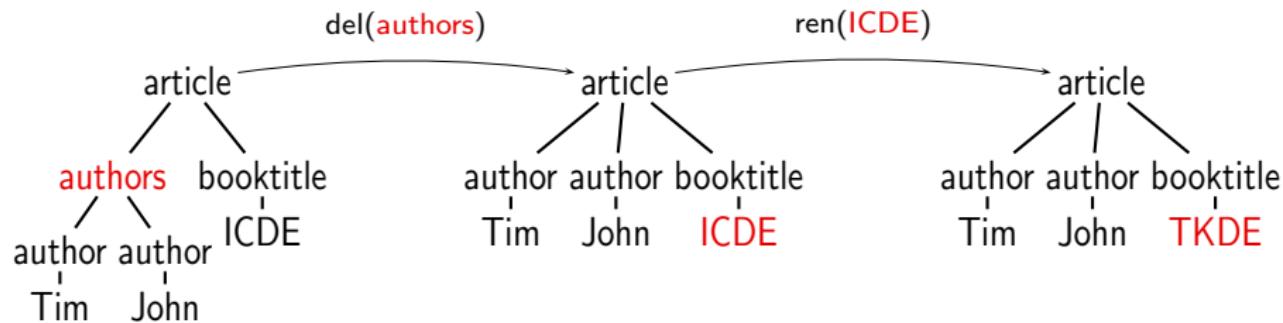
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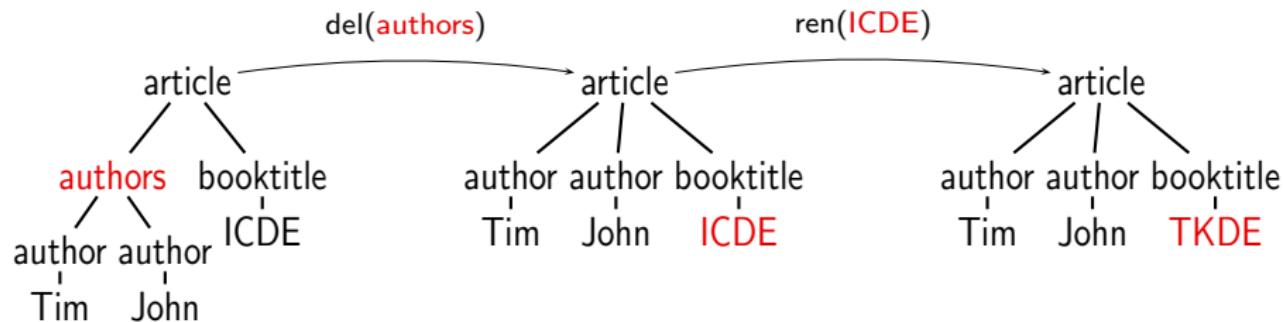
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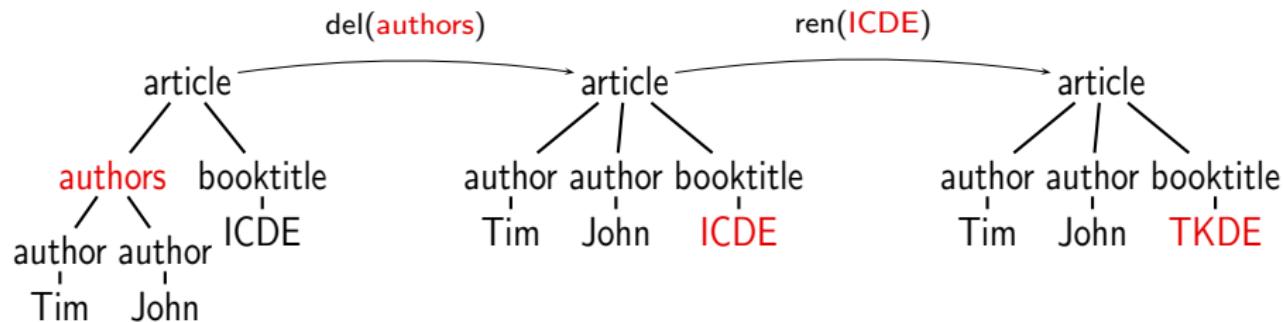
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- **TASM** computes TED between **query** and **document subtrees**
- **Size and number** of computed **subtrees** define TASM complexity

State of the Art

- **TASM-Dynamic:** dynamic programming solution¹
 - computes distance to **every subtree** of the document
 - **use smaller subtrees** to compute larger ones
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 - **Space complexity:** $O(mn)$, *m*: query size, *n*: document size

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- **Space complexity limits** application to databases
 - in database applications *n* is huge (database size!)
 - TASM-Dynamic maintains two $m \times n$ matrixes in RAM
 - > 6GB RAM for our tiny query ($m = 8$) on DBLP ($n = 28 \times 10^6$)

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State-of-the-art algorithms do not scale!

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Problem Definition

Find a solution for **TASM** (Top-k Approximate Subtree Matching) that

- scales to **very large documents**
- runs in **small memory**
- ranks subtrees **correctly** (no heuristics!)

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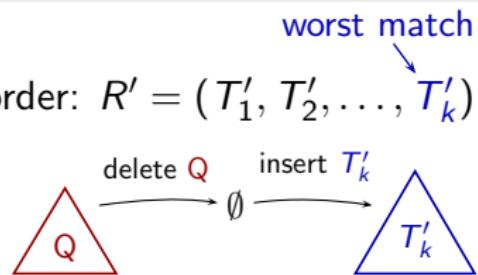
worst match



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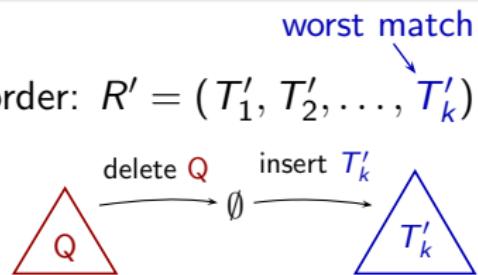
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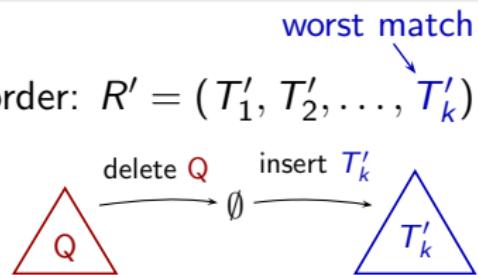


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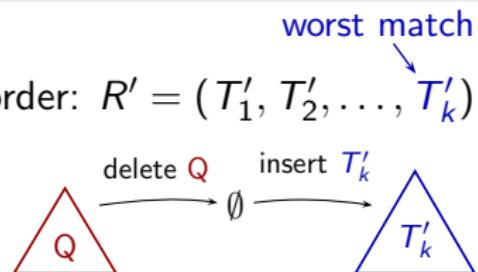
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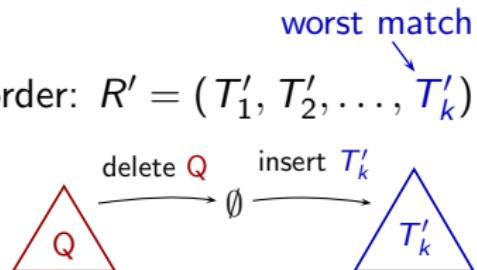
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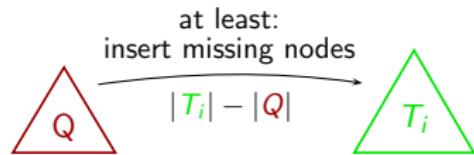
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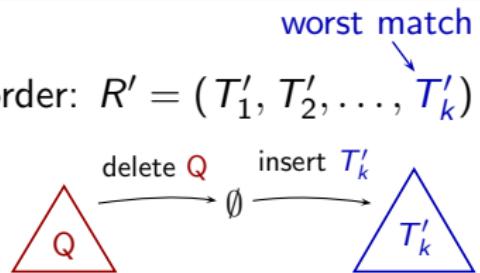
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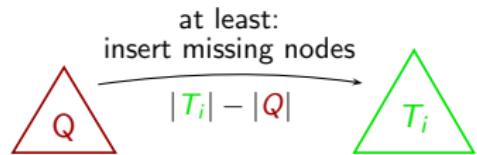
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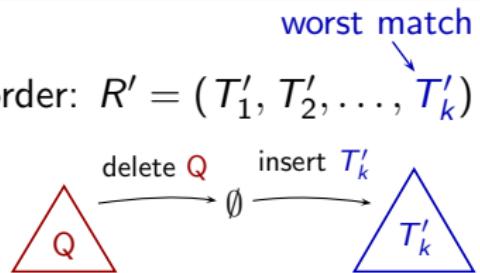
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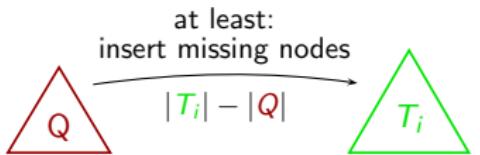
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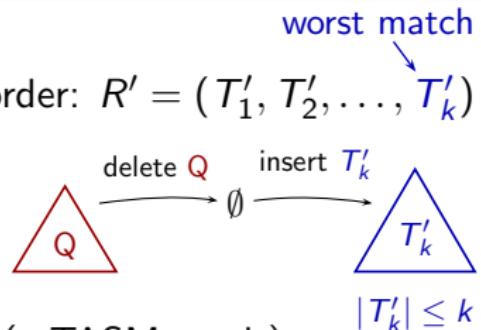


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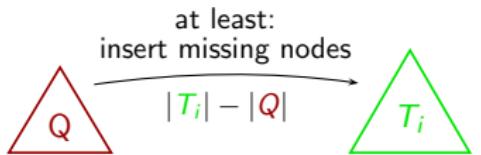
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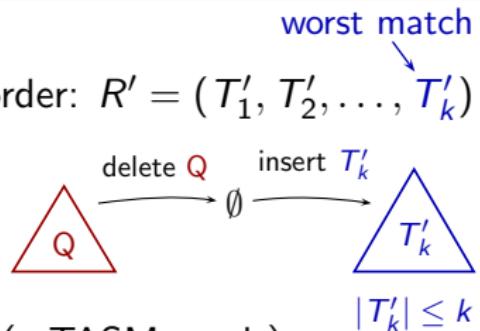


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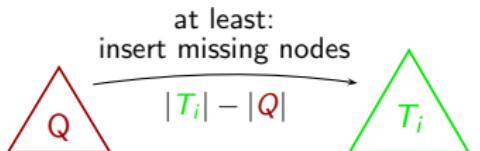
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Example: top-10 with example query $|Q| = 8$ on DBLP (28M nodes)

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Document-independent upper bound on subtree size!

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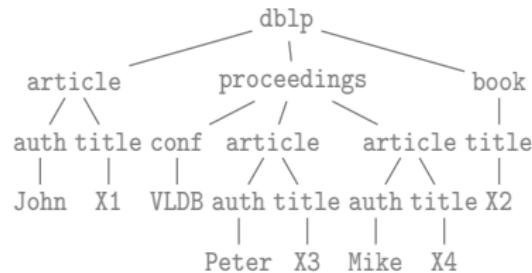
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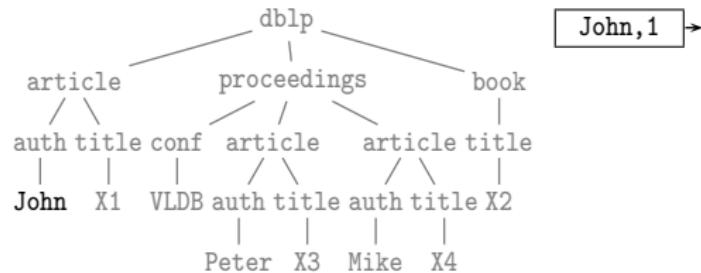
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Document Format: Postorder Queue



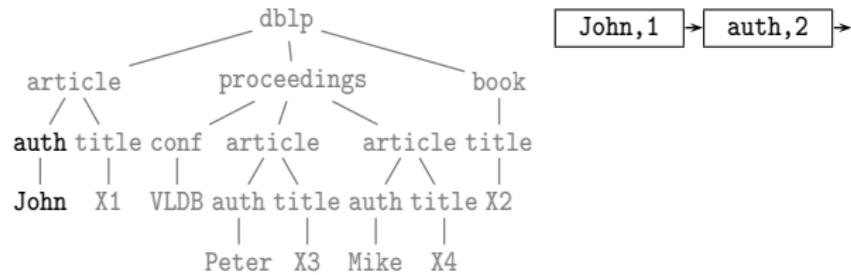
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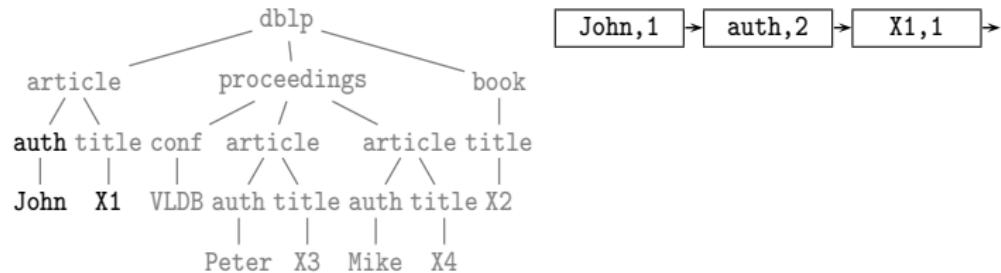
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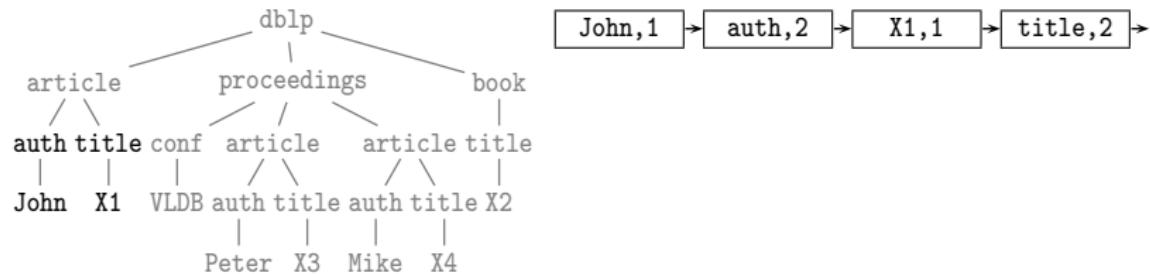
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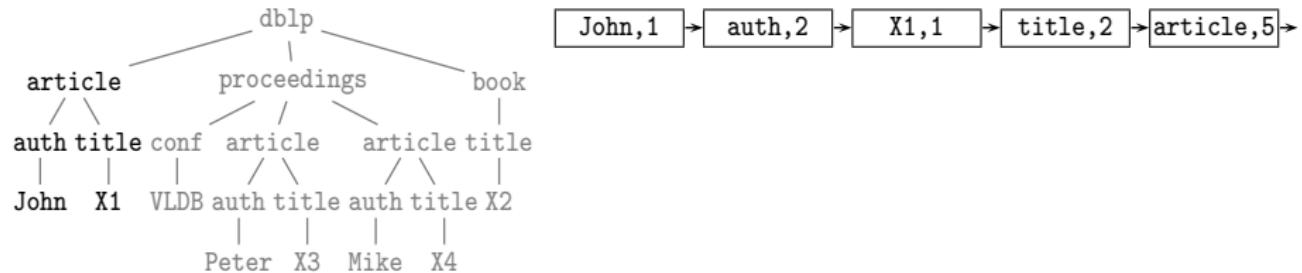
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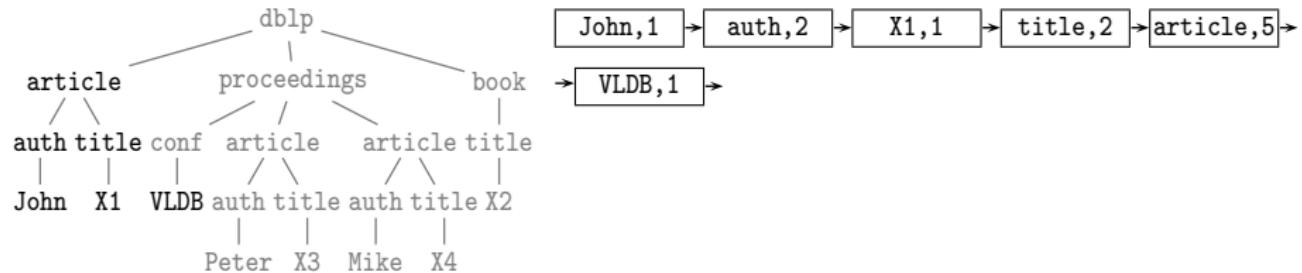
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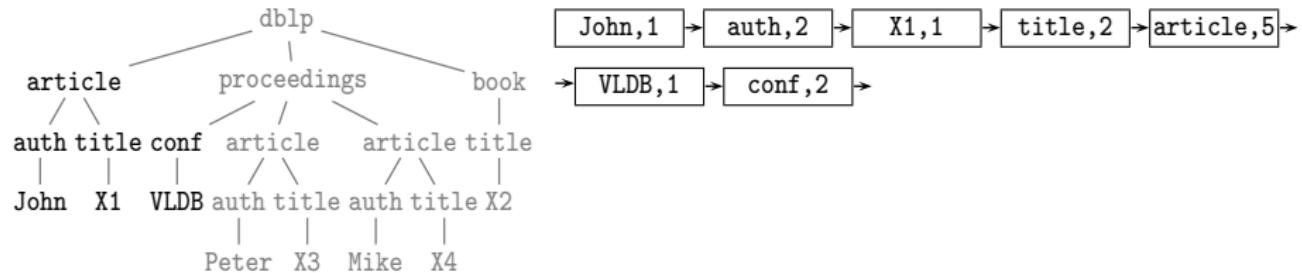
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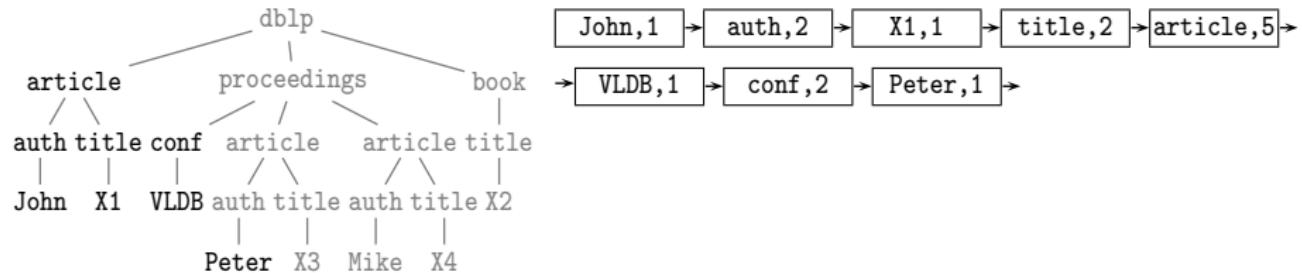
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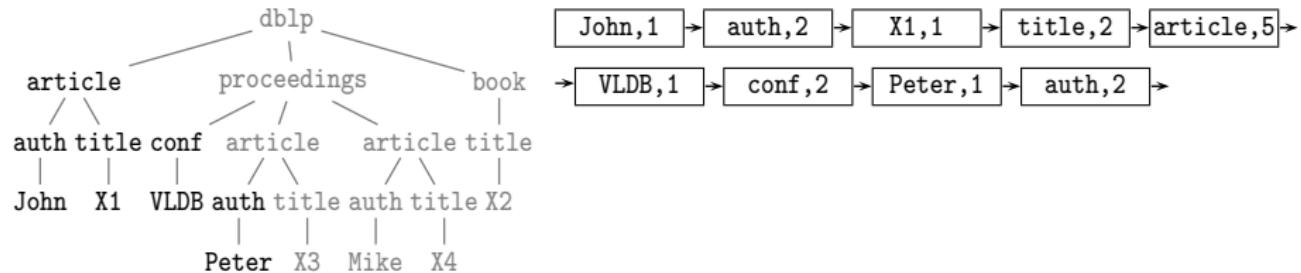
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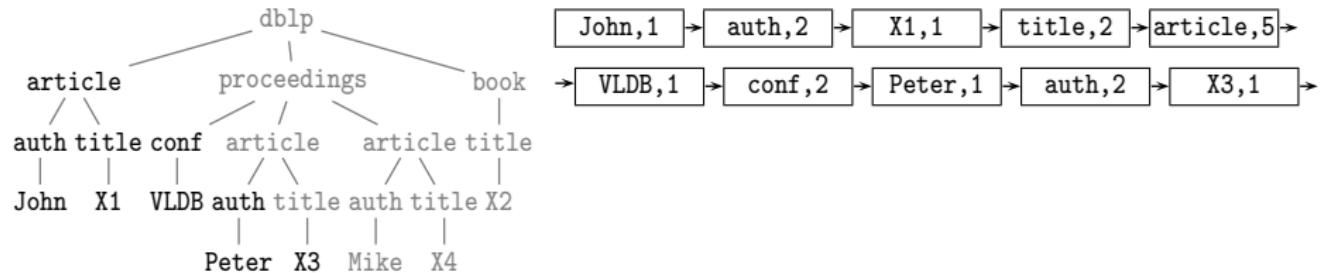
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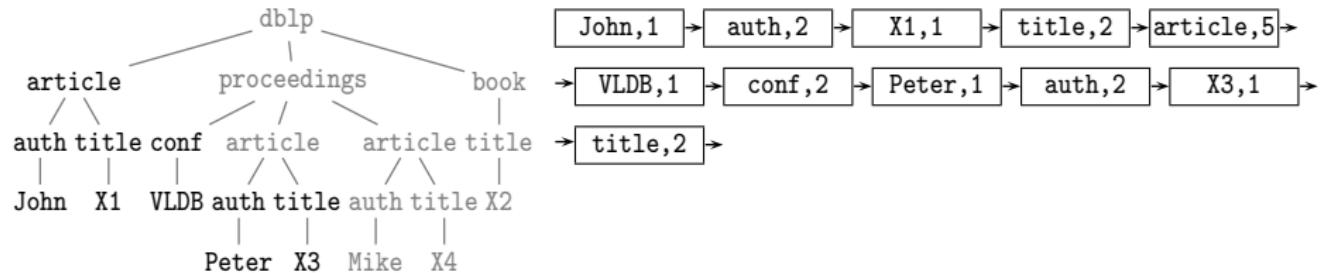
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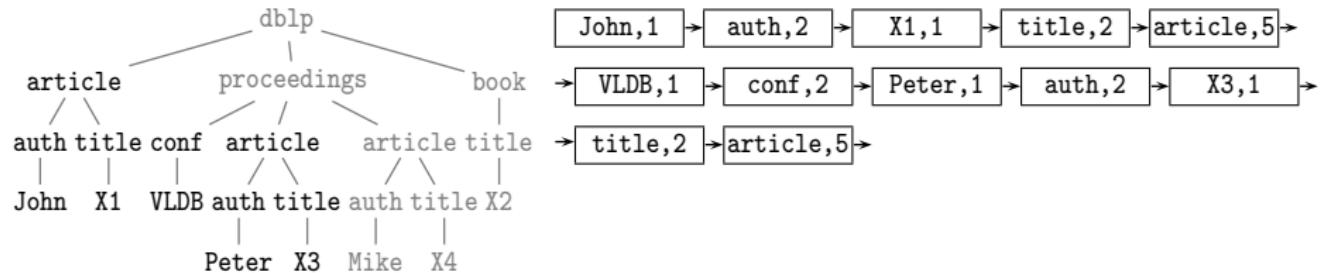
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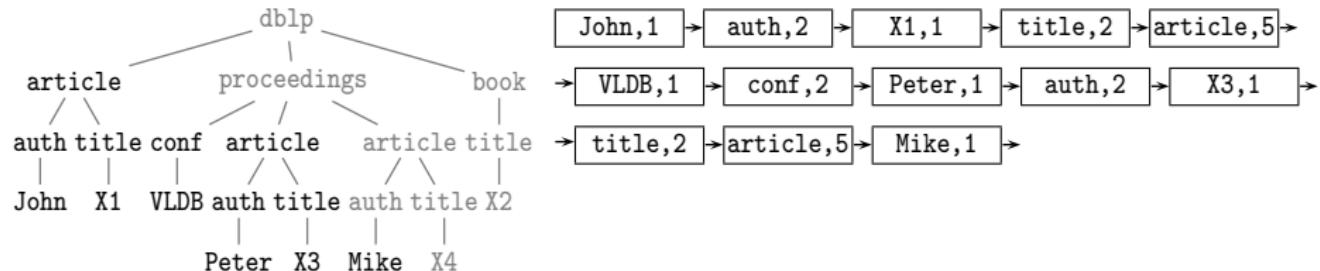
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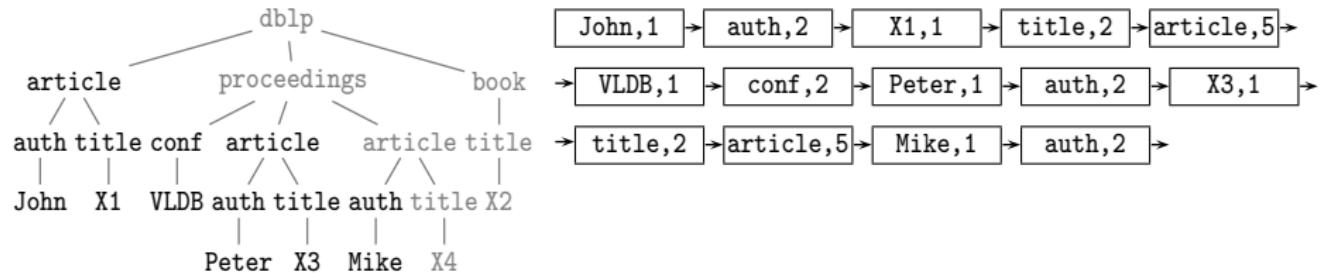
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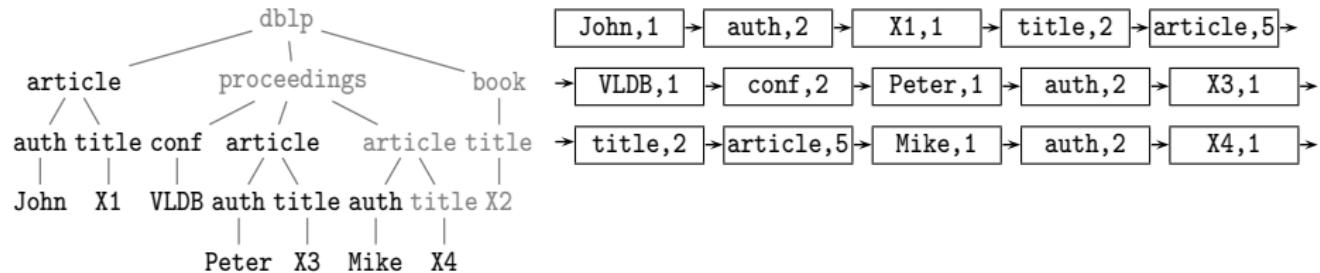
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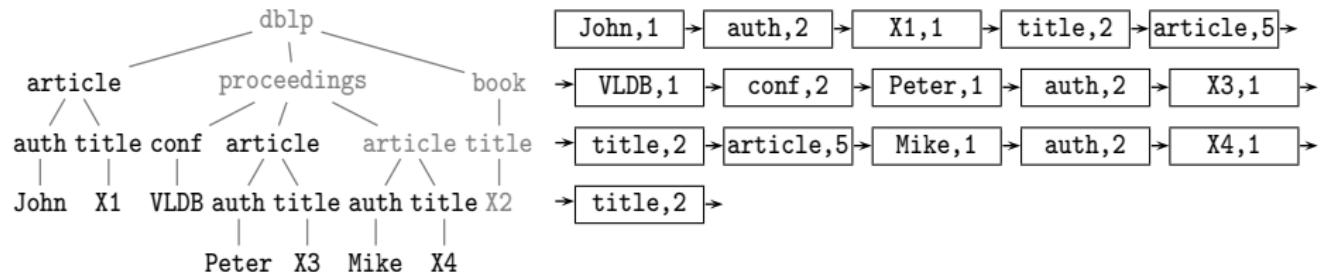
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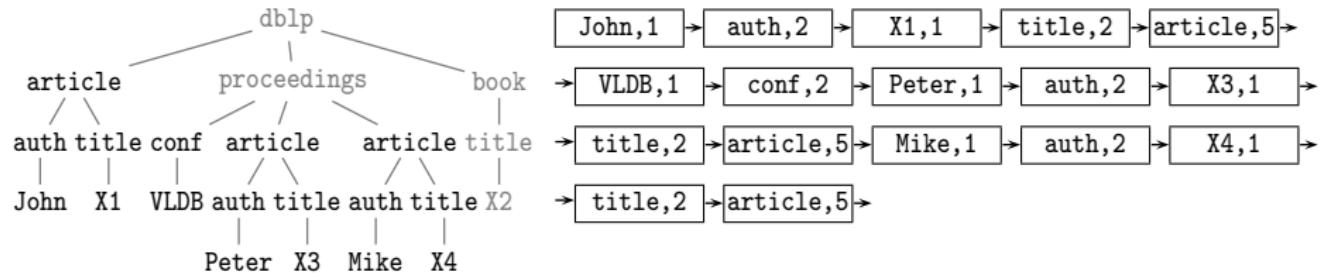
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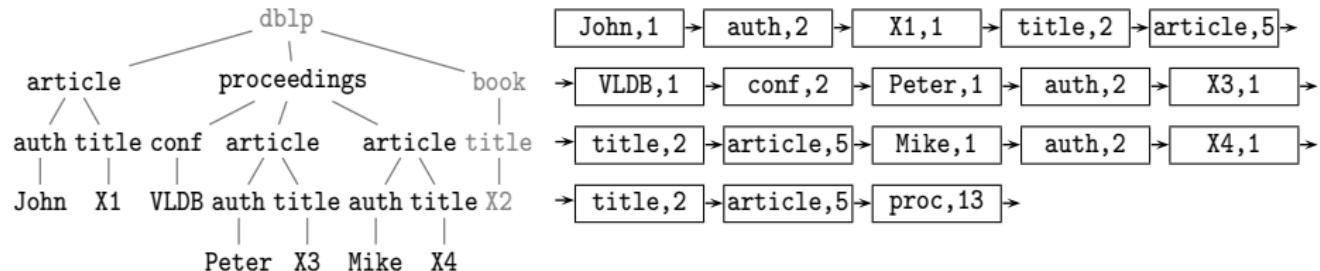
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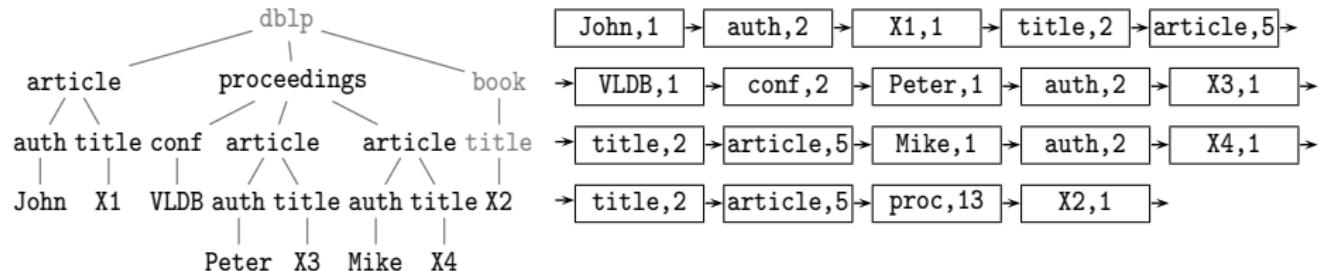
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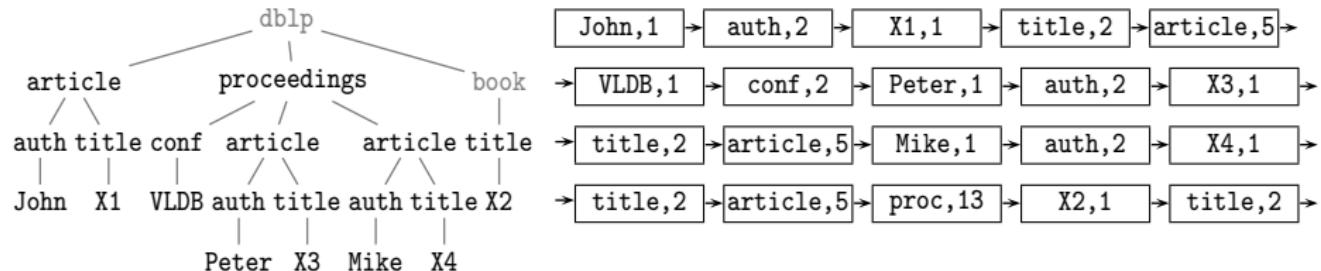
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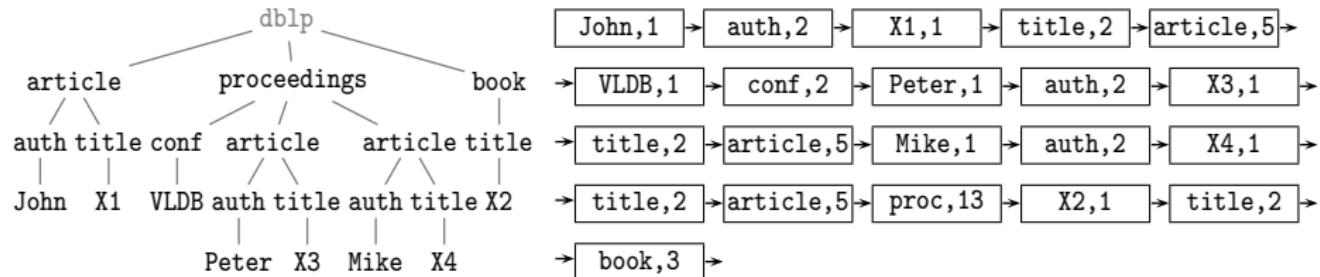
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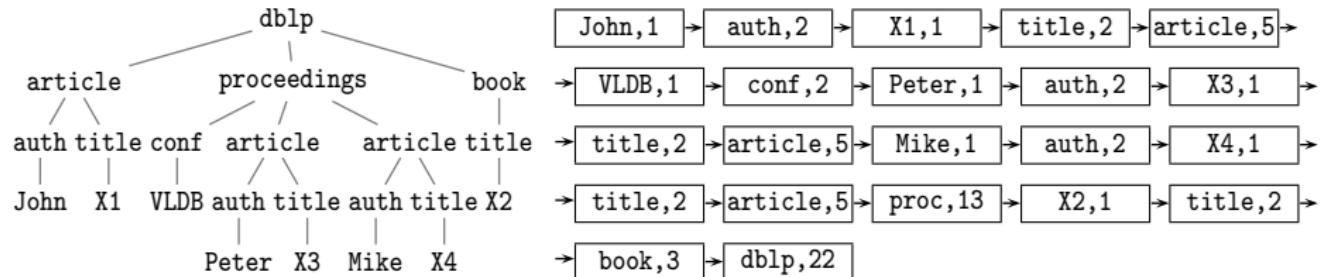
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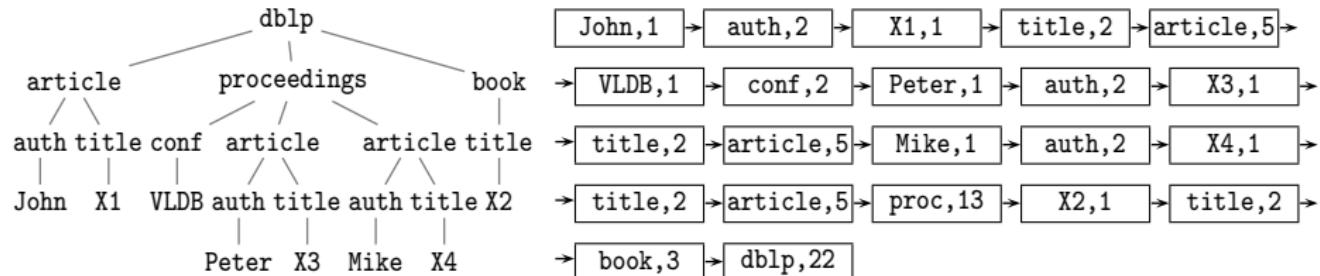
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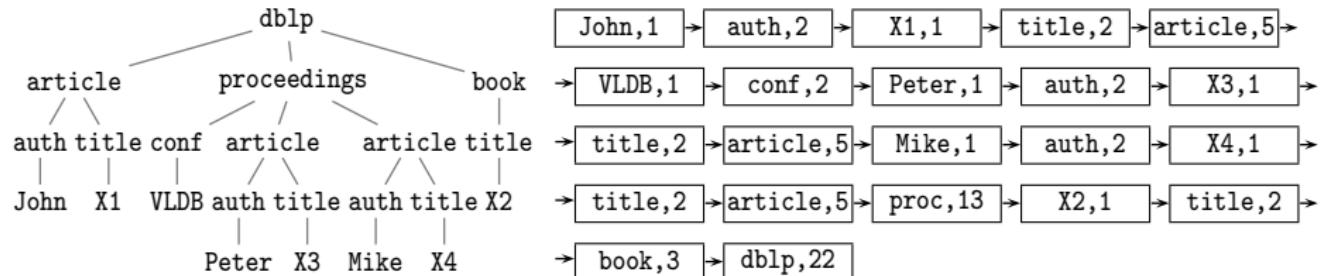
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- **Relevant and state-of-the-art for XML Parsing**
 - full subtree known only at closing tag
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- **Relevant and state-of-the-art for XML Parsing**
 - full subtree known only at closing tag
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- **Implementation** is efficient and heavily used for
 - XML streams
 - plain XML files (e.g., SAX)
 - XML in database (Dewey, interval encoding, ...)

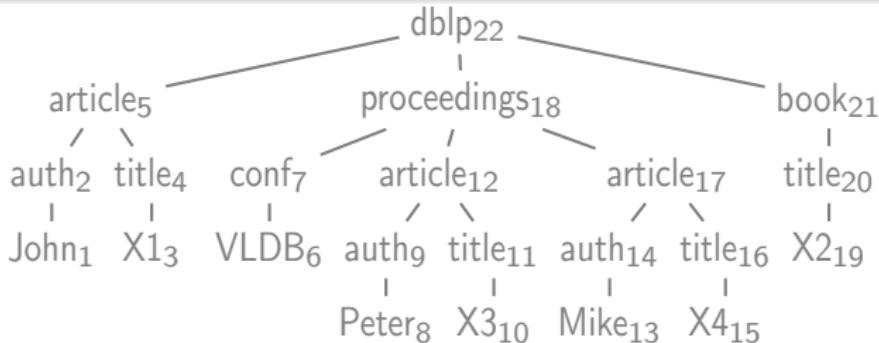
Candidate Subtrees

- **Candidate subtrees** are all subtrees T_i of the document with
 - $|T_i| \leq \tau$ AND
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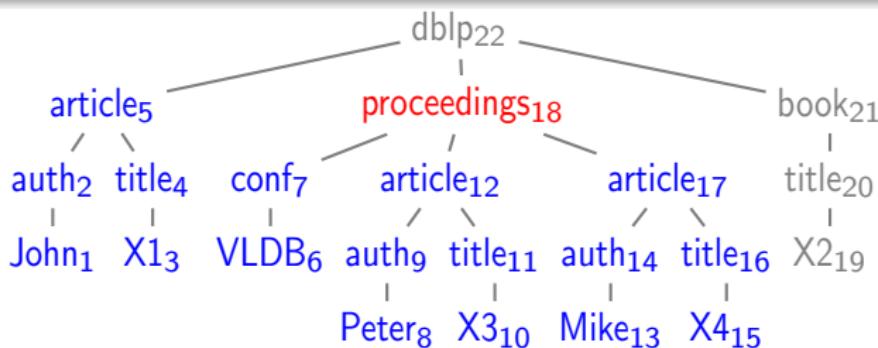
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- **Pruning:** find candidate subtrees

Simple Pruning Approach



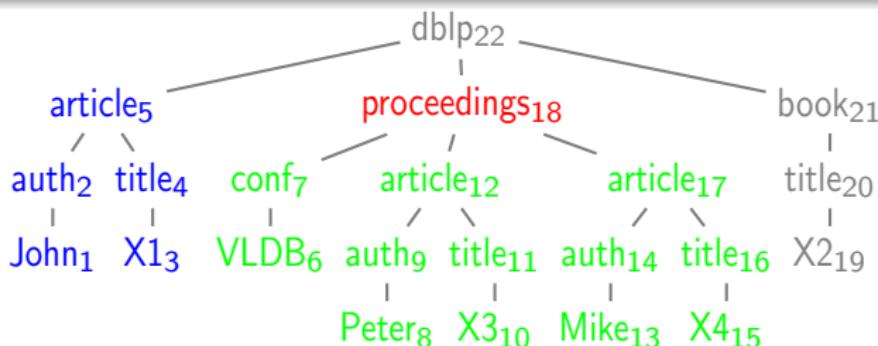
- **Simple pruning** approach: ($\tau = 6$ in example above)
 - add nodes to **memory buffer** until **non-candidate** ($|T_i| > \tau$) is added
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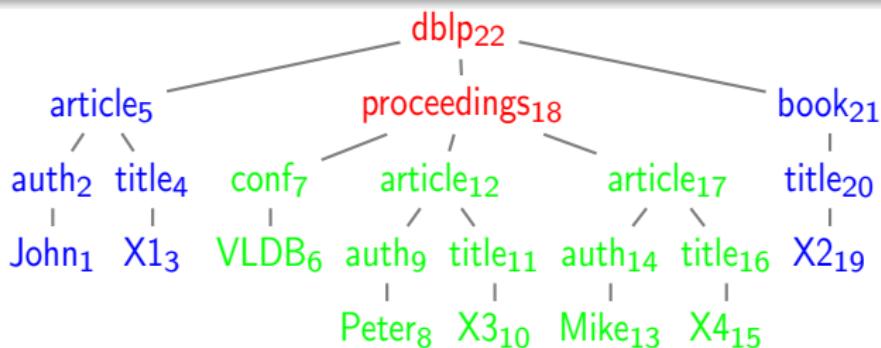
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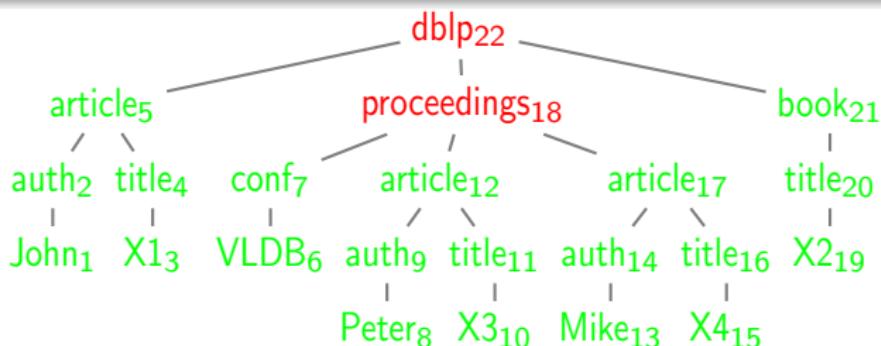
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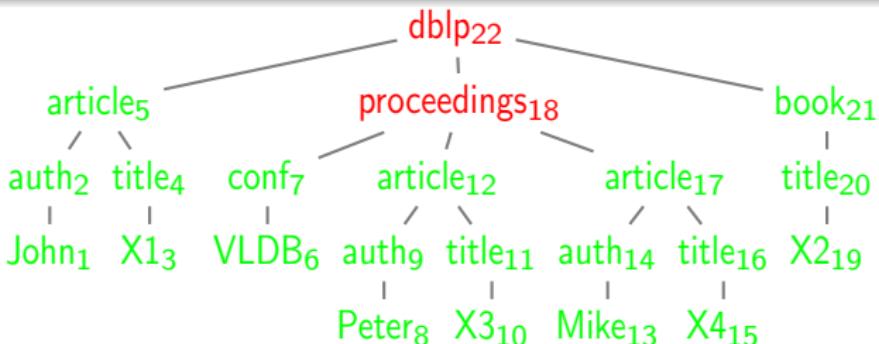
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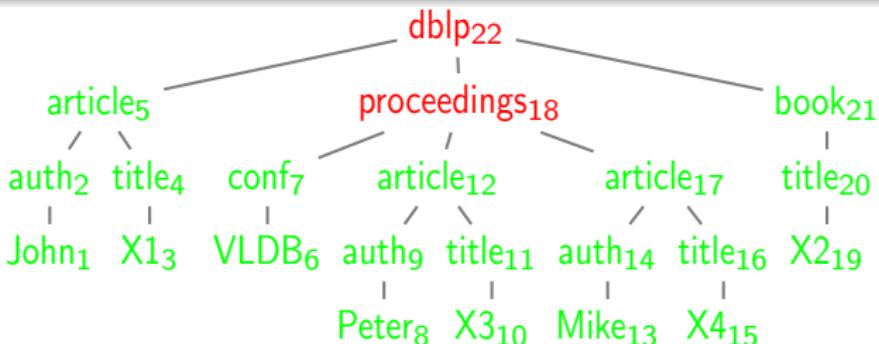
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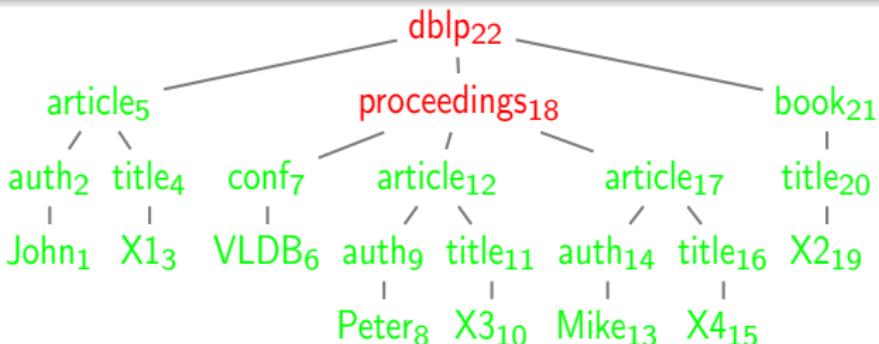
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 - must keep subtrees in memory until non-candidate ancestor is read
 - worst case: memory buffer stores $O(n)$ nodes
(frequent in data-centric XML!)

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- **Simple pruning not feasible** for large documents!

Efficient Pruning is Tricky!

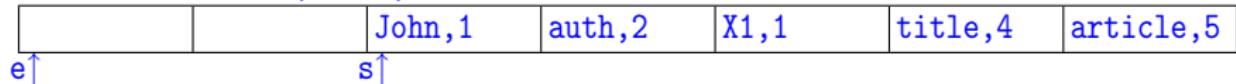
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- **Our Solution** does not wait for parent
 - **prefix ring buffer:** fixed size buffer
 - **pruning rule:** prune based on following nodes

Pruning in Small Memory

prefix ring buffer ($\tau = 6$)

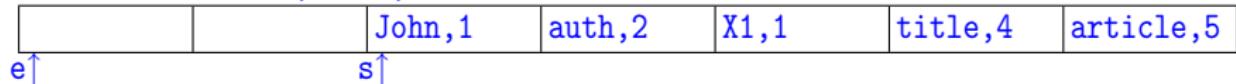


Prefix ring buffer of size $\tau + 1$ (main memory)

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Pruning in Small Memory

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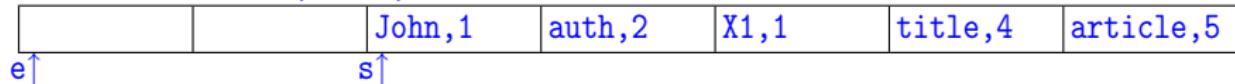


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Pruning in Small Memory

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e↑		s↑				

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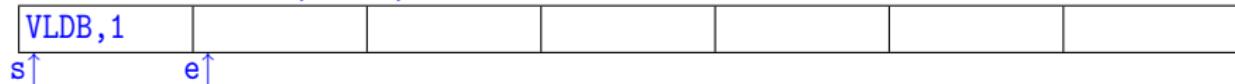
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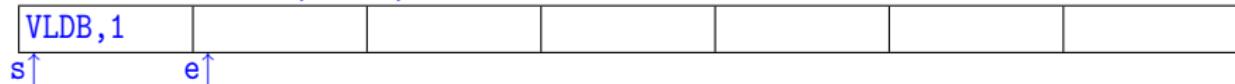


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Pruning rule: If **leftmost node** in full ring buffer is

- **leaf**: leftmost subtree is **candidate subtree**
- **non-leaf**: leftmost node is **non-candidate node**

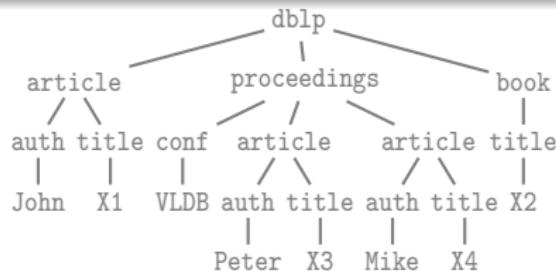
Pruning Rule – Intuition

- **Candidate subtree:** leftmost node is a leaf
 - T_i : leftmost subtree, starts with leftmost node
 - T_j : smallest subtree that contains T_i
 - due to postorder: T_j contains all nodes in buffer
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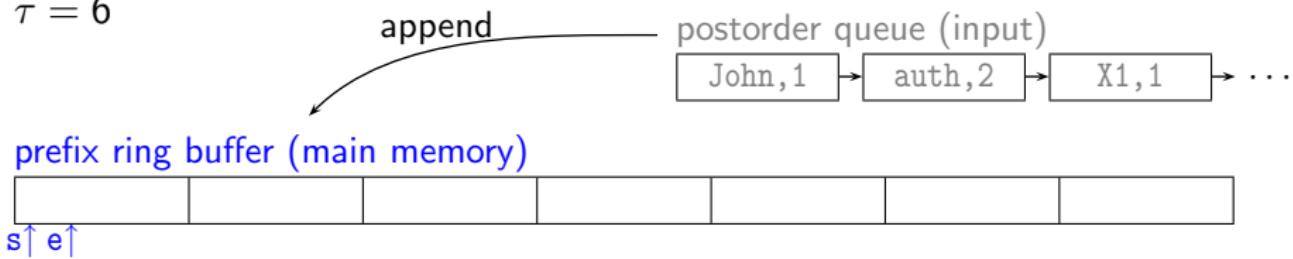
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- **Non-candidate node:** leftmost node is a non-leaf
 - leftmost non-leaf is parent of previously removed nodes
 - we remove either candidate subtrees and non-candidate nodes
 - in both cases: parent is a non-candidate

Prefix Ring Buffer Pruning – Example



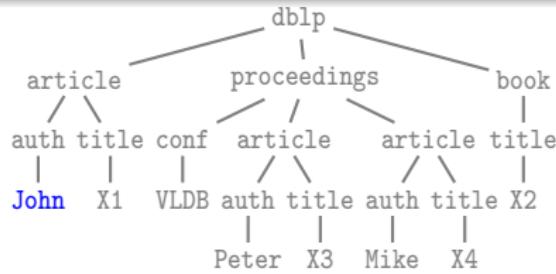
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$\tau = 6$



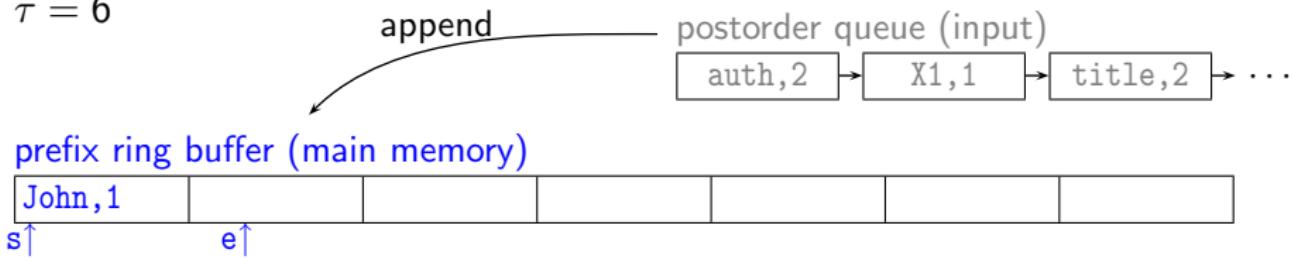
candidate subtrees:
(output)

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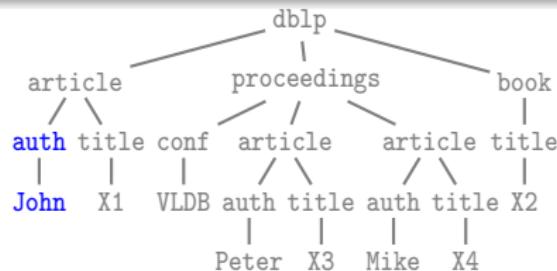
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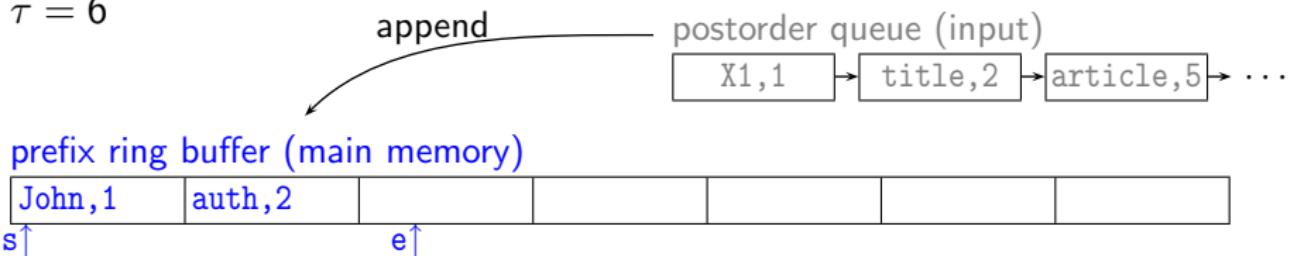
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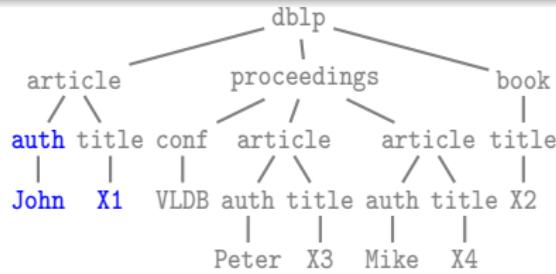
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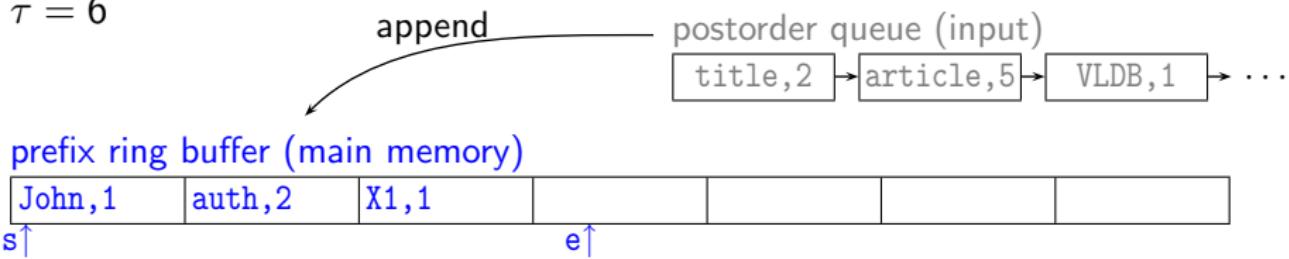
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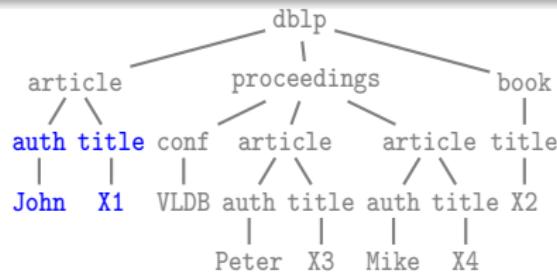
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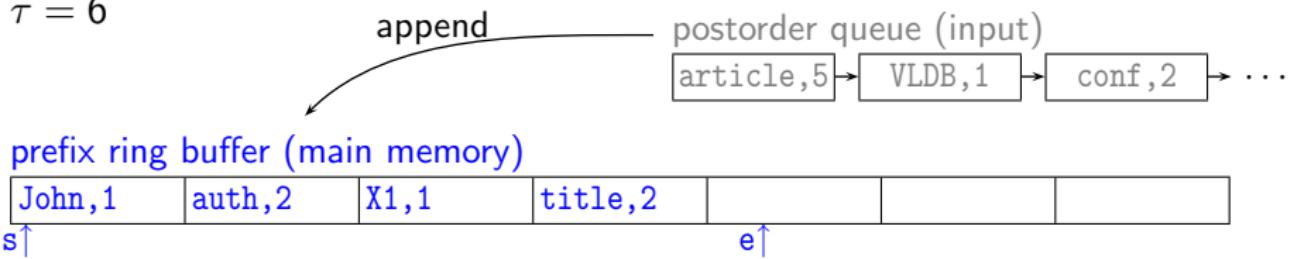
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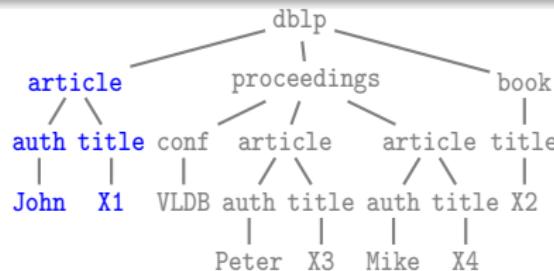
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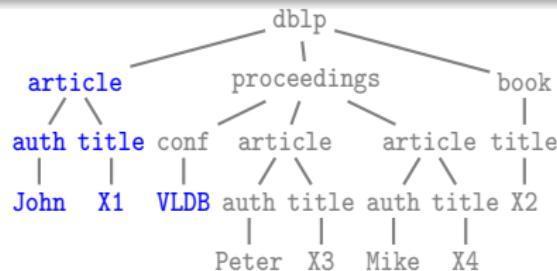
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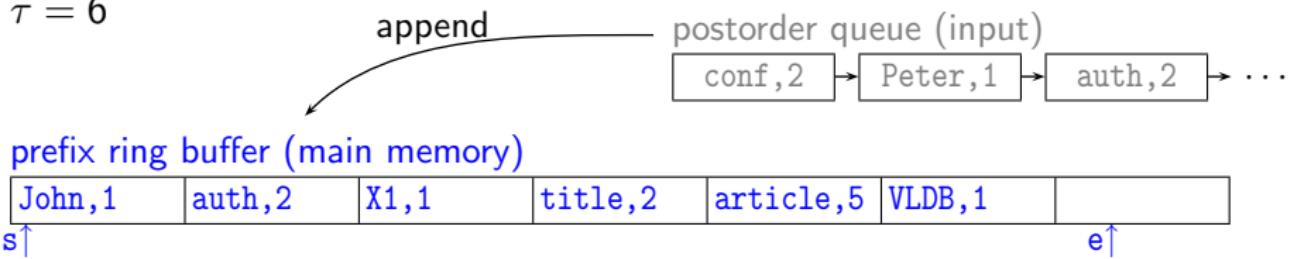
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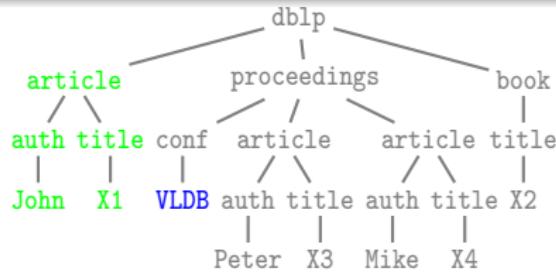
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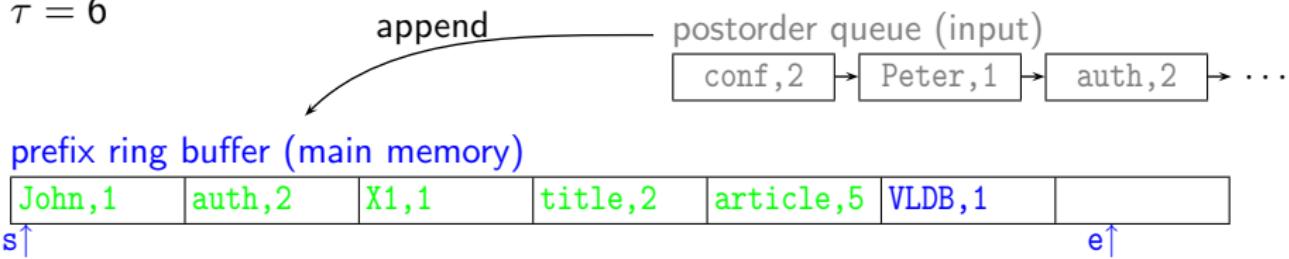
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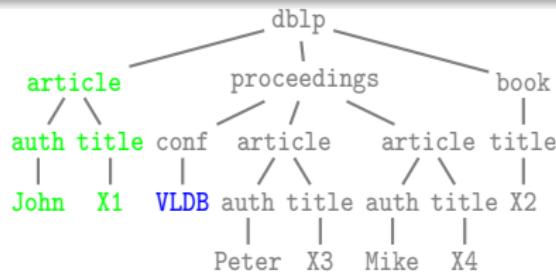
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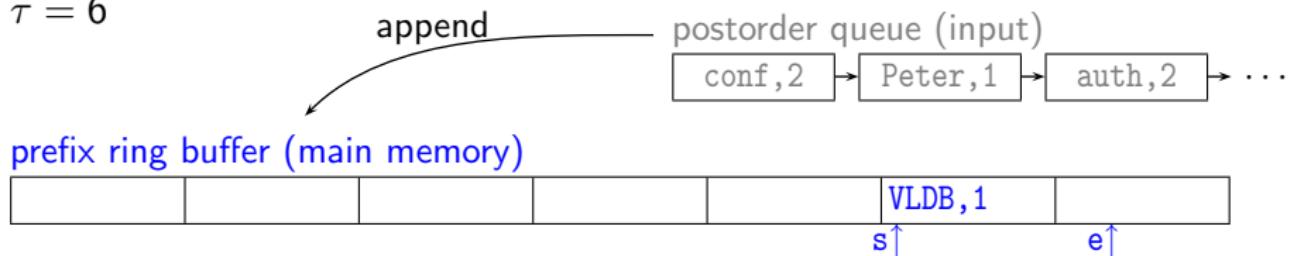
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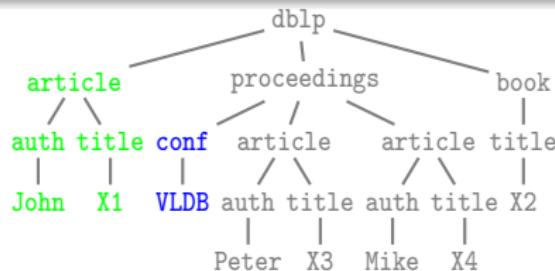
$\tau = 6$



candidate subtrees:
(output)

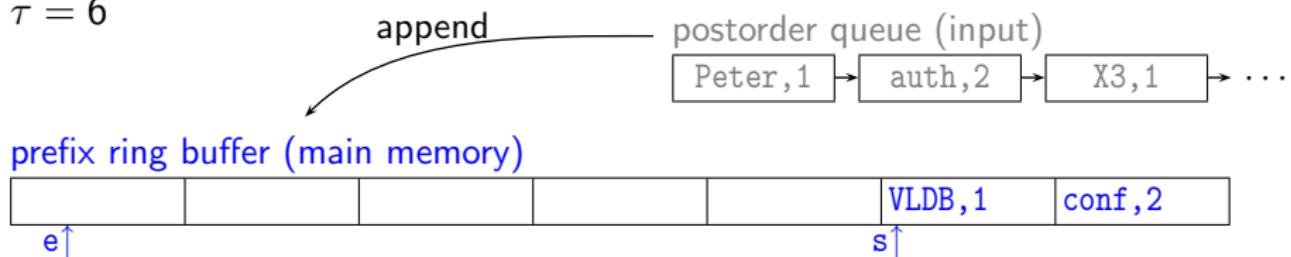


Prefix Ring Buffer Pruning – Example



1. fill ring buffer
2. check leftmost node
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3. until queue and buffer empty

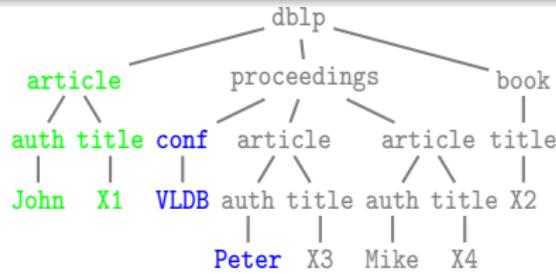
$\tau = 6$



candidate subtrees:
(output)

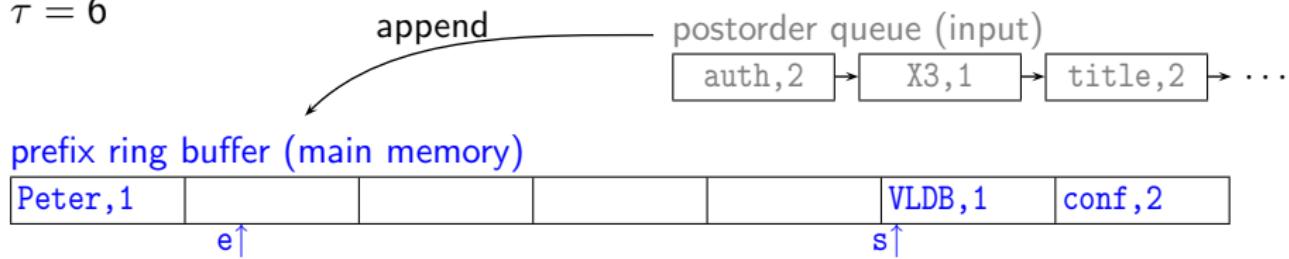


Prefix Ring Buffer Pruning – Example



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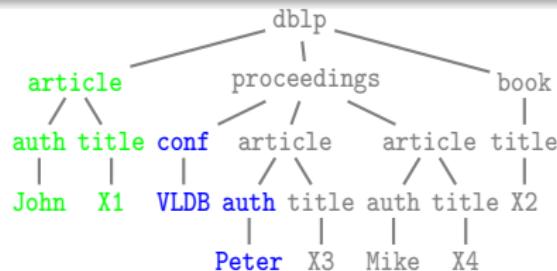
$\tau = 6$



candidate subtrees:
(output)

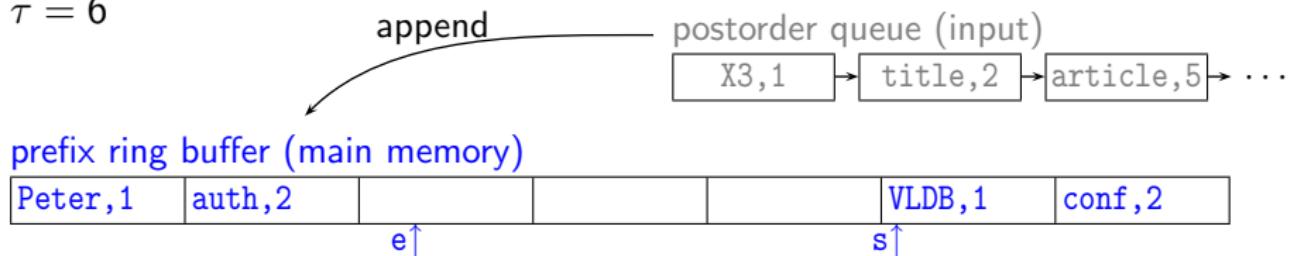


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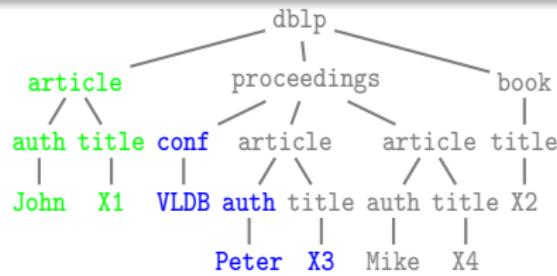
$\tau = 6$



candidate subtrees:
(output)

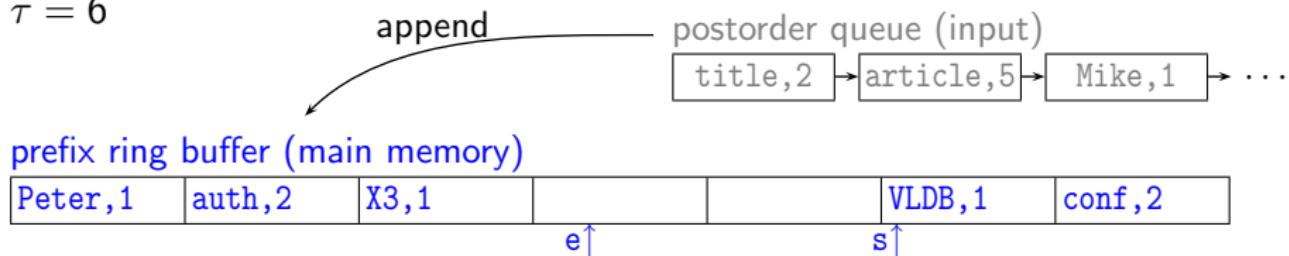


Prefix Ring Buffer Pruning – Example



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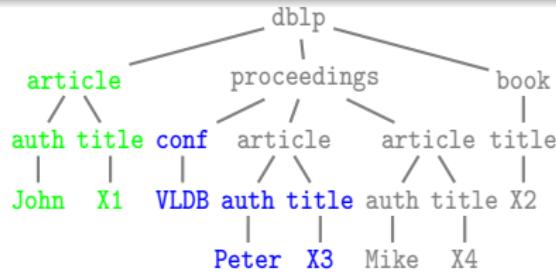
$\tau = 6$



candidate subtrees:
(output)

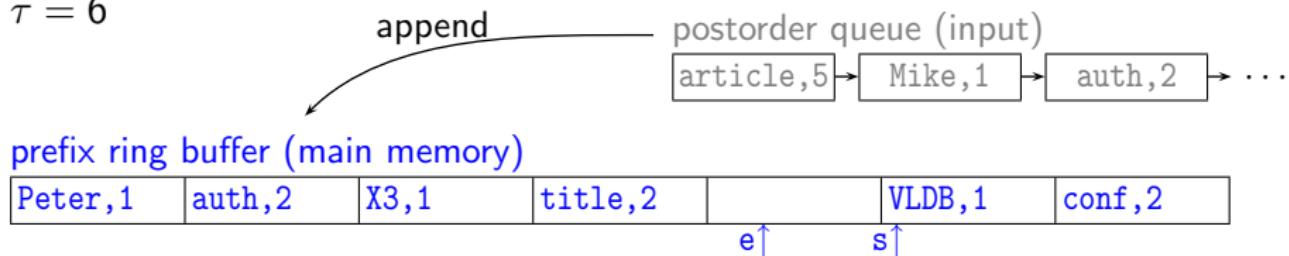


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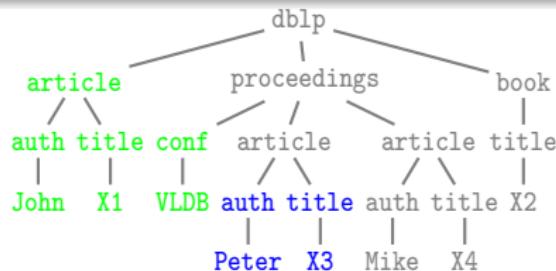
$\tau = 6$



candidate subtrees:
(output)

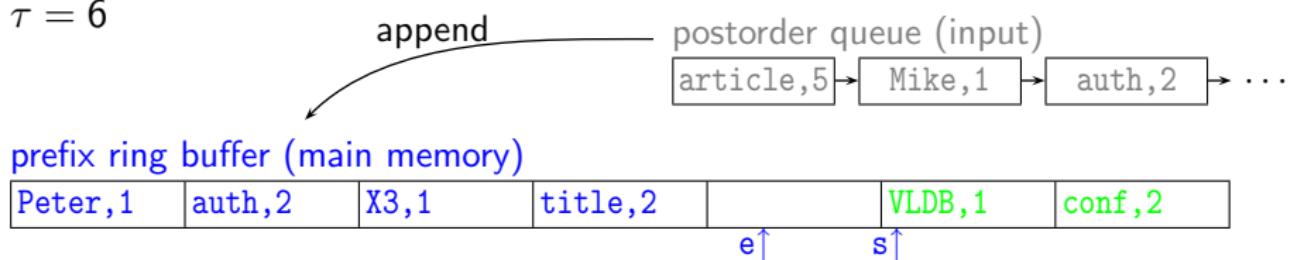


Prefix Ring Buffer Pruning – Example



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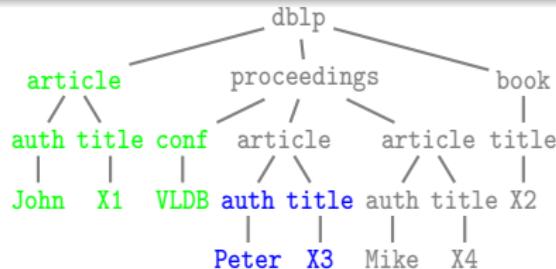
$\tau = 6$



candidate subtrees:
(output)

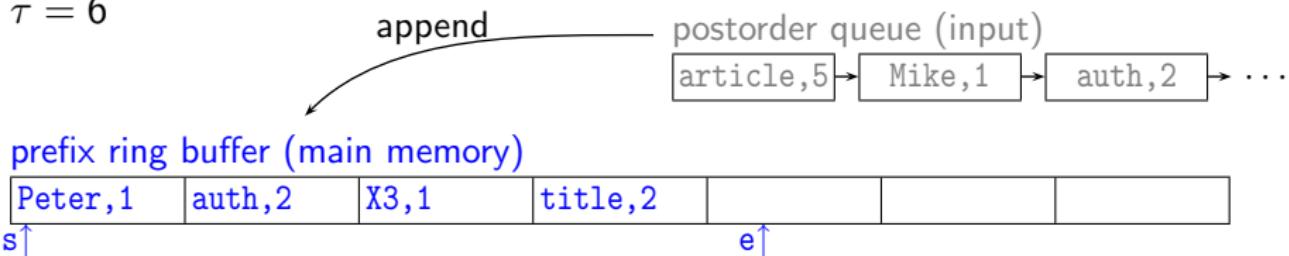


Prefix Ring Buffer Pruning – Example

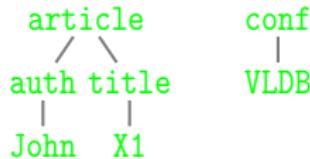


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2. check leftmost node
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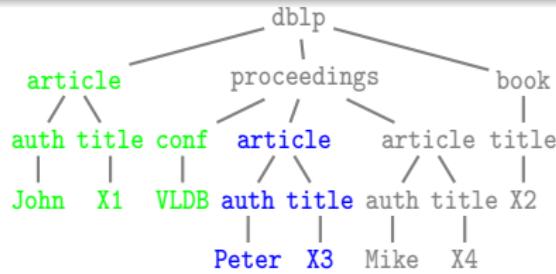
$\tau = 6$



candidate subtrees:
(output)

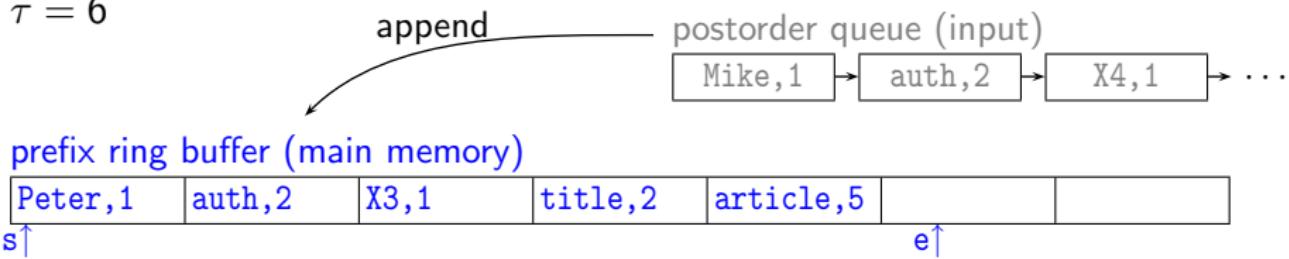


Prefix Ring Buffer Pruning – Example

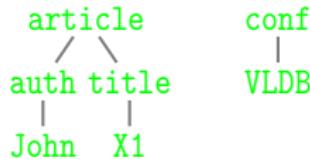


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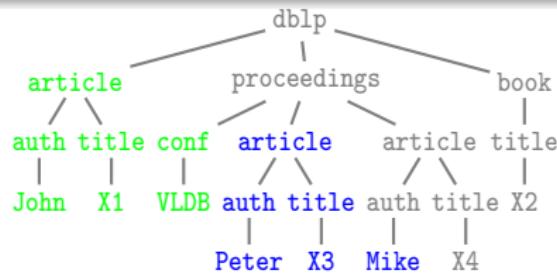
$\tau = 6$



candidate subtrees:
(output)

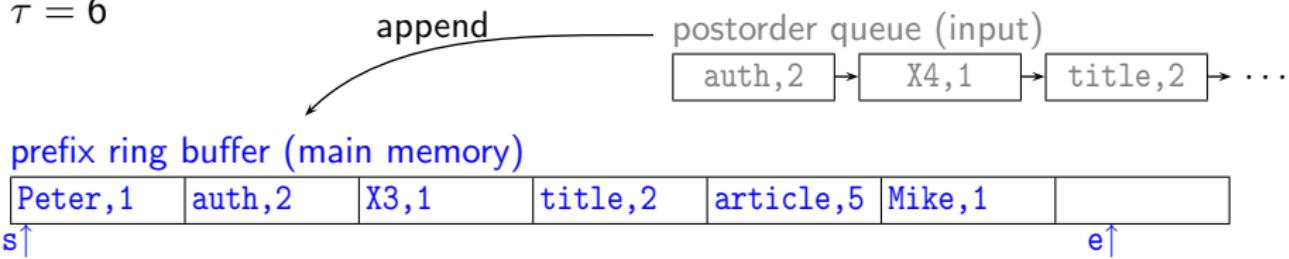


Prefix Ring Buffer Pruning – Example

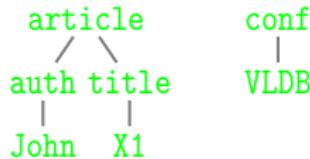


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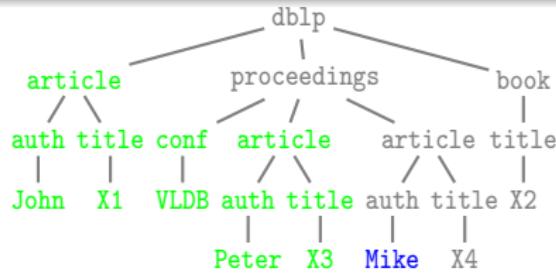
$\tau = 6$



candidate subtrees:
(output)

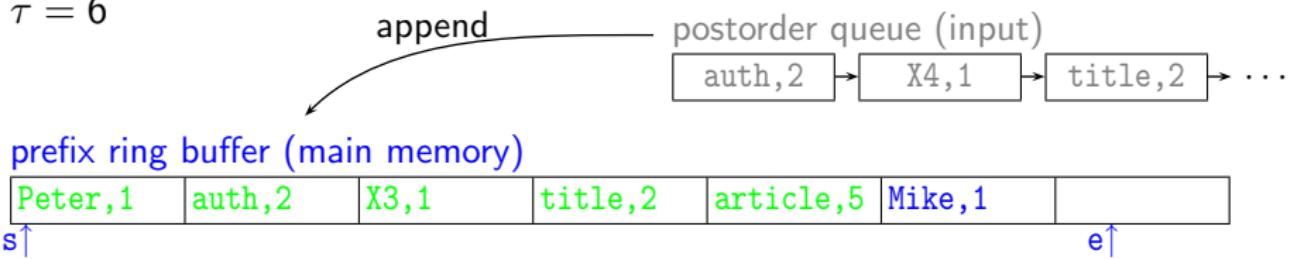


Prefix Ring Buffer Pruning – Example

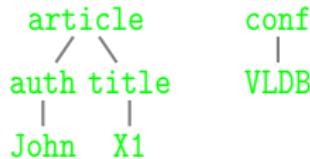


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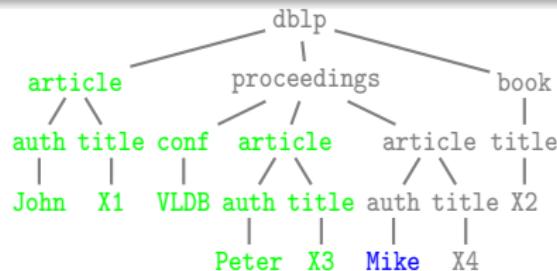
$\tau = 6$



candidate subtrees:
(output)

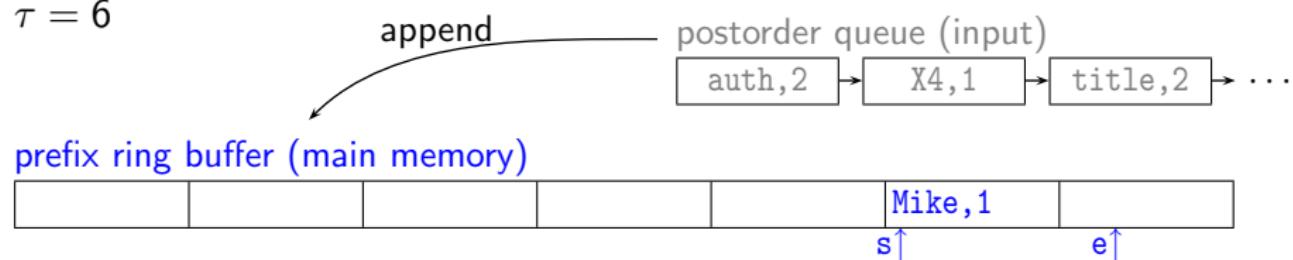


Prefix Ring Buffer Pruning – Example



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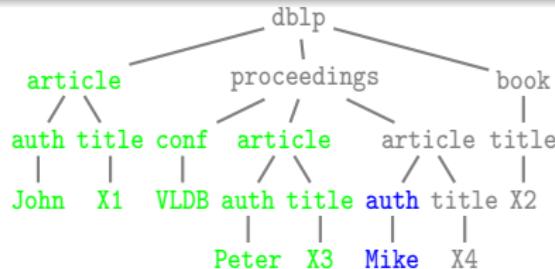
$\tau = 6$



candidate subtrees:
(output)

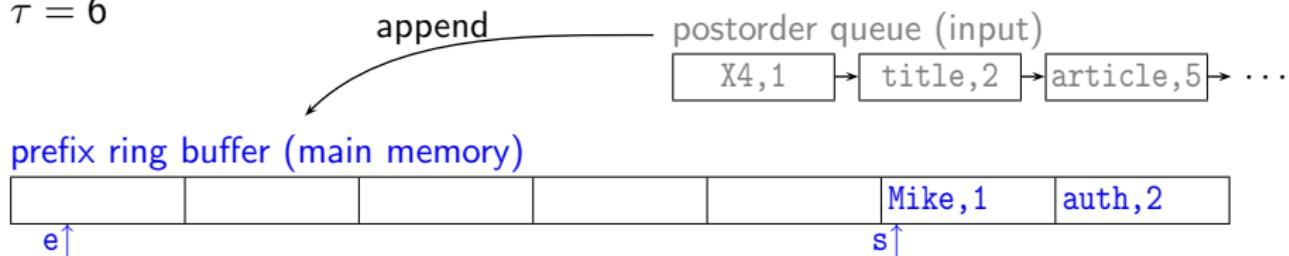


Prefix Ring Buffer Pruning – Example



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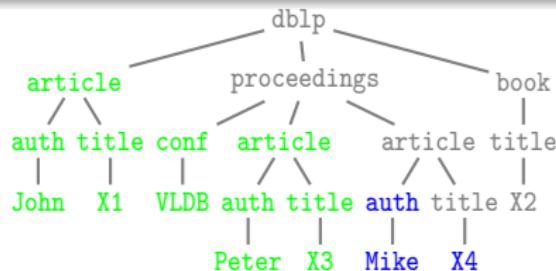
$\tau = 6$



candidate subtrees:
(output)



Prefix Ring Buffer Pruning – Example



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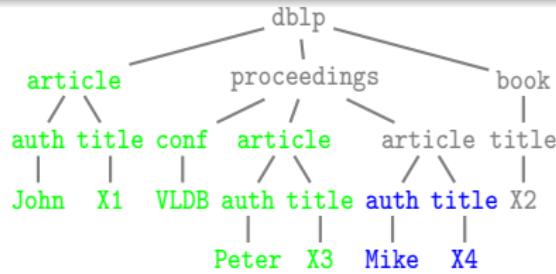
$\tau = 6$



candidate subtrees:
(output)

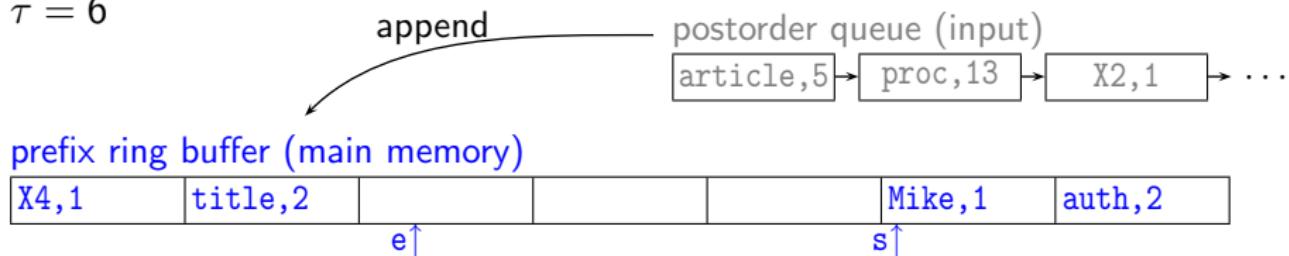


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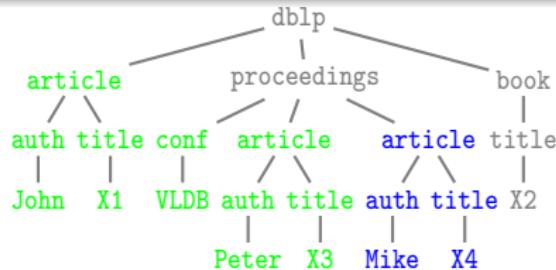
$\tau = 6$



candidate subtrees:
(output)

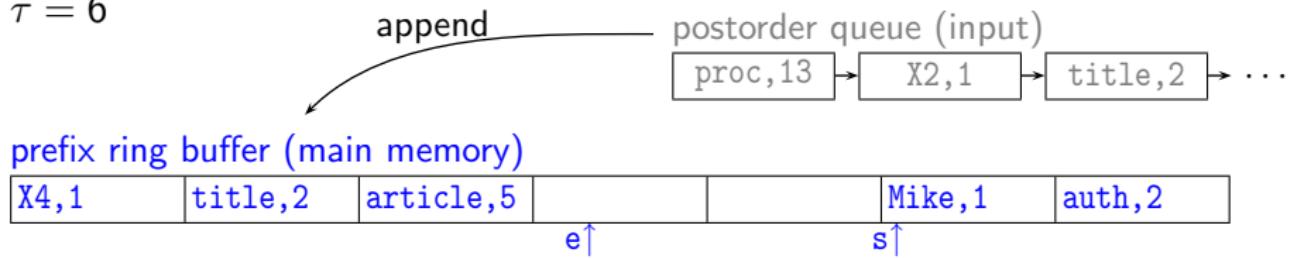


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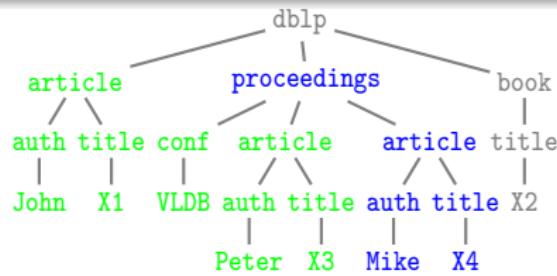
$\tau = 6$



candidate subtrees:
(output)

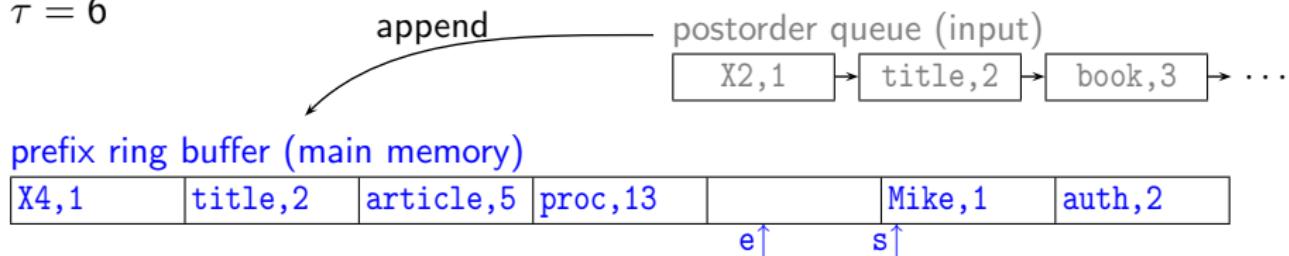


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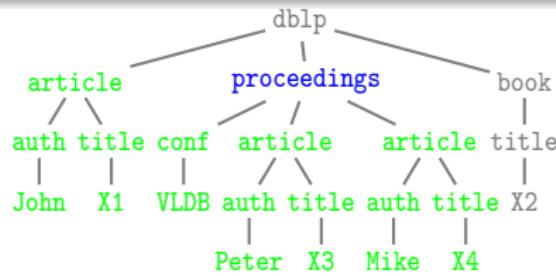
$\tau = 6$



candidate subtrees:
(output)

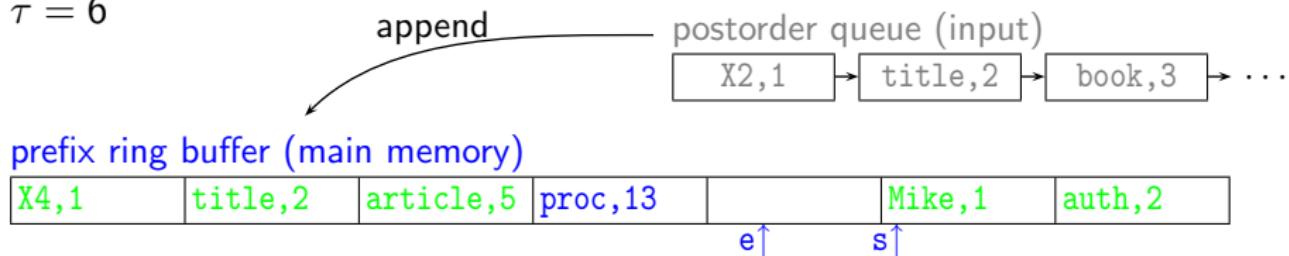


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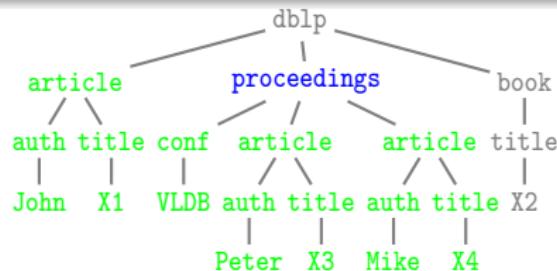
$\tau = 6$



candidate subtrees:
(output)

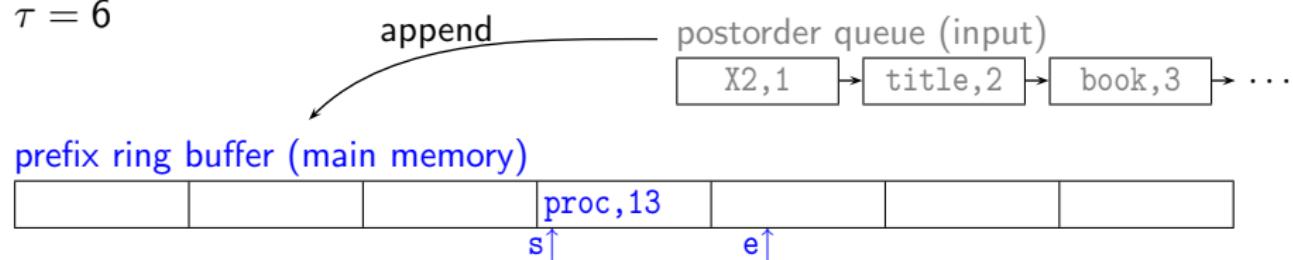


Prefix Ring Buffer Pruning – Example

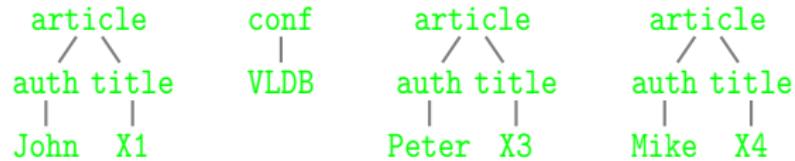


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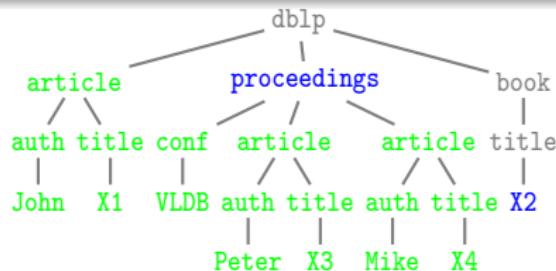
$\tau = 6$



candidate subtrees:
(output)

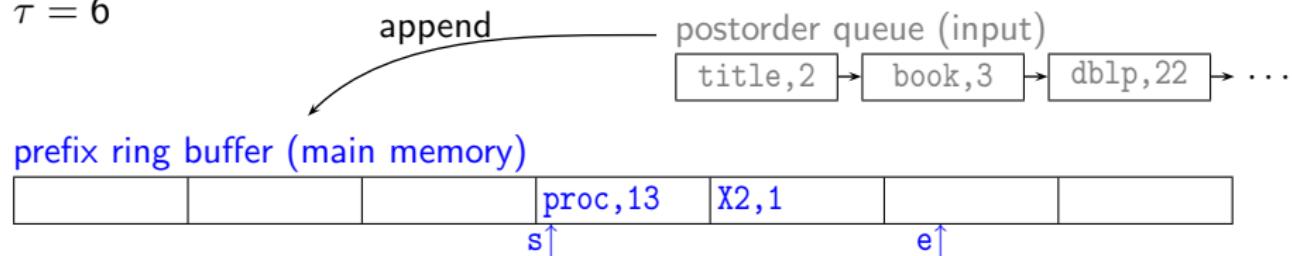


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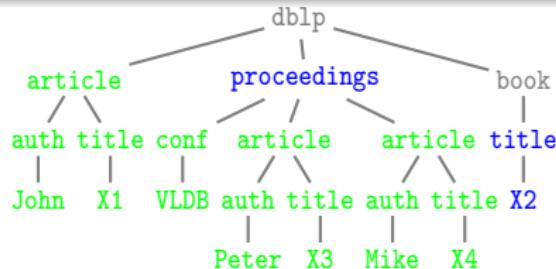
$\tau = 6$



candidate subtrees:
(output)

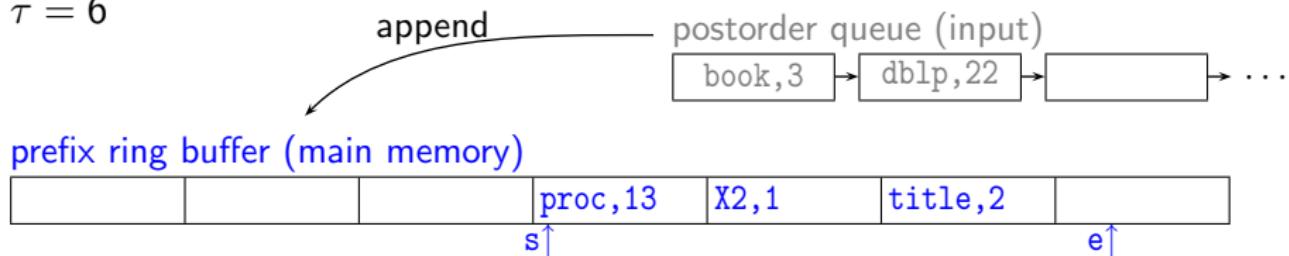


Prefix Ring Buffer Pruning – Example

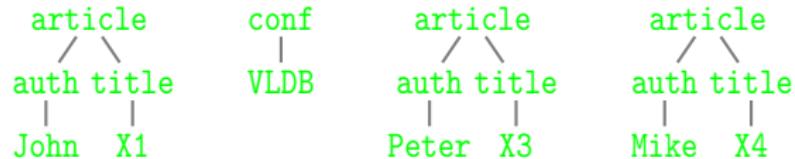


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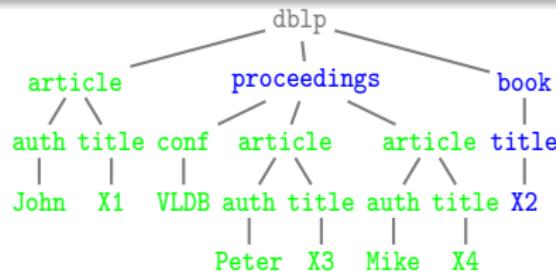
$\tau = 6$



candidate subtrees:
(output)

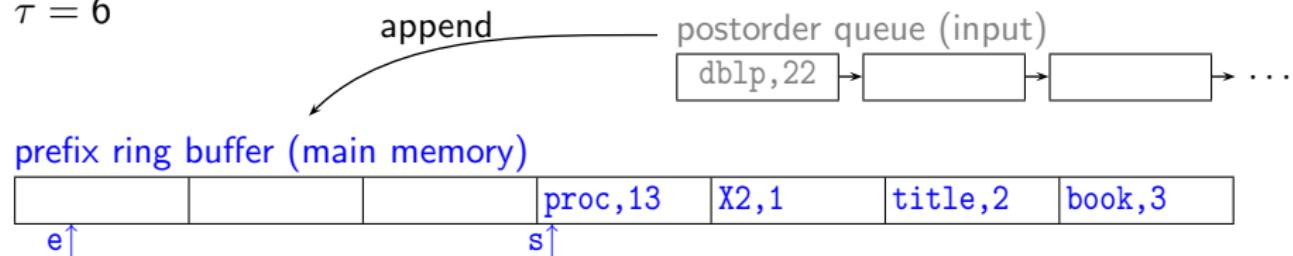


Prefix Ring Buffer Pruning – Example

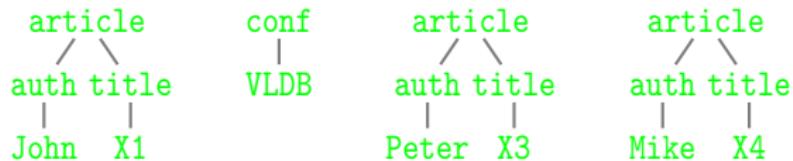


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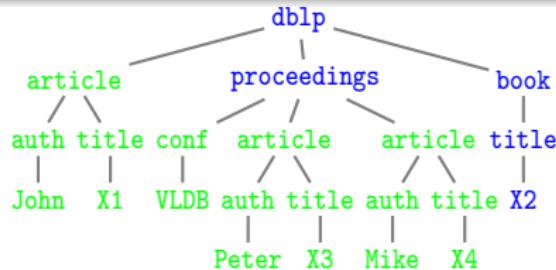
$\tau = 6$



candidate subtrees:
(output)

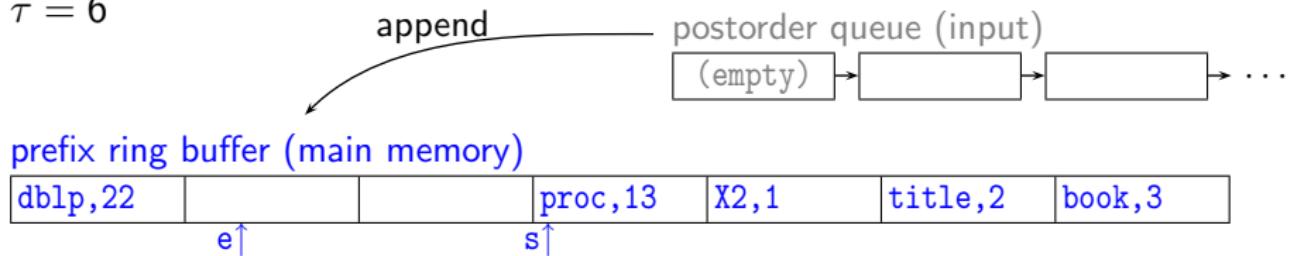


Prefix Ring Buffer Pruning – Example

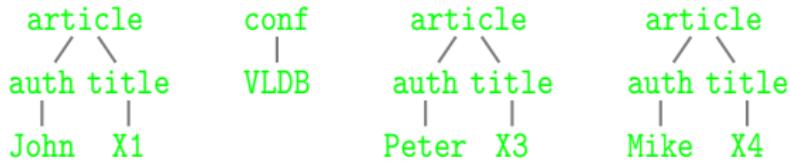


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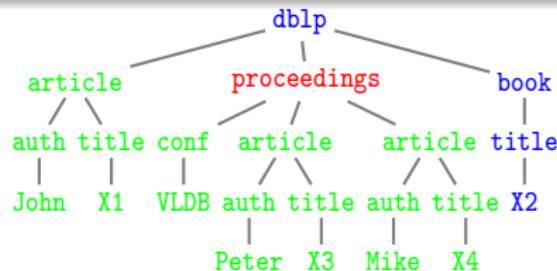
$\tau = 6$



candidate subtrees:
(output)

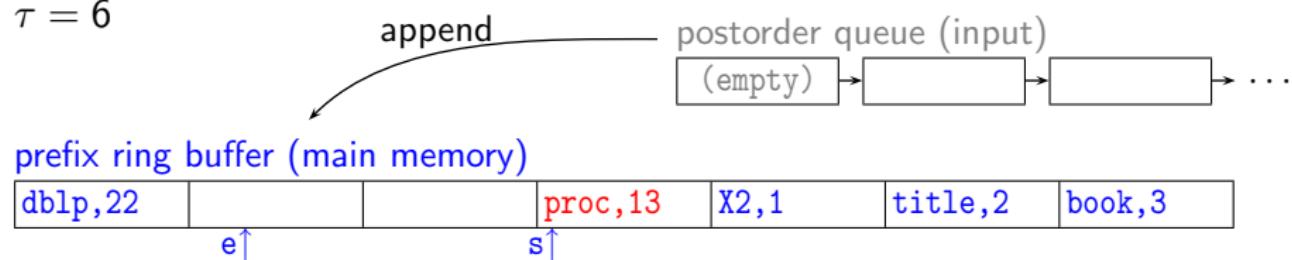


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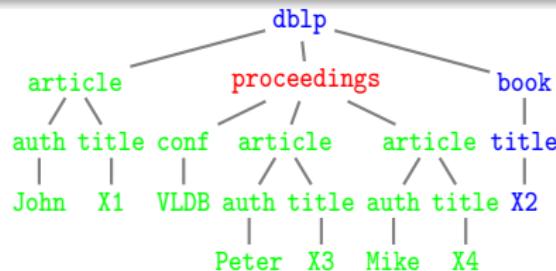
$\tau = 6$



candidate subtrees:
(output)

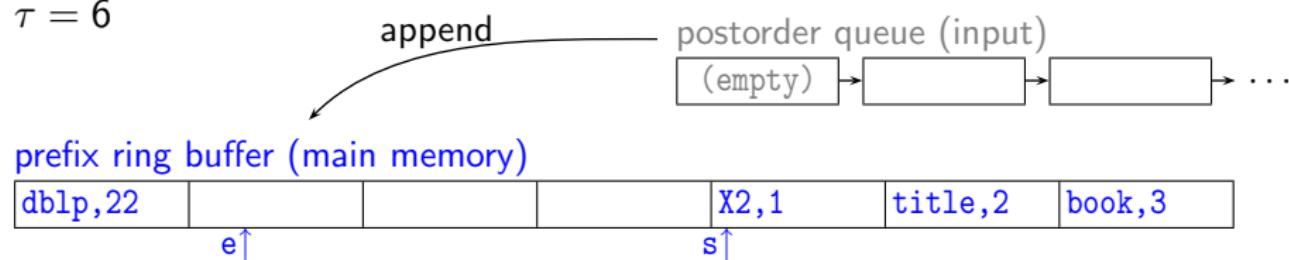


Prefix Ring Buffer Pruning – Example

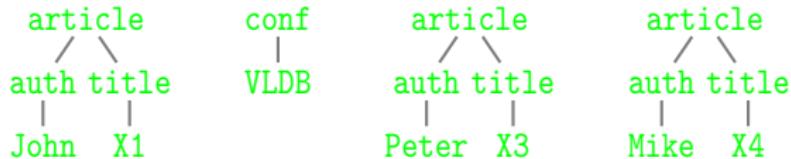


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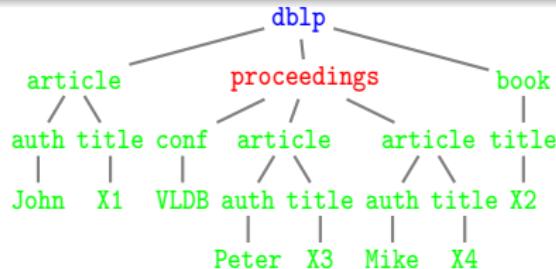
$\tau = 6$



candidate subtrees:
(output)

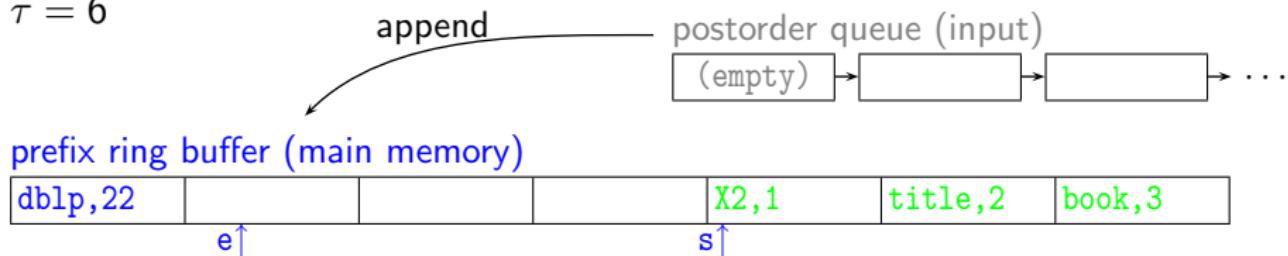


Prefix Ring Buffer Pruning – Example

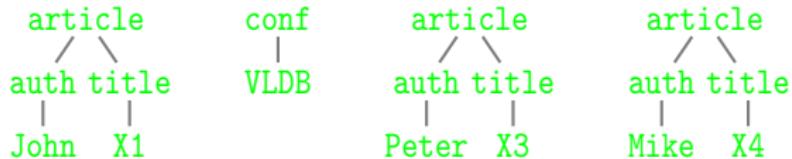


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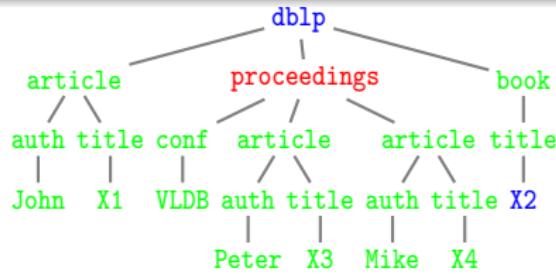
$\tau = 6$



candidate subtrees:
(output)

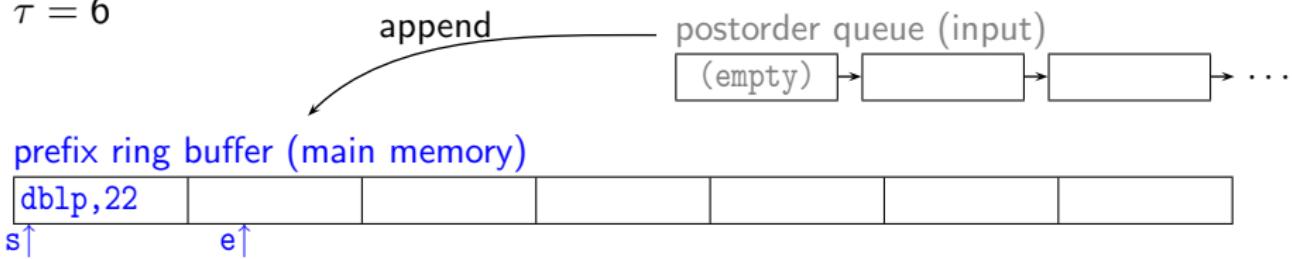


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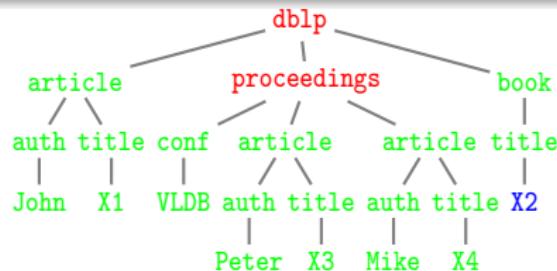
$\tau = 6$



candidate subtrees:
(output)

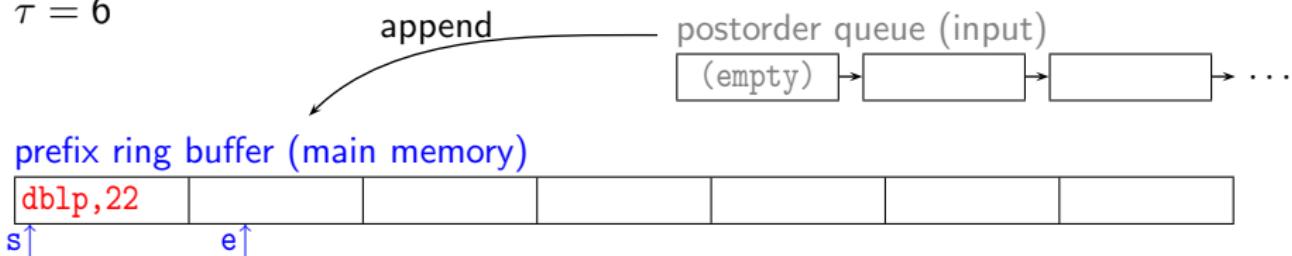


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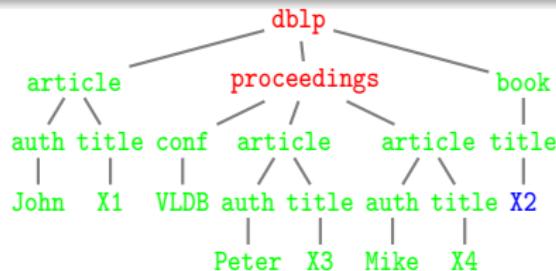
$\tau = 6$



candidate subtrees:
(output)

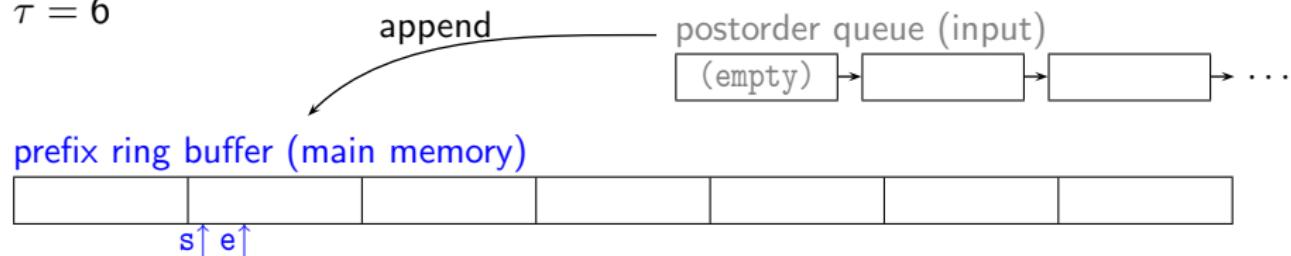


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2. check leftmost node
 - leaf: candidate subtree – to result
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$\tau = 6$



candidate subtrees:
(output)



TASM-Postorder

TASM-postorder

1. empty ranking R , tightening upper bound $\tau' = \tau$
2. for each candidate subtree T_i
 - a. if $|R| = k$: update $\tau' = \min(\tau, \max(R) + |Q|)$
 - b. compute tree edit distance for all subtrees of T_i within τ'
 - c. update ranking R

TASM-Postorder

TASM-postorder

1. empty ranking R , tightening upper bound $\tau' = \tau$
2. for each candidate subtree T_i
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Theorem (TASM-Postorder)

The space complexity of TASM-postorder is independent of the document size:

$$O(m^2 + mk)$$

(*m: query size, k: result size*)

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TASM-postorder scales to very large documents!

Outline

1 Motivation and Problem Definition

2 TASM-Postorder

- Upper Bound on Subtree Size
- Prefix Ring Buffer Pruning

3 Experiments

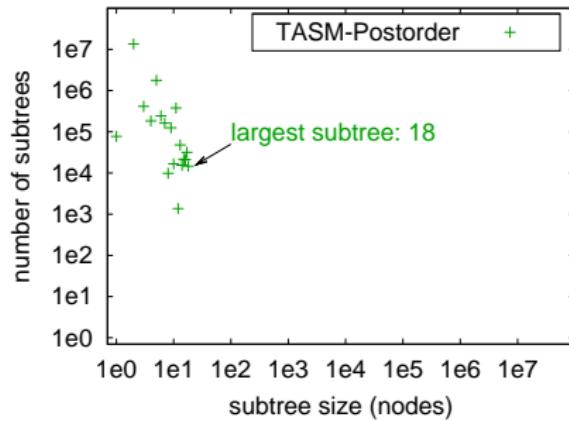
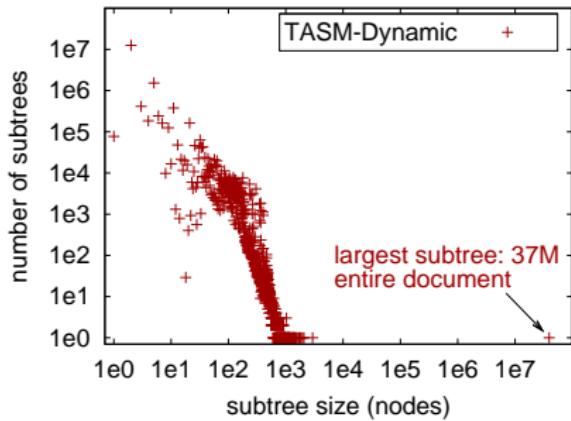
4 Conclusion and Future Work

Pruning Effectiveness

Pruning Effectiveness

Prefix ring buffer pruning is very effective!
Maximum subtree reduced from **37M** to **18** nodes.

- **Dataset:** PSD protein sequences, 37M nodes, 683MB
- Compute TASM ($|Q| = 4, k = 1$)
 - TASM-dynamic (state of the art)
 - TASM-postorder (our solution)
- **Histogram** of computed subtrees

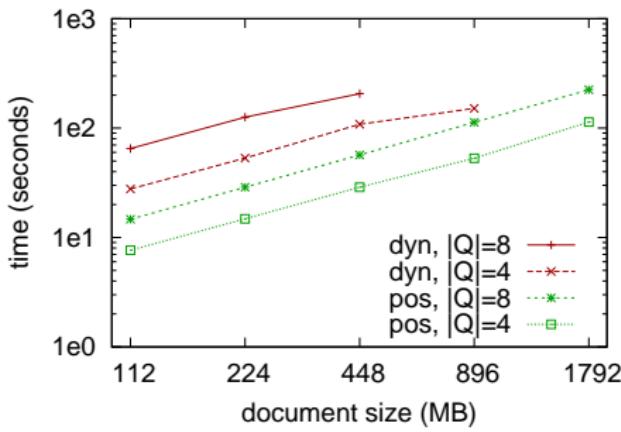
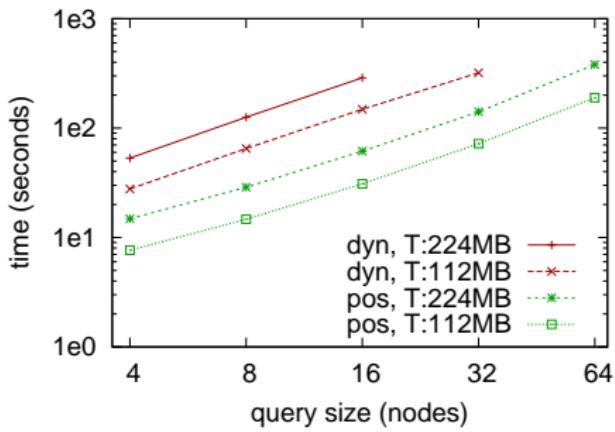


Scalability: TASM-Postorder vs. TASM-Dynamic

Scalability: TASM-Postorder vs. TASM-Dynamic

TASM-postorder much faster than **TASM-dynamic**.

- **Dataset:** XMark (synthetic XML for benchmark)
- Vary **query size** and **document size**
- Compute TASM ($k = 5$)
 - TASM-dynamic (state of the art)
 - TASM-postorder (our solution)
- Measure wall clock **time**

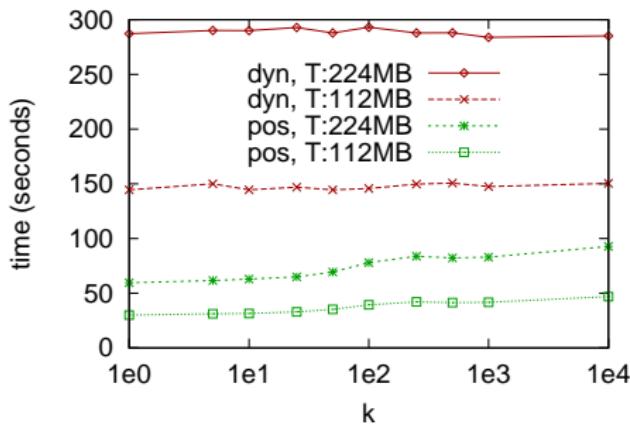


Scalability with Result Size k

Scalability with Result Size k

TASM-postorder scales well with k .

Increasing k by 4 orders of magnitude only doubles runtime.

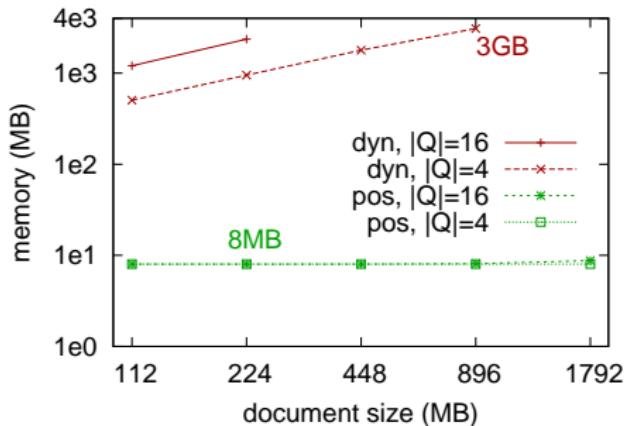


- Dataset: **XMark** (synthetic XML for benchmark)
- Vary k (size of ranking)
- Compute TASM ($|Q| = 16$)
 - TASM-dynamic** (state of the art)
 - TASM-postorder** (our solution)
- Measure wall clock **time**

Space complexity: TASM-Postorder vs. TASM-Dynamic

Space complexity: TASM-Postorder vs. TASM-Dynamic

TASM-postorder: space independent of document!



- Dataset: XMark (synthetic XML for benchmark)
- Vary **document size**
- Compute TASM ($k = 5$)
 - TASM-dynamic (state of the art)
 - TASM-postorder (our solution)
- Measure **main memory usage**

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Conclusion

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- **Prefix Ring Buffer** for space efficient pruning
- **Dynamic programming does not scale** for database size solutions.
- **Upper bound τ** : limit maximum subtree size for TASMS
- **TASM-postorder**: highly scalable TASMS algorithm

TASM-postorder makes TASMS feasible.

Conclusion

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- **Prefix Ring Buffer** for space efficient pruning
- **Dynamic programming does not scale** for database size solutions.
- **Upper bound τ** : limit maximum subtree size for TASMS
- **TASM-postorder**: highly scalable TASMS algorithm

TASM-postorder makes TASMS feasible.

Future Work – New research opportunities:

- tune tree edit distance to different applications
- index the document: can we avoid a document scan?
- parallel TASMS algorithm: where to split document?



Erik D. Demaine, Shay Mozes, Benjamin Rossman, and Oren Weimann.

An optimal decomposition algorithm for tree edit distance.

In *ICALP*, volume 4596 of *LNCS*, pages 146–157, Wroclaw, Poland, July 2007. Springer.



K. Zhang and D. Shasha.

Simple fast algorithms for the editing distance between trees and related problems.

SIAM J. on Computing, 18(6):1245–1262, 1989.