Advanced Safe DAAT Algorithms

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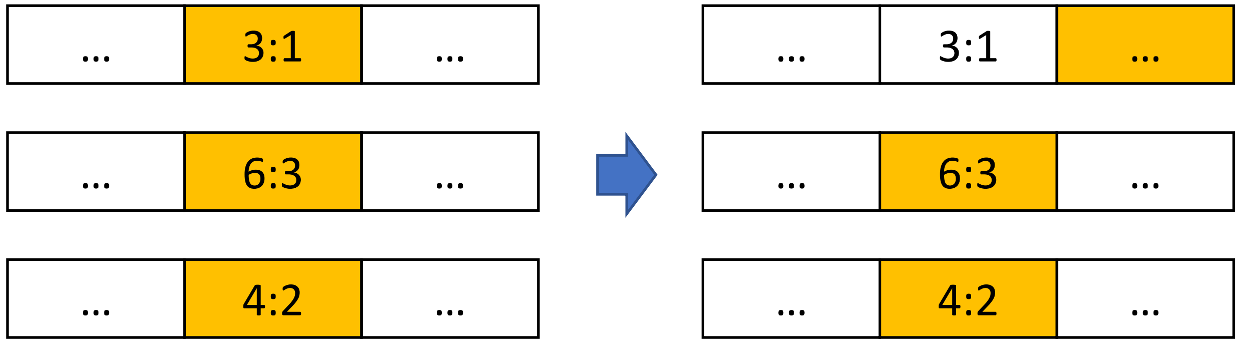
DAAT

- Idea
  - Access and score each document before moving to the next, based on the inverted index
- Invariant
  - All the documents with docID smaller than the curDoc has been processed

#doc to be scored = union of the inverted lists of the query

… : curDoc

Always move the smaller docID



DAAT

- Top-k optimization
  - Current top-k-th document's score = threshold
- Optimization
  - No need to access/score documents whose score is < threshold
    - ➔ Skipping docIDs, but how?
- Preliminaries:
  - UB(w): upper bound of the score contribution of any document in w's postings list

$$UB(w) = \mathrm{idf}(w) \cdot \max_{e \in L} e.\mathrm{tf}$$

w →

1:3	4:2	5:2	7:4	8:1

← Assume no normalization on the raw tf, UB(w) = idf(w)*4

Idea 1

Generating the candidates

Scoring the candidates

- Consider Q = A B C D
  - Assume |A| ≤ |B| ≤ |C| ≤ |D|
  - Can we split the query into, e.g., Q1 = A OR B, and Q2 = C D
  - Answering Q1 is more efficient (why?), and hopefully only accessing lists in Q2 for the final scoring
- Working out a sufficient condition for the above scheme

MaxScore(d3) = ?, if d3 does not exist in A or B's list

➔ ___

If threshold ≥ 2, what can you infer?

Determine the Optional Terms

- Only need to focus on documents that occurred **ONLY** in the lists of optional terms ➔ Estimate their upper bounding score
- Algorithm:
  - sort terms in decreasing order of their UB values
  - find the largest suffix of the terms such that the accumulative UB values is larger than the threshold (current top-k-th document's score)

Simplified MaxScore

- Assume all idf = 1, threshold = 2, and Q1 = A B (required terms)
- Step 1: generate candidates:
  - T = Result(Q1)
- Step 2: score candidates and get top-k
  - Foreach d in T:
    - Score(d) /* using lists in Q2 = C */ optional terms
  - Keep top-k documents as the answer

Any problem with this alg?

- Large candidate size:
  - [|A|, |A|+|B|]
- The same threshold is used throughout

Killing two birds with one stone!

A	…	1:3	…	UB = 5
B	…	23:2	…	UB = 3

T = {1, 23}

C	1:1	33:1	55:1

score(d1) = 4

score(d23) = 2

MaxScore

- [Step 0] Obtain the initial threshold α
  - Update the required terms
- Repeat until the *stopping condition*
  - [Step 1] Perform one DAAT step on required terms ➔ obtain (d, s1), where s1 is the partial score of d on required terms
  - [Step 2] Score d using the optional terms via skipTo(d)
  - [maintenance] If d's final score is larger than α
    - Update the top-k results
    - Update α
    - Update the required terms and optional terms

- Fixed order of terms (decreasing UB values)
- From the rear of the list, find the maximum number of terms such that their UB sum ≤ α

Fixed order = C B A

Example (k = 2)

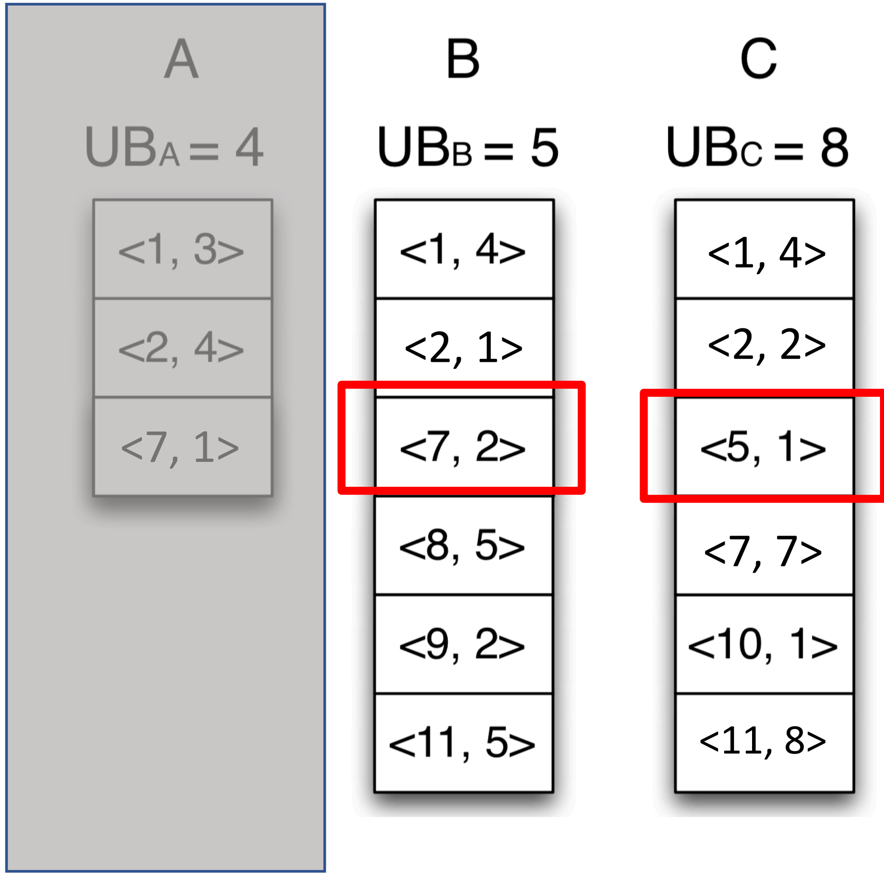
- Step 0:
  - d1 = 11, d2 = 7
  - α =
  - Q1 =

A	B	C
$UB_A = 4$	$UB_B = 5$	$UB_C = 8$
<1, 3>	<1, 4>	<1, 4>
<2, 4>	<2, 1>	<2, 2>
<7, 1>	<7, 2>	<5, 1>
	<8, 5>	<7, 7>
	<9, 2>	<10, 1>
	<11, 5>	<11, 8>

Fixed order = C B A

Example (k = 2)

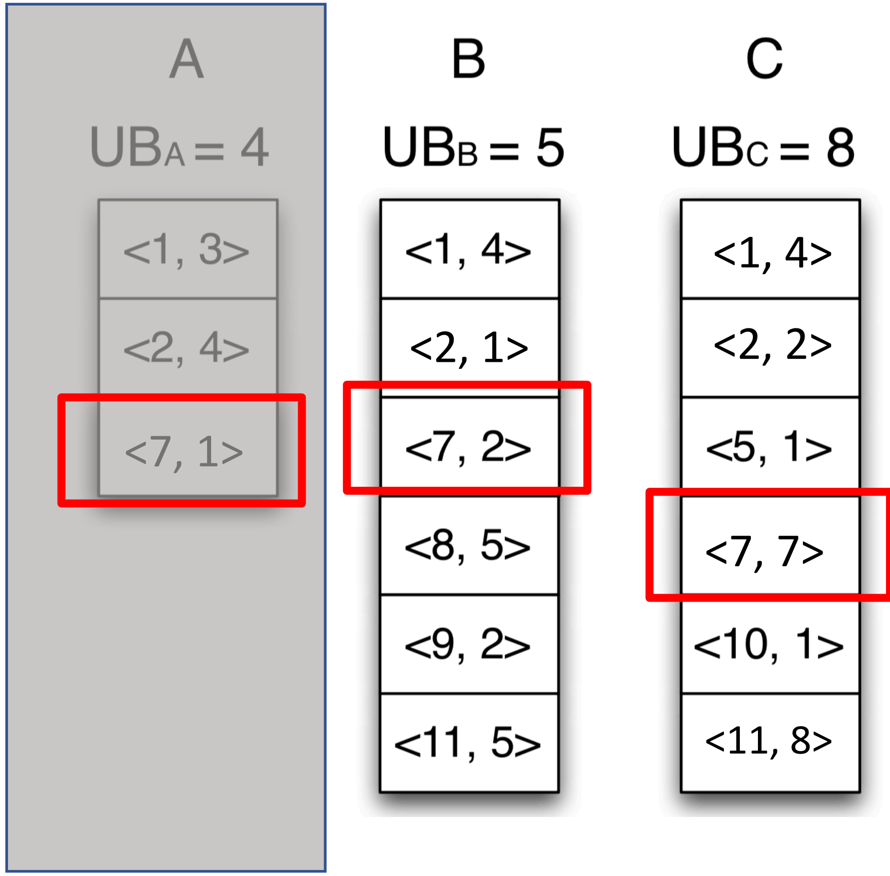
- $\alpha = 7$
- Iter 1:
  - curDoc = d5
  - partial score = 1
  - “probe” A to get full score = 1
  - Nothing to update



Fixed order = C B A

Example (k = 2)

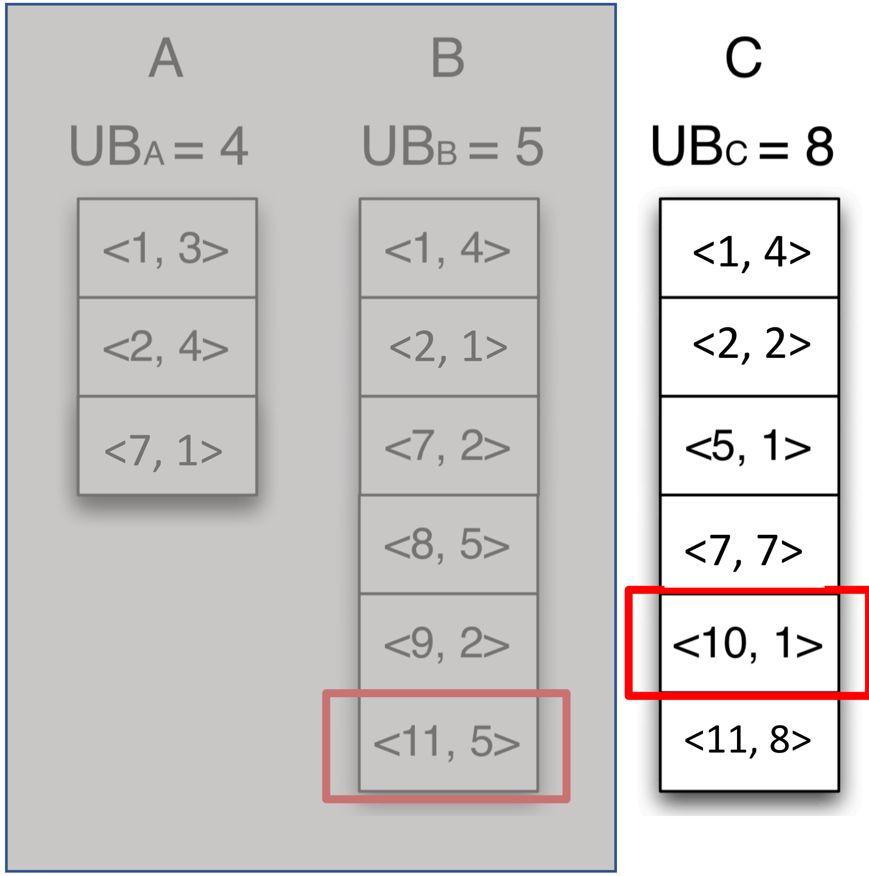
- α = 7
- Iter 2:
  - curDoc = d7
  - partial score = 9
  - “probe” A to get full score = 10
  - Update
    - α = 10
    - Q1 = C



Fixed order = C B A

Example (k = 2)

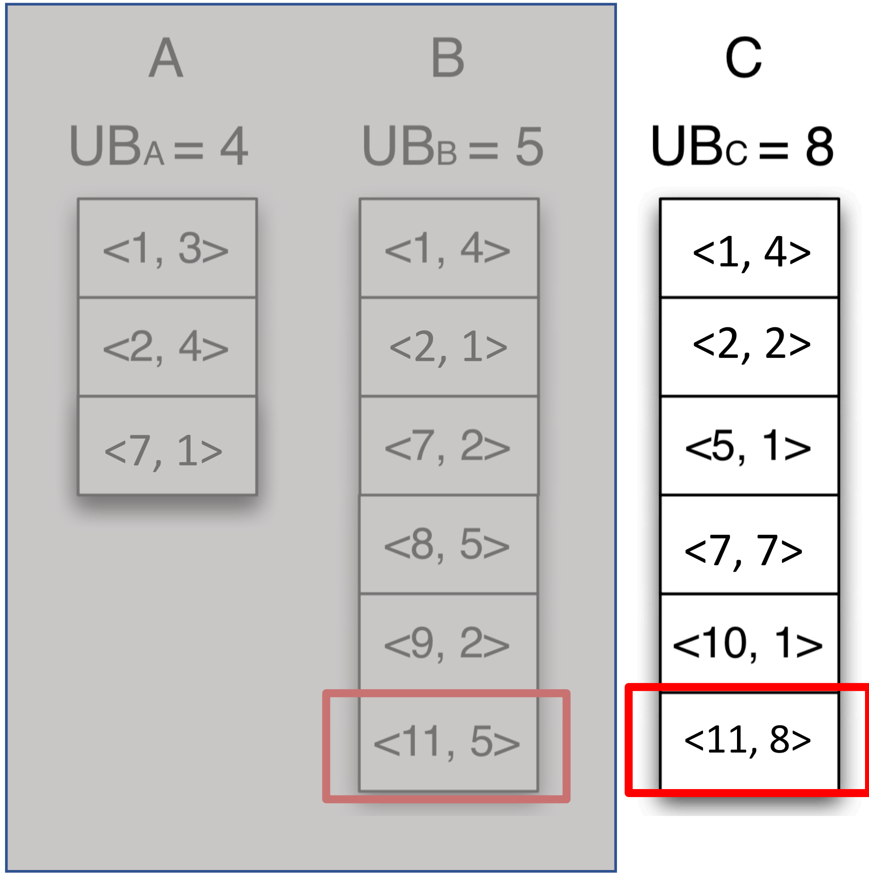
- α = 10
- Iter 3:
  - curDoc = d10
  - partial score = 1
  - “probe” A and B to get full score = 1
  - Nothing to update



Fixed order = C B A

Example (k = 2)

- α = 10
- Iter 3:
  - curDoc = d11
  - partial score = 8
  - “probe” A and B to get full score = 13
  - Update
    - α = 11
    - Q1 = C
- End



- This is the typical stopping condition; There is another possible stopping condition though. Can you figure it out? (not in this example)
- We can further optimize the algorithm to remove unnecessary “probes” on Q2 list(s). Can you find it out?

Idea 2

A	...	2:*	...	UB = 5
B	...	7:*	...	UB = 3
C	...	4:*	...	UB = 2

Sorted Term	A	C	B
Doc	*	*	*
Cumulative Upper Bound	5	7	10

if α = 9, the first document that can score above α is from __B____
Pivot document is the current document for the pivot term

Pivot term = B

Pivot doc = d7

Is it possible for any doc < PivotDoc to enter into top-k?

Case I: smallest DID ≠ PivotDoc

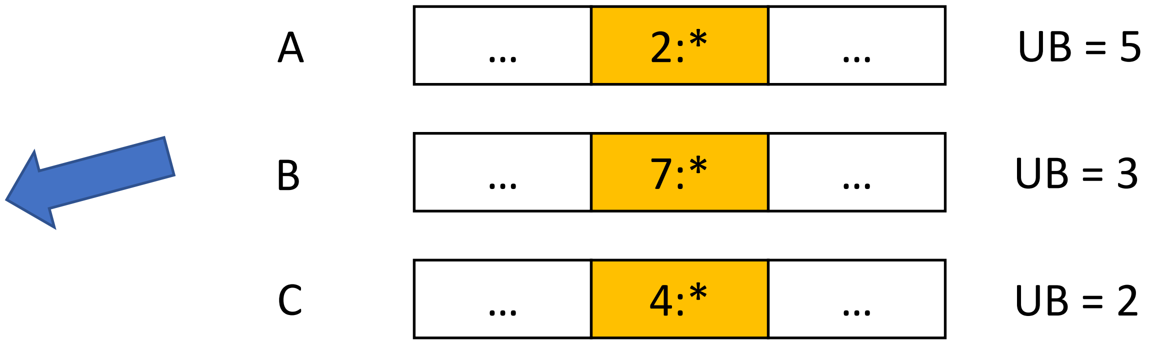
Sorted Term	A	C	B
Doc	2	*	7
Cumulative Upper Bound	5	7	10

score(d2) ≤ 8

➔ align preceding lists to PivotDoc: A.skipTo(d7), C.skipTo(d7)

➔ Check again

Idea 2



Sorted Term	A	C	B
Doc	*	*	*
Cumulative Upper Bound	5	8	10

if α = 9, the first document that can score above α is from __B_____
Pivot document is the current document for the pivot term

Pivot term = B

Pivot doc = d7

Is it possible for any doc < PivotDoc to enter into top-k?

Case II: smallest DID = PivotDoc

Sorted Term	A	C	B
Doc	7	*	7
Cumulative Upper Bound	5	8	10

C.Doc must be d7

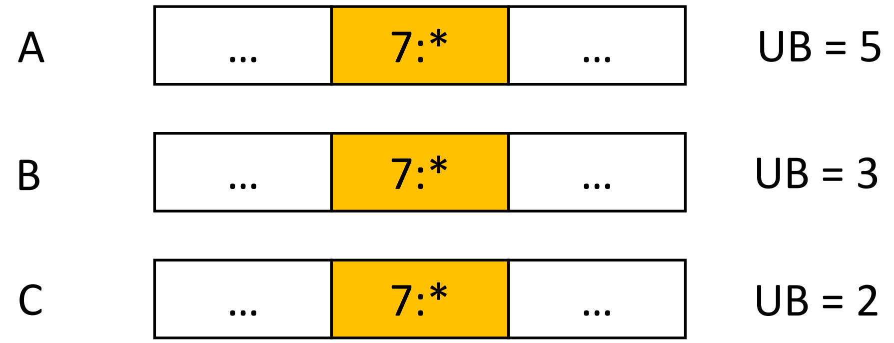
score(d7) could be larger than α

➔ fullScore(d7)

➔ Adjust α if necessary

➔ all list pointing to d7: next()

Idea 2



Sorted Term	A	C	B
Doc	*	*	*
Cumulative Upper Bound	5	8	10

if α = 9, the first document that can score above α is from __B____
Pivot document is the current document for the pivot term

Pivot term = B

Pivot doc = d7

If all term preceding PivotTerm (in the sorted order) agree on PivotDoc, then PivotDoc is the smallest document that may enter into top-k.

Full scoring:

- Need to "probe" lists that are sorted after the PivotTerm

None in our example, but one can easily add D list.

Based on ”Exploring the Magic of WAND” in ADCS 2013

WAND

1. Initialization

Algorithm 1 WAND processing.

function WAND($q, \mathcal{I}, k$)
  for $t \leftarrow 0$ **to** $|q| - 1$ **do**
    $U[t] \leftarrow \max_d\{w_d \mid (d, w_d) \in \mathcal{I}_t\}$
    $(c_t, w_t) \leftarrow \mathit{first\_posting}(\mathcal{I}_t)$
  end for
  $\theta \leftarrow -\infty$ // current threshold
  $Ans \leftarrow \{\,\}$ // k-set of (d, s_d) values

WAND

2. Finding the Pivot

while the set of candidates (c_t, w_t) is non-empty **do**
    permute the candidates so that $c_0 \leq c_1 \leq \cdots c_{|q|-1}$
    $score\_limit \leftarrow 0$
    $pivot \leftarrow 0$
    while $pivot < |q| - 1$ **do**
        $tmp\_s\_lim \leftarrow score\_limit + U[pivot]$
        if $tmp\_s\_lim > \theta$ **then**
            break, and continue from step 20
        end if
        $score\_limit \leftarrow tmp\_score\_lim$
        $pivot \leftarrow pivot + 1$
    end while

Based on ”Exploring the Magic of WAND” in ADCS 2013

WAND

3a. Case II

while the set of candidates (c_t, w_t) is non-empty **do**

fullScore()

update

updatePointers-I

if $c_0 = c_{pivot}$ **then**
    $s \leftarrow 0$ // score document c_{pivot}
    $t \leftarrow 0$
    while $t < |q|$ **and** $c_t = c_{pivot}$ **do**
        $s \leftarrow s + w_t$ // add contribution to score
        $(c_t, w_t) \leftarrow \mathit{next\_posting}(\mathcal{I}_t)$
        $t \leftarrow t + 1$
    end while // s is the score of document c_{pivot}
    if $s > \theta$ **then** // and is a possible top-k answer
        $\mathit{Ans} \leftarrow \mathit{insert}(\mathit{Ans}, (c_{pivot}, s))$
        if $|\mathit{Ans}| > k$ **then**
            $\mathit{Ans} \leftarrow \mathit{delete\_smallest}(\mathit{Ans})$
            $\theta \leftarrow \mathit{minimum}(\mathit{Ans})$
        end if
    end if

Based on ”Exploring the Magic of WAND” in ADCS 2013

WAND

3b. Case I

while the set of candidates (c_t, w_t) is non-empty **do**

35: **else** $c_0 \neq c_{pivot}$ // can't score c_{pivot} (yet)

for $t \leftarrow 0$ **to** $pivot - 1$ **do**

$(c_t, w_t) \leftarrow \textit{seek\_to\_document}(\mathcal{I}_t, c_{pivot})$

end for // all pointers are now at c_{pivot} or greater

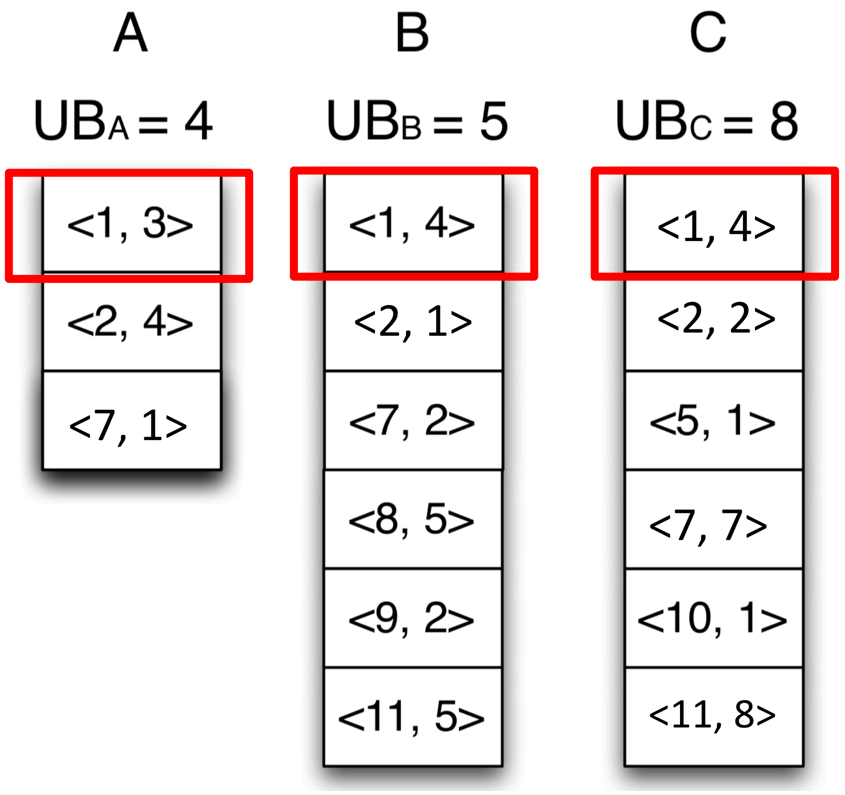
end if

40: **end while**

updatePointers-II

It moves **all** the preceding lists. It is the mWAND optimization for memory-resident index in [Fontoura et al, 2011].

Example (k = 1)



- Step 1:
  - $\alpha = 0$

Sorted Term	A	B	C
Doc	1	1	1
Cumulative Upper Bound	4	9	17

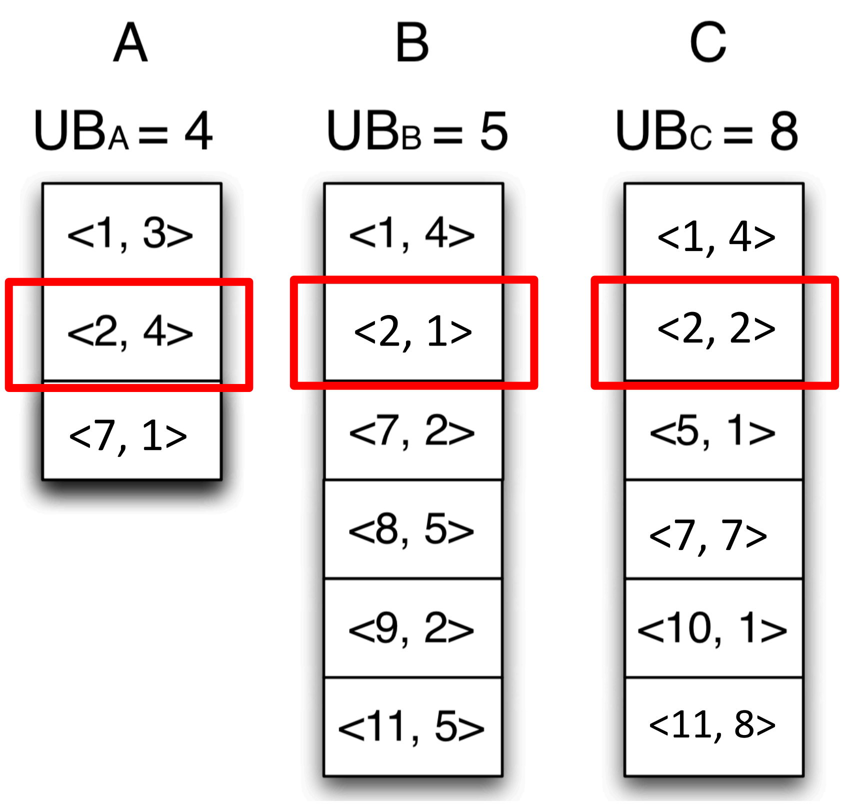
  - PivotTerm = A
  - PivotDoc = 1
  - Case II
    - fullScore() ➔ d1 = 11, α = 11
  - updatePointers()

Example (k = 1)

- Step 2:
  - α = 11

Sorted Term	A	B	C
Doc	2	2	2
Cumulative Upper Bound	4	9	17

- PivotTerm = C
- PivotDoc = 2
- Case II
  - fullScore() → d2 = 7, α = 11
- updatePointers()

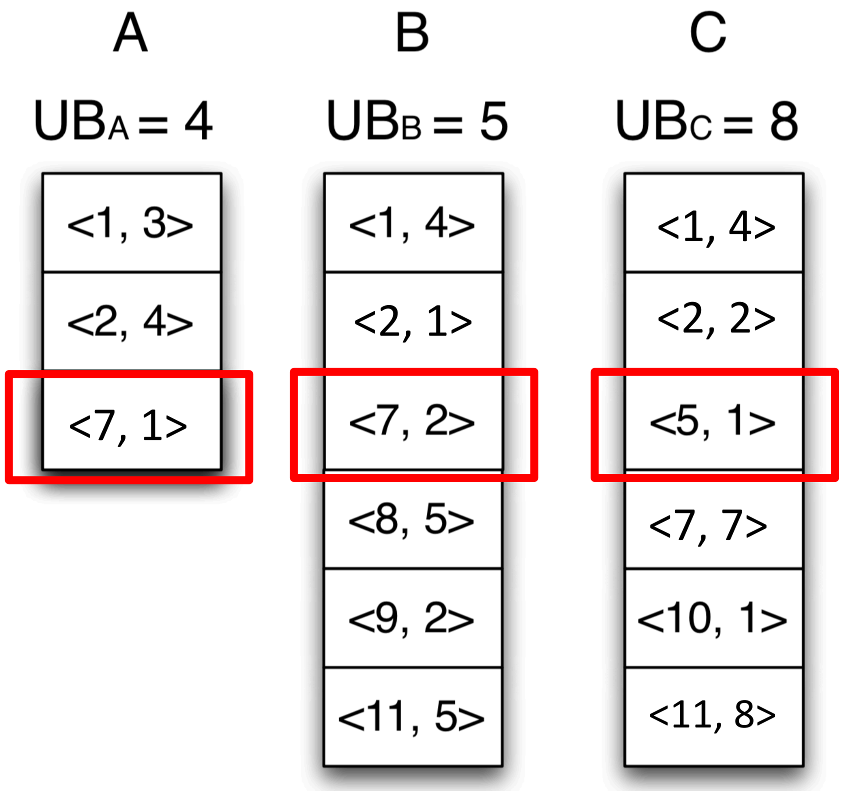


Example (k = 1)

- Step 3:
  - α = 11

Sorted Term	C	B	A
Doc	5	7	7
Cumulative Upper Bound	8	13	17

  - PivotTerm = B
  - PivotDoc = 7
  - Case I
    - updatePointers()

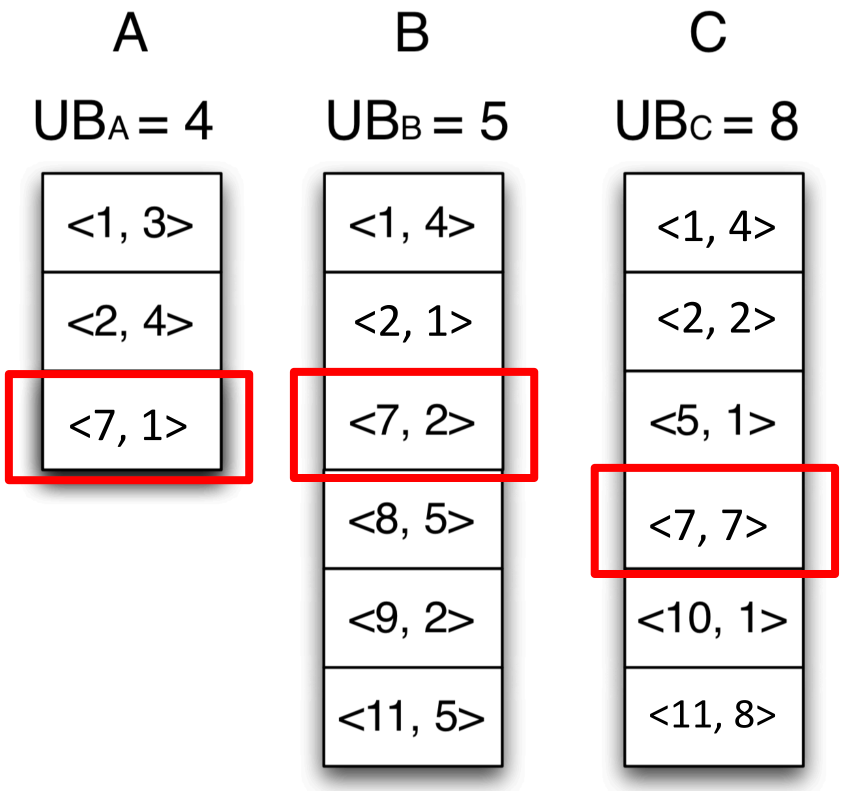


Example (k = 1)

- Step 4:
  - $\alpha = 11$

Sorted Term	C	B	A
Doc	7	7	7
Cumulative Upper Bound	8	13	17

  - PivotTerm = B
  - PivotDoc = 7
  - Case II
    - fullScore() ➔ d7 = 10, $\alpha = 11$
  - updatePointers()
- Step 5: …



Comparisons

	MaxScore	(m)WAND
Pruning Strategy	UB based on fixed ordering of terms ➔ “proactive” pruning	UB based on variable ordering of terms ➔ “passive” pruning
Performance	Better for short queries	Better for long queries
Applicability	DAAT & TAAT	DAAT

SI	SQ	LQ
Naive DAAT	193.0	4,554.6
mWAND	200.0	2,104.6
DAAT *max_score*	169.0	2,685.6

LI	SQ	LQ
Naive DAAT	3,581.3	26,778.3
mWAND	1,867.0	7,556.3
DAAT *max_score*	1,572.6	9,321.3

Table 5: Latency results for naive DAAT, mWAND and DAAT *max_score*.

Hybrid TAAT-DAAT

- Idea
  - Find a good α (with little cost) and run optimized DAAT algorithm
- Q = {A B C D}, in increasing order of list length
  - Q1 = {A, B}, Q2 = Q - Q1 = {C, D}
  - α(Q1), L(Q1) = ProcessQuery(Q1)
    - L(Q1): documents scored for Q1
  - ProcessQueryDAAT(Q2; α(Q1), L(Q1))
    - Treat L(Q1) as another inverted list, UB(L(Q1)) = α(Q1)

TAAT flavor

References

- Efficient Query Evaluation using a Two-Level Retrieval. CIKM 2003.
- Exploring the Magic of WAND. ADCS 2013.
- [Fontoura et al, 2011] Evaluation Strategies for Top-k Queries over Memory-Resident Inverted Indexes. VLDB 2011.
- Howard R. Turtle, James Flood: Query Evaluation: Strategies and Optimizations. Inf. Process. Manag. 31(6): 831-850 (1995)