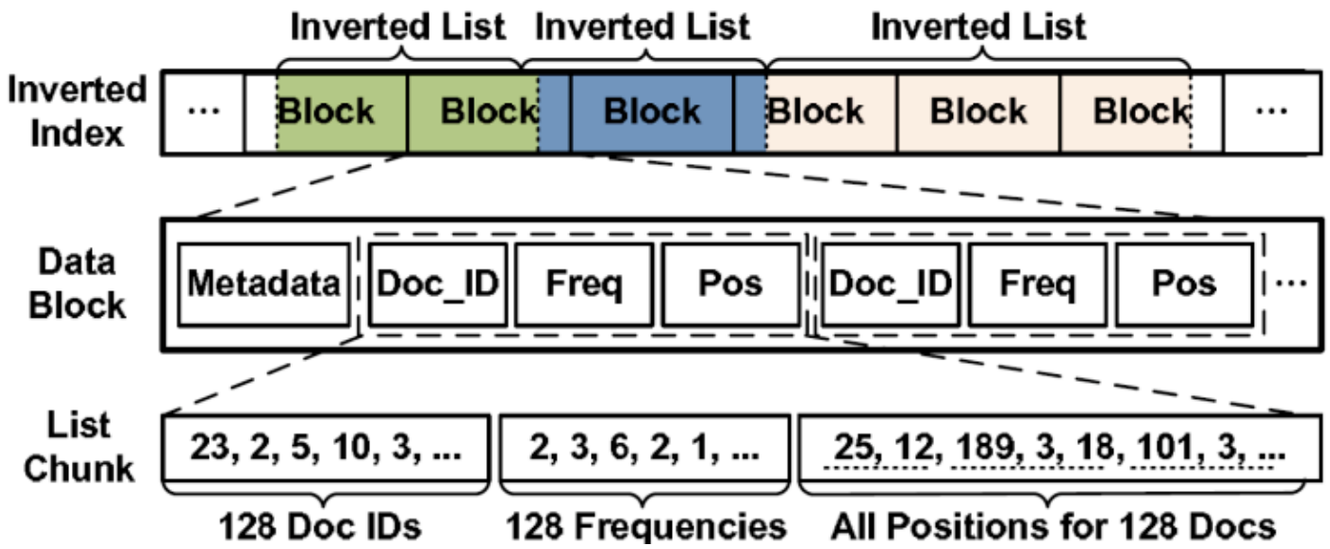
Indexing

Compression and QP

Posting list Layout

Data blocks, say of size 64KB, as basic unit for list caching



List chunks, say of 128 postings, as basic unit of decompression

- Posting list storage is implemented as
  - list of document identifiers (did)
  - list of scores, positions
- Many chunks are skipped over, but very few blocks are
- Also, may prefetch the next, say 2MB of index data from disk

Posting list Compression

- In a collection of 2^{12} documents
- Minimum number of bits required ?
- What is the uncompressed size for this list ?
- Variable byte encoding:
  - **7-bit encoding:** Use 7 bits for every byte and a continuation bit

1220 = 00000000 00000100 11000100

= 00001001 **1**1000100

Doc. id list

2
3
8
15
16
20
1220
1221
1229
1235
1237
1000001
1000003

d-gap Encoding

- Store the first doc. id and gaps or relative differences — d-gaps
- Lists are read sequentially
- compress them using variable byte encoding
- compression and decompression is fast

Doc. id list	Doc. id list (gaps)
2	2
3	1 → 3-2
8	5 → 8-3
15	7
16	1
20	4
1220	1200
1221	1
1229	8
1235	5
1237	2
1000001	998764
1000003	2

13 x 3 bytes

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20	4	
1220	1200	
1221	1	
1229	8	
1235	5	
1237	2	
1000001	998764	
1000003	2	
13 x 3 bytes	(11 x 1 + 2 + 3) bytes	

Rice Encoding

For a given **b**, each number x in the list we do the following:

Doc. id list (gaps)	x-1 / b in unary	x-1 mod b in binary
34	33 / **64**	33 % **64**
144	0	10001
113	rice code	
162		

$2^{\lfloor log(g) \rfloor}$

- **b** is nearest (smaller) power of two of the average of the numbers [g = (34+144+113+162) / 4 = 113.33]
- There are no zeros to encode
- simple to implement (bitwise operations) and better compression than var-byte, but slightly slower

Golomb Encoding

For a given **b**, each number x in the list we do the following:

Doc. id list (gaps)	x-1 / b in unary	x-1 mod b in binary
34	33 / **78**	33 % **78**
144	0	10001
113	golomb code	
162		

- **b** is 0.69 of the average of the numbers [g = (34+144+113+162) / 4 = 113.33]*0.69 ~ 78
- need fixed encoding of number 0 to 77 using 6 or 7 bits
- optimal for random gaps (dart board, random page ordering)

Gamma Encoding

Each number x in the list, **b** = $2^{\lfloor log(x) \rfloor}$

nearest smallest power of 2

log(b) in unary

x-1 mod (b) in binary (b bits)

Doc. id list (gaps)

34 → log(33) = 5 → 33 % **32**

144

113

162

111110 00001

gamma code

- Good compression for small values, e.g., frequencies, bad for large numbers, and fairly slow
- **Delta coding:** Gamma code; then gamma the unary part

Patched Frame of Reference (PFoR) Compression

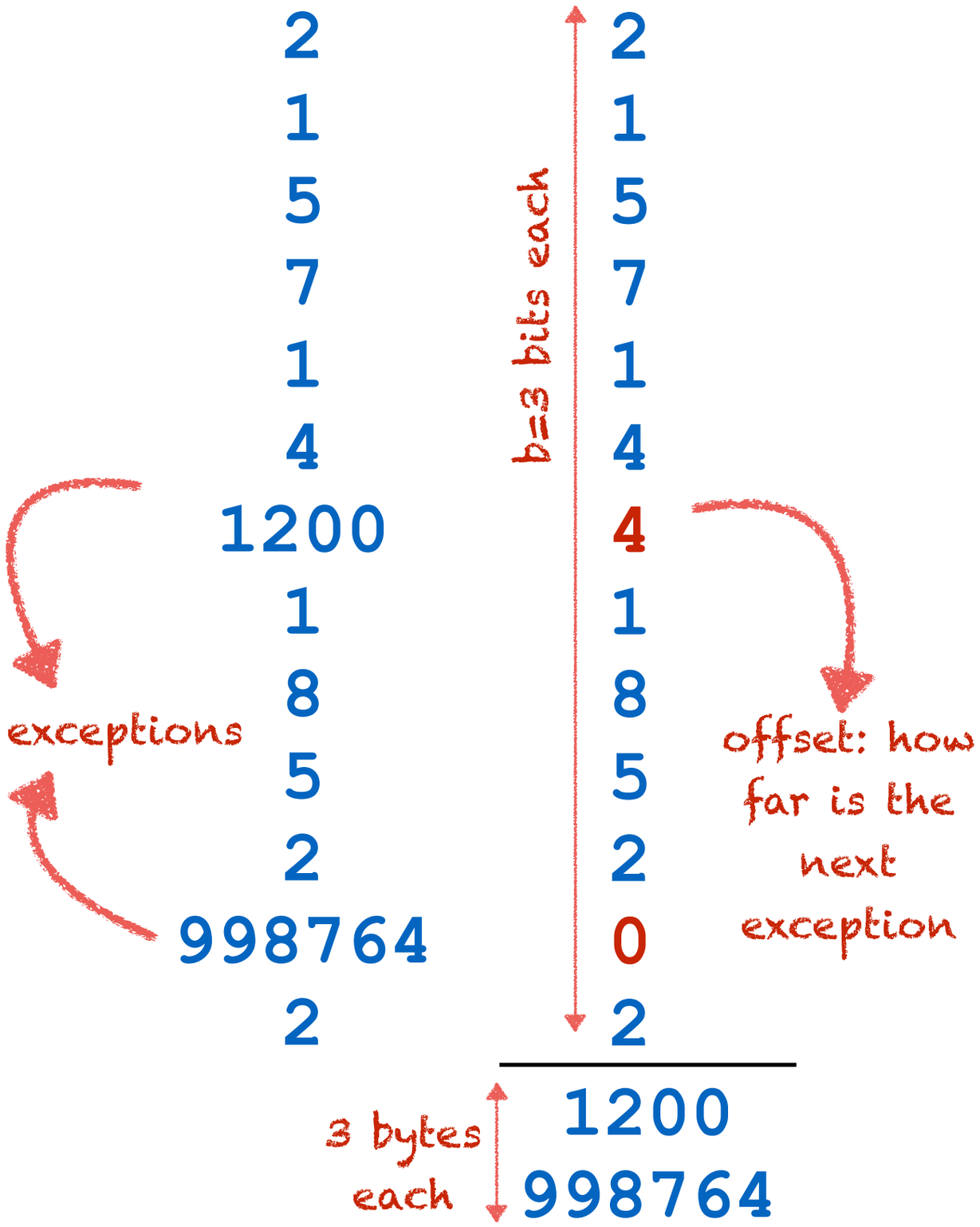
- Variable sizes for each number is bad for decompression due to branching
- Constant size for each number is bad for compression since valuable space is wasted

90% of numbers are small and 10% are large

- Trade-off — Use fixed size for most small integers and treat others as exceptions
- 11 /13 can be encoded in 3 bits and 3 bytes for remaining 2

```
2
1
5
7
1
4
1200
1
8
5
2
998764
2
```

PforDelta Compression



OPT-PFD :

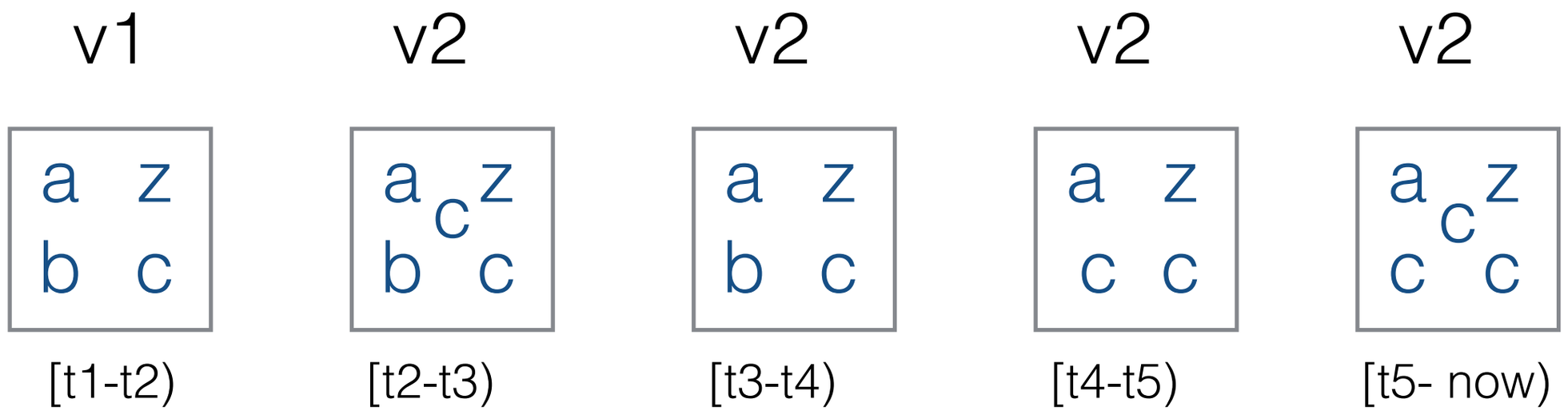
- keep the **last b bits** of exceptions in the original list and
- the **higher-order bits** and the **offsets** of the exceptions are separately encoded using another compression method.
- Instead of choosing a **b** that guarantees less than 10% exceptions in the block, select the b that results in the smallest compressed size for the block

Redundancy in Temporal Collections

- Documents with multiple versions
  - each modification results in a new version
  - Wikipedia, Web Archives
- Most of the edits in versioned collections are minor edits
- Major edits occur in bursts
- Adjacent versions have considerable redundant content
- How do we exploit this for compressing inverted indexes ?

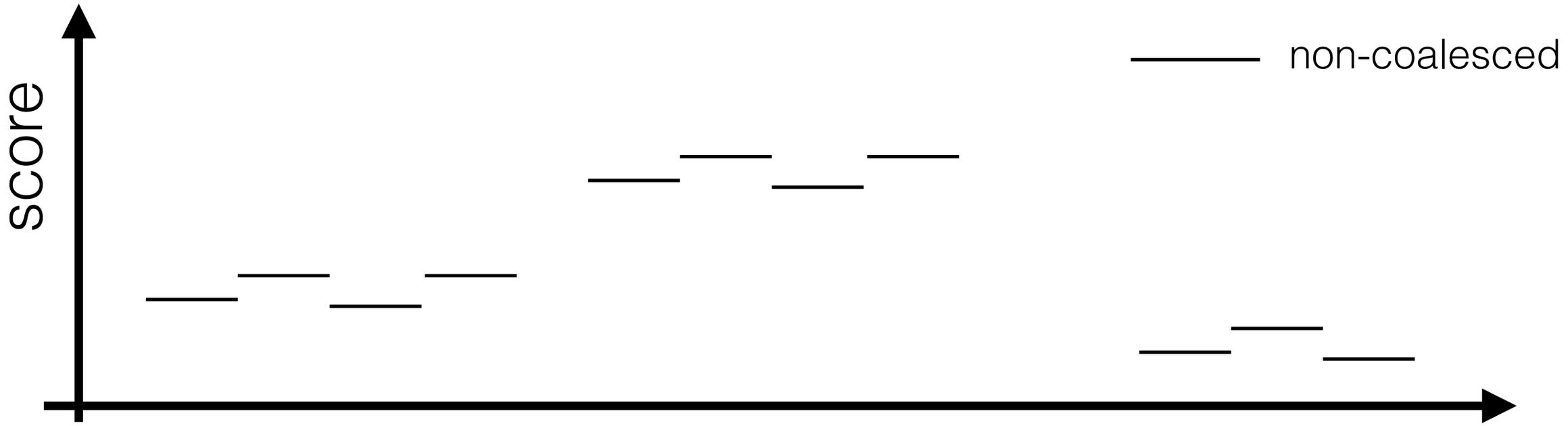
Temporal Coalescing

http://en.wikipedia.org/wiki/Interstellar_(film)



- Recollect time-travel queries: interstellar @ 2013-2014
- Indexing each version results in index blowup
- term frequencies do not change much hence have small impact on the final score
- Coalesce multiple versions of the same doc. into fewer postings

Temporal Coalescing



- Document with multiple versions (hence multiple postings) all having similar scores
- Not much difference in scores, hence no impact on overall scoring
- Coalesce postings for adjacent versions of same doc. with almost identical scores

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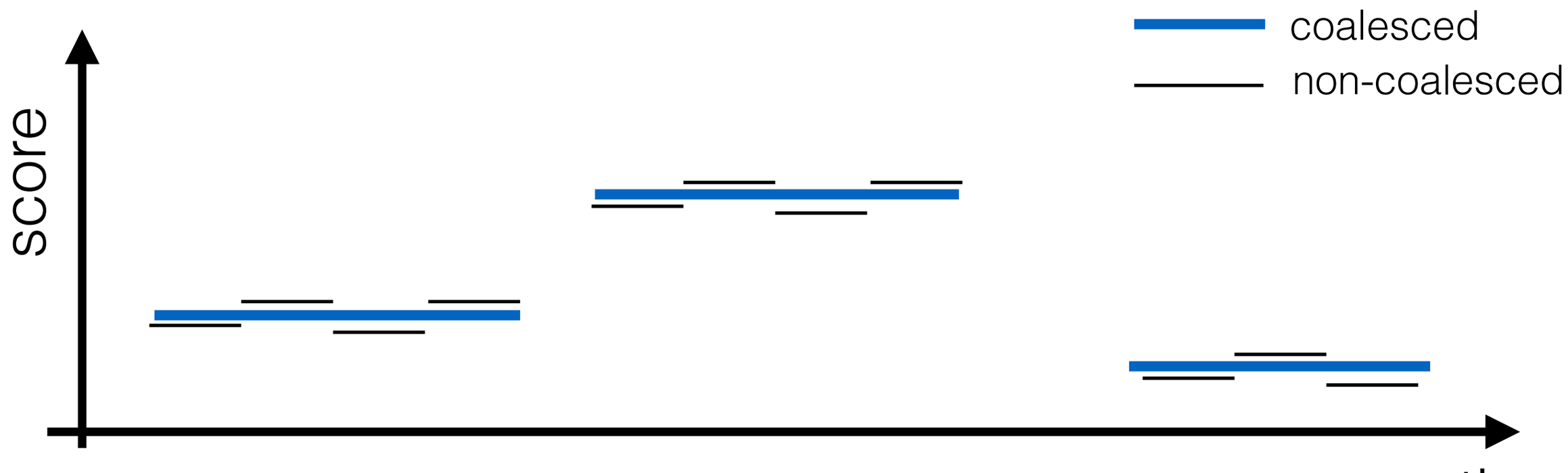

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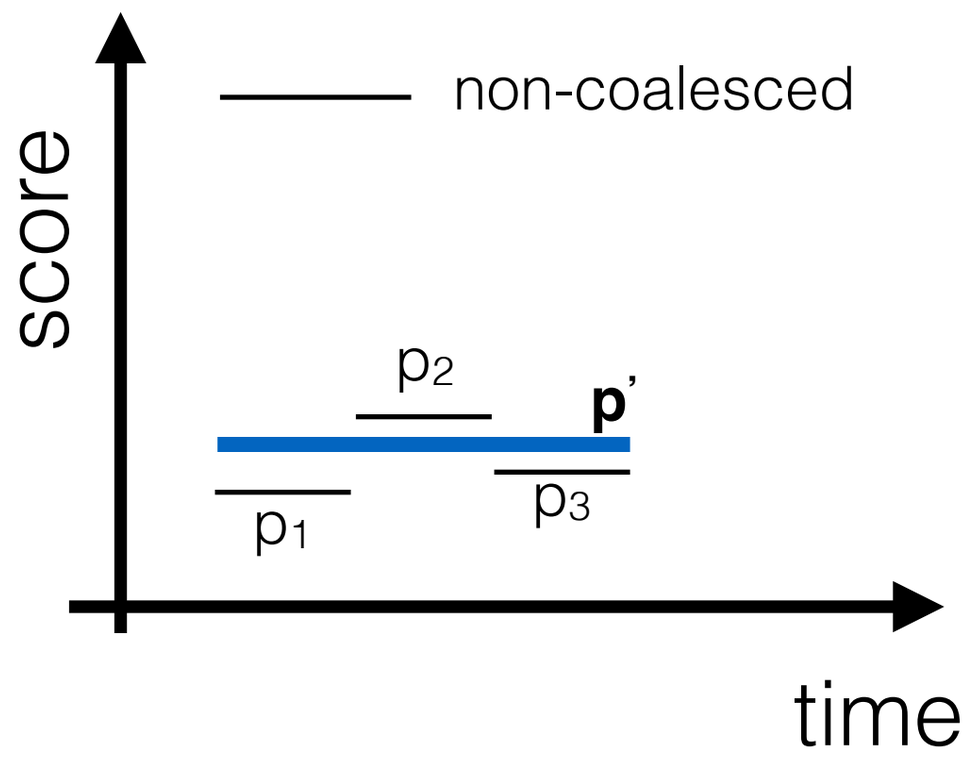
Temporal Coalescing

- Problem Statement: Given sequence I of postings for term v in document d, determine minimal-length output sequence that keeps relative approximation error below threshold ε

$$\forall i \ : \ |p_i - p'| \, / \, |p_i| \ \leq \ \epsilon$$

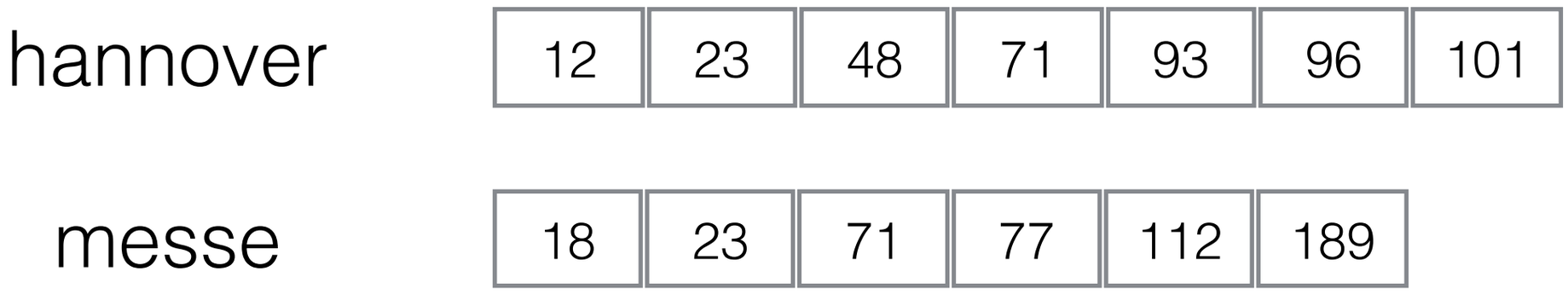
- Approach:
  - Keep a moving average of already seen values
  - Once the average is outside the error bounds of a posting finalize the coalesced posting



Two-Level Index

- Construct a two-level index
- For each posting list for term **t**
  - **first level:** maintains doc. ids if any of its versions mentions the term
  - **second level:** contains a bitmap of the versions which contain **t**
- First level considers a doc. as the union of all terms in its versions
  - Use PforDelta compression as in standard inverted indexes
- Second level is bit-level representation
  - Since terms are bursty, spans consisting bursts can be effectively compressed

Query Processing: Term-At-A-Time



Term-at-a-time

- Process one list at a time
- Maintain accumulators for partial results and update them
- Best for unions

Accumulators in memory

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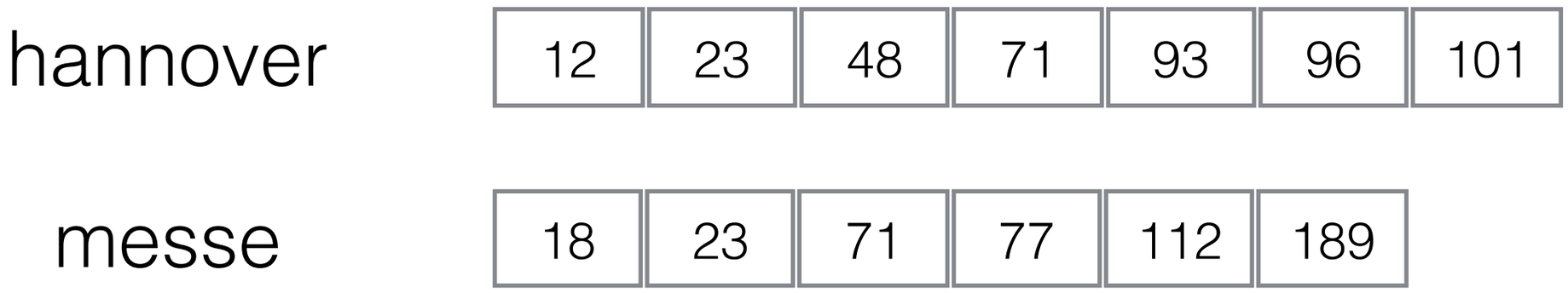

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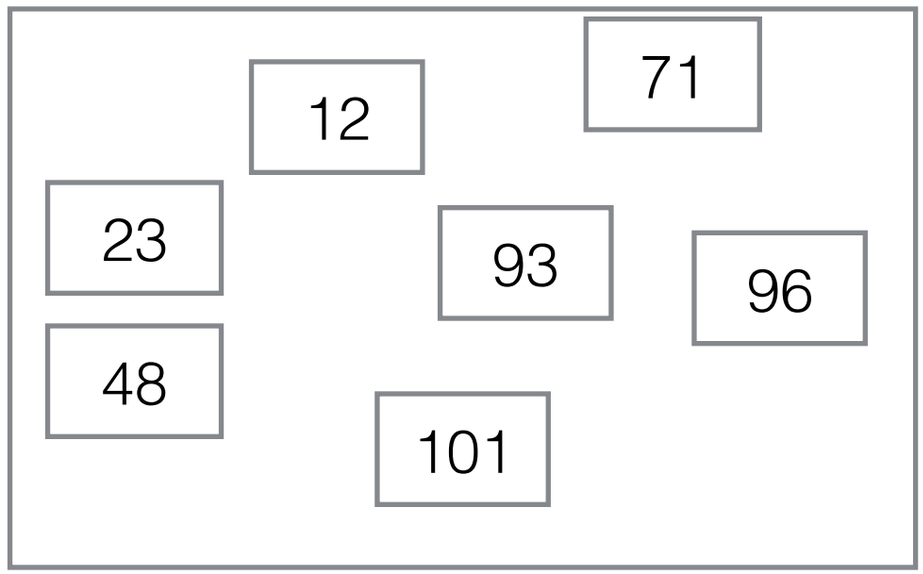

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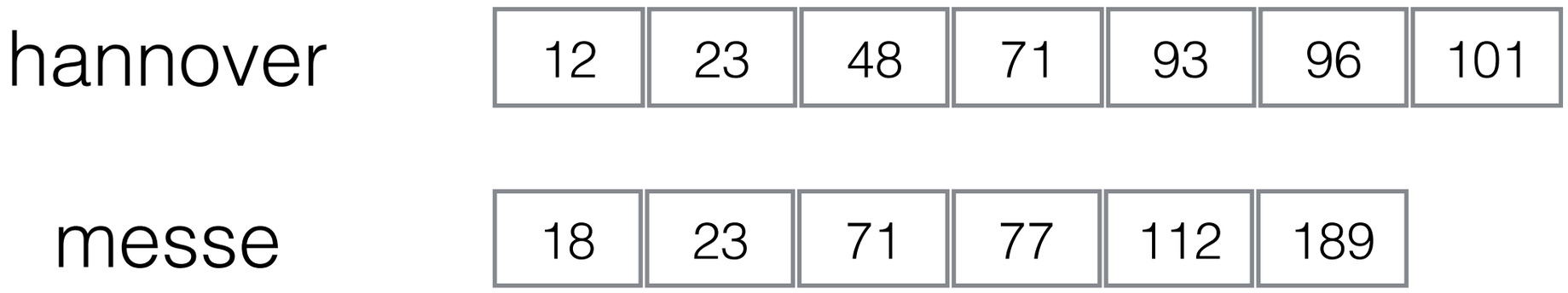

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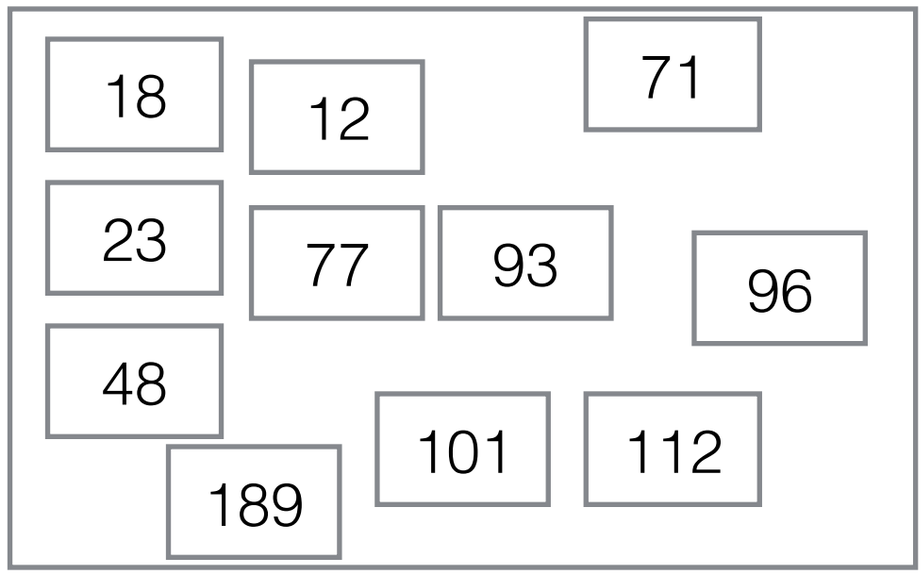

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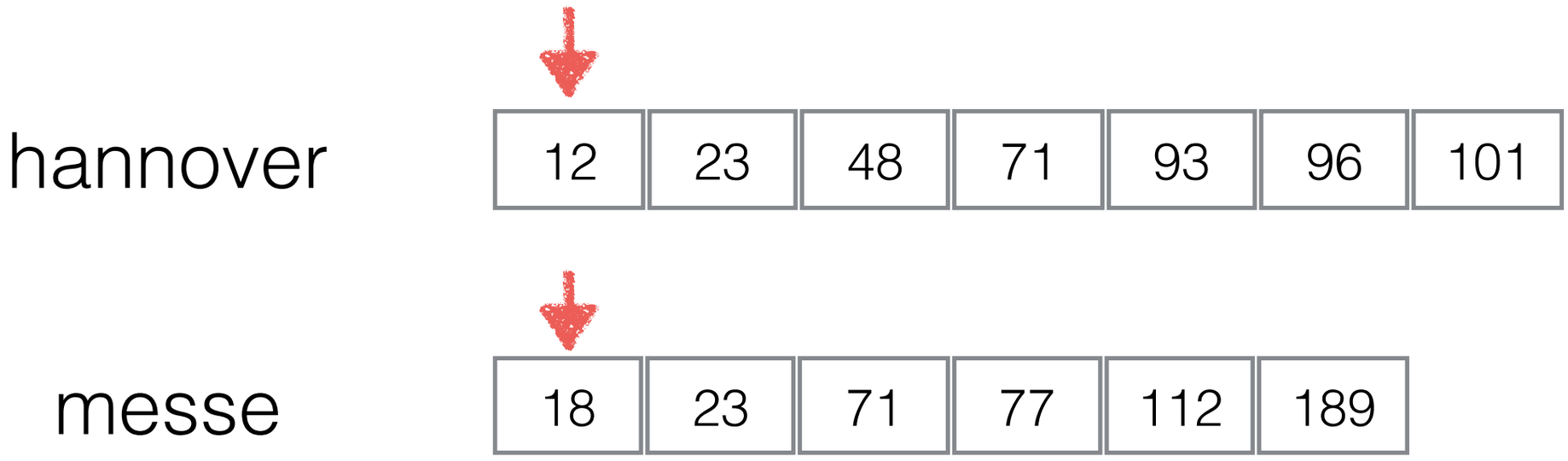

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- Open cursors to all lists
- Systematically move cursors to satisfy boolean expression
- Best for intersections

Conjunctive query semantics

- In each iteration find the max did M
- Move other cursors to greater or equal to M
- If all cursors point to M, move all one step further

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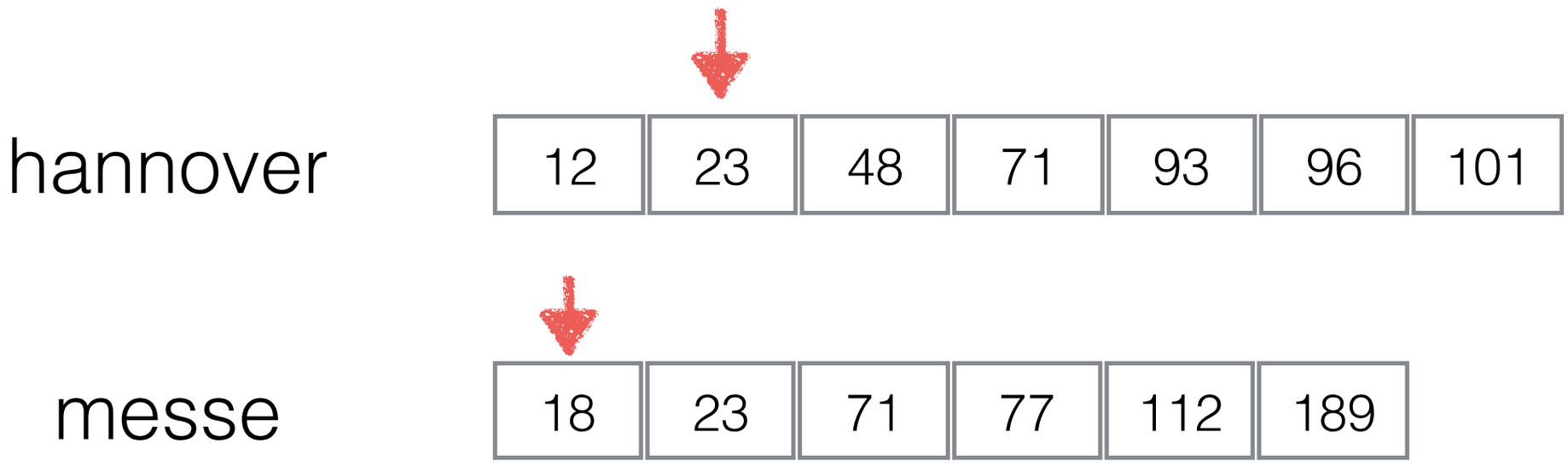

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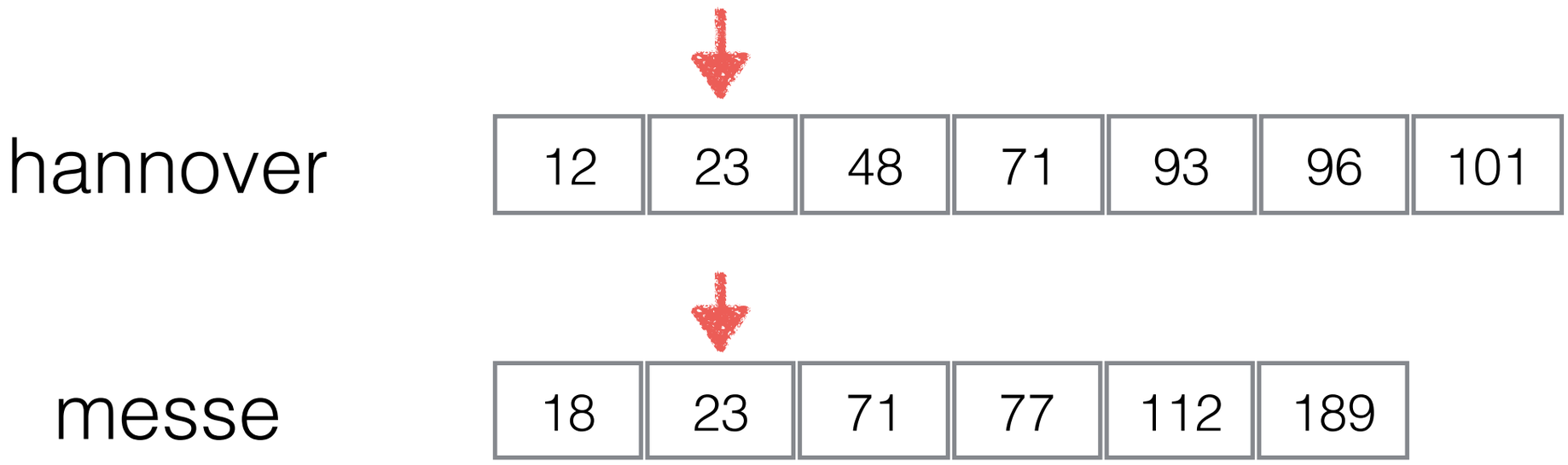

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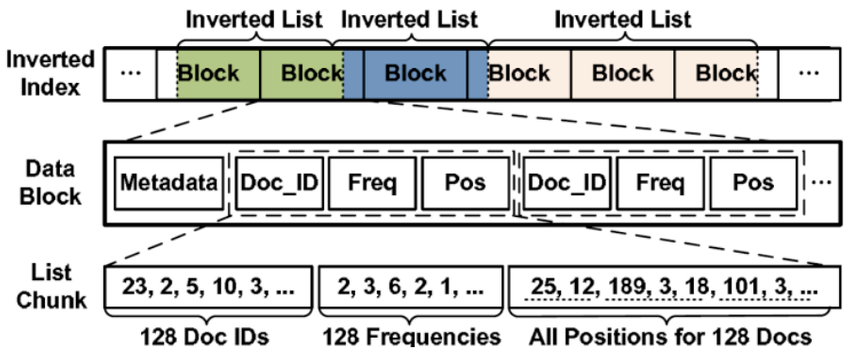

hannover

12	23	48	71	93	96	101	…

messe

18	23	71	105	112	189

What if we are allowed to store extra information for each lists ?

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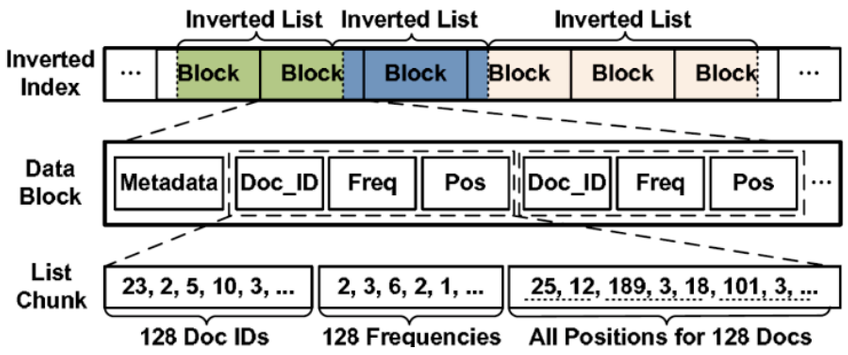

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- Skip list allow fast intersections acting as a secondary index over posting lists
- Typically skip over fixed number of postings and are square root of the length of the postings list

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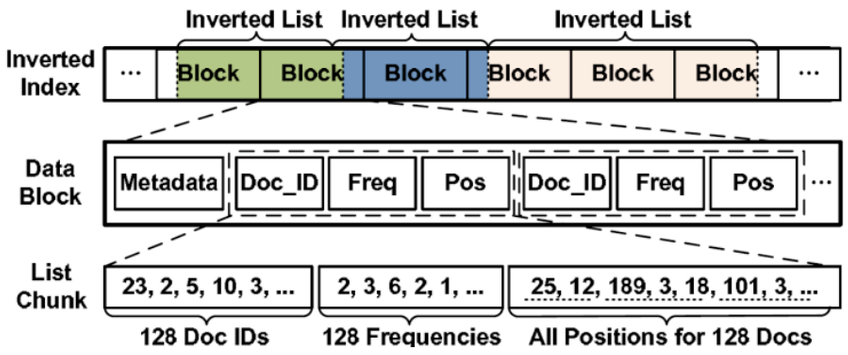

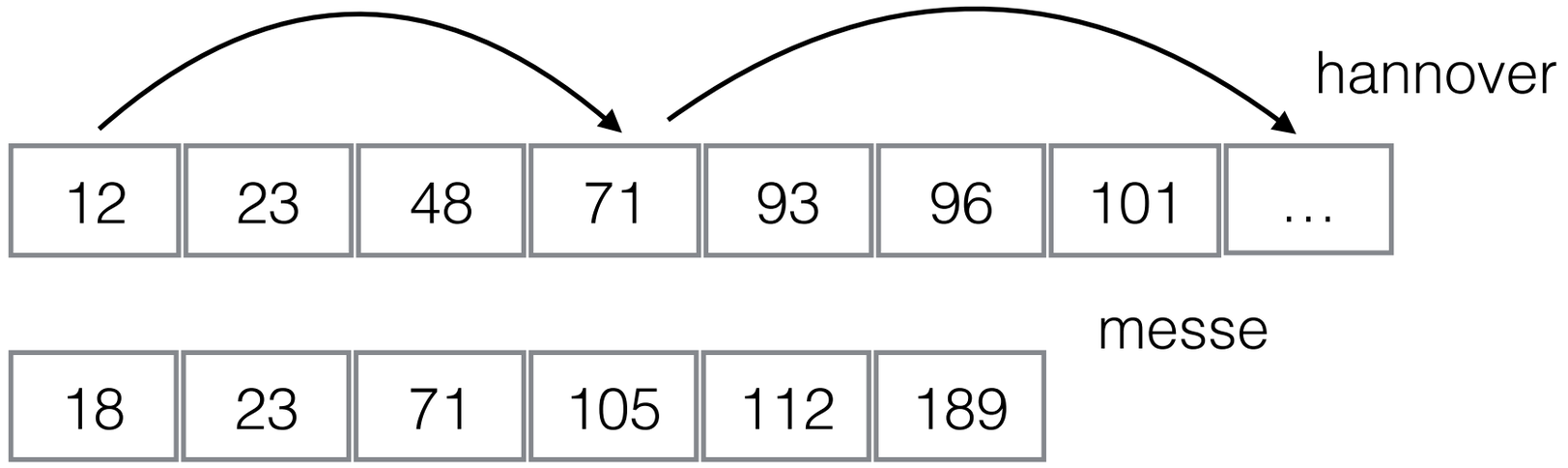

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Weak AND

- Generalized version of AND operation

$$\sum_{1 \leq i \leq k} x_i w_i \geq \theta,$$

for a query of k words

- Weights and indicator variables specify the degree of AND
- Threshold helps avoid computation of non important documents
- An instance of DAAT scoring

Weak AND or WAND

- Assume a special iterator on the postings of the form "go to the first docID greater than *X*"

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- Typical state: we have a "cursor" at some docID in the postings of each query term
  - Each cursor moves only to the right, to larger docIDs

- Invariant – all docIDs lower than any cursor have already been *processed*, meaning
  - These docIDs are either pruned away or
  - Their scores have been computed

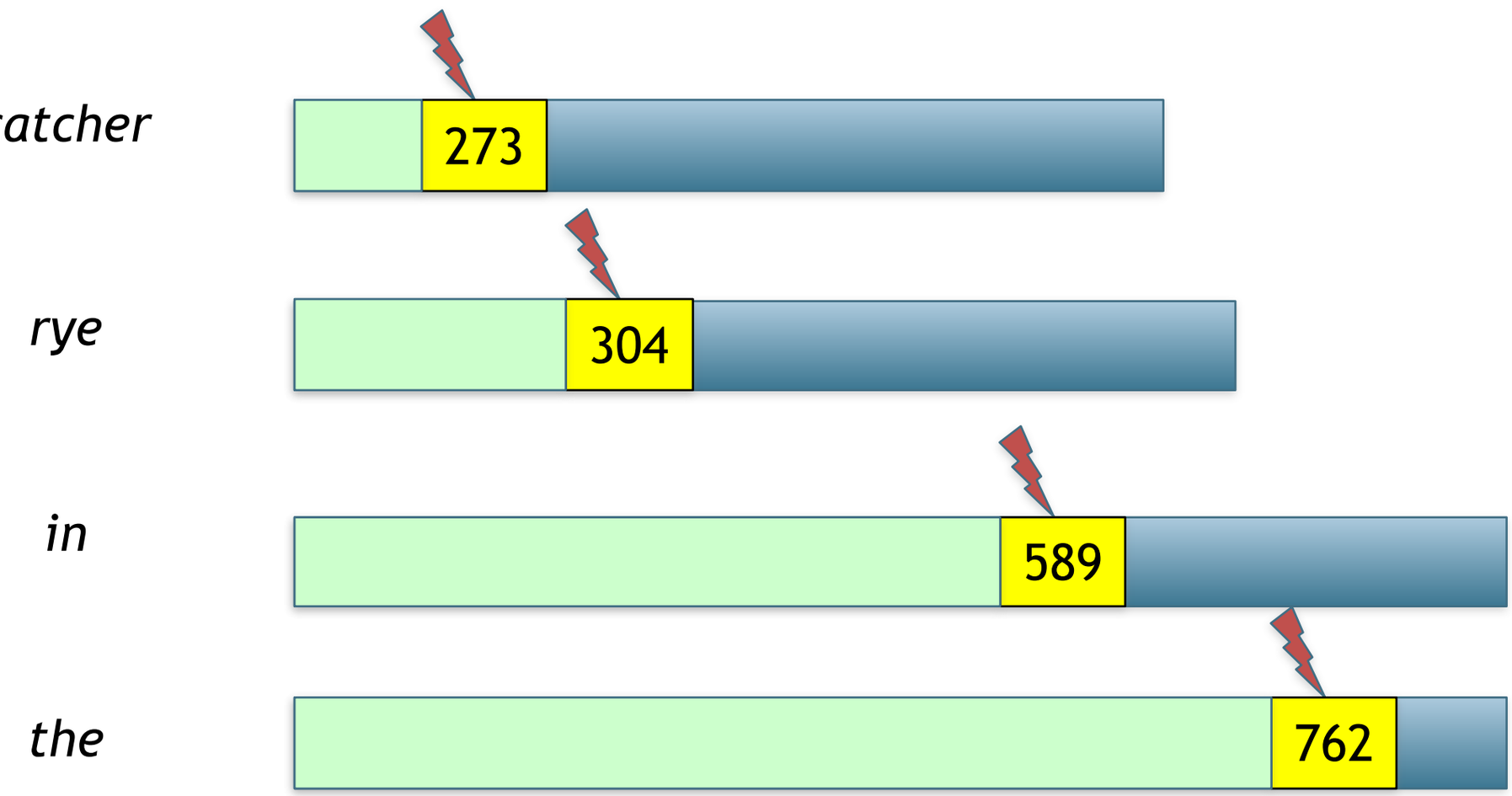
Weak AND

- At all times for each query term *t*, we maintain an *upper bound* UB_t on the score contribution of any doc to the right of the cursor
  - Max (over docs remaining in *t*'s postings) of w_t(doc)
  - As cursor moves right, the UB drops

UB("hannover") = 2.8

WAND - Pivoting

- Query: *catcher in the rye*
- Let's say the current cursor positions are as below



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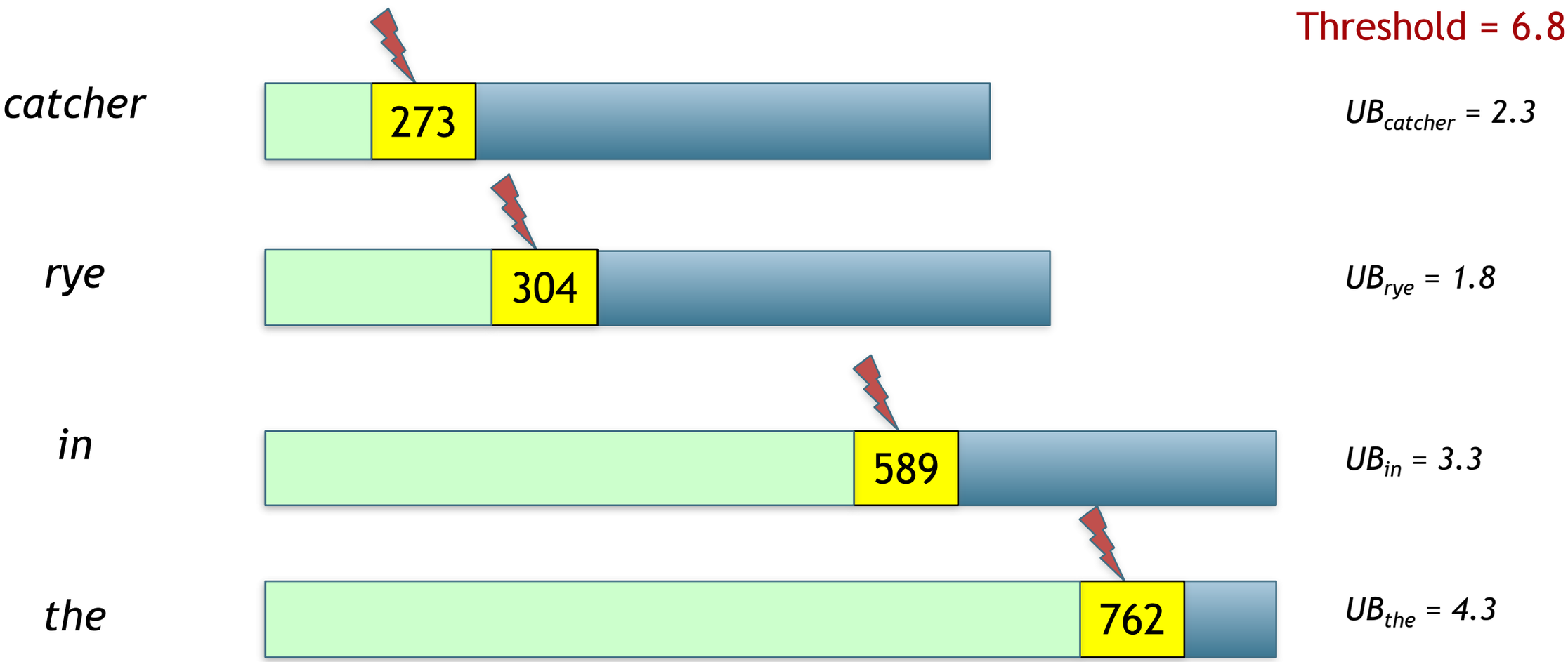

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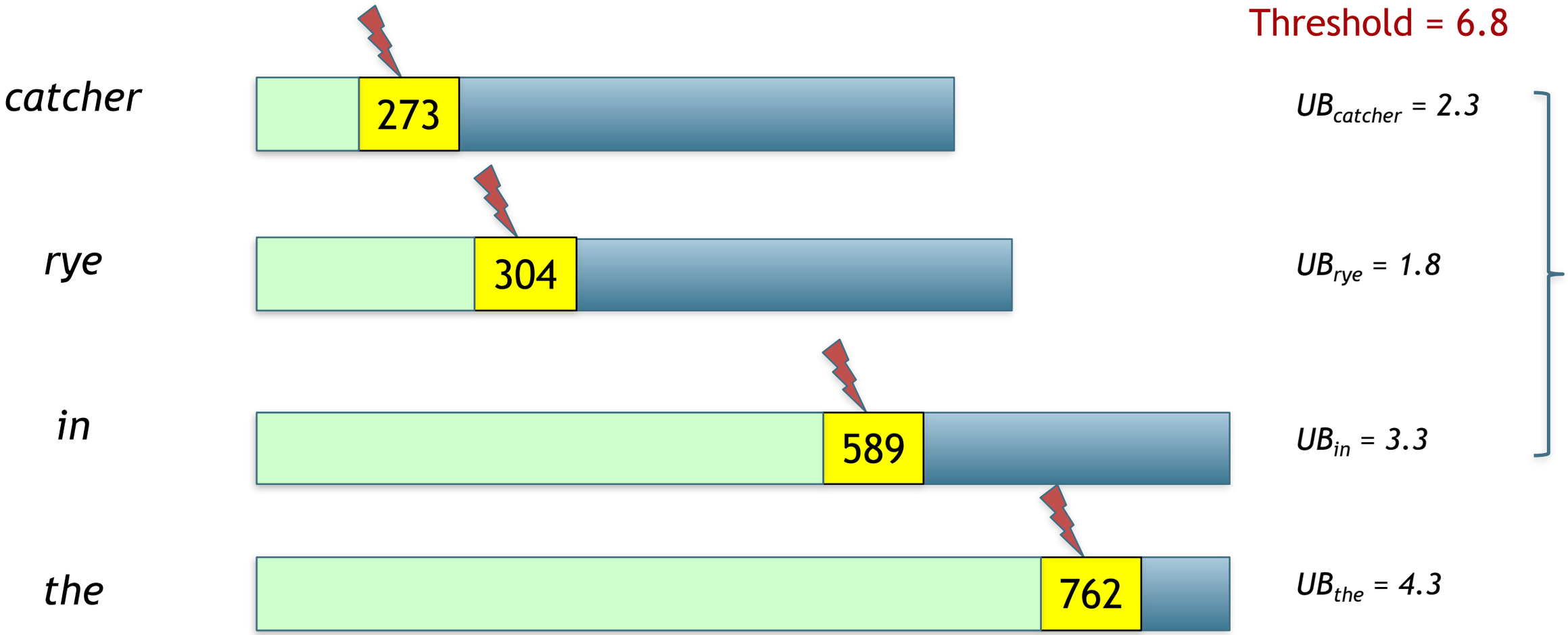

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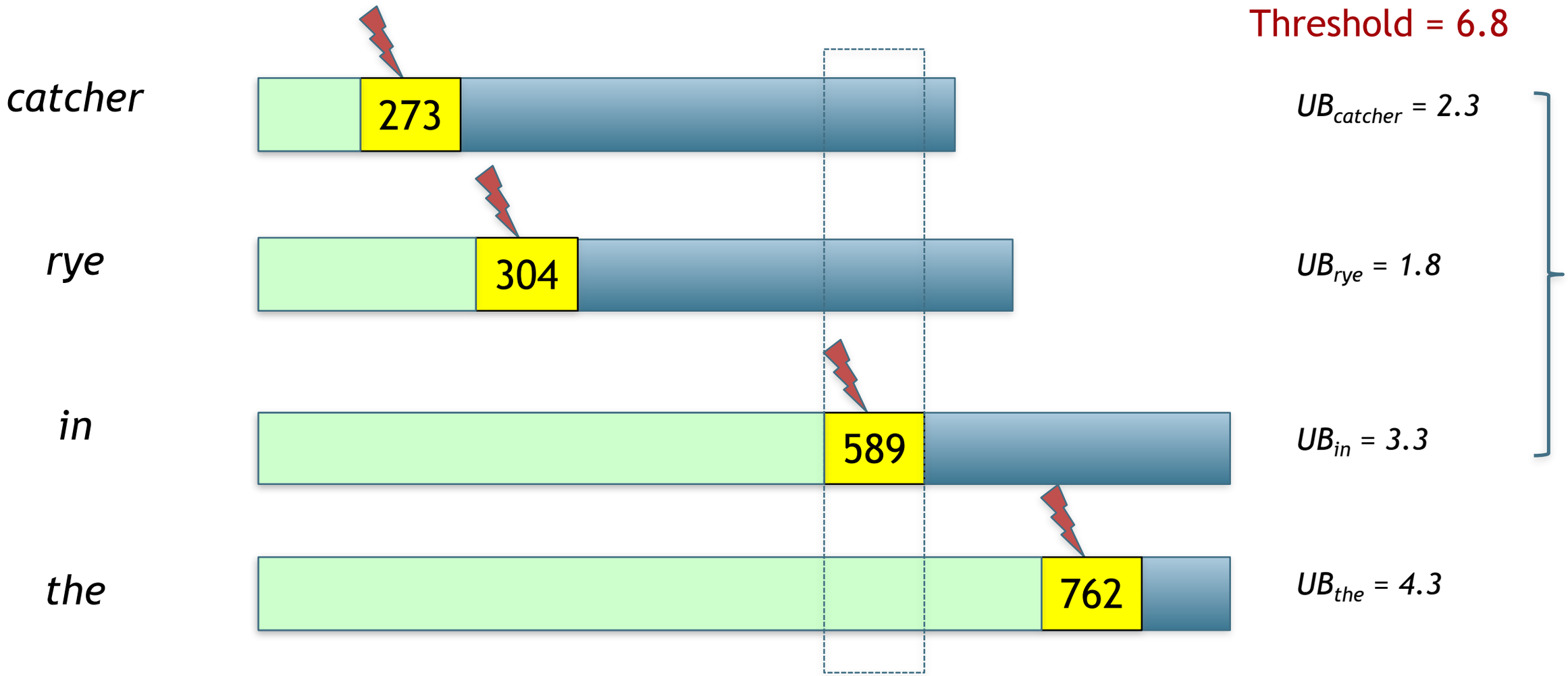
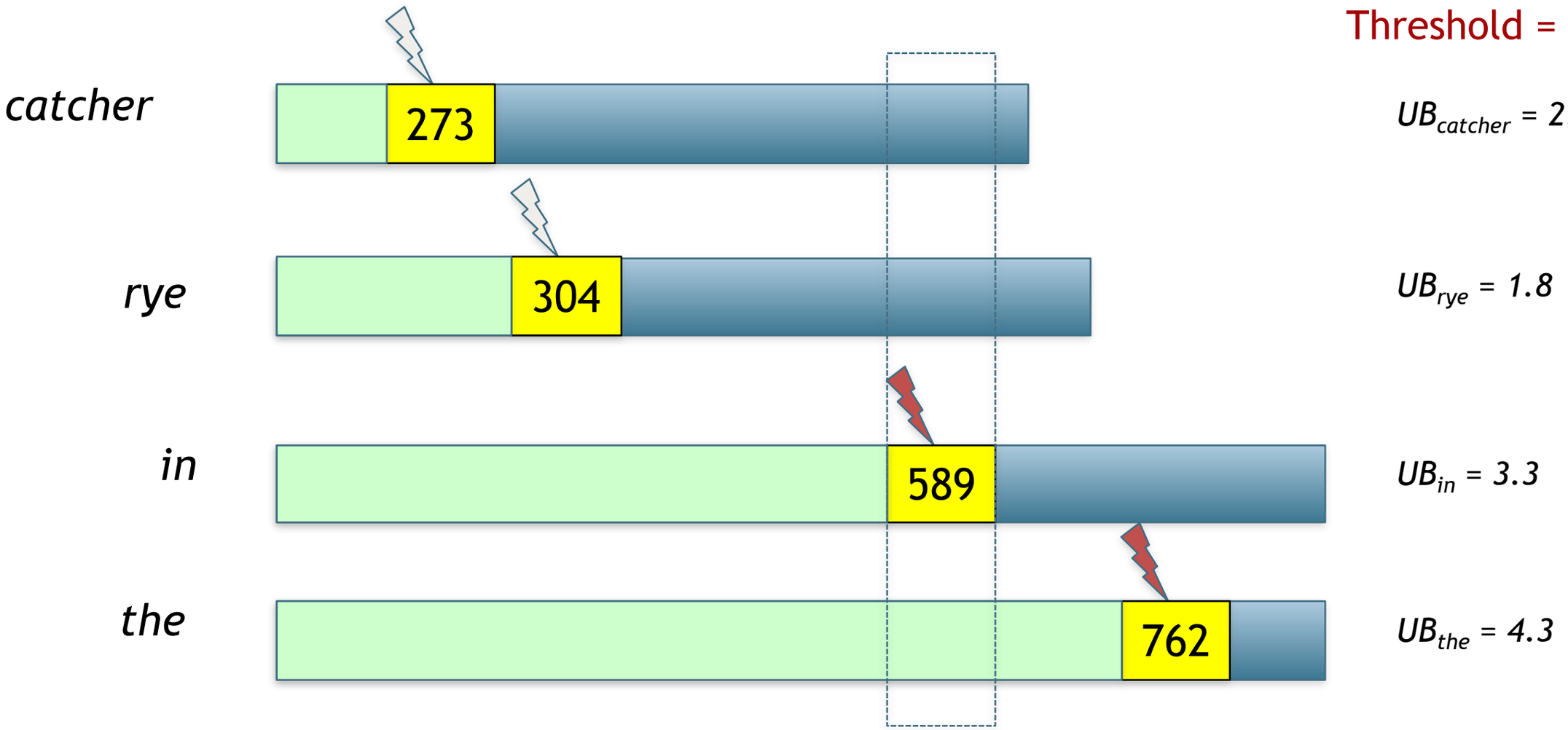


mWAND Algorithm

- Terms sorted in order of cursor positions
- Move cursor to 589 or right



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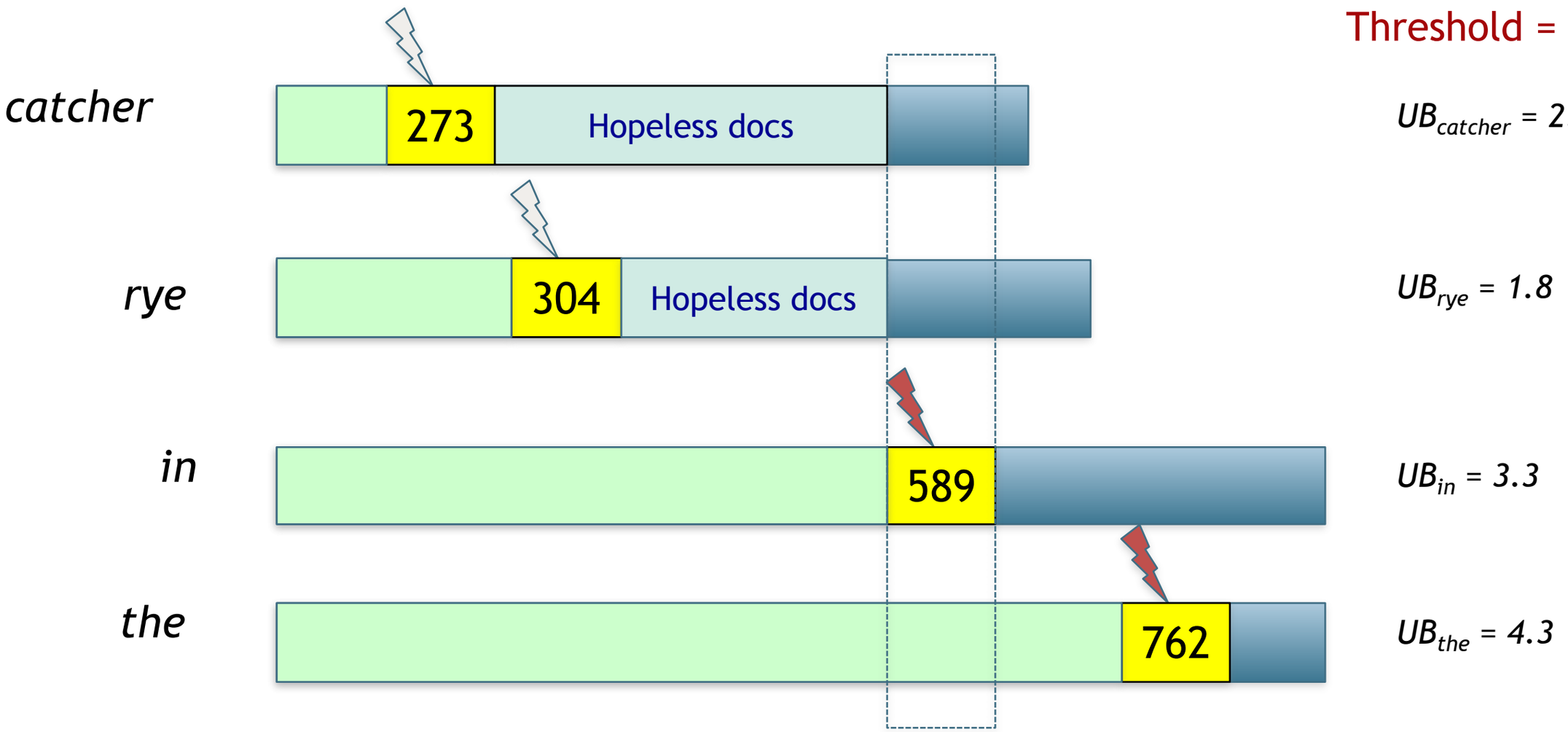

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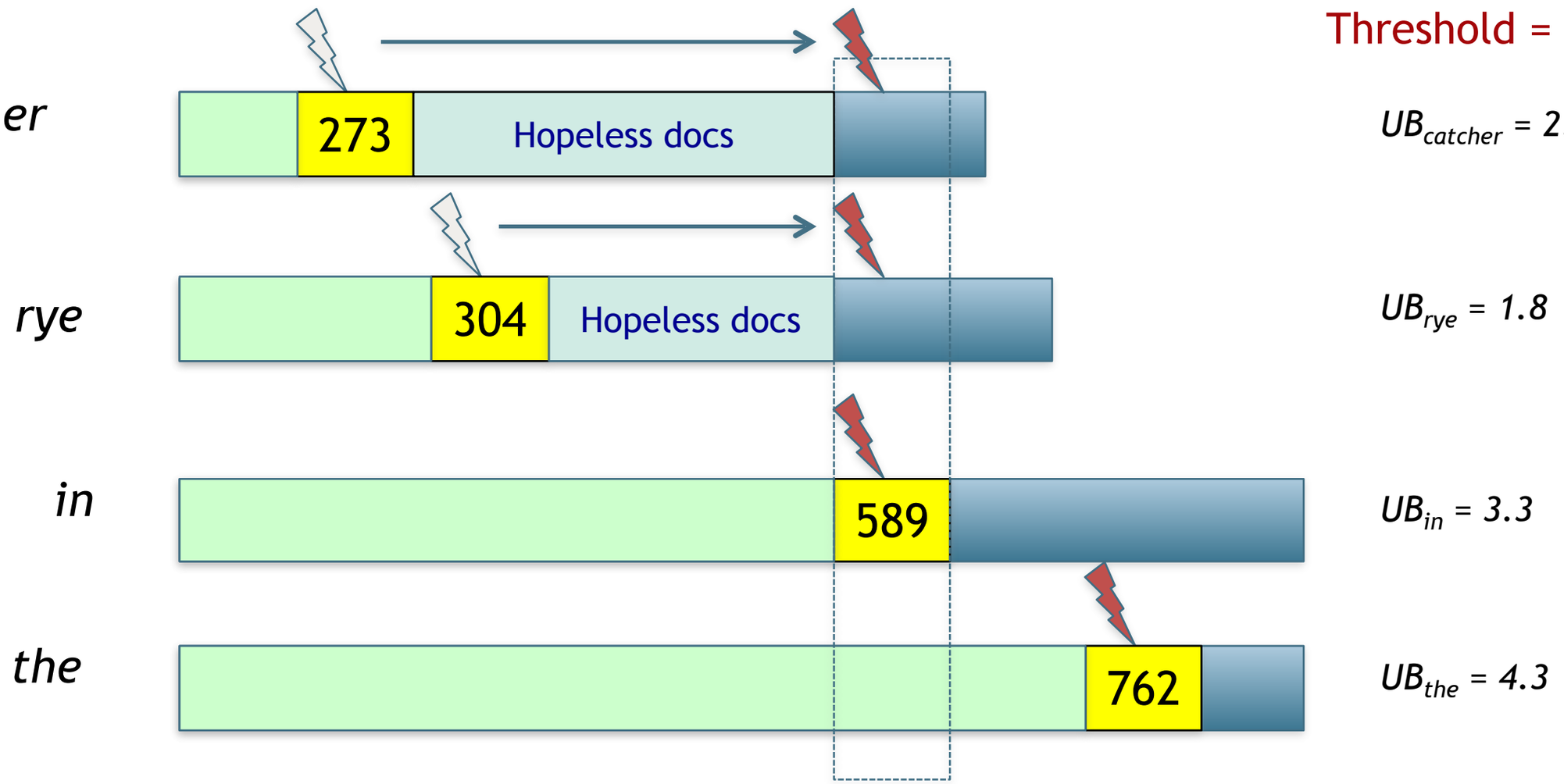

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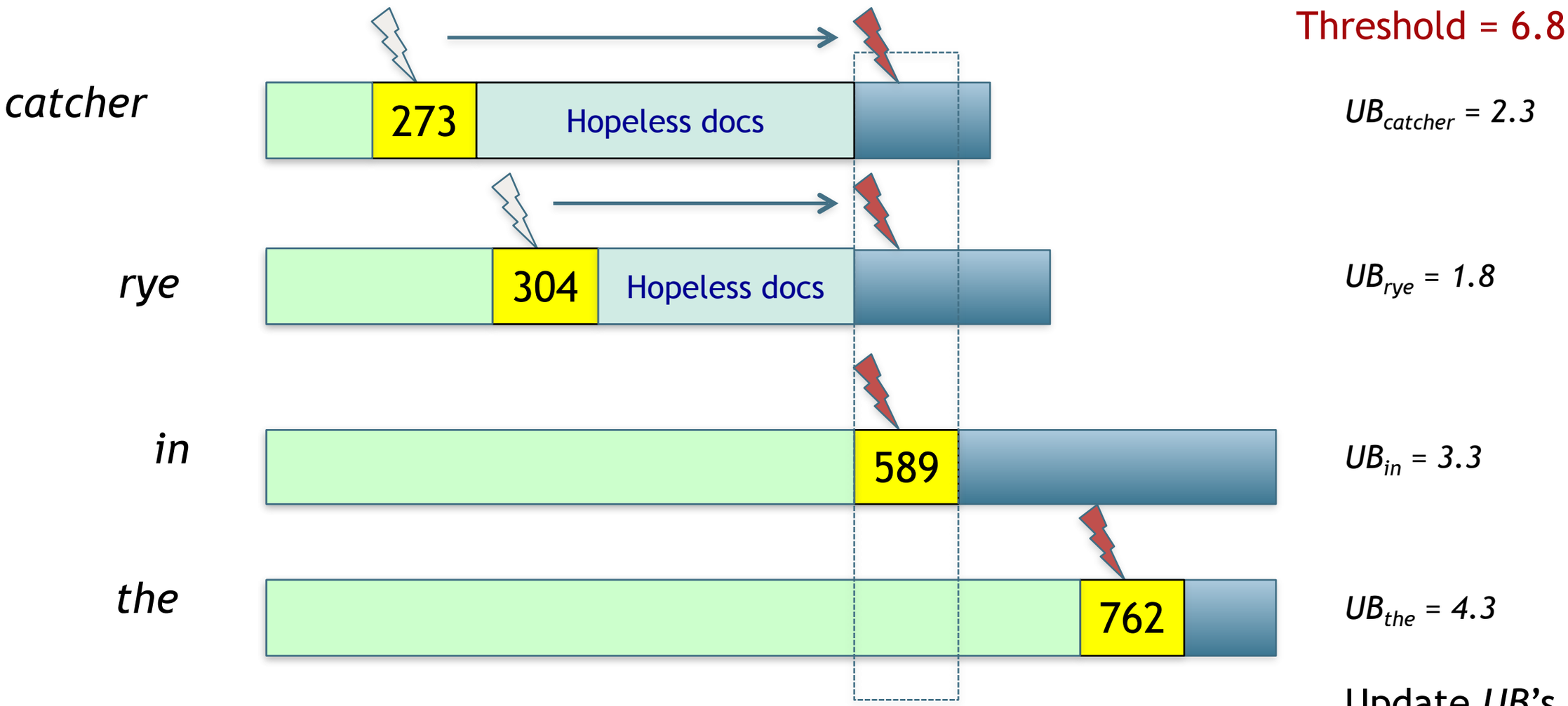
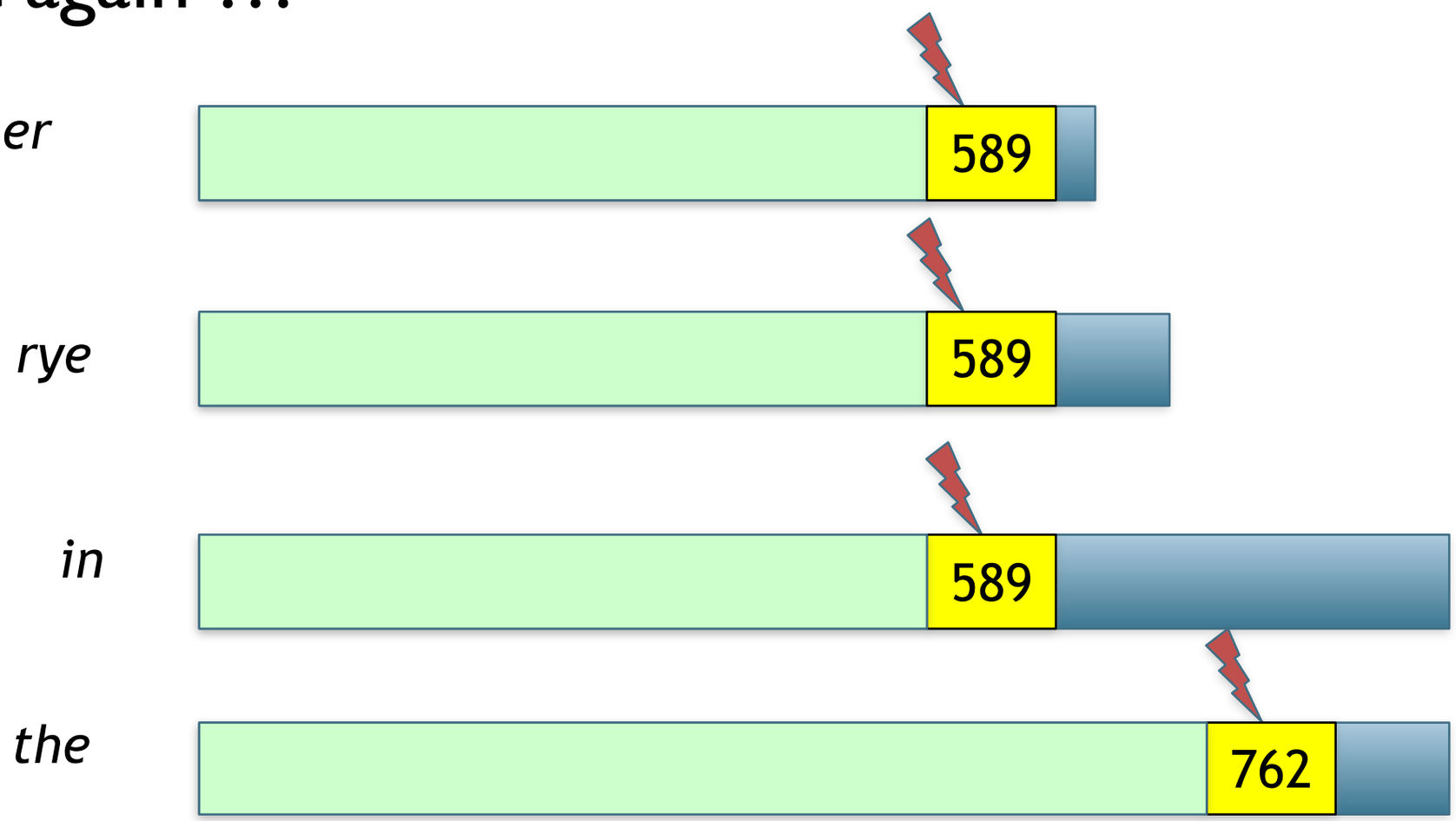


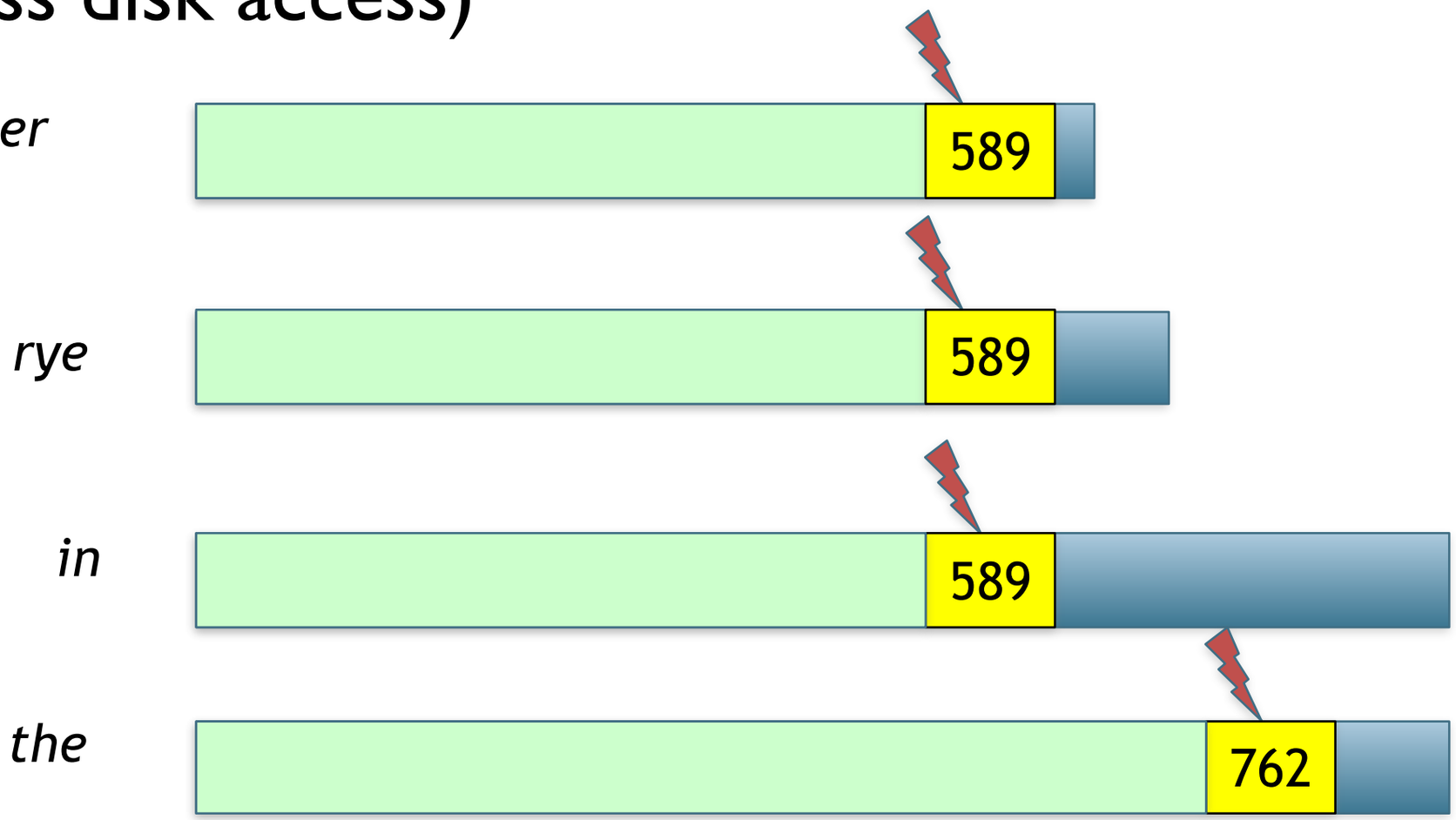
mWAND Algorithm

- If 589 is present in enough postings, compute its full cosine score – else some cursors to right of 589
- Pivot again …



WAND Algorithm

- Disk access typically more expensive
- Can you trade-off sorting and pivoting ?
  - Sorting cost (more CPU intensive) vs Pivoting cost (less disk access)



References and Further Readings

http://www.ir.uwaterloo.ca/book/

Broder et al. Efficient Query Evaluation using a Two-Level Retrieval Process.
http://www.cis.upenn.edu/~jstoy/cis650/papers/WAND.pdf

Fontoura, Marcus, et al. "Evaluation strategies for top-k queries over memory-resident inverted indexes." *Proceedings of the VLDB Endowment* 4.12 (2011): 1213-1224.

http://fontoura.org/papers/vldb2011.pdf