COMP90042 Web Search & Text Analysis

Workshop Week 3

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Road Map

Indexing

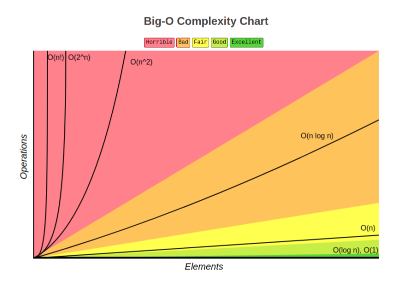
- Data Structure
  - Document-Term Matrix
  - Inverted Index
- Compression
  - Variable Byte Compression
  - OptPFor Delta Compression
- Index Construction
  - Invert Batch Indexing
  - Auxiliary Indexing
  - Logarithmic Indexing

Road Map

Search

- Vector Space Models
  - TF-IDF
  - BM25
- Efficient Query Processing
  - Operation GEQ
  - WAND
- Query Completion
  - Prefix Trie
  - Range Maximum Query
- Query Expansion
  - Relevance Feedback
  - Semantic-Based Methods
- Phrase Search
  - Inverted Index + Positional Information
  - Suffix Array
- Evaluation and Re-rank

Time Complexity



Big O cheat sheet

Notation

- $T(n) = O(f(n)) \Leftrightarrow \exists\, c, n_o, \forall\, n > n_o, T(n) \leq c \cdot O(f(n))$
- $T(n) = \Omega(f(n)) \Leftrightarrow \exists\, c, n_o, \forall\, n > n_o, T(n) \leq c \cdot \Omega(f(n))$
- $T(n) = \Theta(f(n)) \Leftrightarrow \exists\, c_1, c_2, n_o, \forall\, n > n_o,$
  $c_1 \cdot \Theta(f(n)) \leq T(n) \leq c_2 \cdot \Theta(f(n))$

Warm Up - Complexity

Space Complexity

- Amount of auxiliary space the algorithm need in the function of input size.

Example - Merge Sort

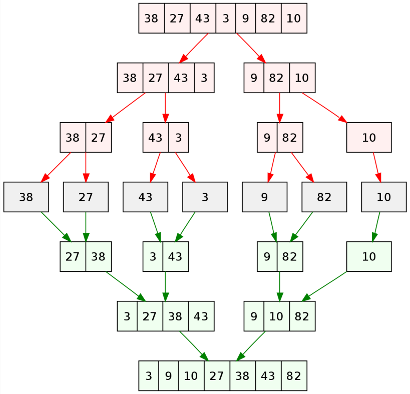


Fig from Wikipedia.

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Variable Byte Compression

$1 Byte = 8 bits$

Biggest integer can be stored in 64/32 bits.

- Max. 64-bits unsigned integer
  $2^{64} - 1 = 18,446,744,073,709,551,615$
- Max. 32-bits unsigned integer
  $2^{32} - 1 = 4,294,967,295$

In practice, 95% of integers in posting lists are < 128
(Can be stored in 7 bits).

Variable Byte Compression

Compression of integer 315700

- Divide the integer by 128 (2^7).
- Add "indicator bit" to the residual.
  1 indicates end of encoded number.

$315700 \Rightarrow 0010011|0100010|0110100$

Indicator	Remainder	Decimal
0	0110100	52
0	0100010	34
1	0010011	147

Decompression of integer 315700

- Multiply the remainder by $2^{7\times(i-1)}$ for the i^{th} chunk.
- Take sum of all chunks.

$52 \times 2^0 + 34 \times 2^7 + (147 - 128) \times 2^{14} = 315700$

OptPFor Delta Compression

More flexible chunk size b than VByte compression

- Encode most numbers in a block by b bits
- Leave exception unchanged.
- Record number and positions of exceptions in header.

Encode [1 4 7 2 4 5 123 48] with $b = 3$

Header	Content	Exceptions
b=3, #e=2, epos=[6, 7]	[1, 4, 7, 2, 4, 5]	[123, 48]

Parameter b need to be tuned to get optimal performance.

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Static Construction

Traverse once to get global vocabulary.
{1:Apple, 2:Pear, 3:Banana, 4:Grape}

Split document collection in to batches and compute inverted indexes in parallel, then merge terms with same ID.

$$
\begin{array}{ll} \text{Apple} & \rightarrow d_1, d_2 \\ \text{Pear} & \rightarrow d_2 \\ \text{Banana} & \rightarrow d_1 \end{array}
\quad + \quad
\begin{array}{ll} \text{Apple} & \rightarrow d_3 \\ \text{Pear} & \rightarrow d_3, d_4 \\ \text{Grape} & \rightarrow d_4 \end{array}
$$

$$\Downarrow$$

$$
\begin{array}{ll} \text{Apple} & \rightarrow d_1, d_2, d_3 \\ \text{Pear} & \rightarrow d_2, d_3, d_4 \\ \text{Banana} & \rightarrow d_1 \\ \text{Grape} & \rightarrow d_4 \end{array}
$$

Auxiliary Indexing

Combination of static and incremental indexing

- 1 static index on disk, 1 incremental index on memory.
- Merge when incremental index is too big.
- Query both indexes and merge results

Note that merge requires number of IOs equals to the size of the posting lists

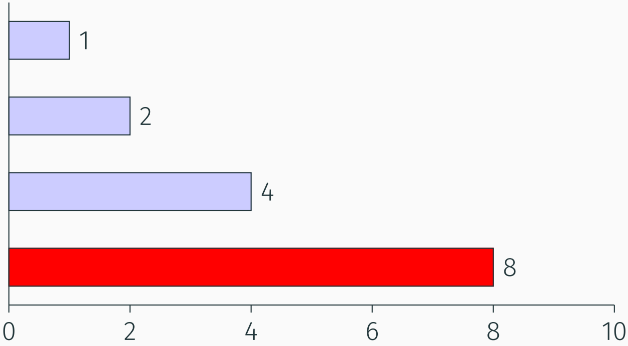
Suppose now we have N postings on disk and we merged the postings when it reaches size n.

$$T(N, n) = \sum_{i=1}^{\frac{N}{n}} i \times n = \frac{(1 + \frac{N}{n})}{2} n \times \frac{N}{n} = \frac{N}{2} + \frac{N^2}{2n} (n < N)$$

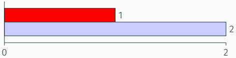
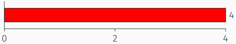
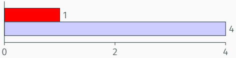
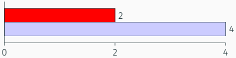
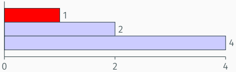
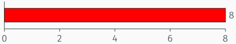
$$T(N, n) = O(\frac{N^2}{n})$$

Logarithmic Indexing

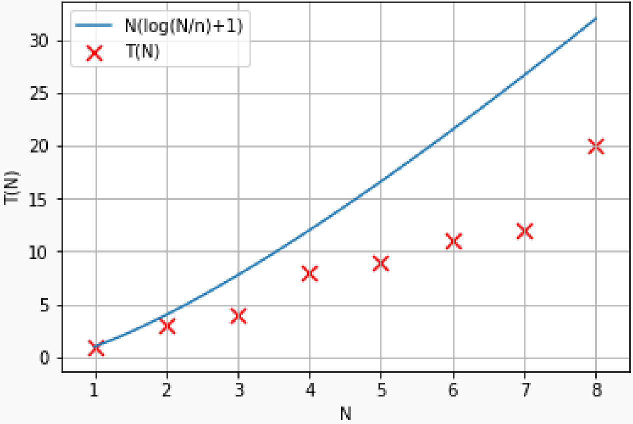
Use $log(N/n)$ indexes, each level i has size $2^i \times n$.



Consider total number of merges needed when $N = 8n$.

N	Index	Cost	$N(log(N/n)+1)$
n		n	n
$2n$		$n + 2n$	$2n \times (log2 + 1)$
$3n$		$3n + n$	$3n \times (log3 + 1)$
$4n$		$4n + 4n$	$4n \times (log4 + 1)$
$5n$		$8n + n$	$5n \times (log5 + 1)$
$6n$		$9n + 2n$	$6n \times (log6 + 1)$
$7n$		$11n + n$	$7n \times (log7 + 1)$
$8n$		$12n + 8n$	$8n \times (log8 + 1)$

Logarithmic Indexing



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Operation GEQ

GEQ - Greater or equal to x.

$$2, 4, 7, 9, 13, 20, 34, 54, 67, 87, 96, 103$$

Binary search in sorted list.

- Time complexity ?
- Space complexity ?

Compressed posting lists with sample value

[2, 4, 7, 9]	[13, 20, 34, 54]	[67, 87, 96, 103]
max=9	max=54	max=103

Recap - BM25

$$W_{d,t} = \frac{(k_1 + 1)tf_{d,t}}{k_1((1-b) + b(\frac{L}{L_{avg}})) + tf_{d,t}} \times \log \frac{N - df_t + 0.5}{df_t + 0.5} \times \frac{(k_3 + 1)tf_{Q,t}}{k_3 + tf_{Q,t}}$$

$$Score(Q, d) = \sum_{q \in Q} W_{d,q}$$

Question: $T(Score(Q, d))$?

WAND

Concepts

- Top-k retrieval
- Maximum Contribution

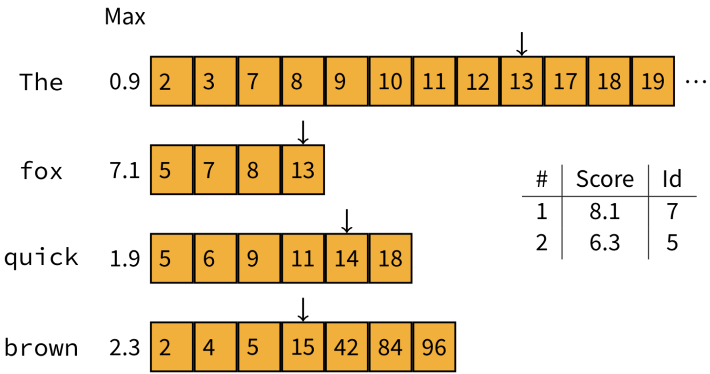
Questions

- Why do we want to sort lists by their current pivot?
- Why do we still need to compute similarity score if Max. contribution of a doc is greater than Min. score in top-k list?
- How does operation GEQ helps WAND?

Benefits and Restrictions

Exercise - What does the WAND do?

Query Q: `The quick brown fox` with $k = 2$



#	Score	Id
1	8.1	7
2	6.3	5