CS 589 Fall 2020

Information retrieval infrastructure

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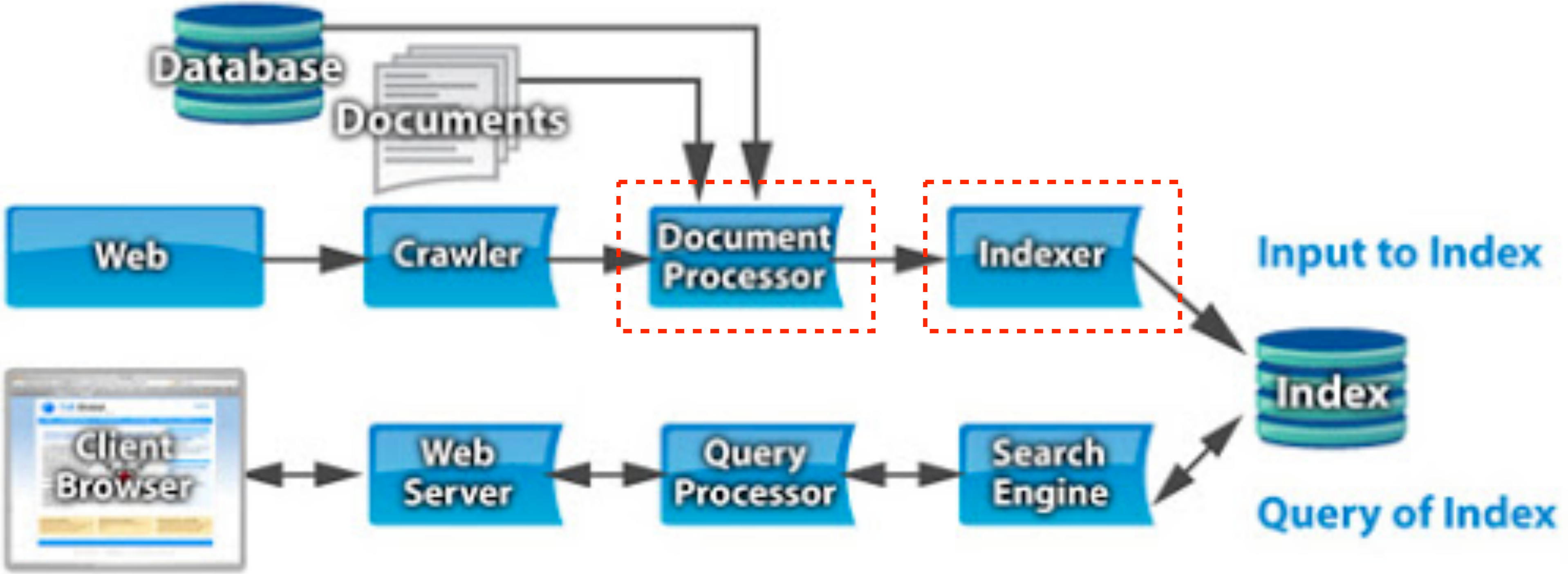
Stevens Institute of Technology

Information Retrieval Infrastructure

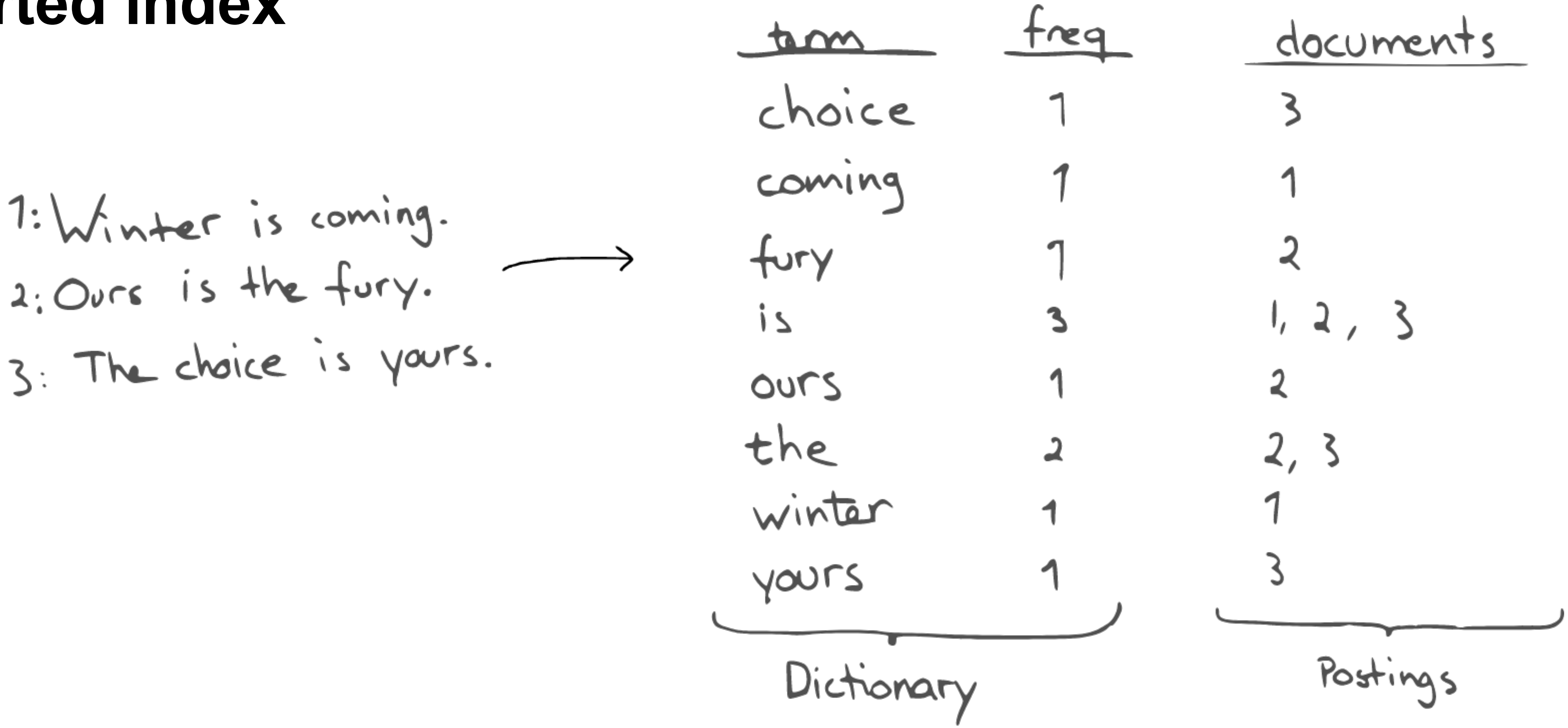


Inverted index

- In Lecture 2, we learned retrieval models
    - Compute score(q, d)
    - Select the d that maximizes score(q, d)

- In an industry scale search engine, there could be trillions of q’s and billions of d’s
    - For each query, search time complexity = O(|D|)
    - Solution for faster retrieval: inverted index

Inverted index



1: Winter is coming.

2: Ours is the fury.

3: The choice is yours.

term	freq	documents
choice	1	3
coming	1	1
fury	1	2
is	3	1, 2, 3
ours	1	2
the	2	2, 3
winter	1	1
yours	1	3

time complexity: O(#unique words in q x avg_len(postings lists))

$$\ll |D|$$

Problems with inverted indexing

- Data processing
  - Choosing the unit for indexing
  - Determining the vocabulary
- Constructing/speeding up inverted index
  - Skipping index
  - Prefix indexing
  - Indexing with blocks
  - MapReduce
- Index compression
- Other issues
  - Indexing position
  - Spelling correction

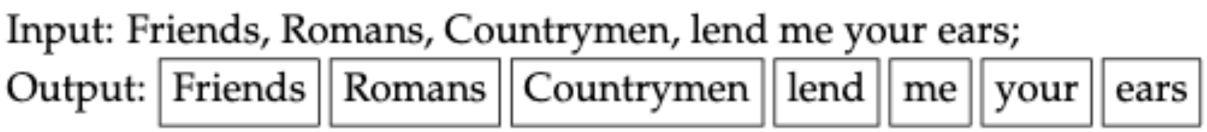
Choosing the correct unit for indexing

- Documents often consists of sub documents
  - e.g., email contains multiple attached documents

- Trade-off on the unit size
  - Smaller units: missing important passages
  - Larger unit: gets spurious matches, e.g., ….**text** messages….gold **mining**…

Determining the vocabulary

- Tokenization

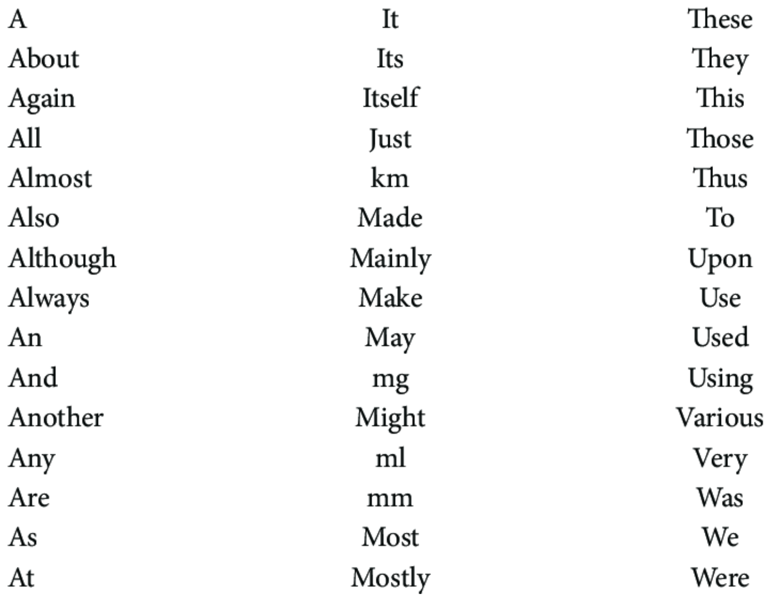


Input: Friends, Romans, Countrymen, lend me your ears;

Output: Friends | Romans | Countrymen | lend | me | your | ears

  - o’neil, aren’t, C#

- Dropping stop words
  - Stop words are common terms
  - **Web search engines generally do not use stop words!**



A
About
Again
All
Almost
Also
Although
Always
An
And
Another
Any
Are
As
At

It
Its
Itself
Just
km
Made
Mainly
Make
May
mg
Might
ml
mm
Most
Mostly

These
They
This
Those
Thus
To
Upon
Use
Used
Using
Various
Very
Was
We
Were

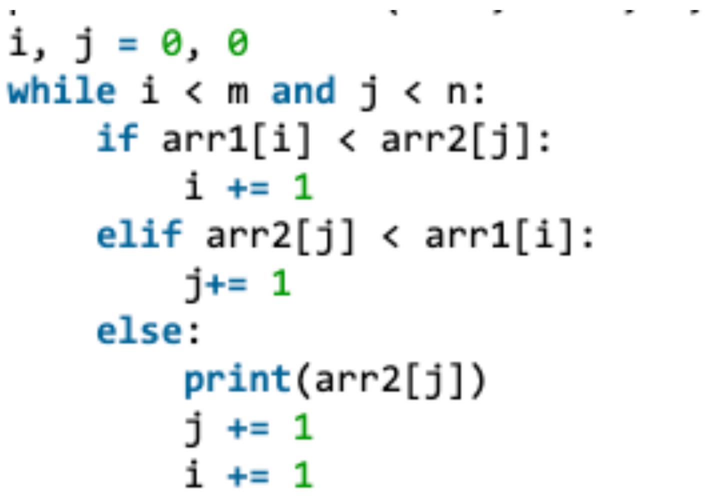
Determining the vocabulary

- Normalization
  - Abbrev: USA vs. United states of America
  - Case:
    - Cat -> cat
    - **SAT** -> **sat**

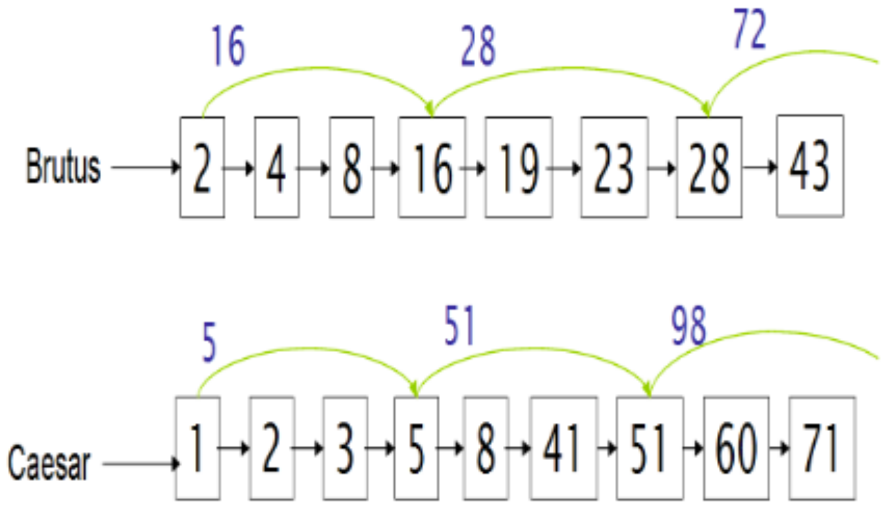
- Stemming/lemmatization
  - singing -> sing, cars -> car, **sat -> sit**
  - porter stemmer, snowball stemmer

Speeding up: skipping lists

- Finding the intersection of two post listings
  - Without skip: O(m + n)

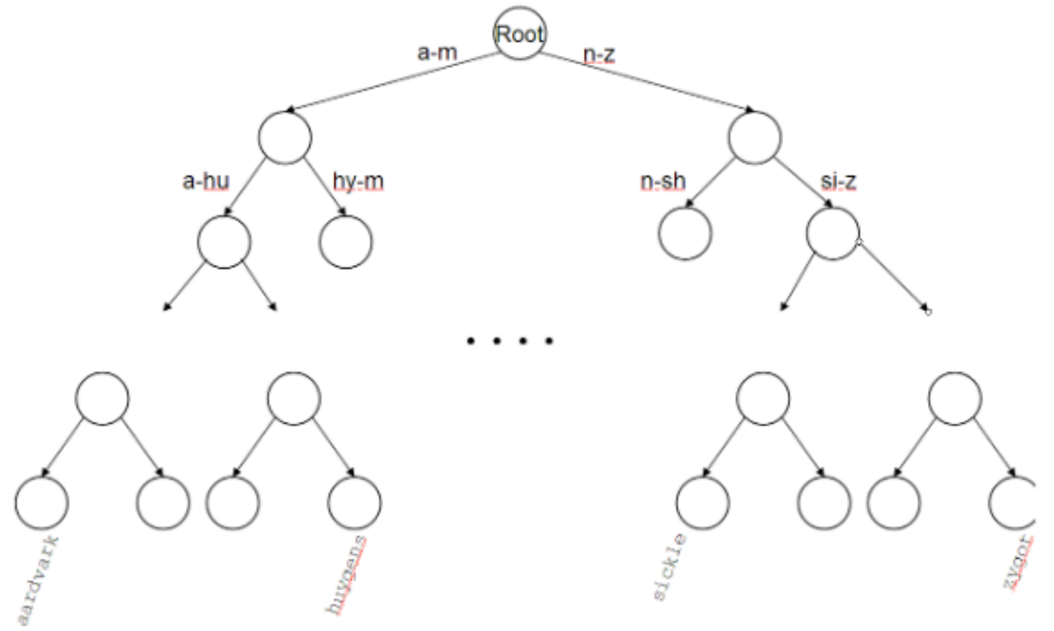


```
i, j = 0, 0
while i < m and j < n:
    if arr1[i] < arr2[j]:
        i += 1
    elif arr2[j] < arr1[i]:
        j+= 1
    else:
        print(arr2[j])
        j += 1
        i += 1
```



Speeding up: prefix indexing

- Speeding up the indexing using prefix tree
  - time complexity: O(**#unique words in q** x avg_len(postings lists))



Constructing inverted index: hardware basics

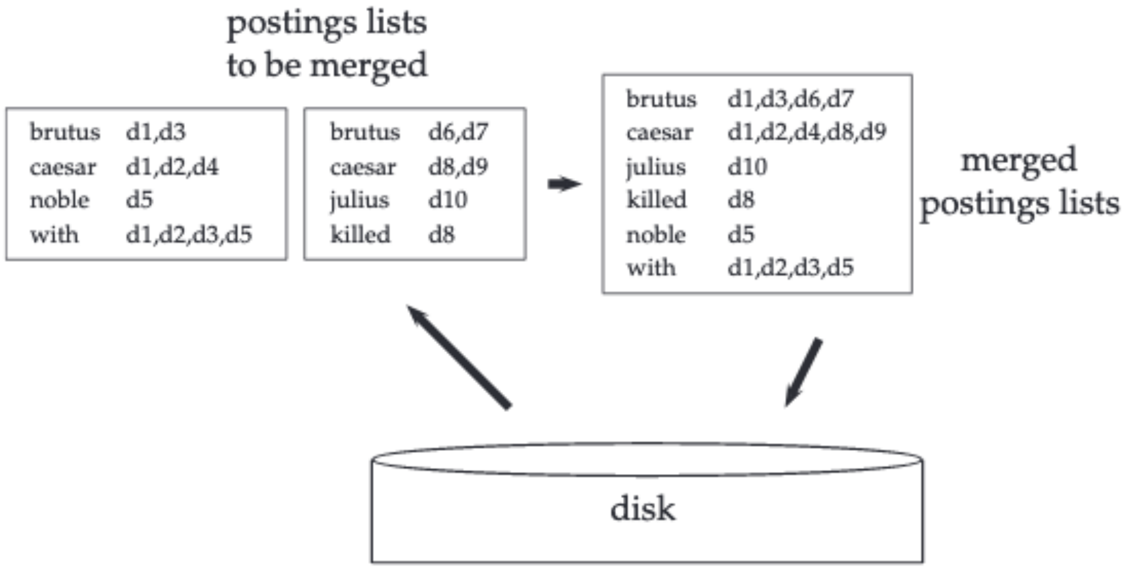
- Decisions on an IR system largely depends on the hardware which the system runs on

- **Chunks**:
  - Splitting data into more chunks takes more *seek time*

- **Blocks**
  - *Accessing data in memory >> accessing data on disk*
  - *Constructing* inverted index using blocks
  - Typical IR system: GBs of memory, disk space orders of magnitude larger

Block sort-based indexing

- Indexing large corpus
  - Reuters-RCV1: 2.5GB = 2.5 x 10^9Bytes, 1 billion
  - Today's text corpus contains petabytes of data: 10^15Bytes
  - Memory << size of corpus



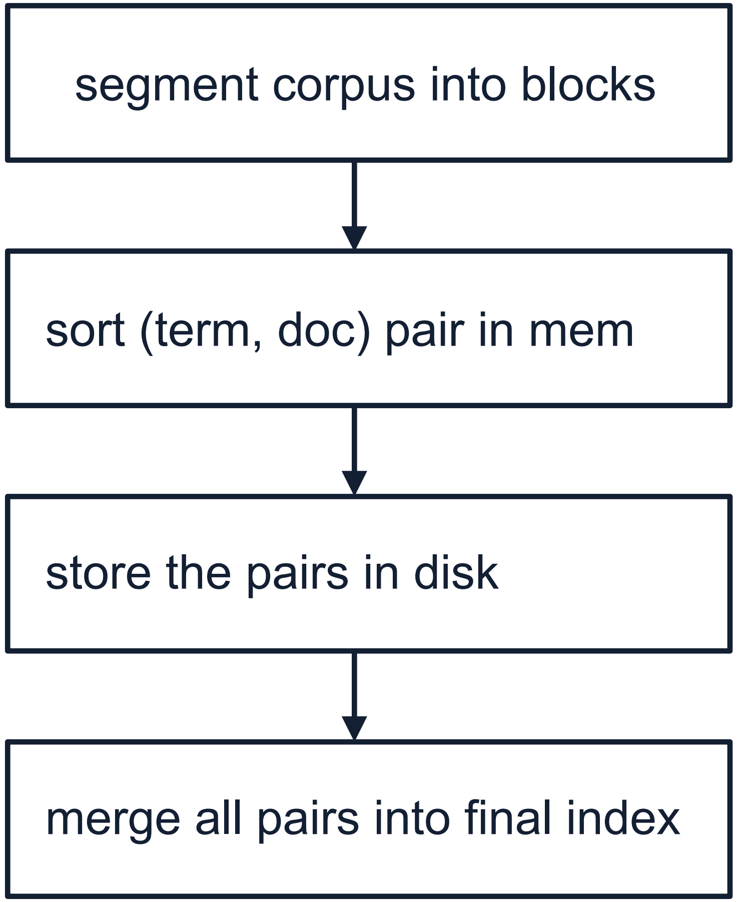
brutus	d1,d3
caesar	d1,d2,d4
noble	d5
with	d1,d2,d3,d5

brutus	d6,d7
caesar	d8,d9
julius	d10
killed	d8

brutus	d1,d3,d6,d7
caesar	d1,d2,d4,d8,d9
julius	d10
killed	d8
noble	d5
with	d1,d2,d3,d5

- Index each block using memory
- Write each blocks' index into disk
- Merge all inverted indices

Block sort-based indexing

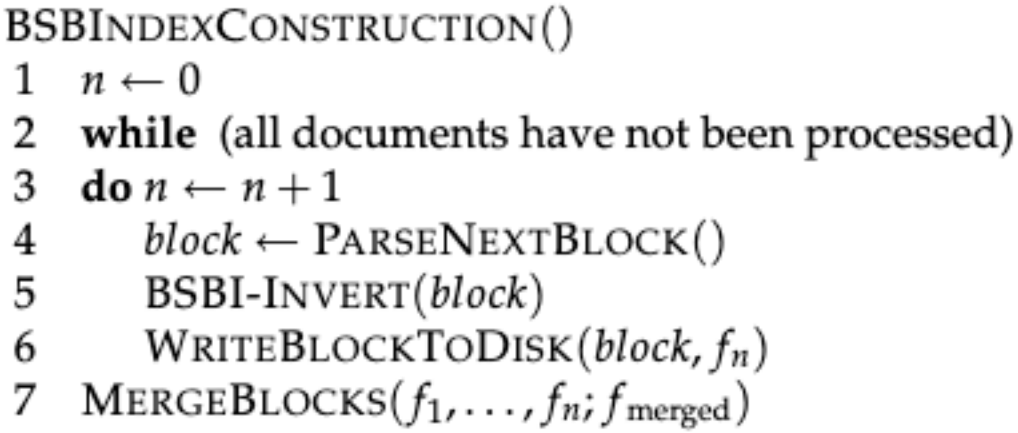


segment corpus into blocks

sort (term, doc) pair in mem

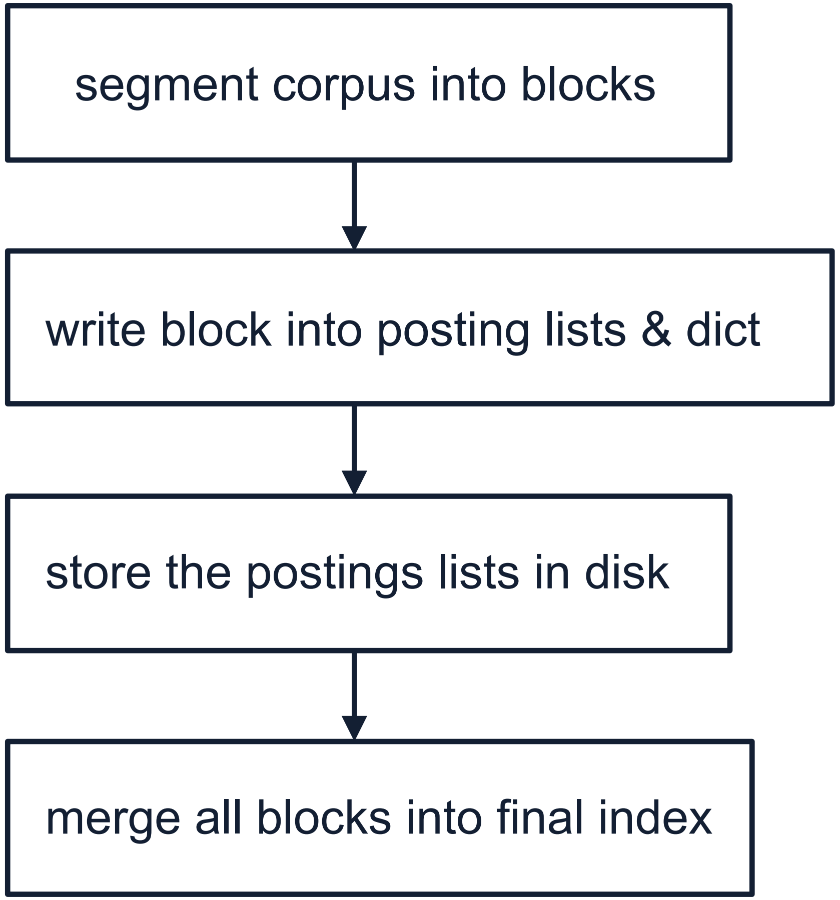
store the pairs in disk

merge all pairs into final index



```
BSBIndexConstruction()
$n \leftarrow 0$
while (all documents have not been processed)
do $n \leftarrow n + 1$
    $block \leftarrow$ ParseNextBlock()
    BSBI-Invert($block$)
    WriteBlockToDisk($block, f_n$)
MergeBlocks($f_1, \ldots, f_n; f_{\text{merged}}$)
```

Single-pass in-memory indexing



segment corpus into blocks

write block into posting lists & dict

store the postings lists in disk

merge all blocks into final index

- Handling posting lists directly
- Eliminating the expensive sorting in BSBI
- Leveraging compression

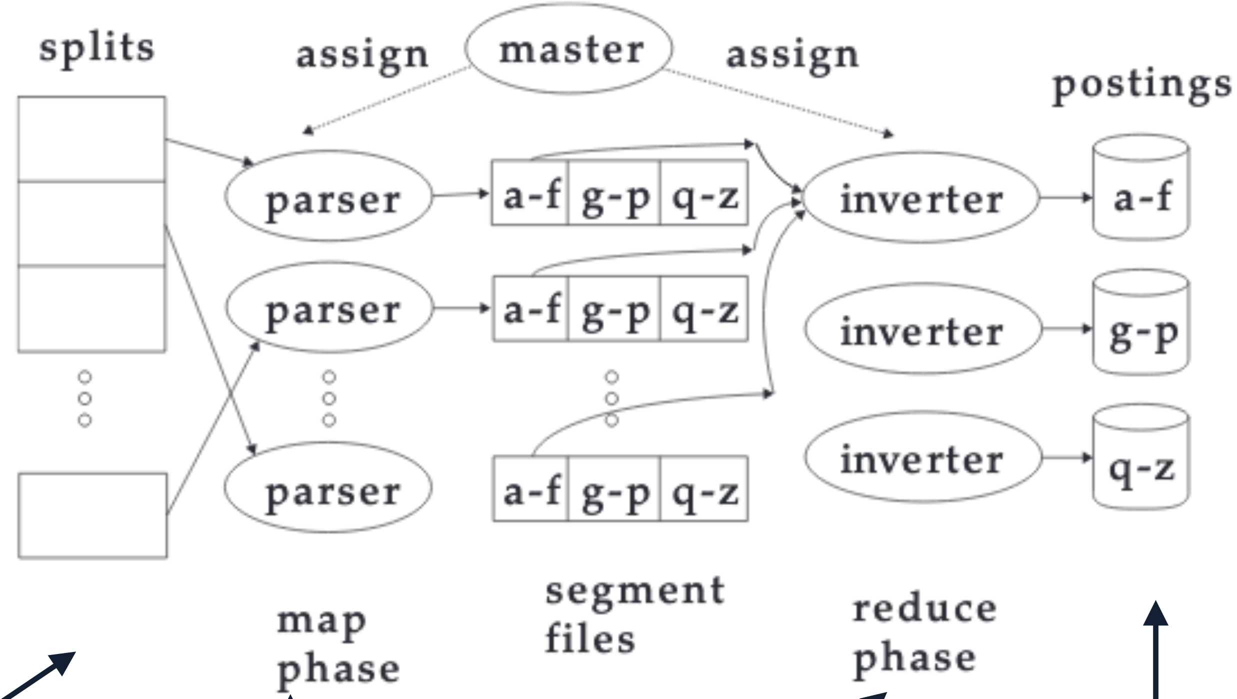
Handling web scale indexing

- Web-scale indexing must use clusters of servers
  - Google had 1 million servers in 2011

- Fault tolerance of a massive data center
  - If a non-fault tolerance system has 1000 nodes, each has 99.9% uptime, then 63% of the time one or more servers is down

- Solution
  - Maintain a “master” server
  - Break indexing into parallel tasks
  - Assign each task to an idle machine

Map-reduce



master assigns split
to idle machine

parser emits
(term,doc) pair

merge partitions
in inverter

complete the
index

Examples of map-reduce

map: d_2 : C died. d_1 : C came, C c'ed.

$\longrightarrow$

(⟨C, d_2⟩, ⟨died,d_2⟩, ⟨C,d_1⟩, ⟨came,d_1⟩, ⟨C,d_1⟩, ⟨c'ed,d_1⟩)

reduce: (⟨C,(d_2,d_1,d_1)⟩,⟨died,(d_2)⟩,⟨came,(d_1)⟩,⟨c'ed,(d_1)⟩)

$\longrightarrow$

(⟨C,(d_1:2,d_2:1)⟩,⟨died,(d_2:1)⟩, ⟨came,(d_1:1)⟩, ⟨c'ed,(d_1:1)⟩)

MapReduce: Industry practice

- Term partition vs. document partition
  - Term-partitioned: one machine handles a subrange of terms
  - Document-partitioned: one machine handles a subrange of documents

- Most industry search engine use document-partitioned index
  - Better load balancing (**why?**)

MapReduce: Simplified Data Processing on Large Clusters

Jeffrey Dean and Sanjay Ghemawat

jeff@google.com, sanjay@google.com

Google, Inc.

Dynamic indexing

- Document collection are updated all the time

- How to handle dynamic indexing?
  - Maintain one-big index
  - New document goes to auxiliary “smaller” index
  - Search across both, merge results
  - Periodically merge the two indices
  - Deletion: maintain bitvectors of deleted documents

Real time search of Twitter

- Requires high real time search
  - Low latency, high throughput query evaluation
  - High ingestion rate and immediate data availability
  - Concurrent reads and writes of the index

- Solution: using segments
  - Each segment consists of 2^32 tweets (in memory)
  - New posts are appended to the posting lists
  - Only one segment can be written to at each time

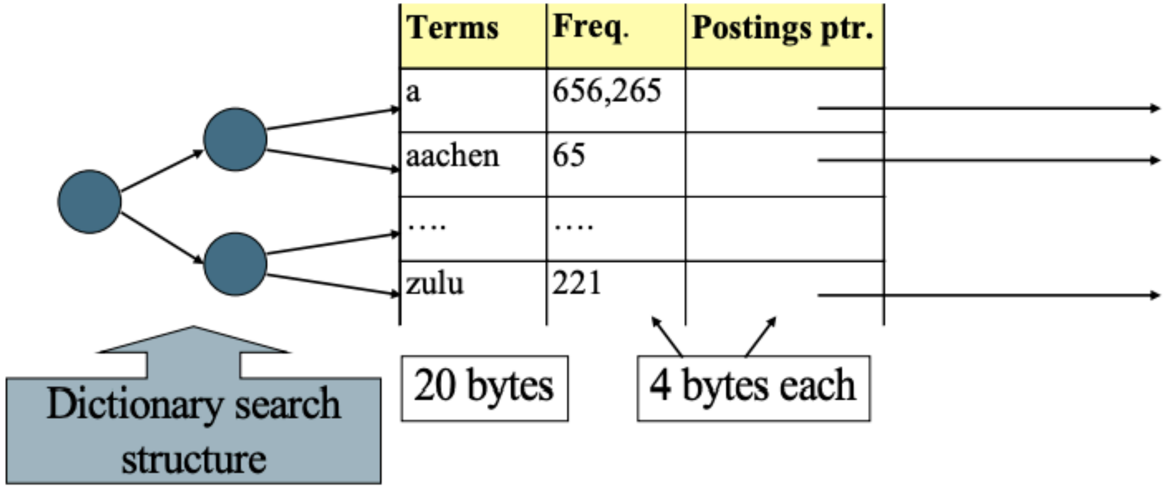
Index compression

- Why compression?
  - Using less disk space
  - Compressing dictionary
    - Allowing the dictionary to be stored in memory
  - Compressing posting files
    - Reducing disk space

- Zipf’s law
  - The ith most frequent term has frequency proportional to 1/i

Dictionary compression

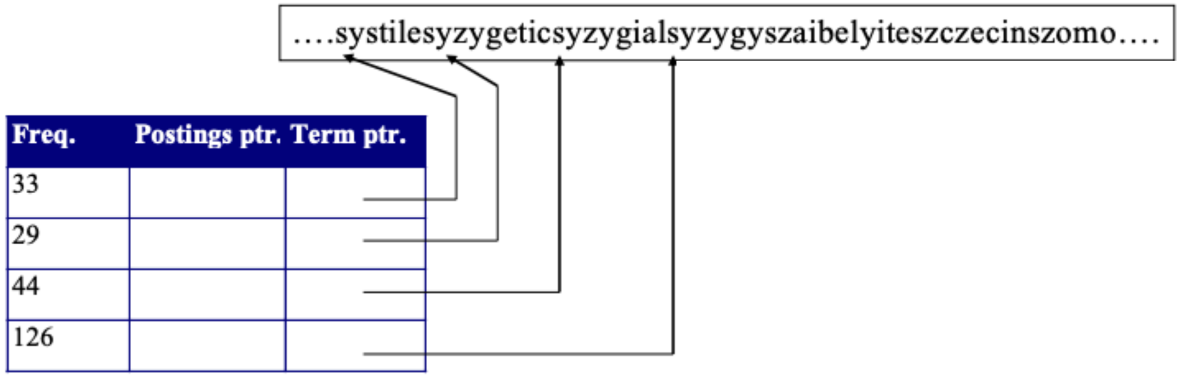
- Most of the space in the table is wasted
  - Most words are no 20 bytes
  - Table storage = 28N



Terms	Freq.	Postings ptr.
a	656,265	
aachen	65	
….	….	
zulu	221	

Dictionary-as-a-string

- Table storage = 11N
- How to further improve the storage space?
  - Instead of storing absolute term pointers, store the gaps



….systilesyzygeticsyzygialsyzygyszaibelyiteszczecinszomo….

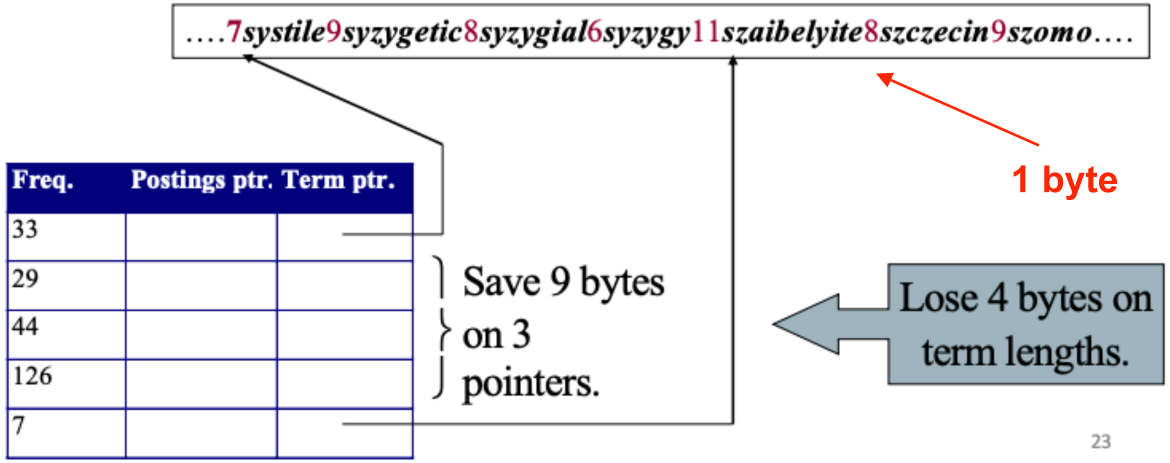
Freq.	Postings ptr.	Term ptr.
33		
29		
44		
126		

4 bytes 4 bytes 3 bytes

Dictionary-as-a-string

- Table storage = 8N + 3N * (7/12) = 9.75N < 11N

- Trade-off between skipping more vs. skipping less



....7systile9syzygetic8syzygial6syzygy11szaibelyite8szczecin9szomo....

Freq.	Postings ptr.	Term ptr.
33		
29		
44		
126		
7		

Save 9 bytes on 3 pointers.

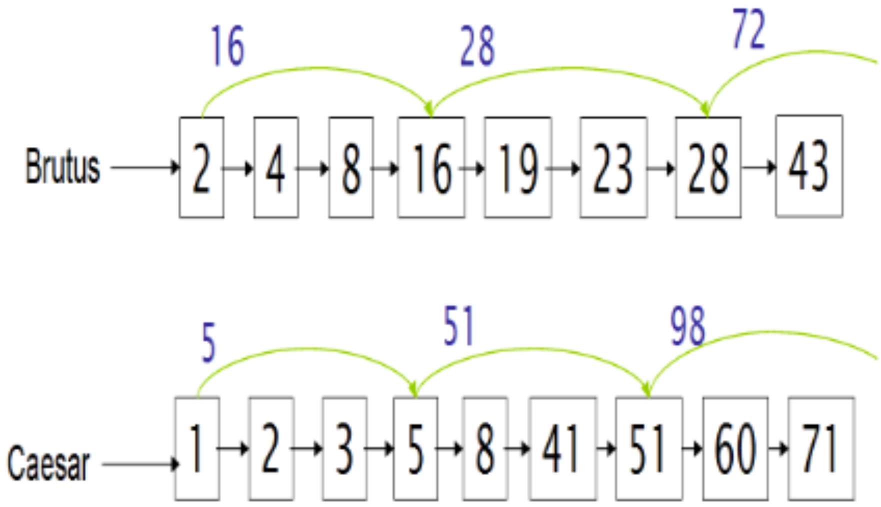
Lose 4 bytes on term lengths.

1 byte

4 bytes 4 bytes 3 bytes

Postings compression

- Observations of posting files
  - Instead of storing docID, store gaps
  - Brutus: 2,4,8,3,4,5,15
  - Binary seq: 10,100,1000,11,100,101,1

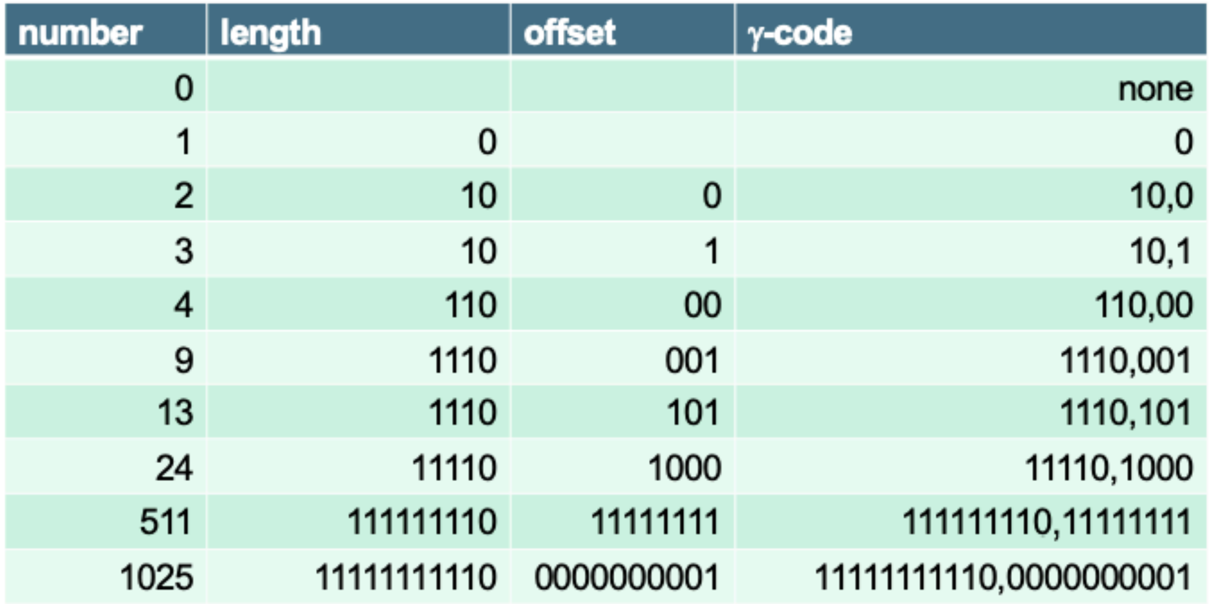


- Prefix encoding
  - Binary encoding such that the sequence can be uniquely decoded
  - e.g., Huffman encoding
  - Unary encoding: {2:110,4:11110, …}
  - A uniquely decodable seq: 1101111011111111101110…

Postings compression

- Problem with unary encoding
  - Too long!

- Gamma code of 13: 1110,101
  - Length: 1110
  - Offset: 13 → 1101 → 101



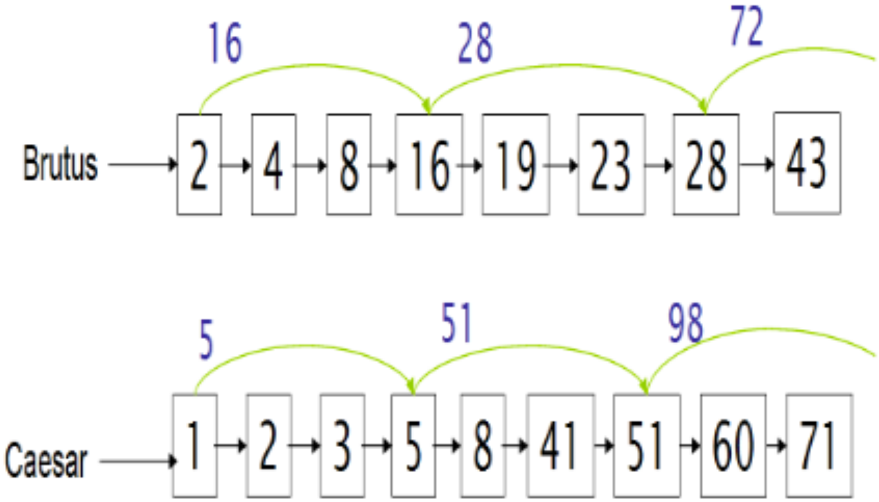
number	length	offset	γ-code
0			none
1	0		0
2	10	0	10,0
3	10	1	10,1
4	110	00	110,00
9	1110	001	1110,001
13	1110	101	1110,101
24	11110	1000	11110,1000
511	111111110	11111111	111111110,11111111
1025	11111111110	0000000001	11111111110,0000000001

- We can prove gamma code is uniquely decodable

- Gamma code compression rate: 11.7%

Indexing Position

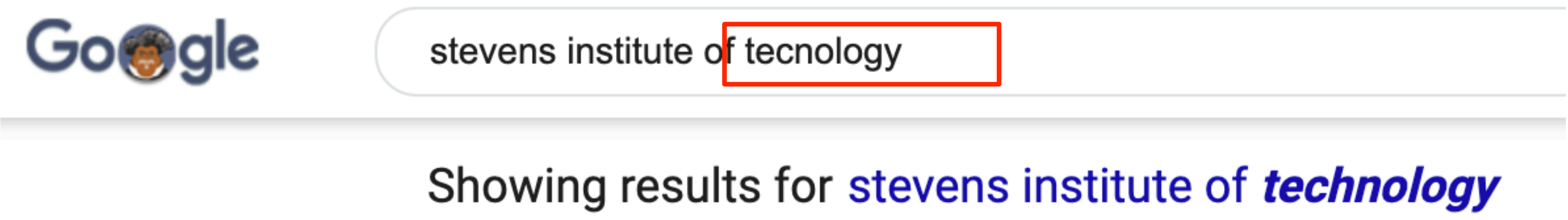
- Indexing the position of word within the document
- Intersection algorithm finds where the two terms appear between within *k* words



Brutus: 2:<0>, 4: <429,433>, 8: <150>, …

Ceasar: 1:<10>, 2: <29>, 8: <17, 250>, …

Spelling correction



stevens institute of tecnology

Showing results for stevens institute of ***technology***

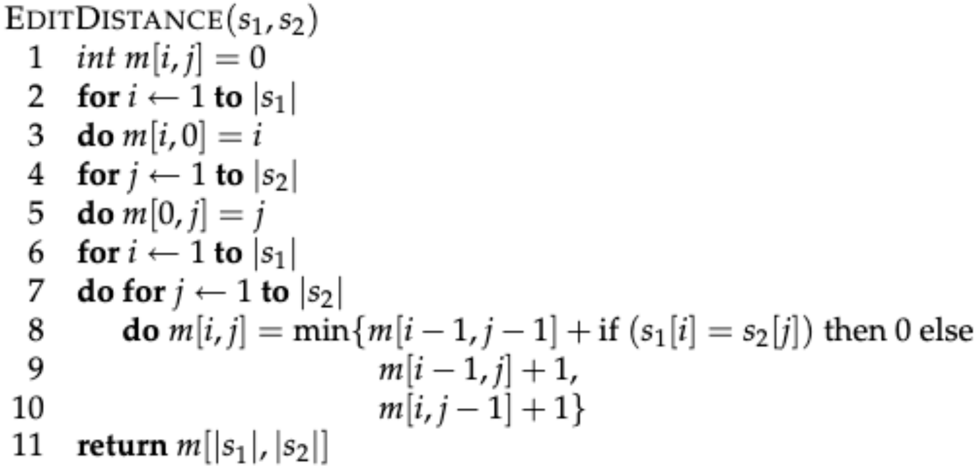
- Edit distance

- k-gram index for spelling correction

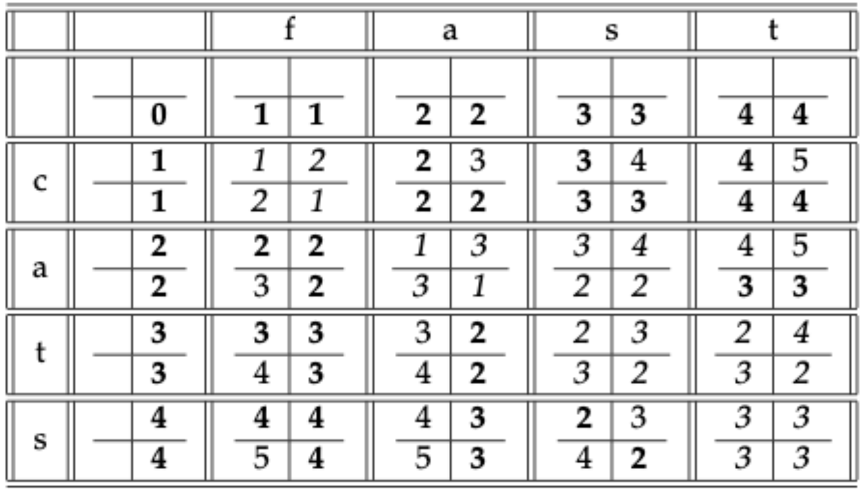
- context sensitive spelling correction

Edit distance

- Dynamic programming: O(|s1| x |s2|)



```
EDITDISTANCE($s_1, s_2$)
  $int\ m[i,j] = 0$
  for $i \leftarrow 1$ to $|s_1|$
  do $m[i,0] = i$
  for $j \leftarrow 1$ to $|s_2|$
  do $m[0,j] = j$
  for $i \leftarrow 1$ to $|s_1|$
  do for $j \leftarrow 1$ to $|s_2|$
      do $m[i,j] = \min\{m[i-1,j-1] + \text{if } (s_1[i] = s_2[j]) \text{ then } 0 \text{ else } 1,$
                          $m[i-1,j] + 1,$
                          $m[i,j-1] + 1\}$
  return $m[|s_1|,|s_2|]$
```

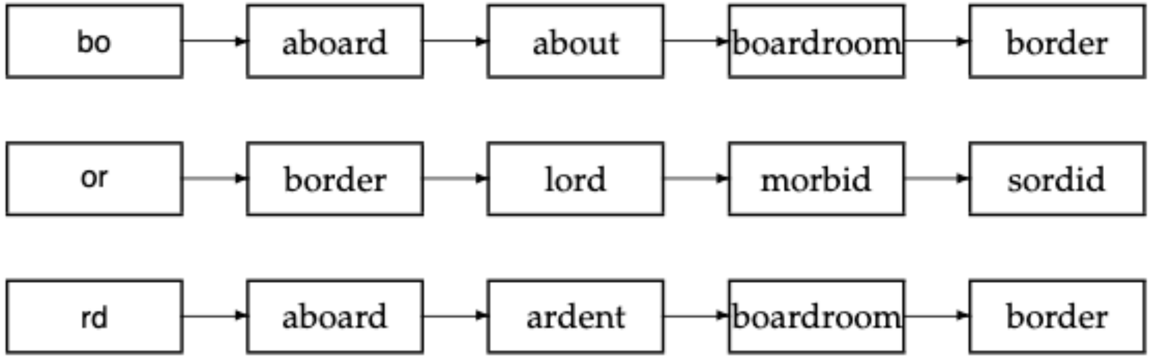


		f	a	s	t
	0	1 1	2 2	3 3	4 4
c	1 1	1 2 2 1	2 3 2 2	3 4 3 3	4 5 4 4
a	2 2	2 2 3 2	1 3 3 1	3 4 2 2	4 5 3 3
t	3 3	3 3 4 3	3 2 4 2	2 3 3 2	2 4 3 2
s	4 4	4 4 5 4	4 3 5 3	2 3 4 2	3 3 3 3

Levenshtein distance

k-gram indexes for spelling correction

- Running DP on all pairs of words is time consuming
- Leveraging k-gram index to speed up spelling correction
  - boardroom vs. bord



bo → aboard → about → boardroom → border

or → border → lord → morbid → sordid

rd → aboard → ardent → boardroom → border

boarder:3

boardroom: 2

aboard: 2

ardent:1

…

Context sensitive spelling correction

- How to correct “flew form healthrow”?
  - All three words are spelled correctly
  - Enumerating each character: the space is large
  - Solution: using logs of queries, e.g., **flew from** vs. fled fore

Li et al. A generalized hidden Markov model with discriminative training for query spelling correction. SIGIR 2012

PageRank

- How to rank webpages?
    - Using retrieval models: only captures relevance

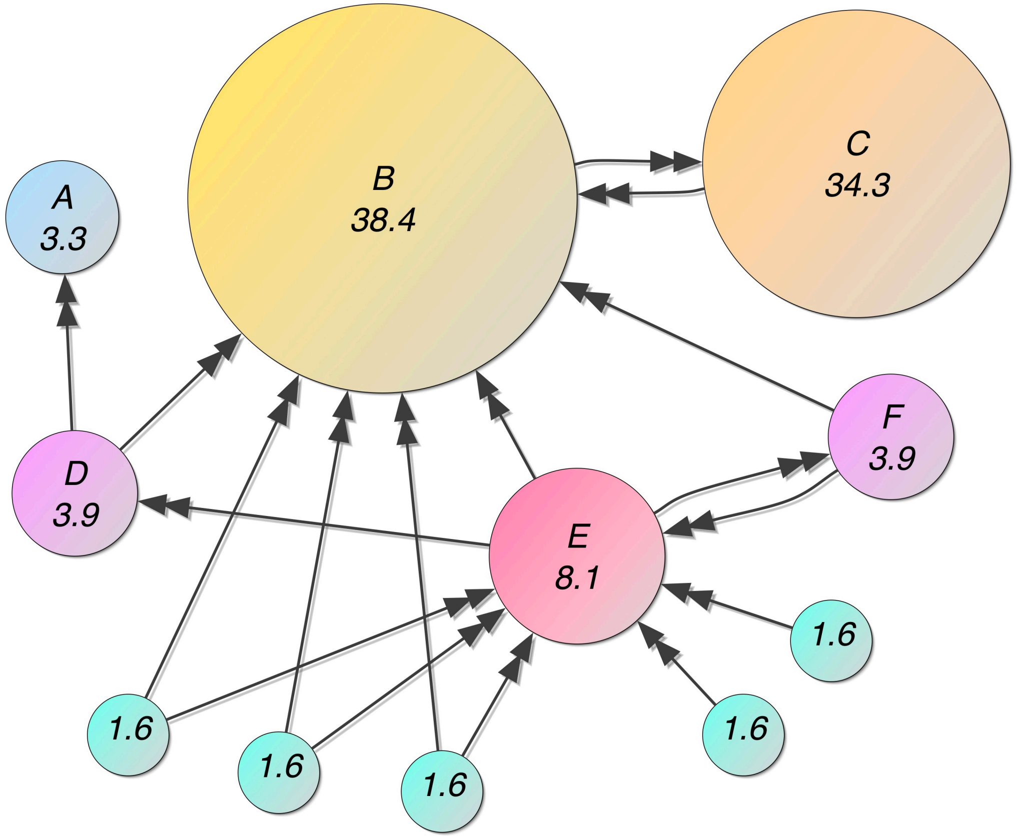
- Capturing quality of web pages:
    - Based on how often the page is cited
    - Intuition: a popular website (e.g., Google) would be cited by a lot of other webpages

PageRank

- ***“The Anatomy of a Large-Scale Hypertextual Web Search Engine”*** *- Sergey Brin and* Lawrence Page, *Computer networks and ISDN systems, 1998*

$$PR(p_i) = \frac{1-d}{N} + d \sum_{p_j \in M(p_i)} \frac{PR(p_j)}{L(p_j)}$$

- Favors pages that are highly cited, and pages cited by highly cited pages

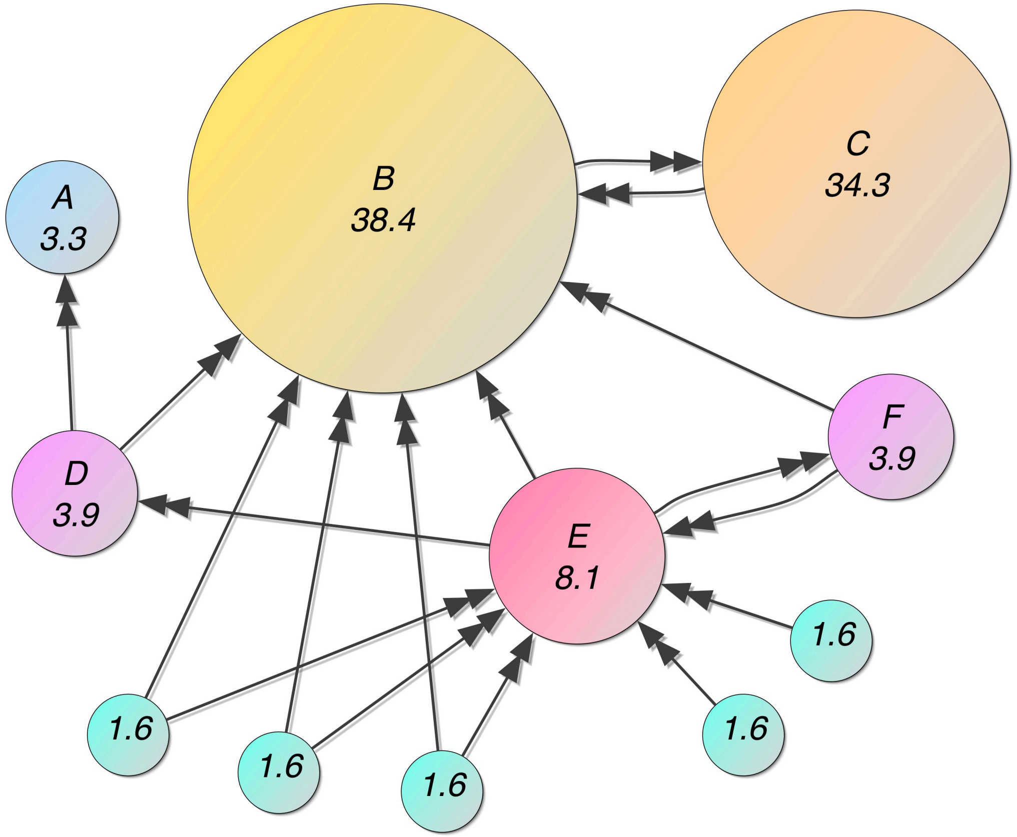


1/2 probability of randomly walking into B

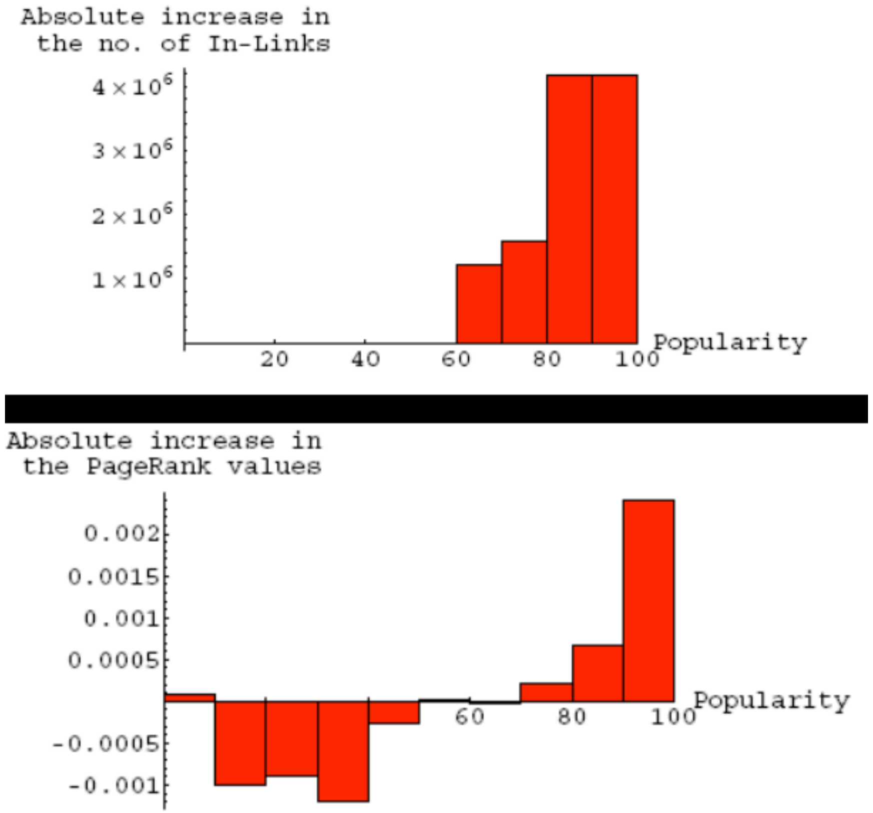
PageRank

- Assign each node an initial page rank
- Repeat until convergence
  - Calculate the page rank of each node using the equation

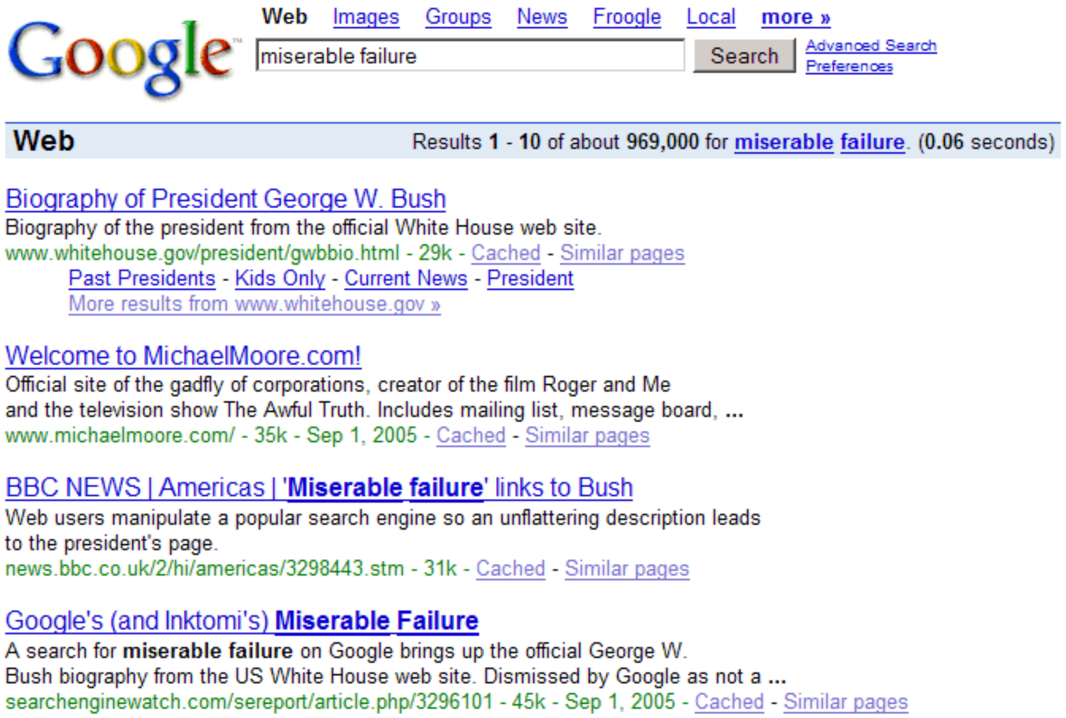
$$PR(p_i) = \frac{1-d}{N} + d \sum_{p_j \in M(p_i)} \frac{PR(p_j)}{L(p_j)}$$



Problems of page rank



rich gets richer



miserable failure

Web Results **1** - **10** of about **969,000** for **miserable failure**. (**0.06** seconds)

Biography of President George W. Bush
Biography of the president from the official White House web site.
www.whitehouse.gov/president/gwbbio.html - 29k - Cached - Similar pages
Past Presidents - Kids Only - Current News - President
More results from www.whitehouse.gov »

Welcome to MichaelMoore.com!
Official site of the gadfly of corporations, creator of the film Roger and Me and the television show The Awful Truth. Includes mailing list, message board, ...
www.michaelmoore.com/ - 35k - Sep 1, 2005 - Cached - Similar pages

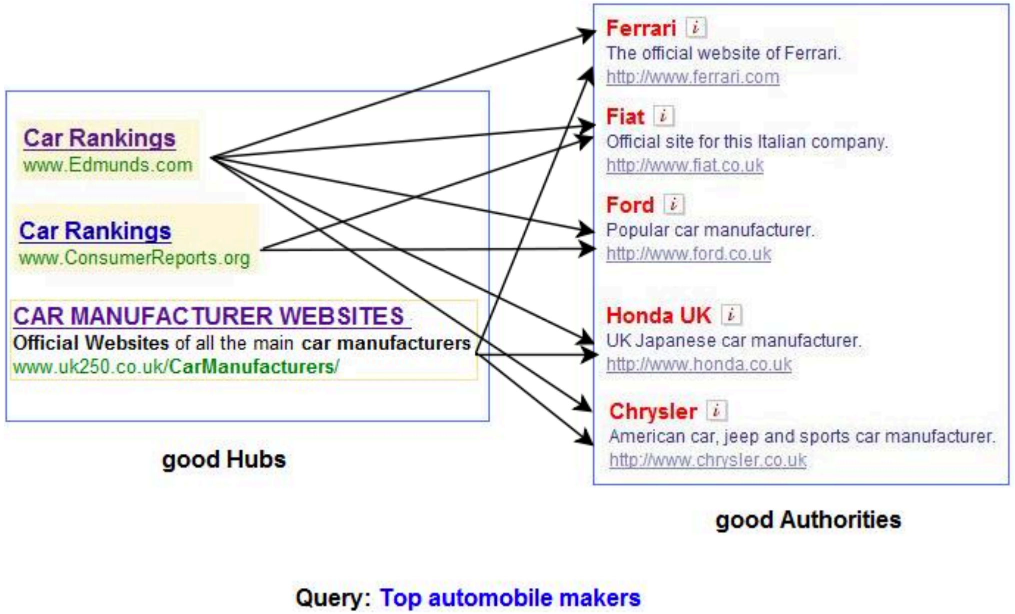
BBC NEWS | Americas | '**Miserable failure**' links to Bush
Web users manipulate a popular search engine so an unflattering description leads to the president's page.
news.bbc.co.uk/2/hi/americas/3298443.stm - 31k - Cached - Similar pages

Google's (and Inktomi's) **Miserable Failure**
A search for **miserable failure** on Google brings up the official George W. Bush biography from the US White House web site. Dismissed by Google as not a ...
searchenginewatch.com/sereport/article.php/3296101 - 45k - Sep 1, 2005 - Cached - Similar pages

Google bombing

HITS

- Hubs: compilations of a broad catalog of information that led users direct to other authoritative pages
- Authorities: a page that is linked by many different hubs



Car Rankings
www.Edmunds.com

Car Rankings
www.ConsumerReports.org

CAR MANUFACTURER WEBSITES
Official Websites of all the main car manufacturers
www.uk250.co.uk/CarManufacturers/

good Hubs

Ferrari
The official website of Ferrari.
http://www.ferrari.com

Fiat
Official site for this Italian company.
http://www.fiat.co.uk

Ford
Popular car manufacturer.
http://www.ford.co.uk

Honda UK
UK Japanese car manufacturer.
http://www.honda.co.uk

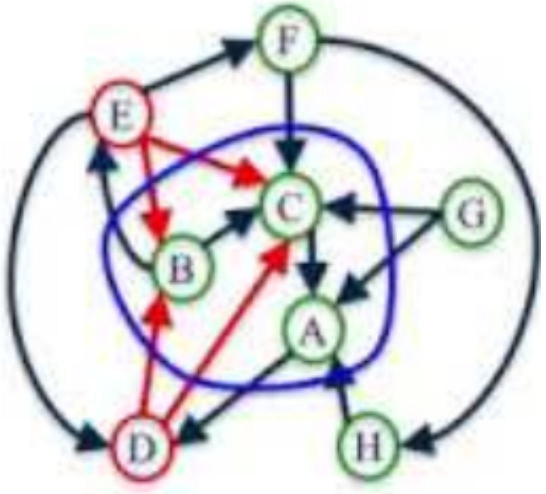
Chrysler
American car, jeep and sports car manufacturer.
http://www.chrysler.co.uk

good Authorities

Query: Top automobile makers

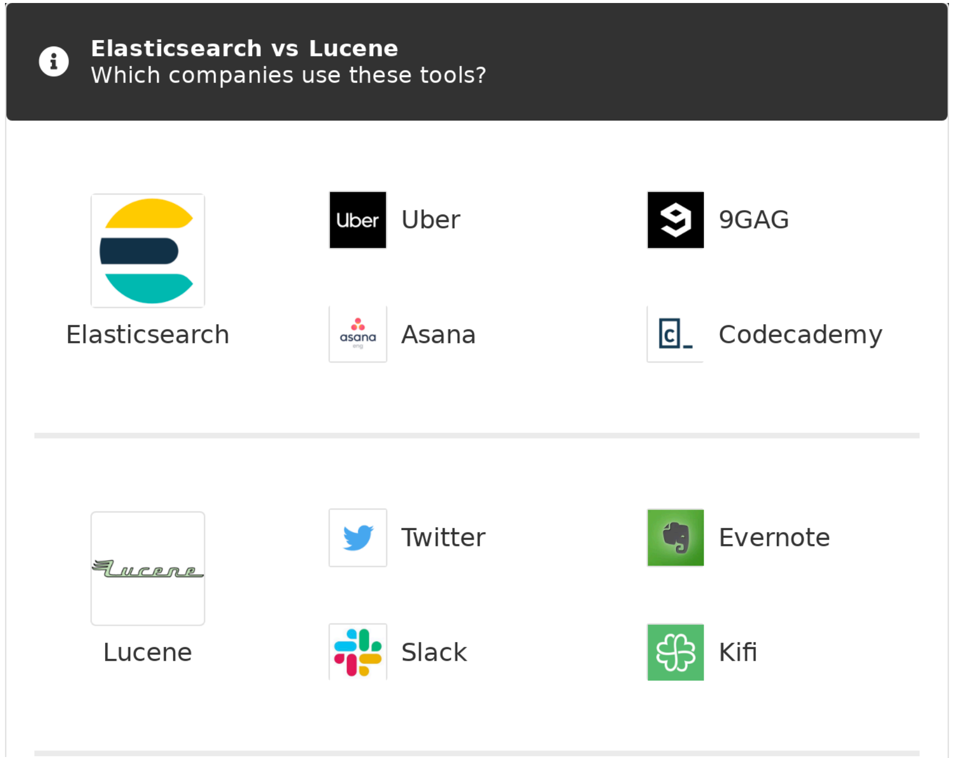
HITS

- Repeat k times
  - Update hub score: v = A^T u
  - Update authority score: u = A^T v



Search engine tools

- Apache Lucene
  - Free and open search engine library
  - First developed in 1999
- ElasticSearch
  - A search engine
  - based on Lucene



Elasticsearch vs Lucene
Which companies use these tools?

Elasticsearch

Uber

9GAG

Asana

Codecademy

Lucene

Twitter

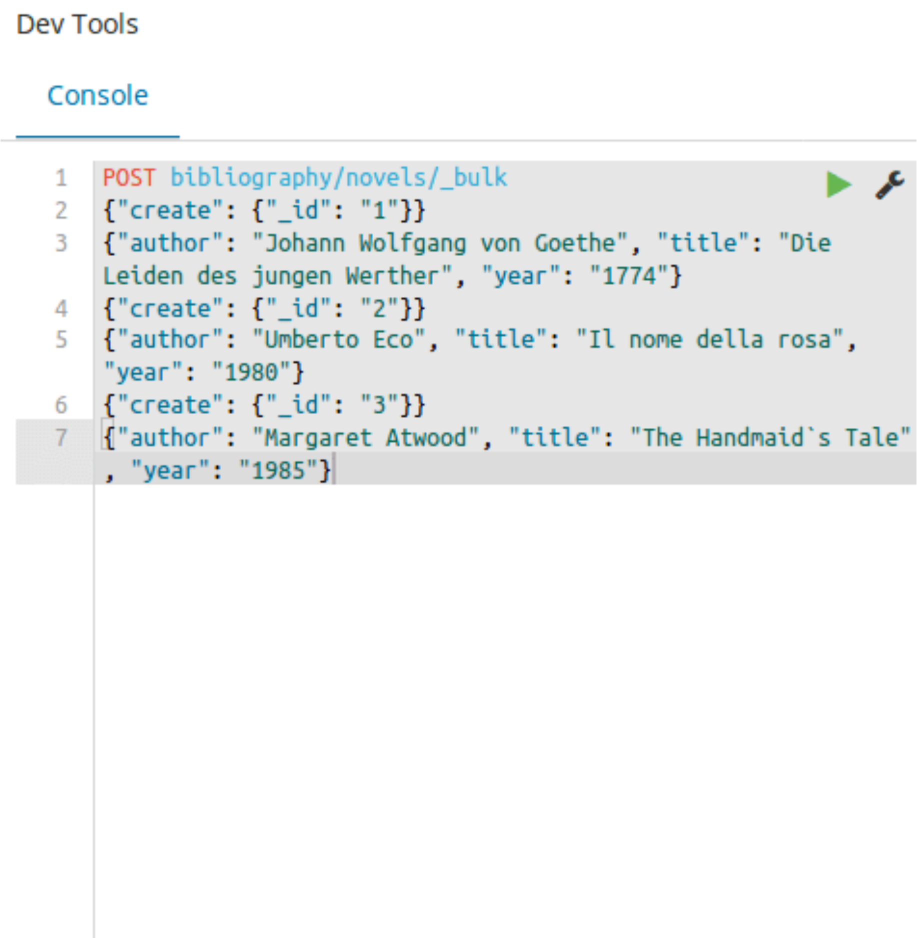
Evernote

Slack

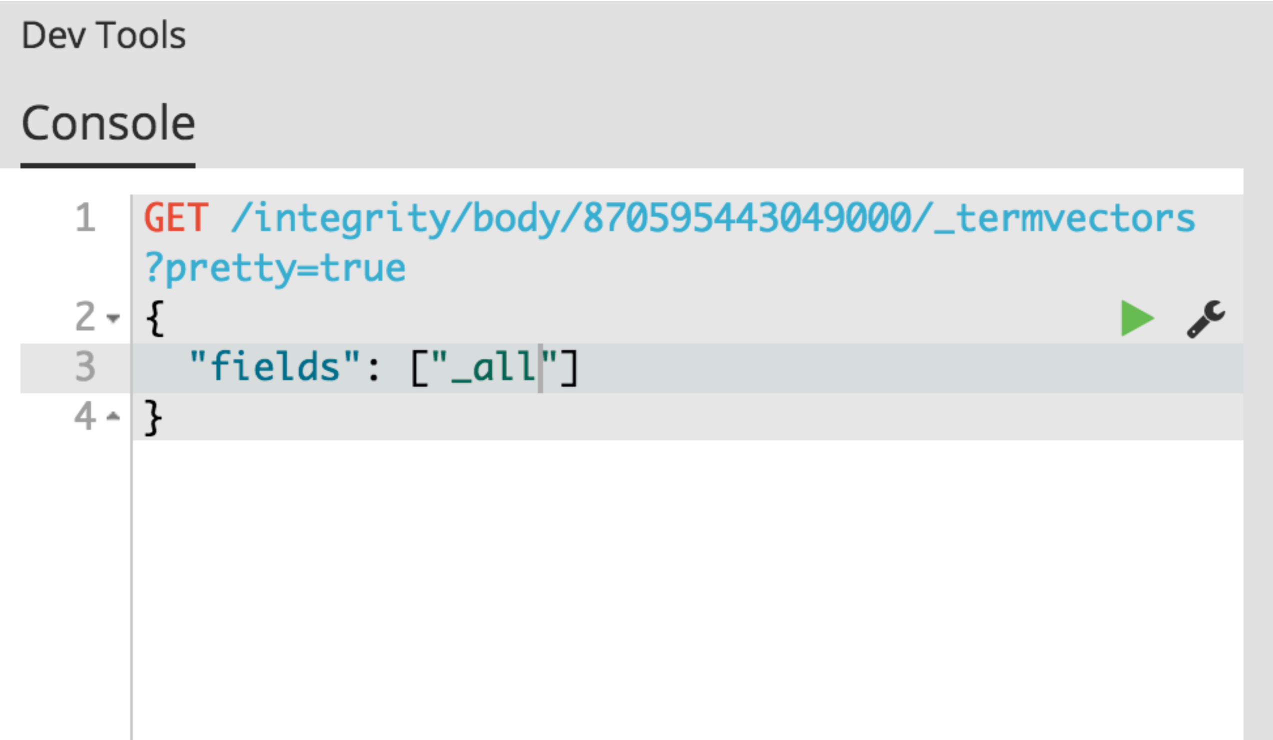
Kifi

ElasticSearch

- Using a REST api



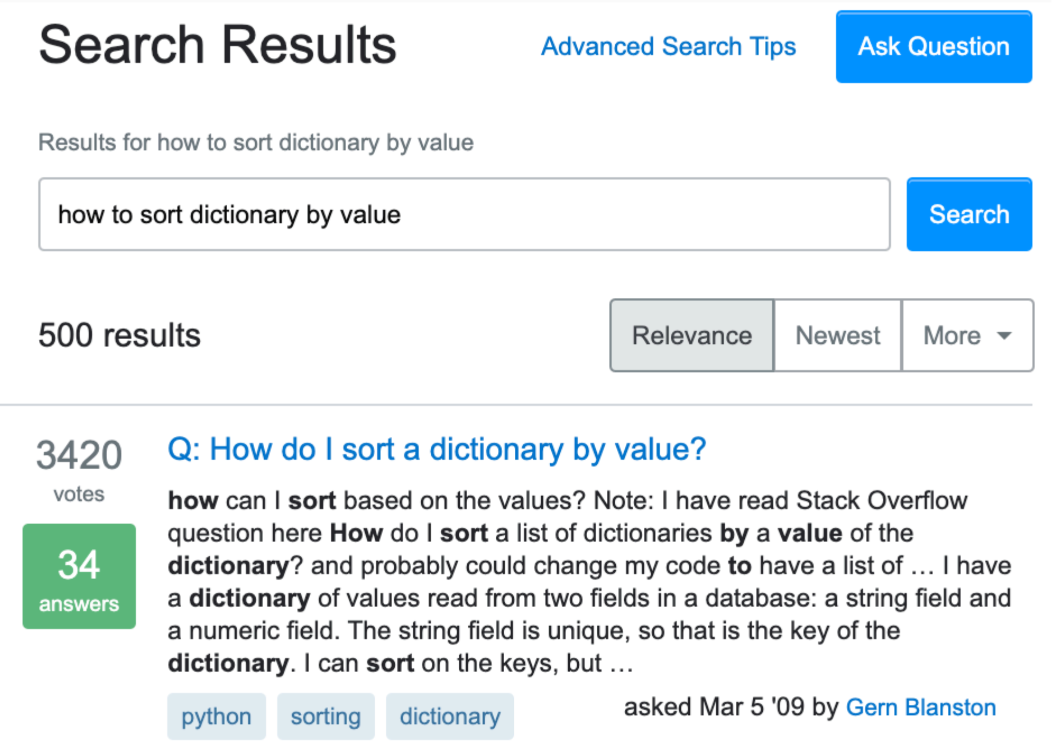
```
POST bibliography/novels/_bulk
{"create": {"_id": "1"}}
{"author": "Johann Wolfgang von Goethe", "title": "Die Leiden des jungen Werther", "year": "1774"}
{"create": {"_id": "2"}}
{"author": "Umberto Eco", "title": "Il nome della rosa", "year": "1980"}
{"create": {"_id": "3"}}
{"author": "Margaret Atwood", "title": "The Handmaid`s Tale", "year": "1985"}
```



```
GET /integrity/body/870595443049000/_termvectors?pretty=true
{
  "fields": ["_all"]
}
```

Homework 2: Using ElasticSearch to build a search engine

- Build an inverted index
- Evaluate three search algorithm's performance
  - TF-IDF
  - BM25
  - Dirichlet-LM



Results for how to sort dictionary by value

how to sort dictionary by value

Q: How do I sort a dictionary by value?

how can I **sort** based on the values? Note: I have read Stack Overflow question here **How** do I **sort** a list of dictionaries **by** a **value** of the **dictionary**? and probably could change my code **to** have a list of … I have a **dictionary** of values read from two fields in a database: a string field and a numeric field. The string field is unique, so that is the key of the **dictionary**. I can **sort** on the keys, but …

asked Mar 5 '09 by Gern Blanston