Boolean retrieval & basics of indexing

CE-324: Modern Information Retrieval

Sharif University of Technology

M. Soleymani

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Most slides have been adapted from: Profs. Manning, Nayak & Raghavan lectures (CS-276, Stanford)

Boolean retrieval model

- Query: Boolean expressions
    - Boolean queries use *AND*, *OR* and *NOT* to join query terms

- Views each doc as a set of words
    - Term-incidence matrix is sufficient
        - Shows presence or absence of terms in each doc

- Perhaps the simplest model to build an IR system on

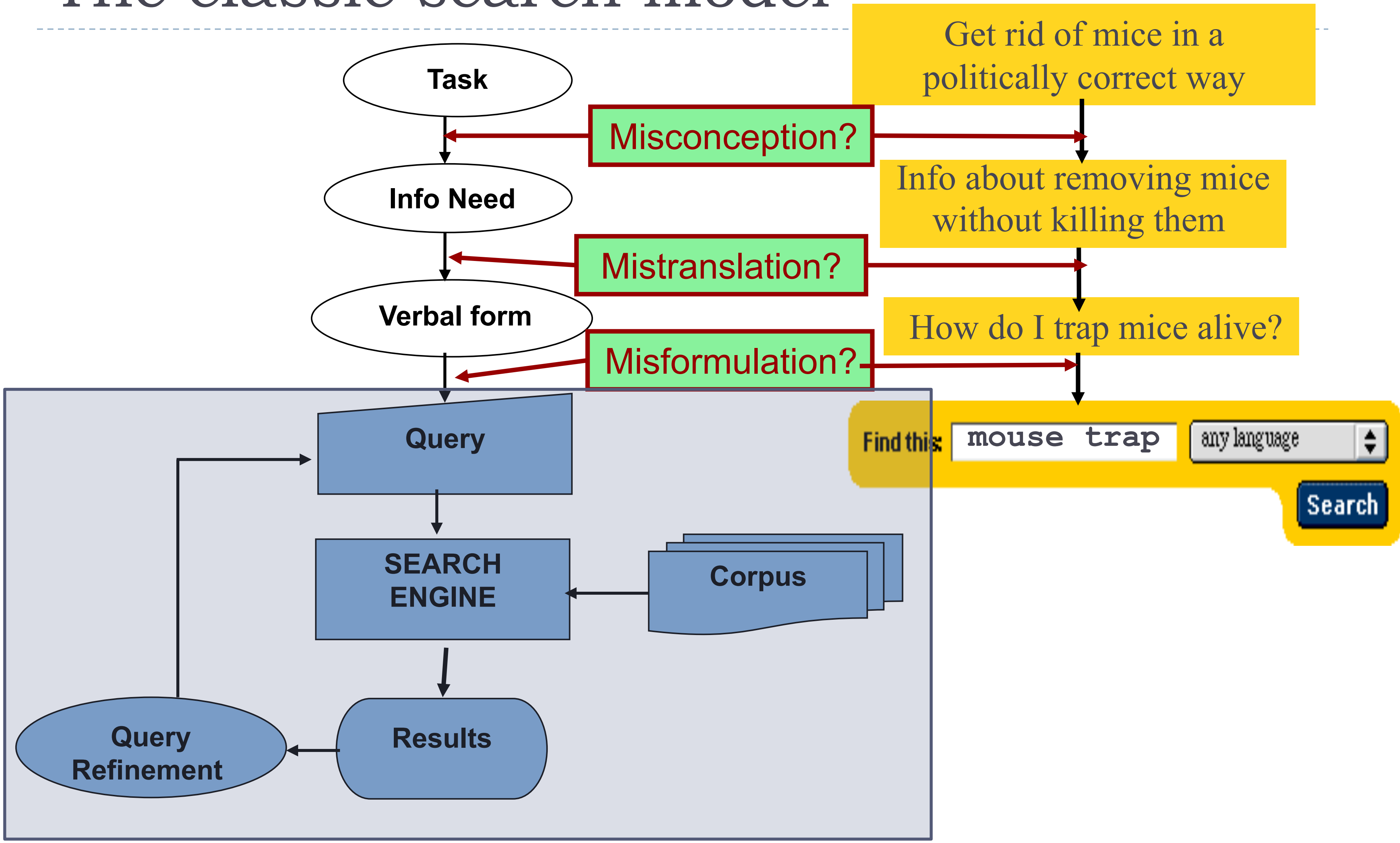
Boolean queries: Exact match

- In pure Boolean model, retrieved docs are not ranked
  - Result is a set of docs.
  - It is precise or exact match (docs match condition or not).

- Primary commercial retrieval tool for 3 decades (Until 1990's).

- Many search systems you still use are Boolean:
  - Email, library catalog, Mac OS X Spotlight

The classic search model



Task

Misconception?

Info Need

Mistranslation?

Verbal form

Misformulation?

Query

SEARCH ENGINE

Corpus

Results

Query Refinement

Get rid of mice in a politically correct way

Info about removing mice without killing them

How do I trap mice alive?

Example: Plays of Shakespeare

- Which plays of Shakespeare contain the words ***Brutus*** *AND* ***Caesar*** but *NOT* ***Calpurnia***?
  - scanning all of Shakespeare's plays for ***Brutus*** and ***Caesar,*** then strip out those containing ***Calpurnia***?
- The above solution cannot be the answer for large corpora (computationally expensive)
- Efficiency is also an important issue (along with the effectiveness)
  - Index: data structure built on the text to speed up the searches

Example: Plays of Shakespeare Term-document incidence matrix

	Antony and Cleopatra	Julius Caesar	The Tempest	Hamlet	Othello	Macbeth
Antony	1	1	0	0	0	1
Brutus	1	1	0	1	0	0
Caesar	1	1	0	1	1	1
Calpurnia	0	1	0	0	0	0
Cleopatra	1	0	0	0	0	0
mercy	1	0	1	1	1	1
worser	1	0	1	1	1	0

1 if play contains word, 0 otherwise

Incidence vectors

- So we have a 0/1 vector for each term.
  - ***Brutus*** *AND* ***Caesar*** but *NOT* ***Calpurnia***

- To answer query: take the vectors for ***Brutus, Caesar*** and ***Calpurnia*** (complemented) ➔ bitwise *AND*.
  - 110100 *AND* 110111 *AND* 101111 = 100100.

	Antony and Cleopatra	Julius Caesar	The Tempest	Hamlet	Othello	Macbeth
Antony	1	1	0	0	0	1
Brutus	1	1	0	1	0	0
Caesar	1	1	0	1	1	1
Calpurnia	0	1	0	0	0	0
Cleopatra	1	0	0	0	0	0
mercy	1	0	1	1	1	1
worser	1	0	1	1	1	0

Answers to query

Brutus** AND **Caesar** but NOT **Calpurnia

- Antony and Cleopatra, Act III, Scene ii

Agrippa [Aside to DOMITIUS ENOBARBUS]: Why, Enobarbus,
When Antony found Julius ***Caesar*** dead,
He cried almost to roaring; and he wept
When at Philippi he found ***Brutus*** slain.

- Hamlet, Act III, Scene ii

Lord Polonius: I did enact Julius ***Caesar*** I was killed i' the
Capitol; ***Brutus*** killed me.

Bigger collections

- Number of docs: N = 10^6
- Average length of a doc≈ 1000 words
- No. of distinct terms: M = 500,000
- Average length of a word ≈ 6 bytes
  - including spaces/punctuation

- 6GB of data

Sparsity of Term-document incidence matrix

- 500K x 1M matrix has half-a-trillion 0's and 1's.
- But it has no more than one billion 1's.
  - matrix is extremely sparse.
  - so a minimum of 99.8% of the cells are zero.

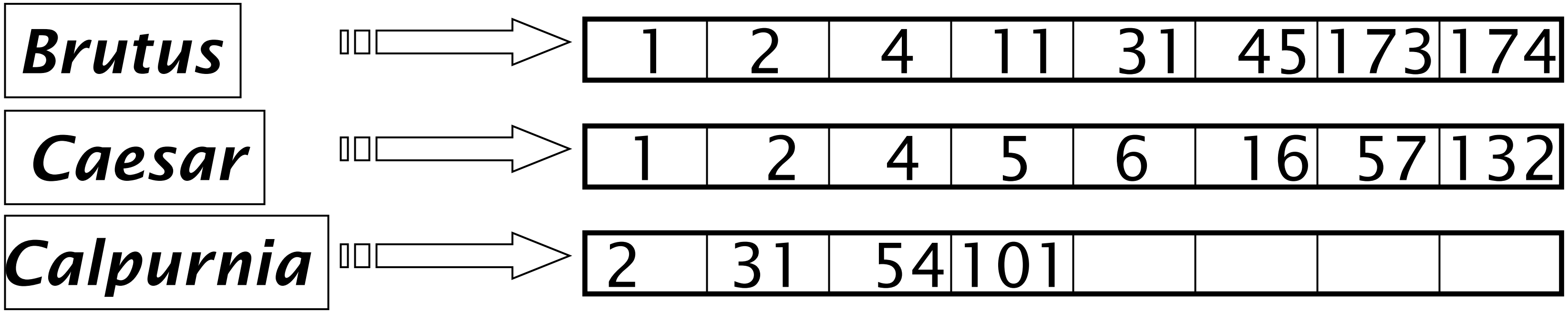
Why?

- What's a better representation?
  - We only record the 1 positions.

Inverted index

- For each term *t*, store a list of all docs that contain *t*.
  - Identify each by a **docID**, a document serial number

- Can we use fixed-size arrays for this?

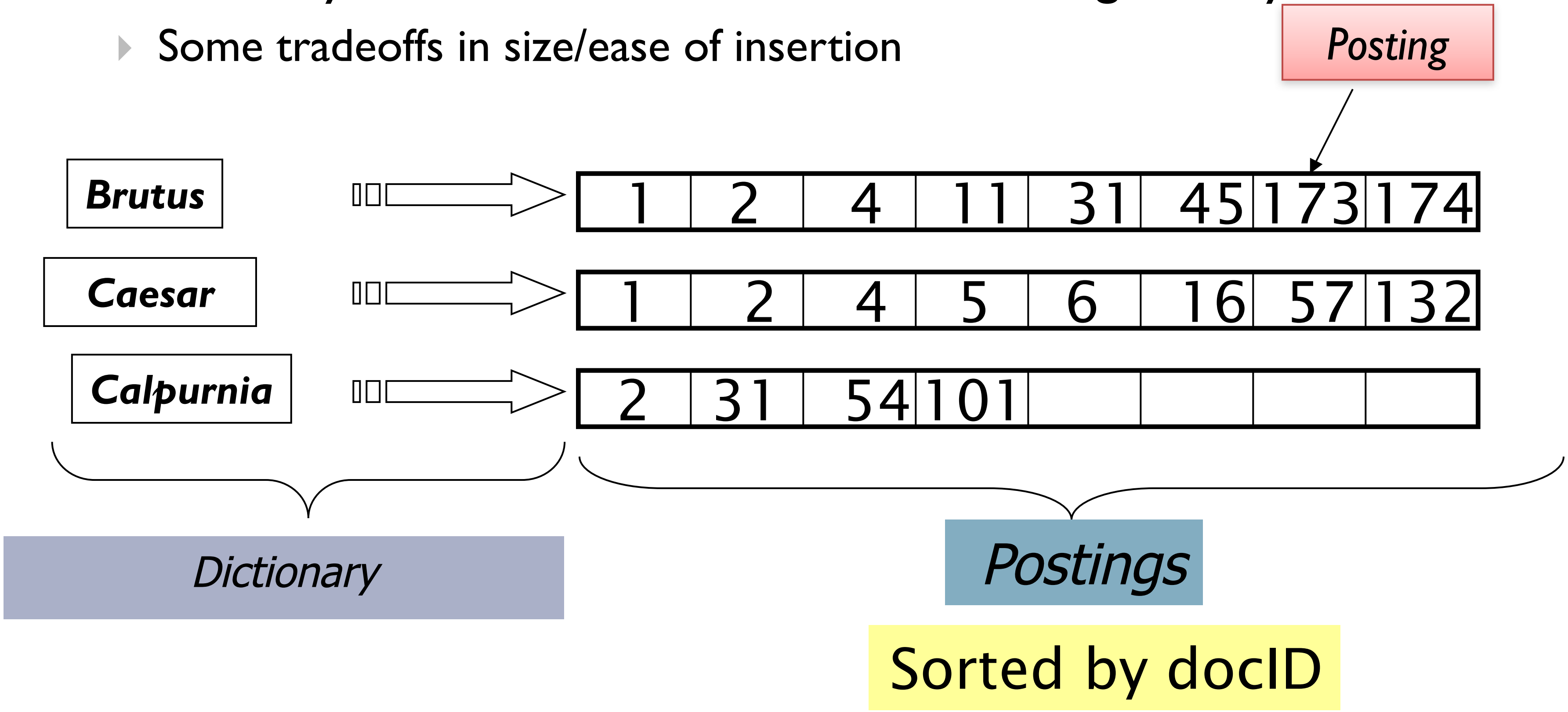


Brutus	1	2	4	11	31	45	173	174
Caesar	1	2	4	5	6	16	57	132
Calpurnia	2	31	54	101				

What happens if the word ***Caesar*** is added to doc 14?

Inverted index

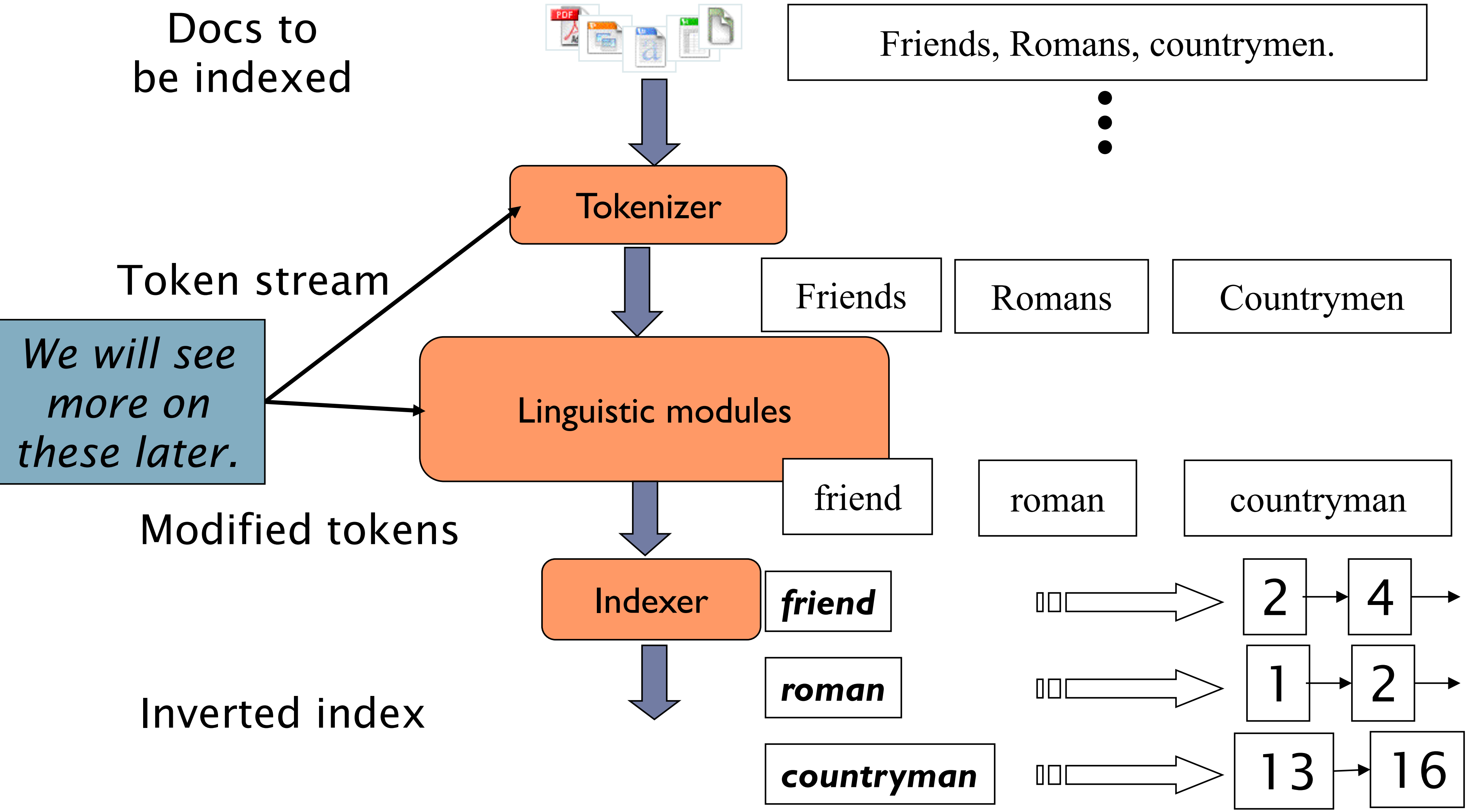
- We need variable-size postings lists
  - On disk, a continuous run of postings is normal and best
  - In memory, can use linked lists or variable length arrays
    - Some tradeoffs in size/ease of insertion



Brutus	1	2	4	11	31	45	173	174
Caesar	1	2	4	5	6	16	57	132
Calpurnia	2	31	54	101				

Sorted by docID

Inverted index construction



Docs to be indexed

Friends, Romans, countrymen.

Tokenizer

Token stream

Friends

Romans

Countrymen

We will see more on these later.

Linguistic modules

Modified tokens

friend

roman

countryman

Indexer

Inverted index

Indexer steps: Token sequence

- Sequence of (Modified token, Document ID) pairs.

Doc 1

I did enact Julius
Caesar I was killed
i' the Capitol;
Brutus killed me.

Doc 2

So let it be with
Caesar. The noble
Brutus hath told you
Caesar was ambitious

Term	docID
I	1
did	1
enact	1
julius	1
caesar	1
I	1
was	1
killed	1
i'	1
the	1
capitol	1
brutus	1
killed	1
me	1
so	2
let	2
it	2
be	2
with	2
caesar	2
the	2
noble	2
brutus	2
hath	2
told	2
you	2
caesar	2
was	2
ambitious	2

Indexer steps: Sort

- Sort by terms
  - And then docID

Core indexing step

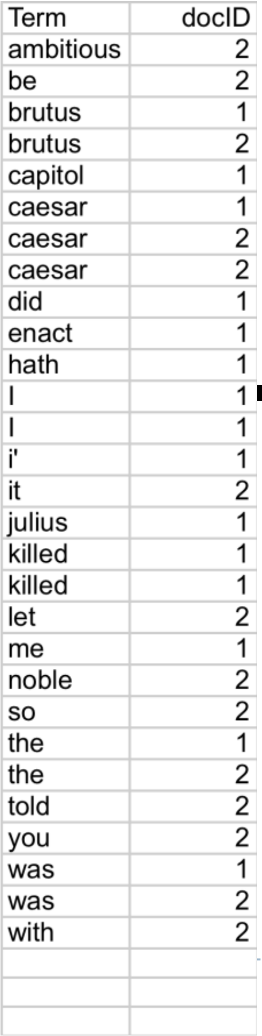
Term	docID
I	1
did	1
enact	1
julius	1
caesar	1
I	1
was	1
killed	1
i'	1
the	1
capitol	1
brutus	1
killed	1
me	1
so	2
let	2
it	2
be	2
with	2
caesar	2
the	2
noble	2
brutus	2
hath	2
told	2
you	2
caesar	2
was	2
ambitious	2

Term	docID
ambitious	2
be	2
brutus	1
brutus	2
capitol	1
caesar	1
caesar	2
caesar	2
did	1
enact	1
hath	1
I	1
I	1
i'	1
it	2
julius	1
killed	1
killed	1
let	2
me	1
noble	2
so	2
the	1
the	2
told	2
you	2
was	1
was	2
with	2

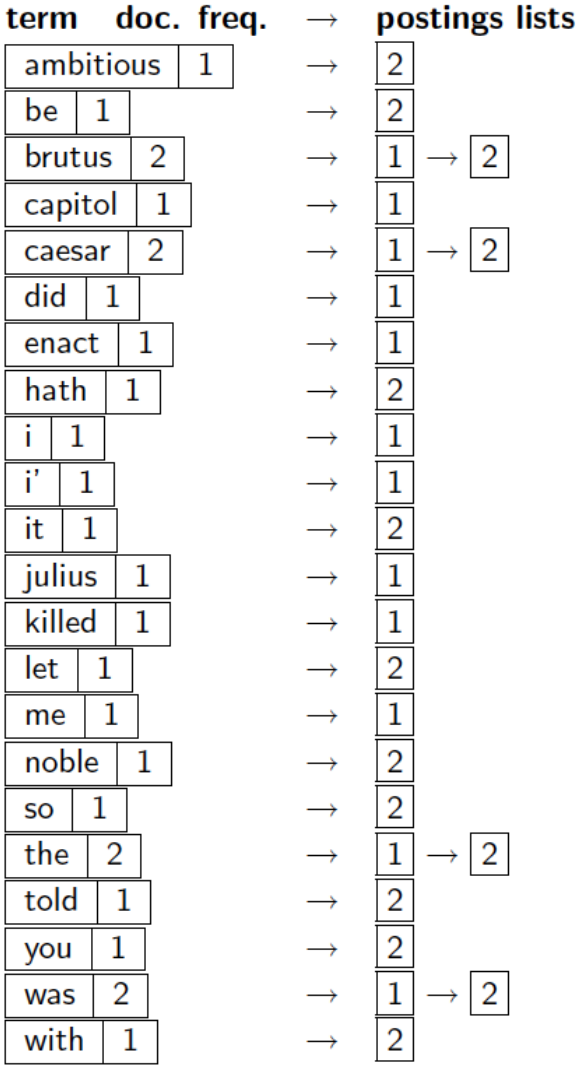
Indexer steps: Dictionary & Postings

- Multiple term entries in a single doc are merged.
- Split into Dictionary and Postings
- Document frequency information is added.

Why frequency?
Will discuss later.

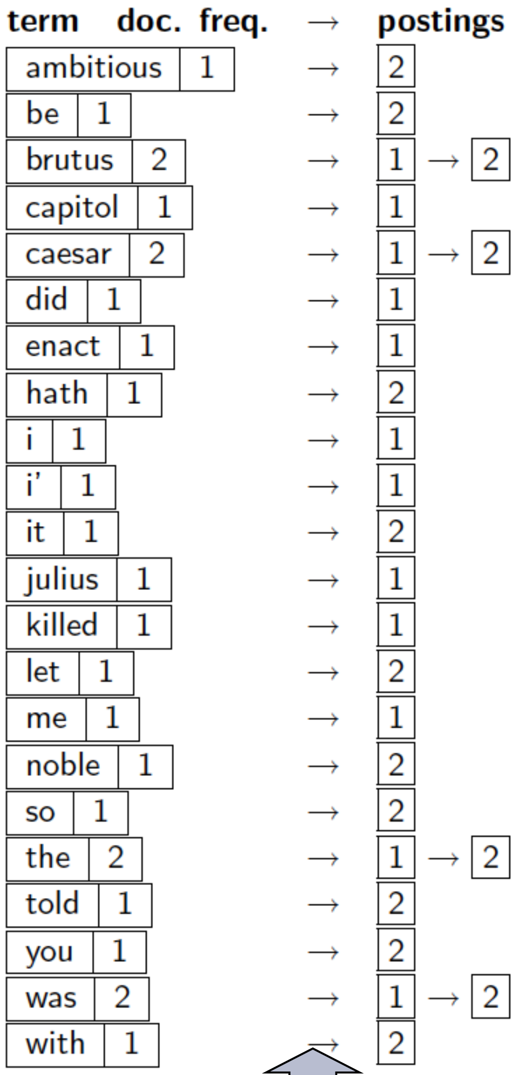


Term	docID
ambitious	2
be	2
brutus	1
brutus	2
capitol	1
caesar	1
caesar	2
caesar	2
did	1
enact	1
hath	1
I	1
I	1
i'	1
it	2
julius	1
killed	1
killed	1
let	2
me	1
noble	2
so	2
the	1
the	2
told	2
you	2
was	1
was	2
with	2



term	doc. freq.	→	postings lists
ambitious	1	→	2
be	1	→	2
brutus	2	→	1 → 2
capitol	1	→	1
caesar	2	→	1 → 2
did	1	→	1
enact	1	→	1
hath	1	→	2
i	1	→	1
i'	1	→	1
it	1	→	2
julius	1	→	1
killed	1	→	1
let	1	→	2
me	1	→	1
noble	1	→	2
so	1	→	2
the	2	→	1 → 2
told	1	→	2
you	1	→	2
was	2	→	1 → 2
with	1	→	2

Where do we pay in storage?



term	doc. freq.	→	postings lists
ambitious	1	→	2
be	1	→	2
brutus	2	→	1 → 2
capitol	1	→	1
caesar	2	→	1 → 2
did	1	→	1
enact	1	→	1
hath	1	→	2
i	1	→	1
i'	1	→	1
it	1	→	2
julius	1	→	1
killed	1	→	1
let	1	→	2
me	1	→	1
noble	1	→	2
so	1	→	2
the	2	→	1 → 2
told	1	→	2
you	1	→	2
was	2	→	1 → 2
with	1	→	2

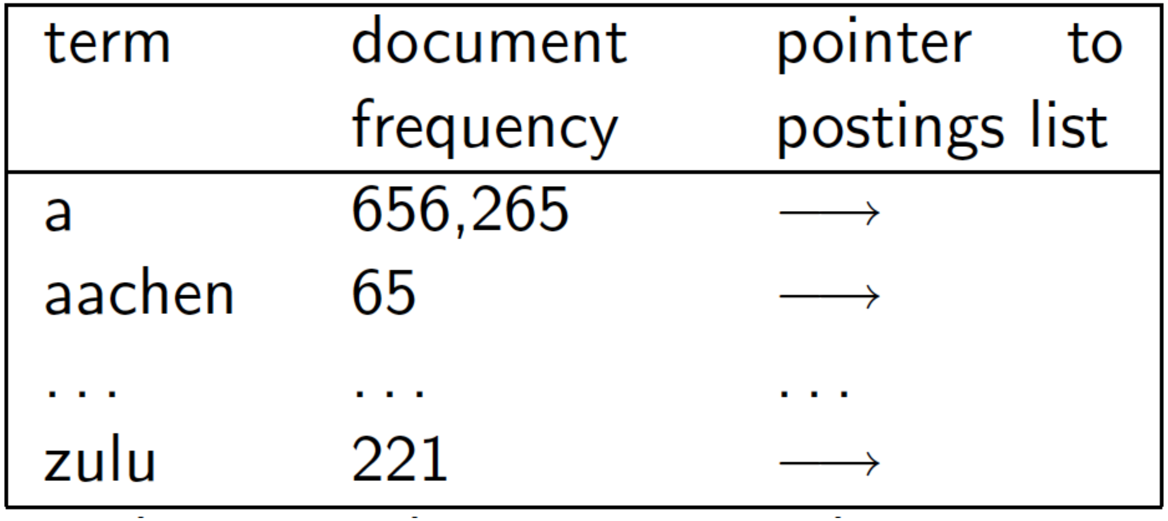
Lists of docIDs

Terms and counts

Pointers

A naïve dictionary

- An array of struct:



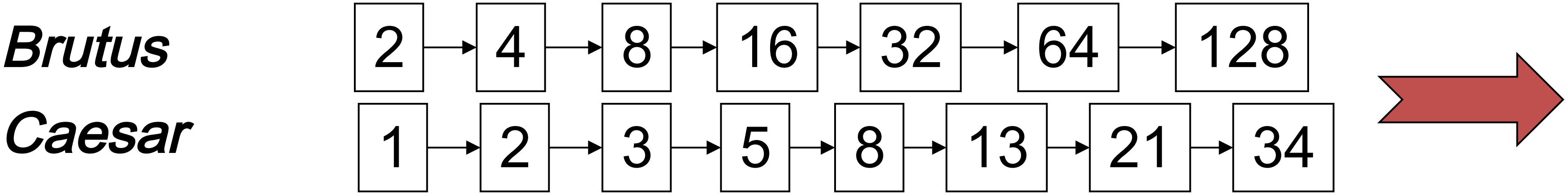
term	document frequency	pointer to postings list
a	656,265	$\longrightarrow$
aachen	65	$\longrightarrow$
...	...	...
zulu	221	$\longrightarrow$

Query processing: AND

- Consider processing the query:

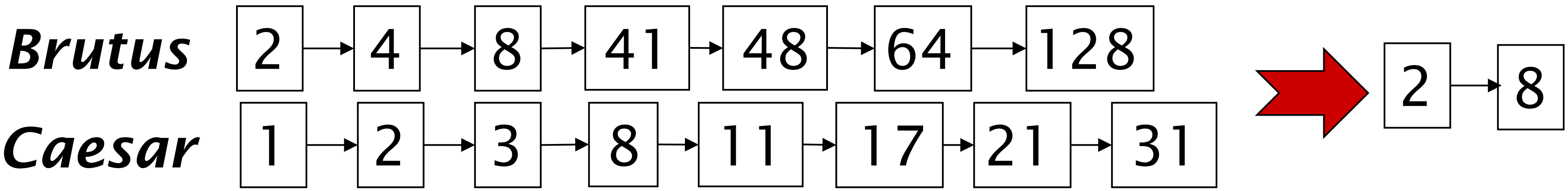
  Brutus *AND* ***Caesar***

  - Locate ***Brutus*** in the dictionary;
    - Retrieve its postings.
  - Locate ***Caesar*** in the dictionary;
    - Retrieve its postings.
  - "Merge" (intersect) the two postings:



The merge

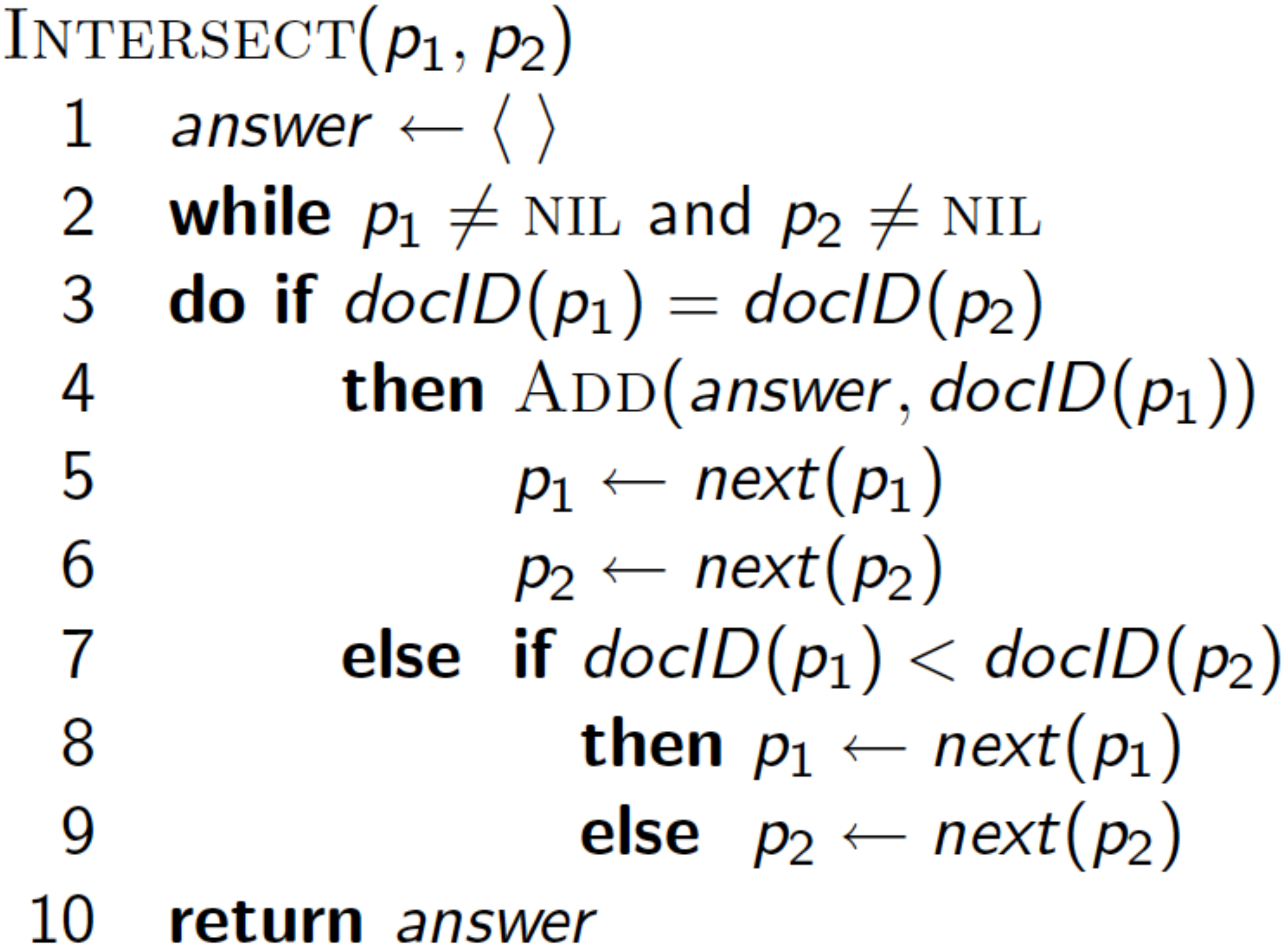
- Walk through the two postings simultaneously, in time linear in the total number of postings entries



If list lengths are *x* and *y*, merge takes O(*x*+*y*) operations.

Crucial: postings sorted by docID.

Intersecting two postings lists (a "merge" algorithm)



```
INTERSECT($p_1, p_2$)
$answer \leftarrow \langle\ \rangle$
while $p_1 \neq$ NIL and $p_2 \neq$ NIL
do if $docID(p_1) = docID(p_2)$
      then ADD($answer, docID(p_1)$)
           $p_1 \leftarrow next(p_1)$
           $p_2 \leftarrow next(p_2)$
      else if $docID(p_1) < docID(p_2)$
              then $p_1 \leftarrow next(p_1)$
              else $p_2 \leftarrow next(p_2)$
return $answer$
```

Boolean queries: More general merges

- Exercise: Adapt the merge for the queries:

  Brutus *AND NOT* ***Caesar***

  Brutus *OR NOT* ***Caesar***

Can we still run through the merge in time $O(x+y)$?

Merging

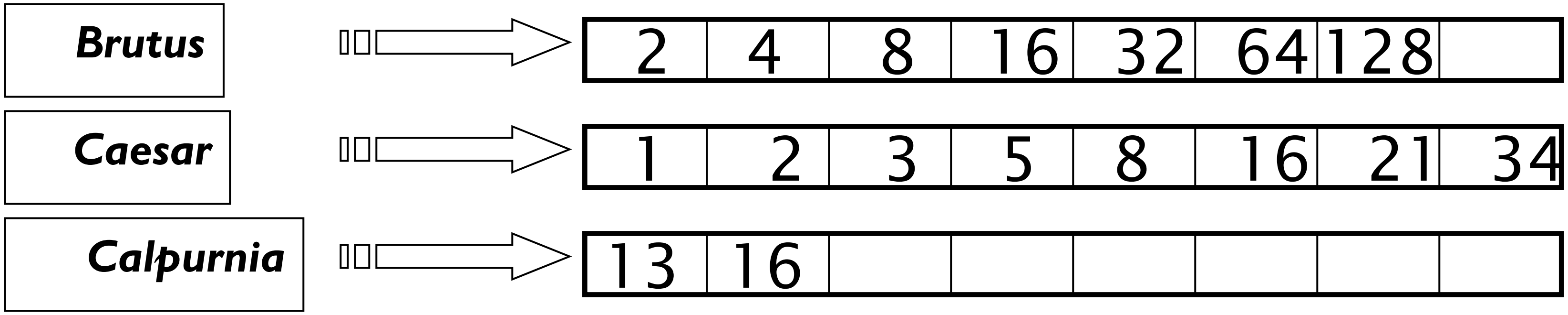
What about an arbitrary Boolean formula?

(Brutus *OR* ***Caesar)*** *AND NOT* ***(Antony*** *OR* ***Cleopatra)***

- Can we merge in “linear” time for general Boolean queries?
  - Linear in what?
- Can we do better?

Query optimization

- What is the best order for query processing?
- Consider a query that is an *AND* of n terms.
- For each of the n terms, get its postings, then *AND* them together.



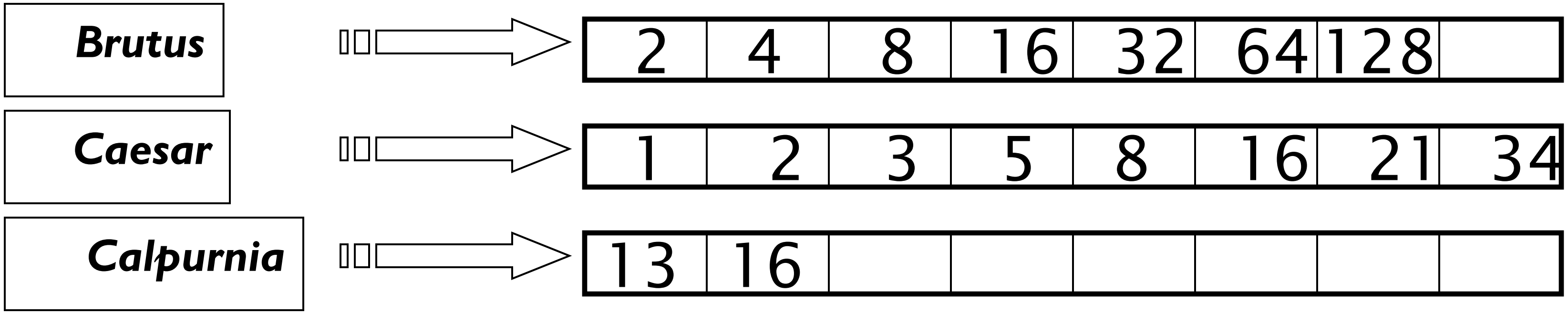
Brutus	2	4	8	16	32	64	128	
Caesar	1	2	3	5	8	16	21	34
Calpurnia	13	16						

Query: ***Brutus*** *AND* ***Calpurnia*** *AND* ***Caesar***

Query optimization example

- Process in order of increasing freq:
  - *start with smallest set, then keep cutting further.*

This is why we kept document freq. in dictionary



Brutus	2	4	8	16	32	64	128	
Caesar	1	2	3	5	8	16	21	34
Calpurnia	13	16						

Execute the query as (***Calpurnia*** *AND* ***Brutus)*** *AND* ***Caesar***.

More general optimization

- Example:

  *(**madding** OR **crowd**) AND (**ignoble** OR **strife**)*

- Get doc frequencies for all terms.
- Estimate the size of each *OR* by the sum of its doc. freq.'s (conservative).
- Process in increasing order of *OR* sizes.

Summary of Boolean IR: Advantages of exact match

- It can be implemented very efficiently
- Predictable, easy to explain
  - precise semantics
- Structured queries for pinpointing precise docs
  - neat formalism
- Work well when you know exactly (or roughly) what the collection contains and what you're looking for

Summary of Boolean IR: Disadvantages of the Boolean Model

- Query formulation (Boolean expression) is difficult for most users
  - Too simplistic Boolean queries by most users
  - AND, OR as opposite extremes in a precision/recall tradeoff
    - Usually either too few or too many docs in response to a user query

- Retrieval based on binary decision criteria
  - No ranking of the docs is provided

- Difficulty increases with collection size

Ranking results in advanced IR models

- Boolean queries give inclusion or exclusion of docs.
  - Results of queries in Boolean model as a set

- Modern information retrieval systems are no longer based on the Boolean model

- Often we want to rank/group results
  - Need to measure proximity from query to each doc.
  - Index term weighting can provide a substantial improvement