CS3245

Information Retrieval

2

Lecture 2: Boolean retrieval

Live Q&A
https://pollev.com/jin

Blanks on slides, you may want to fill in

Last Time: Ngram Language Models

- Unigram LM: Bag of words
- Ngram LM: use n-1 tokens of context to predict n^{th} token
- Larger n-gram models more accurate but each increase in order requires exponentially more space

Your turn: How to assign a probability to a sequence of words in ngram models where n >= 2?

We'll return to this in probabilistic information retrieval.

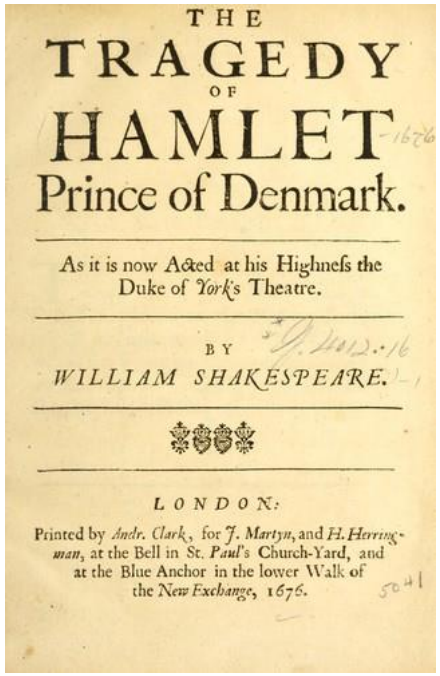
Information Retrieval

- Information Retrieval (IR) is **finding materials** (usually documents) of an unstructured nature (usually text) that satisfies an **information need** from within large collections (usually stored on computers).

Let's start with Boolean Retrieval with Shakespeare!

Boolean Retrieval with Shakespeare

- **The collection**: ~40 plays by Shakespeare
  - http://shakespeare.mit.edu/index.html



THE
TRAGEDY
OF
HAMLET
Prince of Denmark.

As it is now Acted at his Highness the Duke of York's Theatre.

BY
WILLIAM SHAKESPEARE.

LONDON:
Printed by Andr. Clark, for J. Martyn, and H. Herringman, at the Bell in St. Paul's Church-Yard, and at the Blue Anchor in the lower Walk of the New Exchange, 1676.

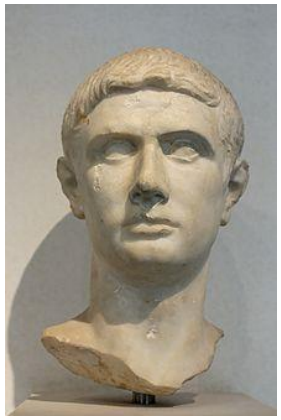
Enter HAMLET

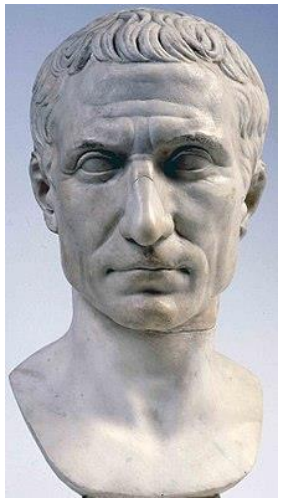
HAMLET

To be, or not to be, that is the question,
Whether 'tis nobler in the mind to suffer
The slings and arrows of outrageous fortune,
Or to take arms against a sea of troubles,

Boolean Retrieval with Shakespeare

- **The information need** (in verbal form): Which plays of Shakespeare mention ***Brutus*** *and* ***Caesar*** but *not* ***Calpurnia***?





Boolean Retrieval with Shakespeare

- **The information need** (in verbal form): Which plays of Shakespeare mention ***Brutus*** *and* ***Caesar*** but *not* ***Calpurnia***?

- 3 conditions to be satisfied at the same time
  1. Mentions Brutus
  2. Mentions Caesar
  3. Does not mention Calpurnia

- **The query**: Brutus AND Caesar AND (NOT Calpurnia)

Boolean Retrieval with Shakespeare

- **The query**: Brutus AND Caesar AND (NOT Calpurnia)

- Naïve Approach:
  - For each play, run CTRL+F for **Brutus**, **Caesar**, and **Calpurnia**, separately
  - If there is **at least one** match for **Brutus**, **at least one** for Caesar, but **none** for **Calpurnia**, add this play to the result

- It's one solution, but why isn't it the only solution?
  - Too Slow! (for large corpora)

Indexing

- **The Index**: 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 the play contains the word, 0 otherwise

Blanks on slides, you may want to fill in

Query processing

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

Brutus AND Caesar AND (NOT Calpurnia)

- Take the rows for ***Brutus, Caesar*** and ***Calpurnia*** (complemented, why?) and bitwise *AND* them.

Results

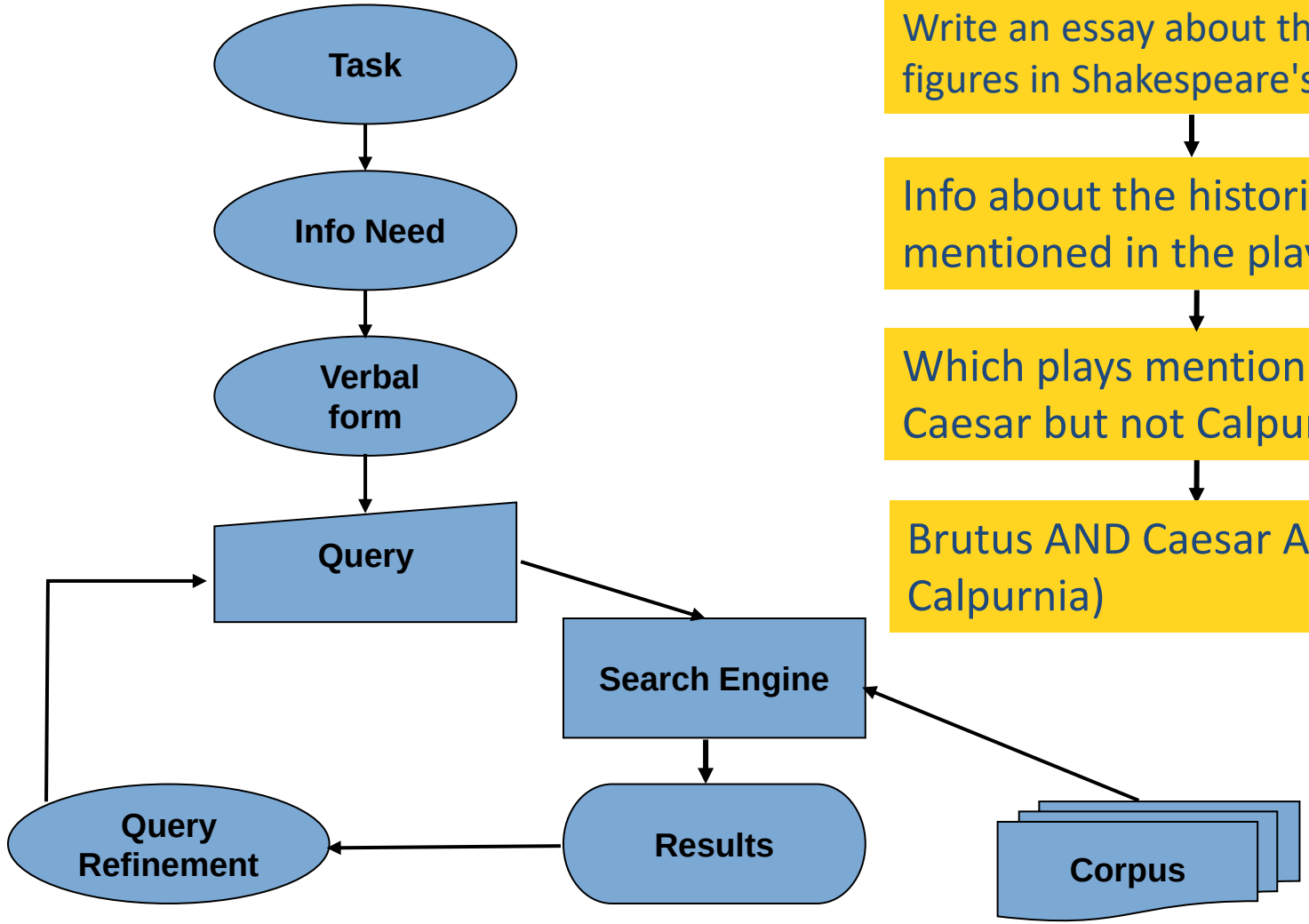
- Antony and Cleopatra, Act III, Scene ii

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.

The classic search model



Write an essay about the historical figures in Shakespeare's plays

↓

Info about the historical figures mentioned in the plays

↓

Which plays mention Brutus and Caesar but not Calpurnia?

↓

Brutus AND Caesar AND (NOT Calpurnia)

Relevance is the key!

- Information Retrieval (IR) is finding material (usually documents) … that satisfies an information need …
- **Relevance**: Whether the documents returned help to satisfy the information need.
- Evaluation metrics (to be covered in Week 9)
  - **Precision** : Fraction of retrieved docs that are relevant to user's information need
  - **Recall** : Fraction of relevant docs in collection that are retrieved

Bigger collections

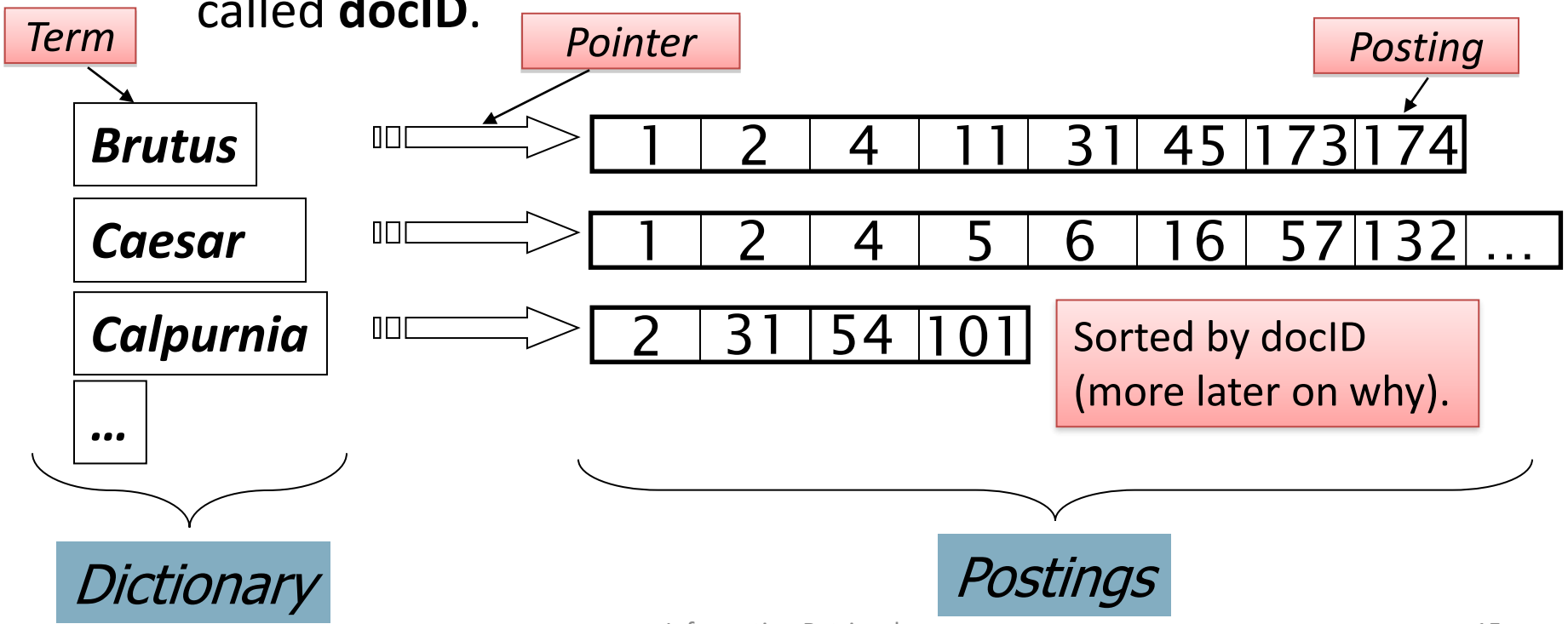
- Consider *N* = 1 million documents, each with about 1000 words.
  - 1000 x 1 million = 1 billion words in total
- Avg 6 bytes/word including spaces/punctuation
  - 6GB of data in the documents.
- Say there are *M* = 500K *distinct* terms among these.

Tough to build the matrix

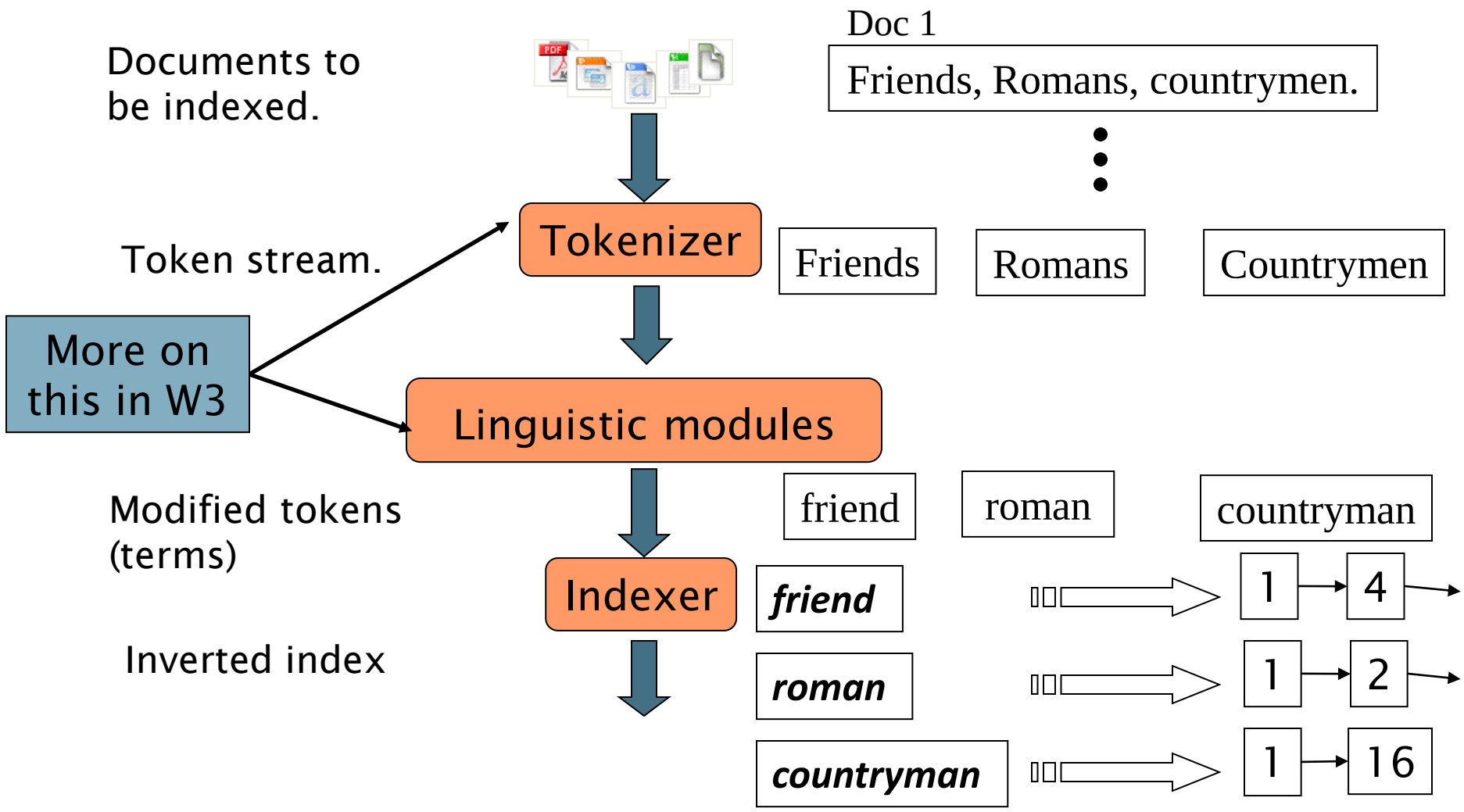
- 500K × 1M matrix has half a trillion 0s and 1s. B-I-G
- But it is extremely sparse.
  - Each document is 1000 words long →
  - At most **1K** 1s among the **500K** cells in each **column** (i.e., document).
- What's a better representation?
  - Only record the positions of the 1s for each **row** (i.e., term).

Inverted index

- For each term *t*, we must store a list of all documents that contain *t*.
  - Each document is identified by a unique serial number called **docID**.



Inverted index construction



Indexer steps: Generate token sequence

- Sequence of (Term, 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

→

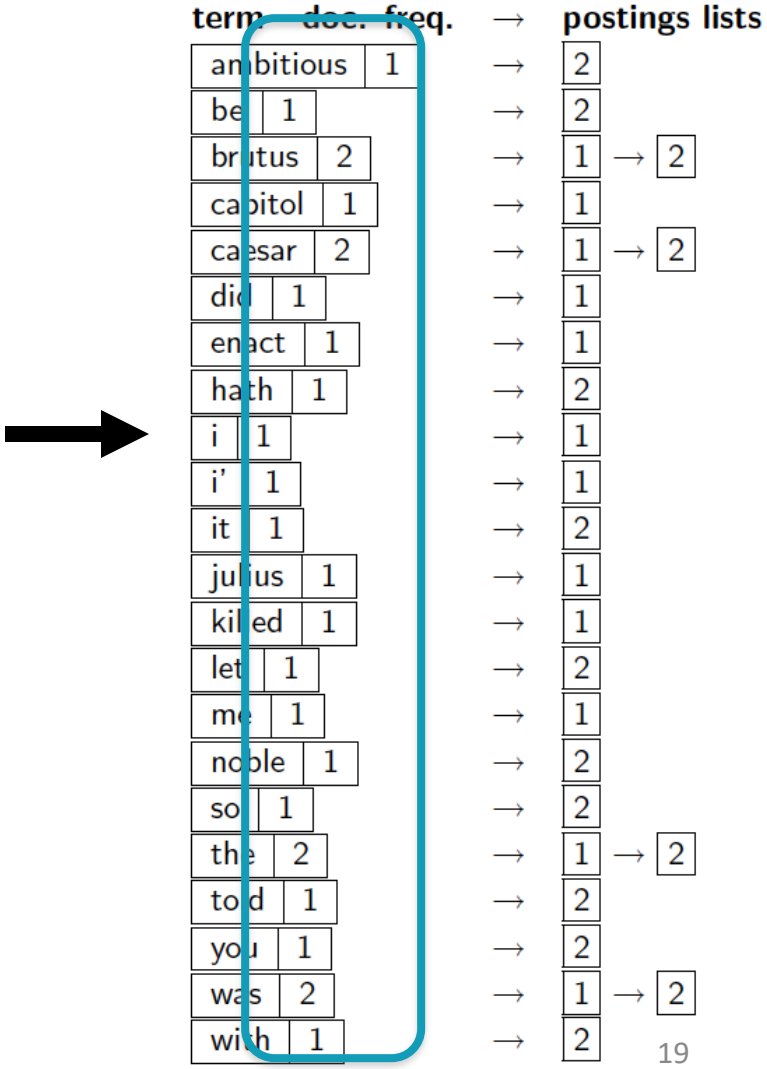
Term	docID
ambitious	2
be	2
brutus	1
brutus	2
capitol	1
caesar	1
caesar	2
caesar	2
did	1
enact	1
hath	1
I	1
I	1
i'	1
it	2
julius	1
killed	1
killed	1
let	2
me	1
noble	2
so	2
the	1
the	2
told	2
you	2
was	1
was	2
with	2

Indexer steps: Dictionary & Postings

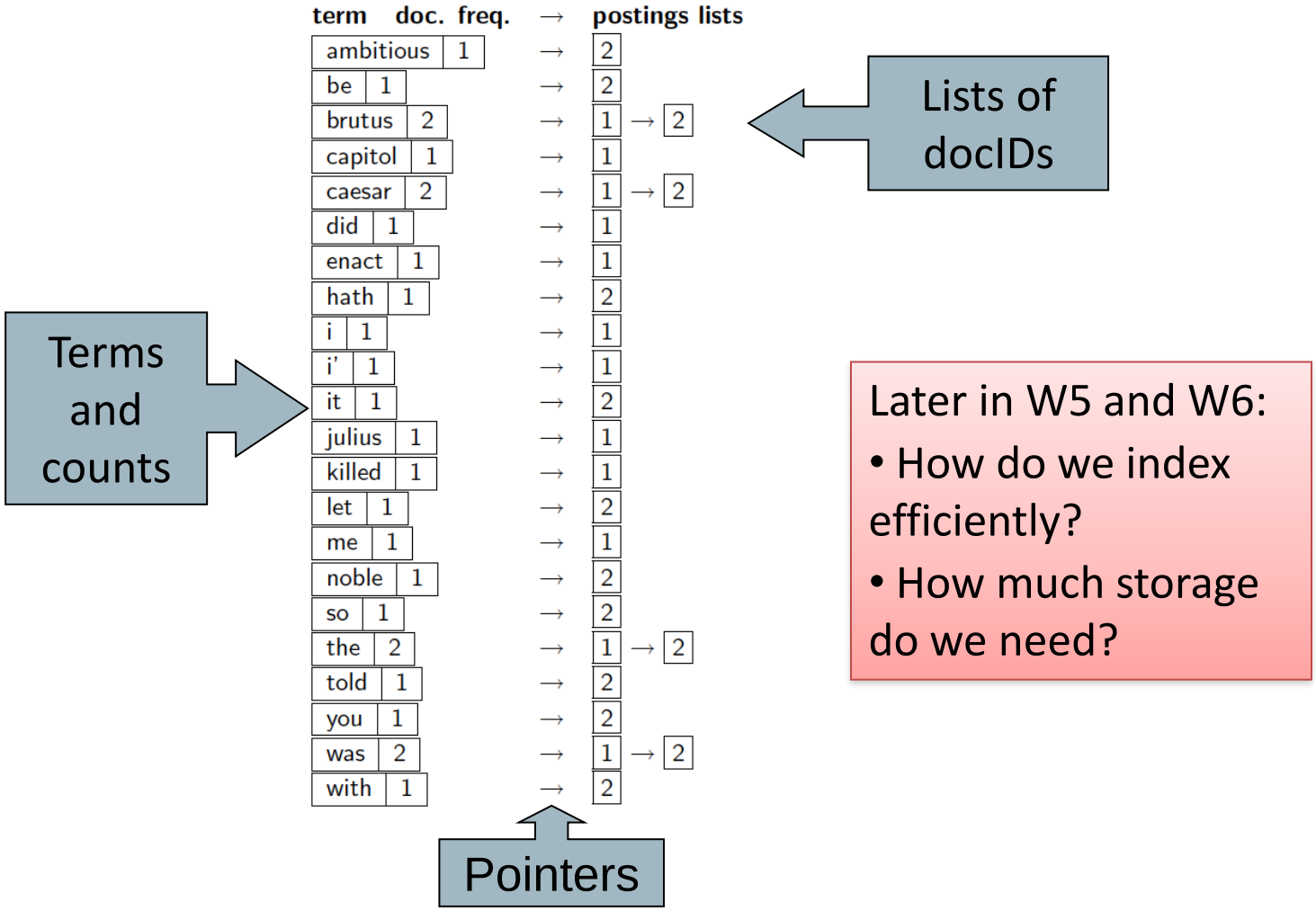
- Multiple term entries in a single document are merged.
- Split into Dictionary and Postings
- Document frequency information is also stored.

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



What do we pay in storage?



Later in W5 and W6:

- How do we index efficiently?
- How much storage do we need?

How do we process queries?

- Boolean queries
  - AND
  - OR
  - NOT
- Basic query optimization

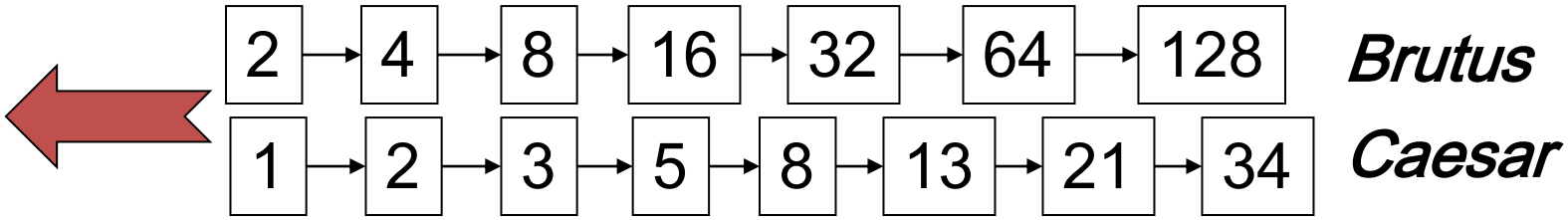
Later in W3 and W4 –
- How to further optimize query processing ?
- What other kinds of queries can we process?

Query processing: AND

- How to process this query?

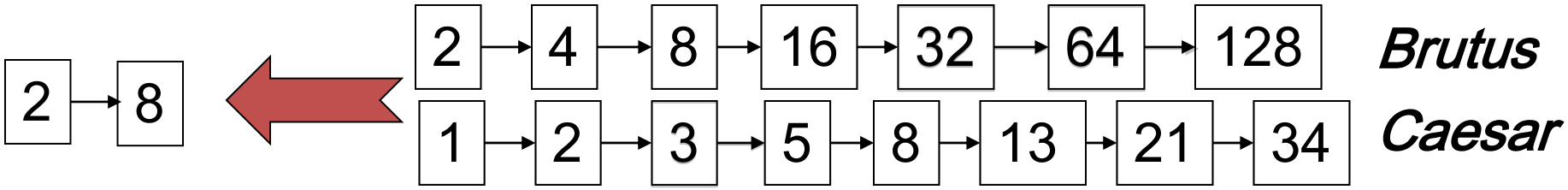
  Brutus *AND* ***Caesar***

  - Locate ***Brutus*** in the Dictionary;
    - Retrieve its postings.
  - Locate ***Caesar*** in the Dictionary;
    - Retrieve its postings.
  - "Merge" the two postings
    - Keep only the common entries.



The merge

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



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

Crucial: postings must be sorted by docID.

Intersecting two postings lists (a "merge" algorithm)

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```
INTERSECT(p1, p2)
 1  answer ← ⟨ ⟩
 2  while p1 ≠ NIL and p2 ≠ NIL
 3  do if docID(p1) = docID(p2)
 4        then ADD(answer, docID(p1))
 5             p1 ← next(p1)
 6             p2 ← next(p2)
 7        else if docID(p1) < docID(p2)
 8                then p1 ← next(p1)
 9                else p2 ← next(p2)
10  return answer
```

Query processing: OR

- How to process this query?

  Brutus *OR* ***Caesar***

  - Locate ***Brutus*** in the Dictionary;
    - Retrieve its postings.
  - Locate ***Caesar*** in the Dictionary;
    - Retrieve its postings.
  - "Merge" the two postings
    - Keep all entries that appear in any of the two postings.

Query processing: NOT

- How to process this query?

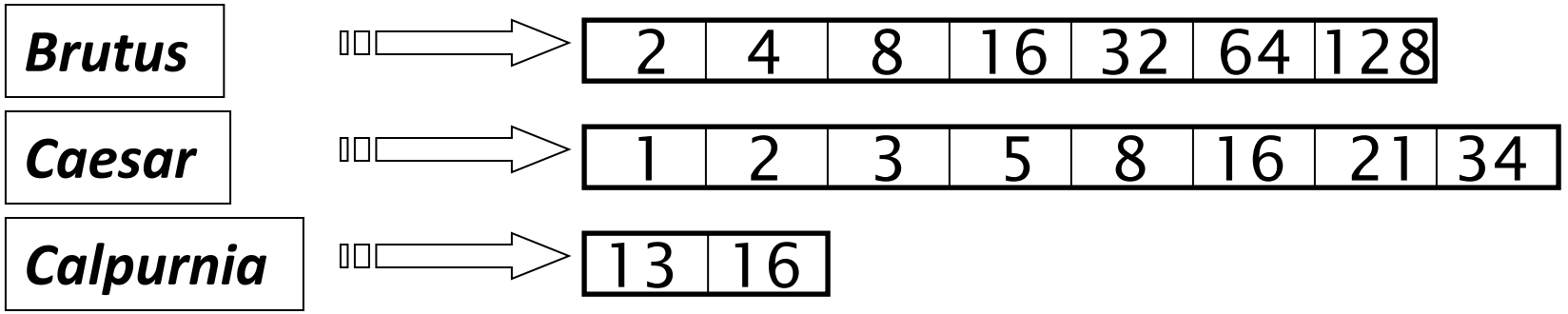
  NOT ***Brutus***

  - Retrieve the full list of documents
  - Locate ***Brutus*** in the Dictionary;
    - Retrieve its postings.
  - "Merge" the full list and the postings
    - Keep all entries that appear the full list but not in the postings.

Query optimization

- Consider a query that is an *AND* of *n* terms.
  Brutus *AND* ***Caesar*** *AND* ***Calpurnia***

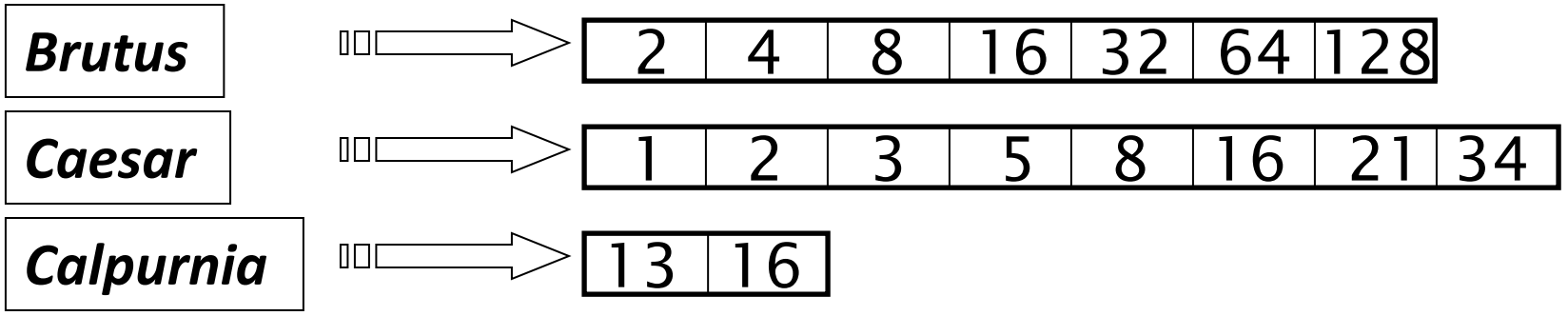
- What is the best order for query processing?



Query optimization example

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

This is why we kept
document frequency in the dictionary!



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

More general optimization

e.g., *(**madding** OR **crowd**) AND (**ignoble** OR **strife**) AND (**killed** OR **slain**)*

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

Check your understanding

- Recommend a query processing order for

***(tangerine** OR **trees)** AND*
***(marmalade** OR **skies)** AND*
(kaleidoscope** OR **eyes)

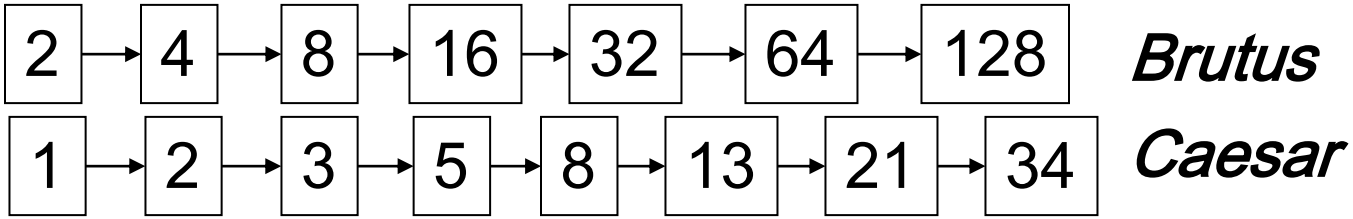
Term	Freq
eyes	213312
kaleidoscop	87009
marmalade	107913
skies	271658
tangerine	46653
trees	316812

Mixing AND/OR with NOT

- How about these queries?

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

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



Question: Can we still process the query in O(*x*+*y*)?

What can we achieve?

Boolean Retrieval

- The Boolean retrieval model is able to process queries which are based on Boolean expressions:
  - Views each document as a set of words
  - Is precise: document matches condition or not.
- Perhaps the simplest model to build an IR system on
- Primary commercial retrieval tool for 3 decades.
- Many search systems you still use are Boolean:
  - E.g., Library Catalog in NUS https://linc.nus.edu.sg/search/Y

Example: WestLaw http://www.westlaw.com/

- Largest commercial (paying subscribers) legal search service (started 1975; ranking added 1992)
  - Tens of terabytes of data; 700,000 users

- Long, precise queries; proximity operators; incrementally developed; not like web search
  - What is the statute of limitations in cases involving the federal tort claims act?
    LIMIT! /3 STATUTE ACTION /S FEDERAL /2 TORT /3 CLAIM
    - /3 = within 3 words, /S = in same sentence

Example: WestLaw http://www.westlaw.com/

- Many professional searchers still like Boolean search
  - You know exactly what you are getting
- But that doesn't mean it actually works better…

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Summary

Covered the whole of information retrieval from 1000 feet up

- Indexing to store information efficiently for both space and query time.
- Run time builds relevant document list. Must be *f a s t*.

Resources for today's lecture

- *Introduction to Information Retrieval*, chapter 1