# Multimedia Information Extraction and Retrieval

## Introduction

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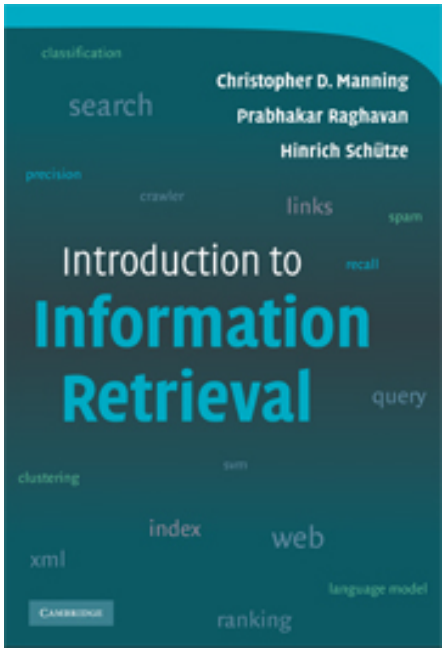
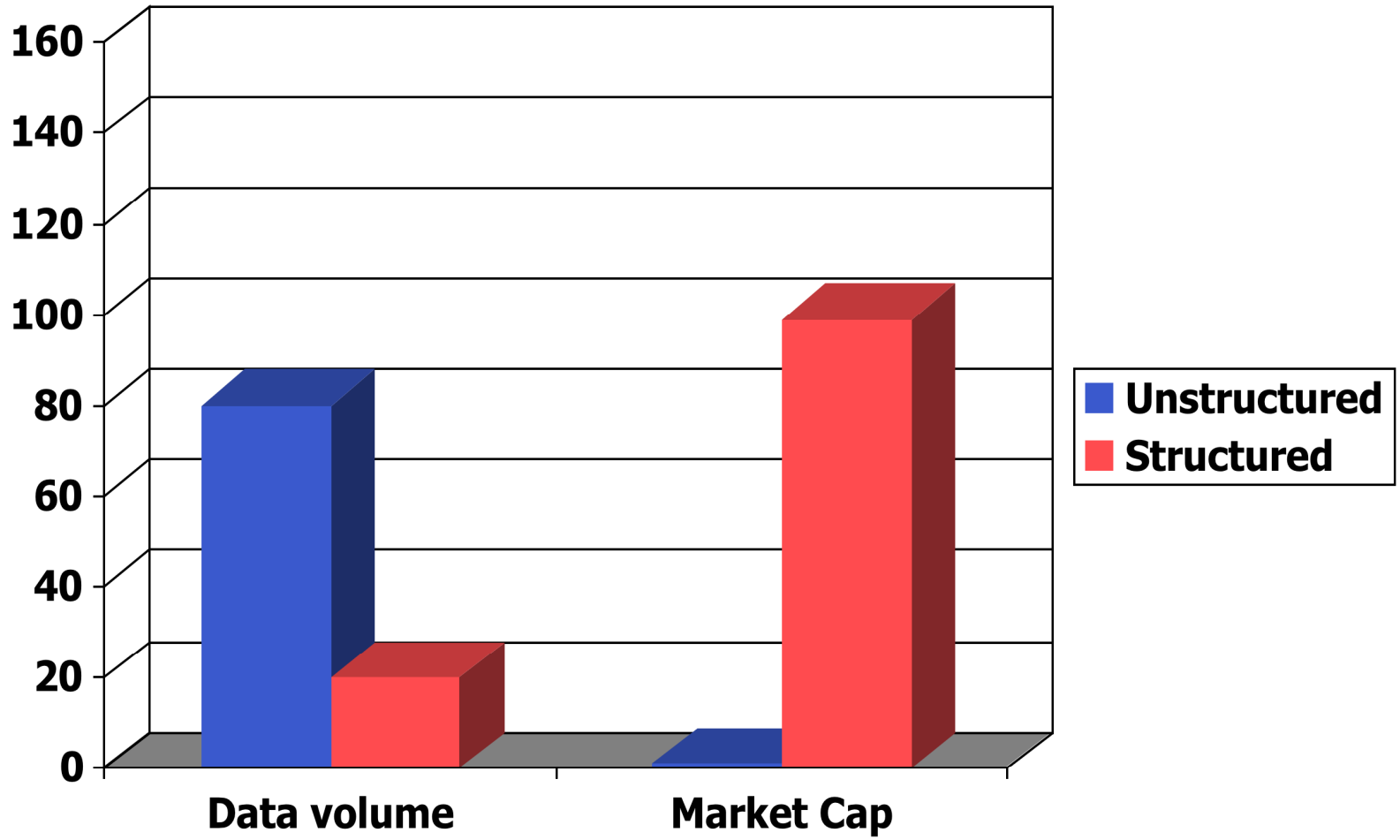
# Literature

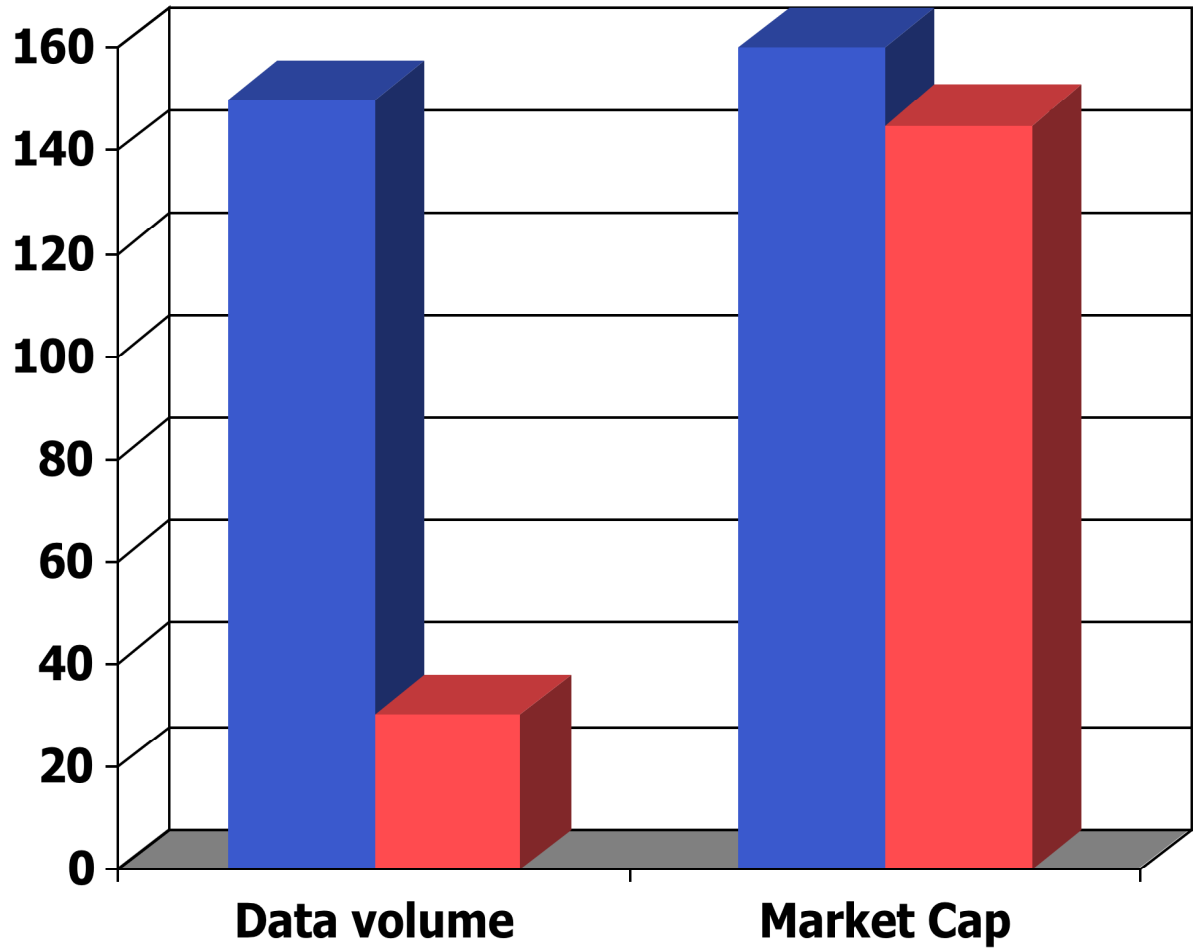
- Christopher D. Manning, Prabhakar Raghavan and Hinrich Schütze, *Introduction to Information Retrieval, Cambridge University Press. 2008.*
- http://nlp.stanford.edu/IR-book/information-retrieval-book.html



# Unstructured (text) vs. structured (database) data in 1996



# Unstructured (text) vs. structured (database) data in 2006




Google

YAHOO!

Ask.com

# Unstructured data in 1650

- Which plays of Shakespeare contain the words ***Brutus*** *AND* ***Caesar*** but *NOT* ***Calpurnia***?
- One could grep all of Shakespeare's plays for ***Brutus*** and ***Caesar,*** then strip out lines containing ***Calpurnia***?
  - Slow (for large corpora)
  - *NOT* ***Calpurnia*** is non-trivial
  - Other operations (e.g., find the word ***Romans*** near ***countrymen***) not feasible
  - Ranked retrieval (best documents to return)
    - Later lectures

# Term-document incidence

| | 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*

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

# Incidence vectors

- So we have a 0/1 vector for each term.
- To answer query: take the vectors for ***Brutus,*** ***Caesar*** and ***Calpurnia*** (complemented) ➨ bitwise *AND*.
- 110100 *AND* 110111 *AND* 101111 = 100100.

# Answers to query

- 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

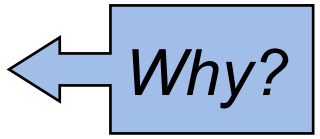
*Lord Polonius:* I did enact Julius ***Caesar*** I was killed i' the
Capitol; ***Brutus*** killed me.

# Bigger corpora

- Consider $N$ = 1M documents, each with about 1K terms.
- Avg 6 bytes/term incl spaces/punctuation
  - 6GB of data in the documents.
- Say there are $m$ = 500K *distinct* terms among these.

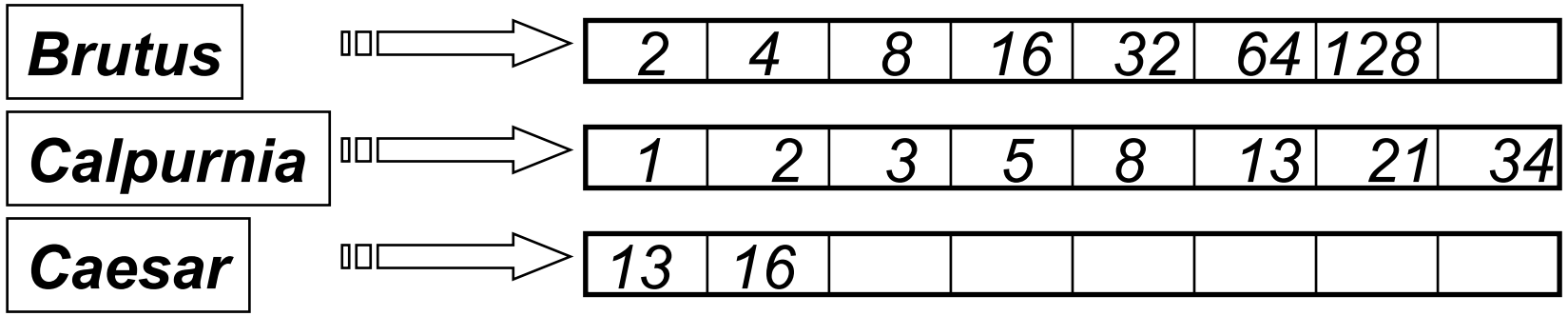
# Can't build the matrix

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



# Inverted index

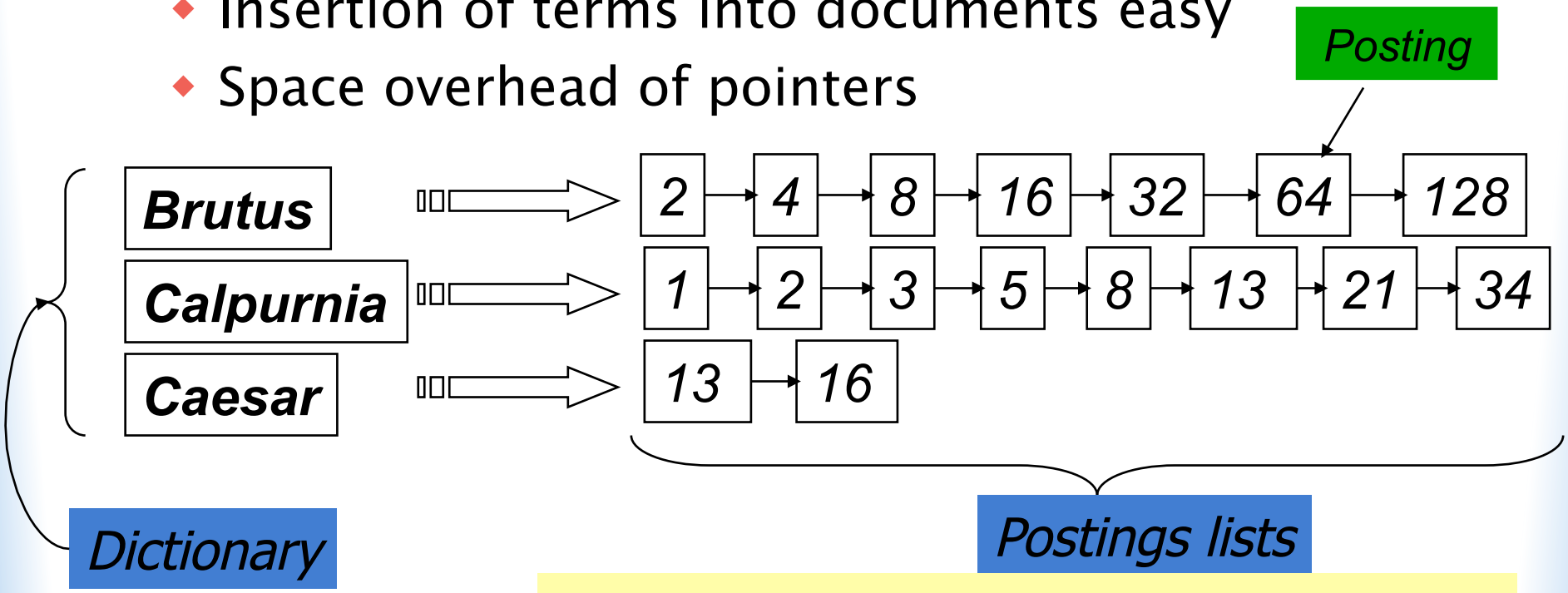
- For each term *T*, we must store a list of all documents that contain *T*.
- Do we use an array or a list for this?




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

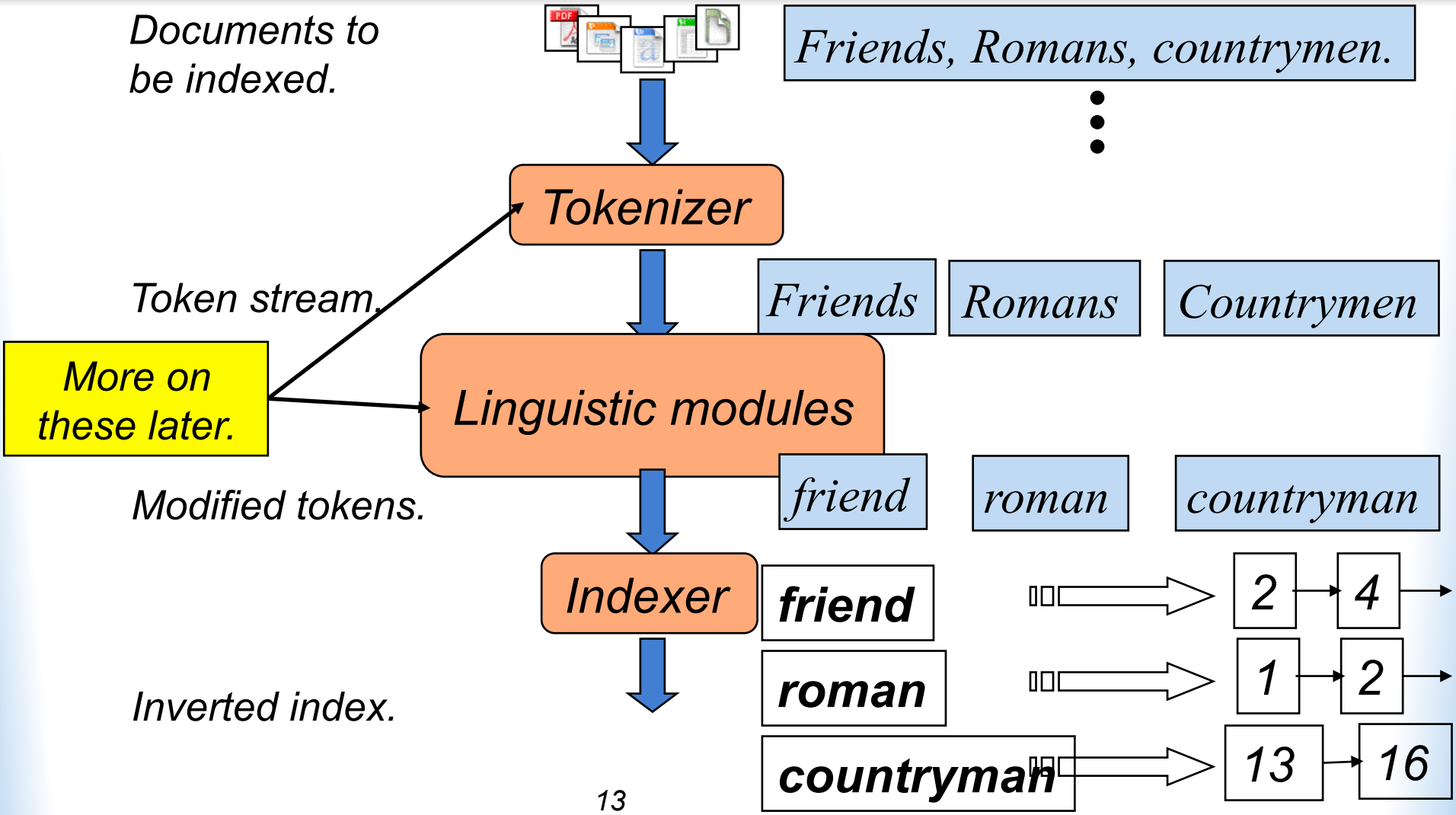
# Inverted index

- Linked lists generally preferred to arrays
  - Dynamic space allocation
  - Insertion of terms into documents easy
  - Space overhead of pointers




Sorted by docID (more later on why).

# Inverted index construction



# Indexer steps

- 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*

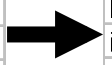
| Term | Doc # |
|---|---|
| I | 1 |
| did | 1 |
| enact | 1 |
| julius | 1 |
| caesar | 1 |
| I | 1 |
| was | 1 |
| killed | 1 |
| i' | 1 |
| the | 1 |
| capitol | 1 |
| brutus | 1 |
| killed | 1 |
| me | 1 |
| so | 2 |
| let | 2 |
| it | 2 |
| be | 2 |
| with | 2 |
| caesar | 2 |
| the | 2 |
| noble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

# Indexer steps

- Sort by terms.

***Core indexing step.***

| Term | Doc # |
|---|---|
| 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 | Doc # |
|---|---|
| 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

- Multiple term entries in a single document are merged.
- Frequency information is added.

*Why frequency? Will discuss later.*

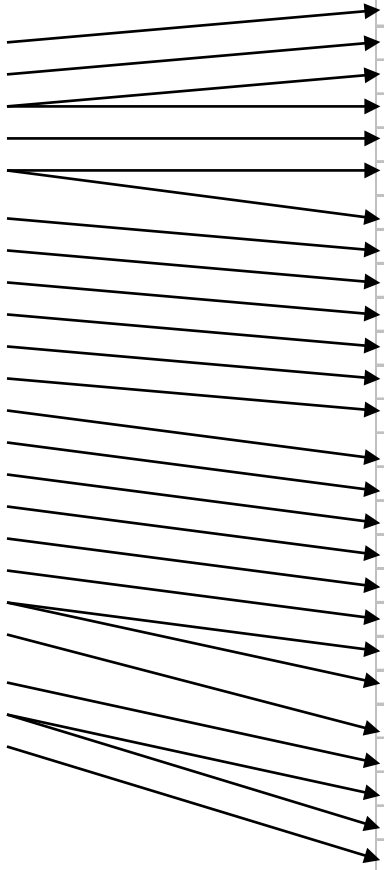
| Term | Doc # |
|---|---|
| ambitious | 2 |
| be | 2 |
| brutus | 1 |
| brutus | 2 |
| capitol | 1 |
| caesar | 1 |
| caesar | 2 |
| caesar | 2 |
| did | 1 |
| enact | 1 |
| hath | 1 |
| I | 1 |
| I | 1 |
| i' | 1 |
| it | 2 |
| julius | 1 |
| killed | 1 |
| killed | 1 |
| let | 2 |
| me | 1 |
| noble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

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

- The result is split into a *Dictionary* file and a *Postings* file.

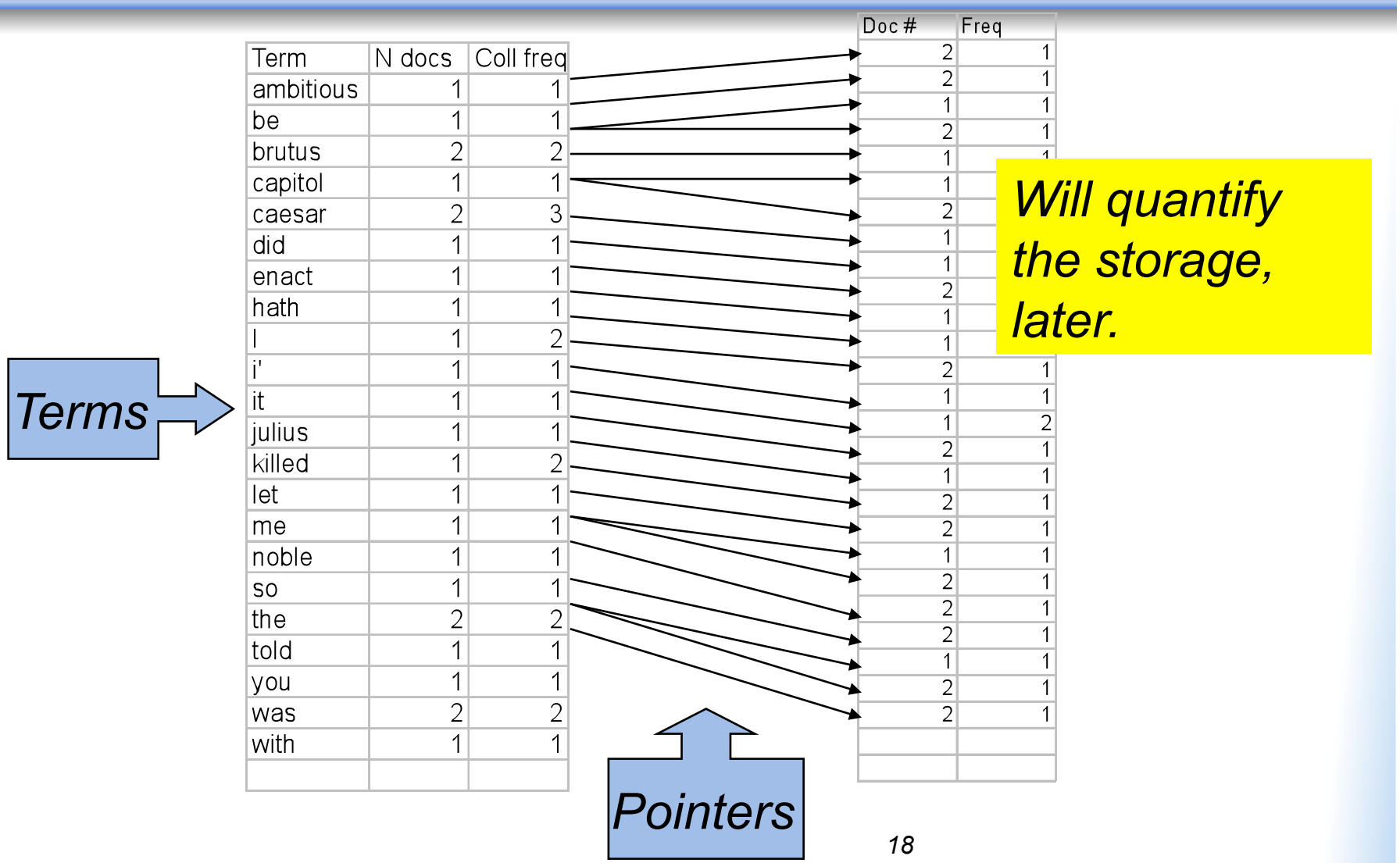
| Term | Doc # | Freq |
|---|---|---|
| ambitious | 2 | 1 |
| be | 2 | 1 |
| brutus | 1 | 1 |
| brutus | 2 | 1 |
| capitol | 1 | 1 |
| caesar | 1 | 1 |
| caesar | 2 | 2 |
| did | 1 | 1 |
| enact | 1 | 1 |
| hath | 2 | 1 |
| I | 1 | 2 |
| i' | 1 | 1 |
| it | 2 | 1 |
| julius | 1 | 1 |
| killed | 1 | 2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

| Term | N docs | Coll freq |
|---|---|---|
| ambitious | 1 | 1 |
| be | 1 | 1 |
| brutus | 2 | 2 |
| capitol | 1 | 1 |
| caesar | 2 | 3 |
| did | 1 | 1 |
| enact | 1 | 1 |
| hath | 1 | 1 |
| I | 1 | 2 |
| i' | 1 | 1 |
| it | 1 | 1 |
| julius | 1 | 1 |
| killed | 1 | 2 |
| let | 1 | 1 |
| me | 1 | 1 |
| noble | 1 | 1 |
| so | 1 | 1 |
| the | 2 | 2 |
| told | 1 | 1 |
| you | 1 | 1 |
| was | 2 | 2 |
| with | 1 | 1 |



| Doc # | Freq |
|---|---|
| 2 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 1 | 1 |
| 1 | 1 |
| 2 | 2 |
| 1 | 1 |
| 1 | 1 |
| 2 | 1 |
| 1 | 2 |
| 1 | 1 |
| 2 | 1 |
| 1 | 1 |
| 1 | 2 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 2 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 2 | 1 |

- Where do we pay in storage?

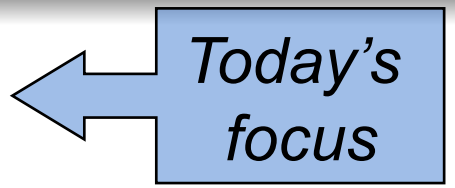



| Term | N docs | Coll freq |
|---|---|---|
| ambitious | 1 | 1 |
| be | 1 | 1 |
| brutus | 2 | 2 |
| capitol | 1 | 1 |
| caesar | 2 | 3 |
| did | 1 | 1 |
| enact | 1 | 1 |
| hath | 1 | 1 |
| I | 1 | 2 |
| i' | 1 | 1 |
| it | 1 | 1 |
| julius | 1 | 1 |
| killed | 1 | 2 |
| let | 1 | 1 |
| me | 1 | 1 |
| noble | 1 | 1 |
| so | 1 | 1 |
| the | 2 | 2 |
| told | 1 | 1 |
| you | 1 | 1 |
| was | 2 | 2 |
| with | 1 | 1 |

| Doc # | Freq |
|---|---|
| 2 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 1 | 1 |
| 1 | 2 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 2 | 1 |
| 2 | 1 |
| 1 | 1 |
| 2 | 1 |
| 2 | 1 |

# The index we just built

- How do we process a query?
  - Later – what kinds of queries can we process?

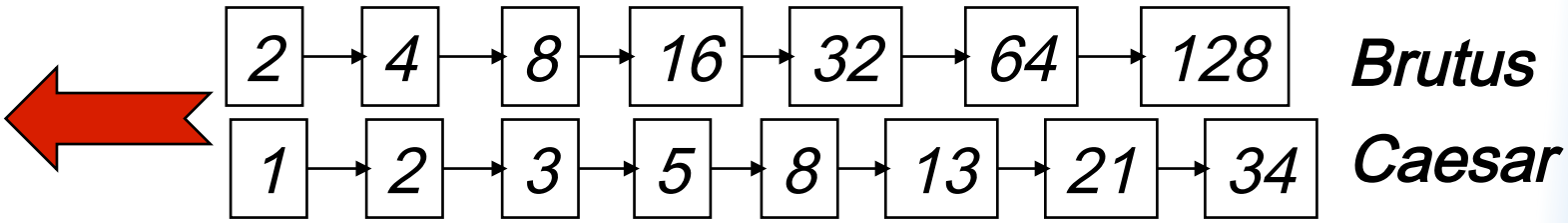


# Query processing: AND

- Consider processing the query:

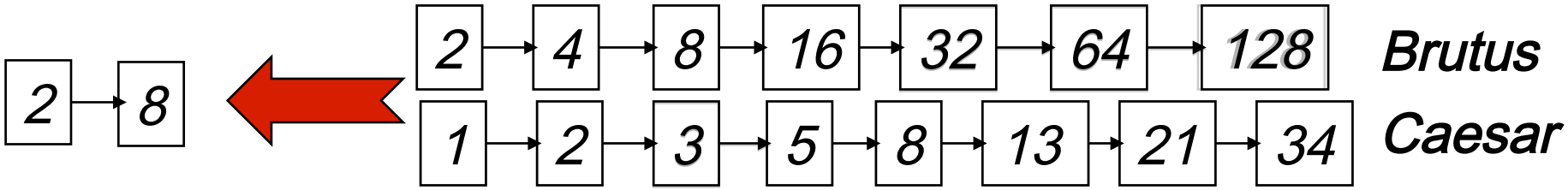
  ***Brutus*** *AND* ***Caesar***

  - Locate ***Brutus*** in the Dictionary;
    - Retrieve its postings.
  - Locate *Caesar* in the Dictionary;
    - Retrieve its postings.
  - "Merge" the two postings:



# 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 sorted by docID.*

# Boolean queries: Exact match

- The Boolean Retrieval model is being able to ask a query that is a Boolean expression:
  - Boolean Queries are queries using *AND*, *OR* and *NOT* to join query terms
    - Views each document as a set of words
    - Is precise: document matches condition or not.
- Primary commercial retrieval tool for 3 decades.
- Professional searchers (e.g., lawyers) still like Boolean queries:
  - You know exactly what you're getting.

# 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
- Majority of users *still* use boolean queries
- Example query:
  - 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/**

- Another example query:
  - Requirements for disabled people to be able to access a workplace
  - disabl! /p access! /s work-site work-place (employment /3 place
- Note that SPACE is disjunction, not conjunction!
- Long, precise queries; proximity operators; incrementally developed; not like web search
- Professional searchers often like Boolean search:
  - Precision, transparency and control
- But that doesn't mean they actually work better….

# 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 ($x+y$) or what can we achieve?

# Merging

What about an arbitrary Boolean formula?

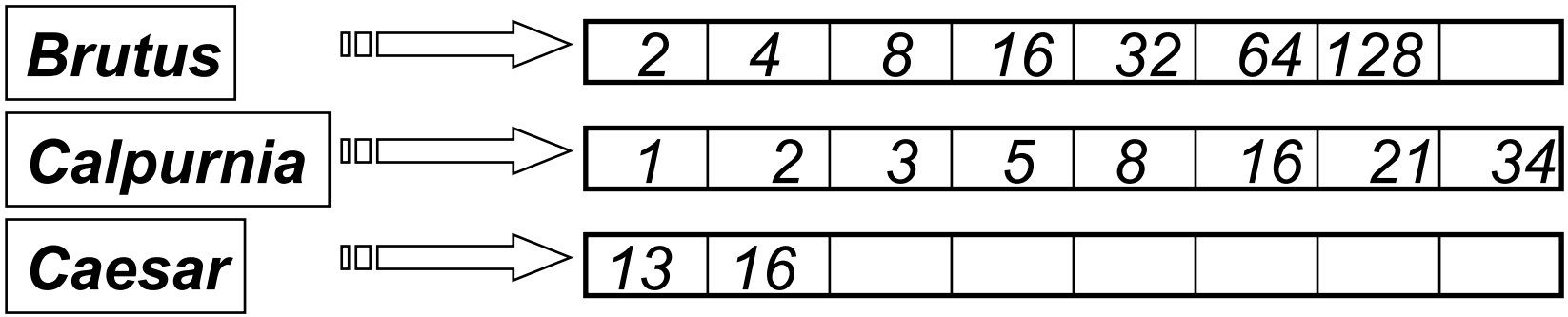
***(Brutus** OR **Caesar)** AND NOT*

***(Antony** OR **Cleopatra)***

- Can we always merge in "linear" time?
  - Linear in what?
- Can we do better?

# Query optimization

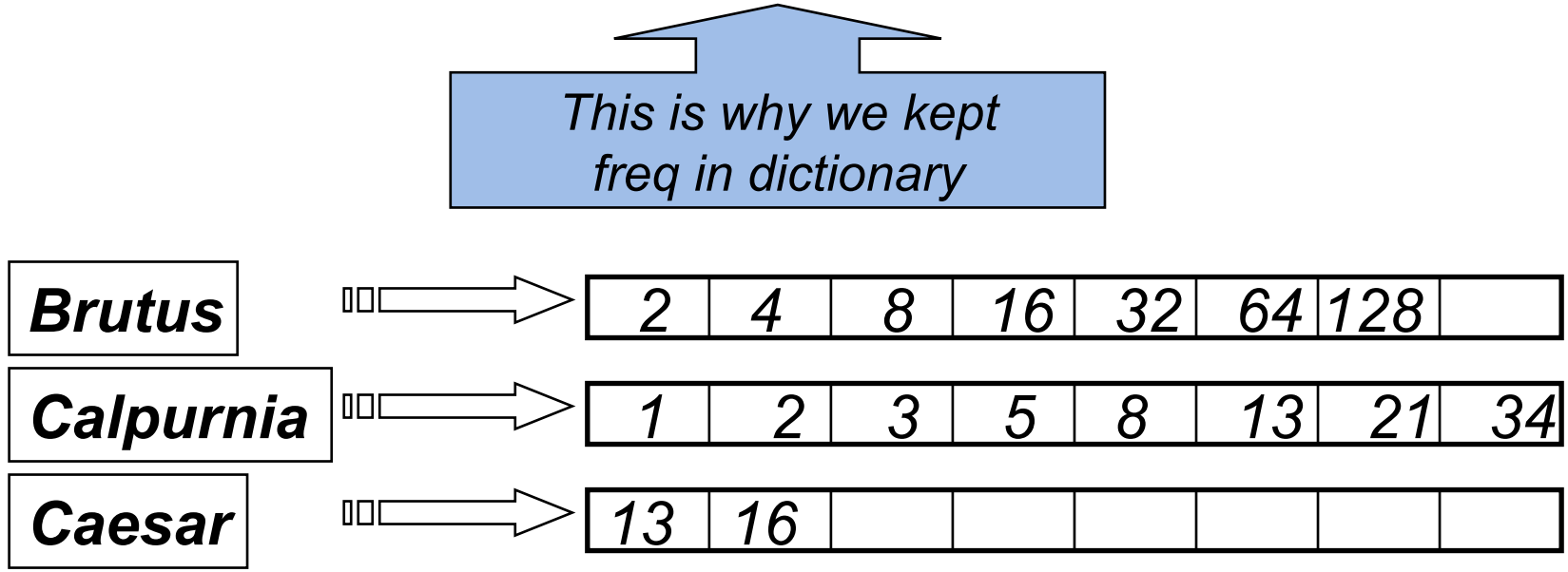
- What is the best order for query processing?
- Consider a query that is an *AND* of *t* terms.
- For each of the *t* terms, get its postings, then *AND* them together.




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

# Query optimization example

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




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

# More general optimization

- E.g., *(**madding** OR **crowd**) AND (**ignoble** OR **strife**)*
- Get freq's for all terms.
- Estimate the size of each *OR* by the sum of its freq's (conservative).
- Process in increasing order of *OR* sizes.

# Exercise

- Recommend a query processing order for

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

| Term | Freq |
|---|---|
| eyes | 213312 |
| kaleidoscope | 87009 |
| marmalade | 107913 |
| skies | 271658 |
| tangerine | 46653 |
| trees | 316812 |

# Query processing exercises

- If the query is ***friends*** *AND* ***romans*** *AND (NOT* ***countrymen****),* how could we use the freq of ***countrymen***?
- Exercise: Extend the merge to an arbitrary Boolean query. Can we always guarantee execution in time linear in the total postings size?
- Hint: Begin with the case of a Boolean *formula* query: in this, each query term appears only once in the query.

# What's ahead in IR? Beyond term search

- What about phrases?
  - ***Stanford University***
- Proximity: Find ***Gates*** *NEAR* ***Microsoft***.
  - Need index to capture position information in docs. More later.
- Zones in documents:
  Find documents with
  (*author* = ***Ullman***) *AND* (text contains ***automata***).

# Evidence accumulation

- 1 vs. 0 occurrence of a search term
  - 2 vs. 1 occurrence
  - 3 vs. 2 occurrences, etc.
  - Usually more seems better
- Need term frequency information in docs

# Ranking search results

- Boolean queries give inclusion or exclusion of docs.
- Often we want to rank/group results
  - Need to measure proximity from query to each doc.
  - Need to decide whether docs presented to user are singletons, or a group of docs covering various aspects of the query.

# IR vs. databases: Structured vs unstructured data

- Structured data tends to refer to information in "tables"

| *Employee* | *Manager* | *Salary* |
|---|---|---|
| *Smith* | *Jones* | *50000* |
| *Chang* | *Smith* | *60000* |
| *Ivy* | *Smith* | *50000* |

*Typically allows numerical range and exact match (for text) queries, e.g.,*
*Salary < 60000 AND Manager = Smith.*

# Unstructured data

- Typically refers to free text
- Allows
  - Keyword queries including operators
  - More sophisticated “concept” queries e.g.,
    - find all web pages dealing with *drug abuse*
- Classic model for searching text documents

# Semi-structured data

- In fact almost no data is “unstructured”
- E.g., this slide has distinctly identified zones such as the *Title* and *Bullets*
- Facilitates “semi-structured” search such as
  - *Title* contains data AND *Bullets* contain search

… to say nothing of linguistic structure

# More sophisticated semi-structured search

- *Title* is about Object Oriented Programming AND *Author* something like stro*rup
- where * is the wild-card operator
- Issues:
  - how do you process “about”?
  - how do you rank results?
- The focus of XML search.

# Clustering and classification

- Given a set of docs, group them into clusters based on their contents.
- Given a set of topics, plus a new doc *D*, decide which topic(s) *D* belongs to.

# The web and its challenges

- Unusual and diverse documents
- Unusual and diverse users, queries, information needs
- Beyond terms, exploit ideas from social networks
  - link analysis, clickstreams ...
- How do search engines work? And how can we make them better?

# More sophisticated *information* retrieval

- Cross-language information retrieval
- Question answering
- Summarization
- Text mining
- …