# CS7330 Introduction to Web Search and Mining



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# Kenny Q. Zhu

## Research Interests:

**NLP & Knowledge Engineering**
Information extraction
Knowledge discovery
Commonsense reasoning
Text generation (Dialogue/QA/QG/Summarization)

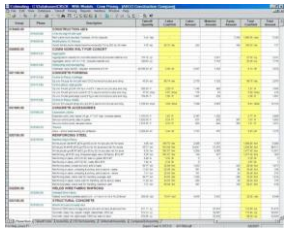
**Programming Languages**
Concurrent and Distributed Languages
Data Processing
Probabilistic Programming

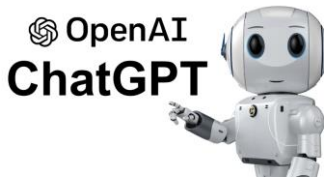
## Recent Publications:

WWW, AAAI, IJCAI, ACL, EMNLP, SIGMOD

Degrees: ***National University of Singapore***
Postdoc: ***Princeton University***
Experiences: *Microsoft Redmond, USA*
*Microsoft Research Asia*
Faculty Member (PhD. Advisor) at *SJTU* since 2009
Director of **ADAPT Lab**

# Evolution of Information Retrieval




Library Science

Before 1950's

Data Mining/
Info Retrieval

After 1950's

Web Search &
Mining

After 1995

QA, Summary
& ChatBots

After 2015

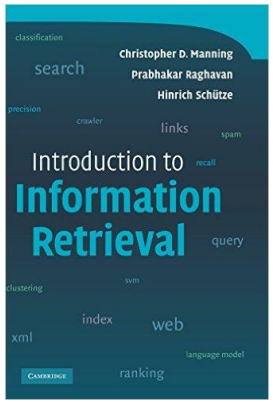
Term &
Vector based

Large
Language
Model based

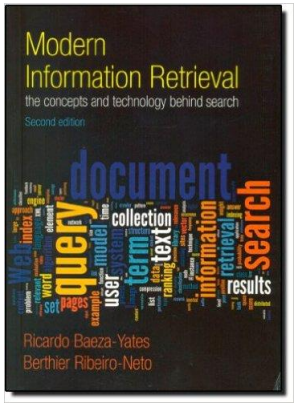
# Administrative Info (I)

- All-English Course: everything in English!
- Lecturer:
  - Kenny Zhu, SEIEE #03-407, kzhu@cs.sjtu.edu.cn
  - Office hours: by appointment or after class
- Teaching Assistant:
  - Apple Chen, SEIEE #03-329, chp33@126.com
  - Xukai Wang, SEIEE #03-329, wangxukai@sjtu.edu.cn
  - Office hours: Thursday 16:00 - 17:00
- Course Web Page (definitive source!): http://www.cs.sjtu.edu.cn/~kzhu/wsm/

# Administrative Info (II)




- Format:
  - Lectures on Friday (3 periods with 1-2 breaks)
  - Part of lectures may be tutorials – Led by TAs; Your participation is REQUIRED!




- Reference Texts:
  - Introduction to Information Retrieval, by Christopher D. Manning and Prabhakar Raghavan
  - Modern Information Retrieval: The Concepts and Technology behind Search (2nd Edition), by Ricardo Baeza-Yates, Berthier Ribeiro-Neto
  - Other research papers
  - Web Data Mining: Exploring Hyperlinks, Contents, and Usage Data (Data-Centric Systems and Applications), by Bing Liu
- Lecture materials on course web page

# Administrative Info (III)

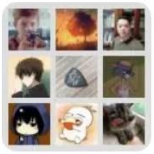
- 2-credit course
- Modes of Assessment:
  - In-class quizzes: 30%
  - Assignments: 30%
  - Programming Project: 40%
- Quizzes
  - Given out at random times during class.
  - Submit to me immediately after class.
- Tutorials (ad hoc)
  - Discuss hard assignment questions and also issues in project.
  - You may be asked to present your answers.
  - Volunteer to win bonus points!

# Administrative Info (IV)

- Assignments
  - Released (usually) on weekend
  - Due date printed on assignment sheet
  - Submit to OC by the due date
  - Late submission: -30% of full score for each additional day

- Programming Project
  - Group project (max 3 people)
  - Implement a crawler to crawl large amount of data and then develop a search engine for the data
  - Produce a report + code + data: due end of semester
  - More details on the course website

# WECHAT GROUP



Group: WSM 2023

Valid until 2/24 and will update upon joining group

# Disclaimer

- Part of the materials in this presentation were adapted from the slides created by Manning et al. of Stanford University and Schütze et al. of University of Stuttgart.

# Boolean Retrieval

# Outline

- Introduction
- Inverted index
- Processing Boolean queries
- Query optimization

# Definition of *information retrieval*

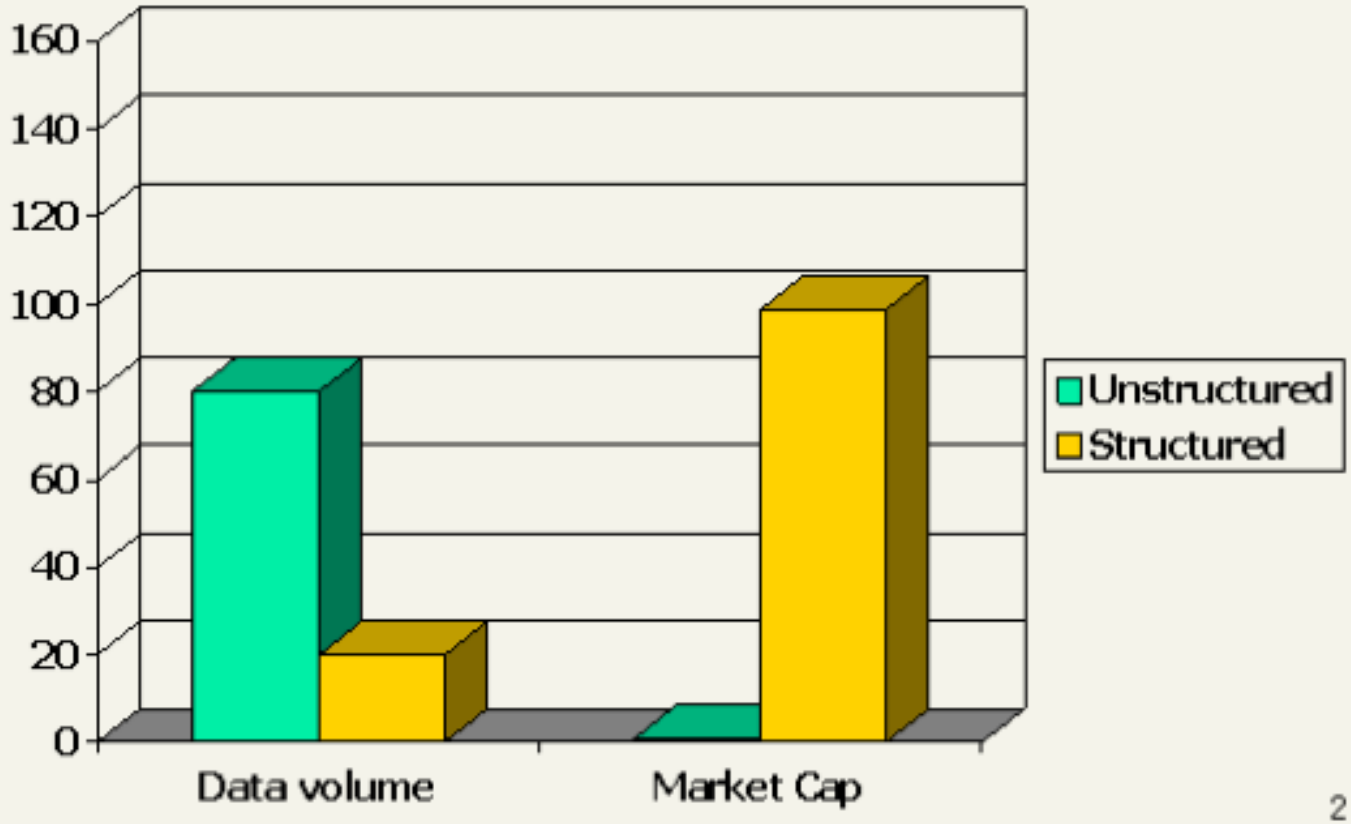
Information retrieval (IR) is finding material (usually documents) of an unstructured nature (usually text) that satisfies an information need from within large collections (usually stored on computers).

# How good are the retrieved docs?

- *Precision* : Fraction of retrieved docs that are relevant to the user's information need
- *Recall* : Fraction of relevant docs in collection that are retrieved

  - More precise definitions and measurements to follow later

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

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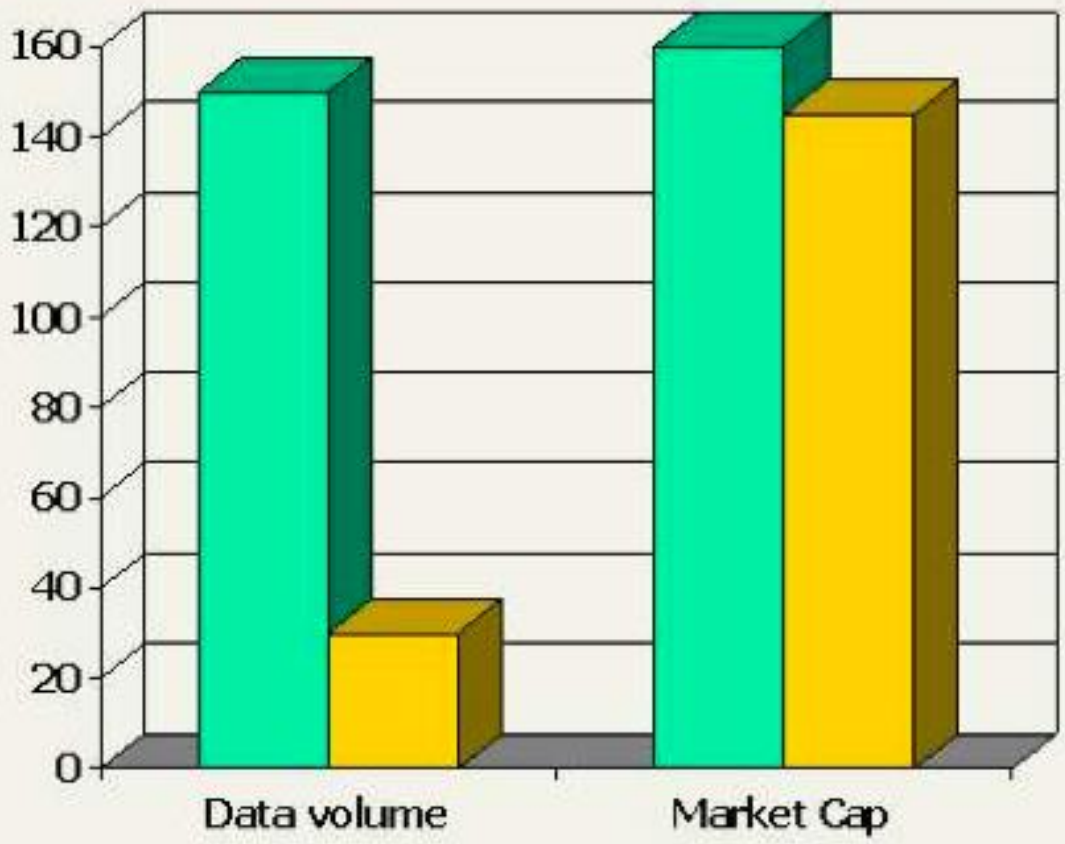
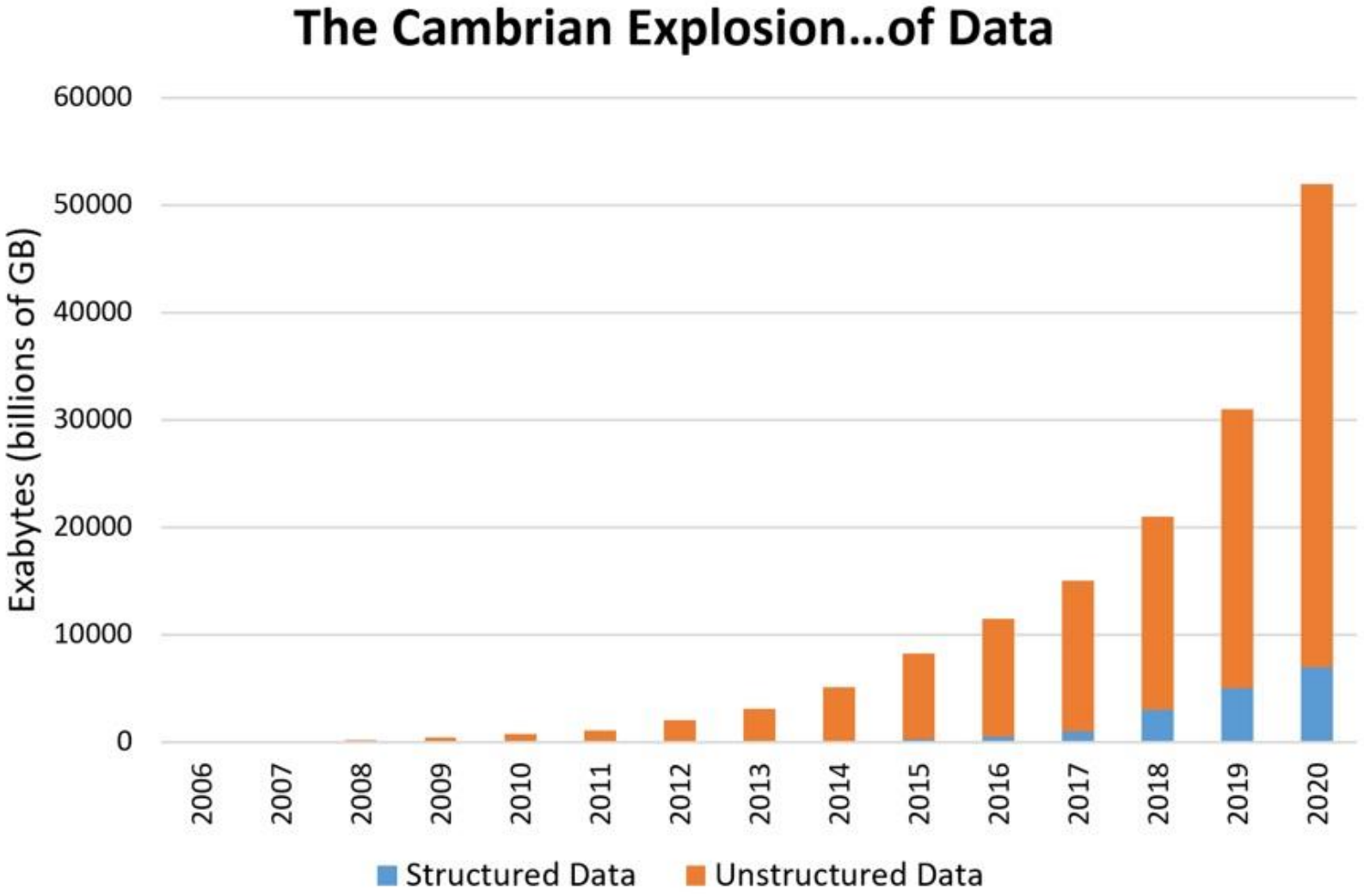
# Unstructured (text) vs. structured (database) data in 2006



# After 2006…


The Cambrian Explosion…of Data
Exabytes (billions of GB)
60000
50000
40000
30000
20000
10000
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Structured Data
Unstructured Data

# Boolean retrieval

- The Boolean model is arguably the simplest model to base an information retrieval system on.
- Queries are Boolean expressions, e.g., CAESAR AND BRUTUS
- The search engine returns all documents that satisfy the Boolean expression.

# Does Google use the Boolean model?

- On Google, the default interpretation of a query [$w_1$ $w_2$ . . .$w_n$] is $w_1$ AND $w_2$ AND . . .AND $w_n$
- Cases where you get hits that do not contain one of the $w_i$ :
  - anchor text to the page contains $w_i$
  - page contains variant of $w_i$ (morphology, spelling correction, synonym)
  - long queries ($n$ large)
  - boolean expression generates very few hits
- Simple Boolean vs. Ranking of result set
  - Simple Boolean retrieval returns matching documents in no particular order.
  - Google (and most well designed Boolean engines) rank the result set – they rank good hits (according to some estimator of relevance) higher than bad hits.

# Quiz

Does Baidu use the simple Boolean model?

a) Yes

b) No

# Outline

- Introduction
- Inverted index
- Processing Boolean queries
- Query optimization

# Unstructured data in 1650: Shakespeare

# 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
- Why isn't "grep" a good solution?
  - Slow (for large collections)
  - grep is line-oriented, IR is document-oriented
  - "NOT CALPURNIA" is non-trivial
  - Other operations (e.g., find where word ROMANS near COUNTRYMAN ) not feasible

# Term-document incidence matrix

| | Anthony and Cleopatra | Julius Caesar | The Tempest | Hamlet | Othello | Macbeth |
|---|---|---|---|---|---|---|
| ANTHONY | 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 |
| . . . | | | | | | |

Entry is 1 if term occurs. Example: CALPURNIA occurs in *Julius Caesar*. Entry is 0 if term doesn't occur. Example: CALPURNIA doesn't occur in *The tempest*.

# Incidence vectors

- So we have a 0/1 vector for each term.
- To answer the query BRUTUS AND CAESAR AND NOT CALPURNIA:
  - Take the vectors for BRUTUS, CAESAR AND NOT CALPURNIA
  - Complement the vector of CALPURNIA
  - Do a (bitwise) **and** on the three vectors
  - 110100 AND 110111 AND 101111 = 100100

# 0/1 vector for BRUTUS AND CAESAR AND NOT CALPURNIA:

| | Anthony and Cleopatra | Julius Caesar | The Tempest | Hamlet | Othello | Macbeth |
|---|---|---|---|---|---|---|
| ANTHONY | 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 |
| . . . | | | | | | |
| result: | 1 | 0 | 0 | 1 | 0 | 0 |

# Answers to query

*Anthony 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

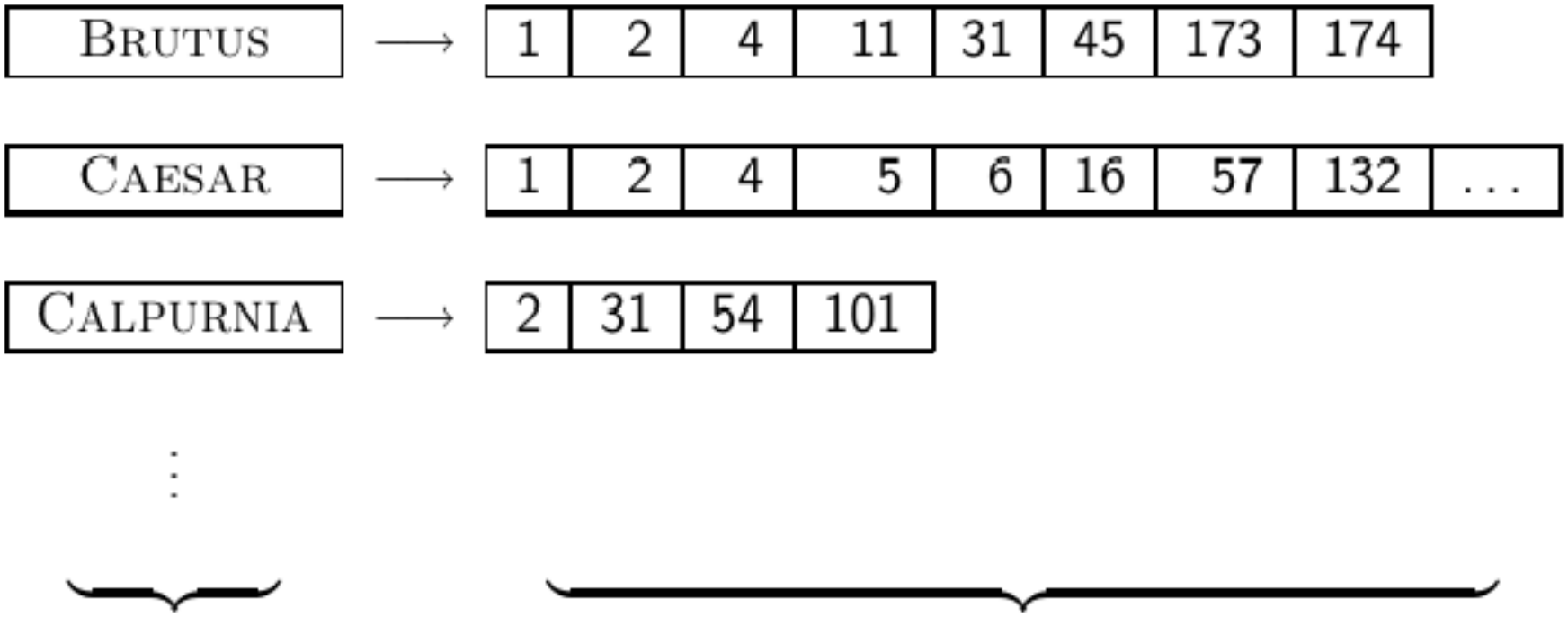
- Consider $N = 10^6$ documents, each with about 1000 tokens
- ⇒ total of $10^9$ (1 billion) tokens
- On average 6 bytes per token, including spaces and punctuation
- ⇒ size of document collection is about $6 \cdot 10^9 = 6$ GB
- Assume there are $M = 500{,}000$ distinct terms in the collection
- (Notice that we are making a term/token distinction.)

# Can't build the incidence matrix

- $M = 500{,}000 \times 10^6$ = half a trillion 0s and 1s.
- But the matrix has no more than one billion 1s.
  - Matrix is extremely sparse.
- What is a better representations?
  - We only record the 1s.

# Inverted Index

For each term $t$, we store a list of all documents that contain $t$.



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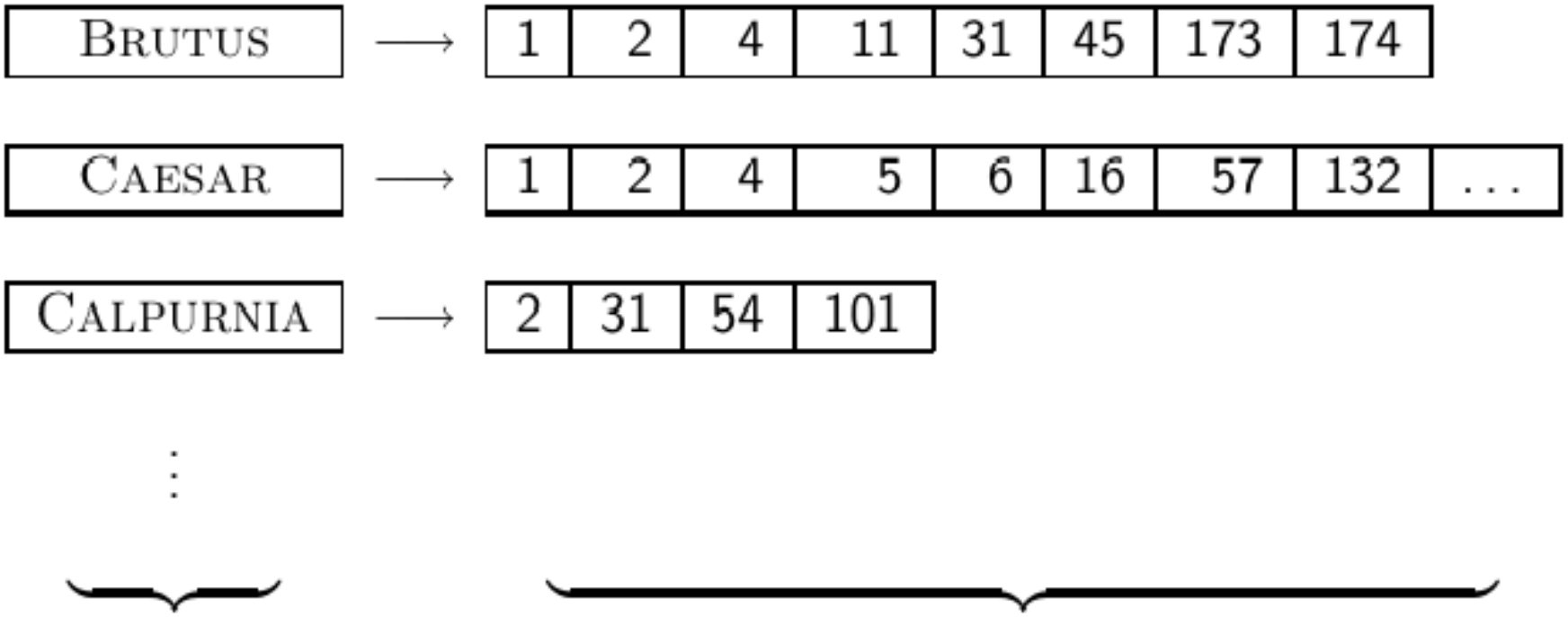

# Inverted Index

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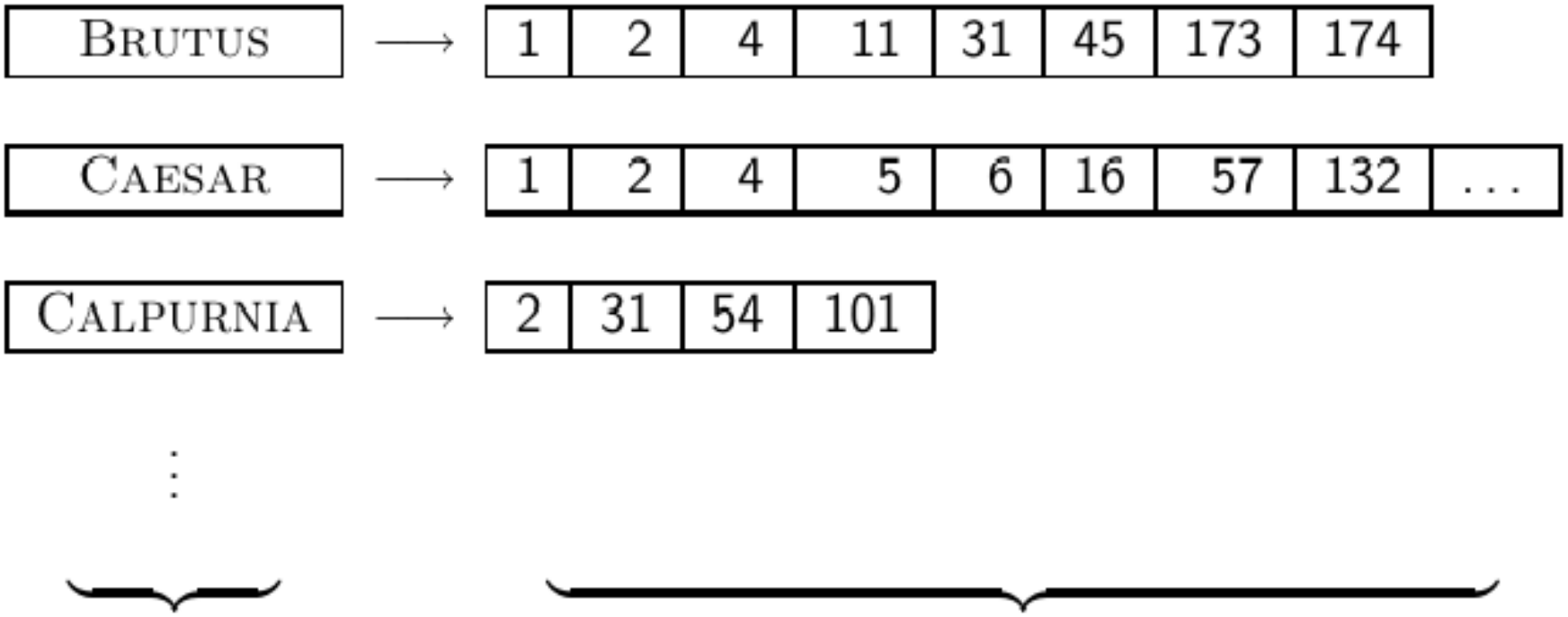
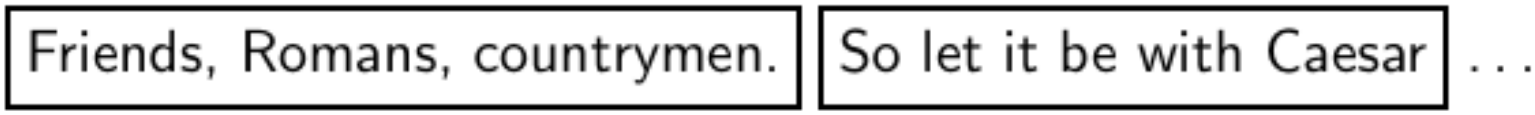


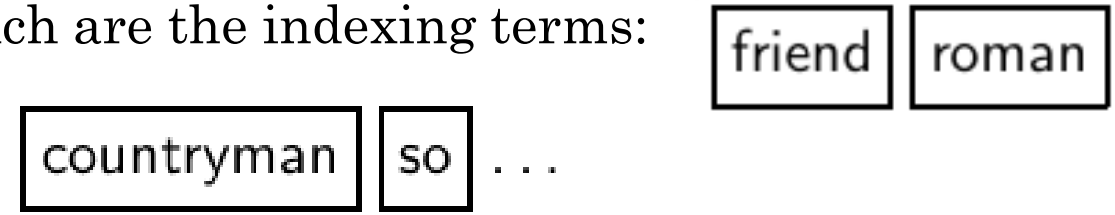
# Inverted index construction

1. Collect the documents to be indexed:




2. Tokenize the text, turning each document into a list of tokens:


3. Do linguistic preprocessing, producing a list of normalized tokens, which are the indexing terms:




4. Index the documents that each term occurs in by creating an inverted index, consisting of a dictionary and postings.

# Initial stages of text processing

- Tokenization
  - Cut character sequence into word tokens
    - Deal with ***"John's"***, ***a state-of-the-art solution***
- Normalization
  - Map text and query term to same form
    - You want ***U.S.A.*** and ***USA*** to match
- Stemming
  - We may wish different forms of a root to match
    - ***authorize***, ***authorization***
- Stop words
  - We may omit very common words (or not)
    - ***the, a, to, of***

# Tokenizing and preprocessing

**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:

**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

# Generate posting

**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 |

# Sort postings

| 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 |

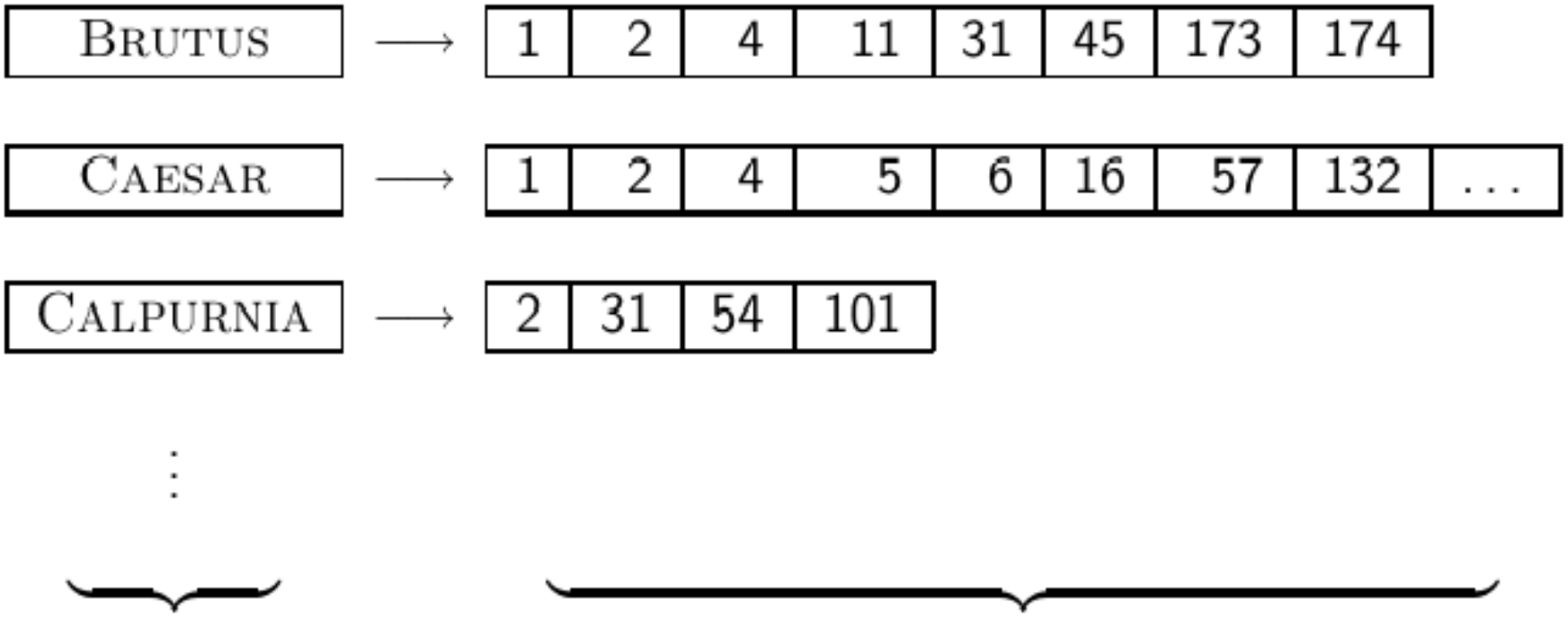
| term | docID |
|---|---|
| ambitious | 2 |
| be | 2 |
| brutus | 1 |
| brutus | 2 |
| capitol | 1 |
| caesar | 1 |
| caesar | 2 |
| caesar | 2 |
| did | 1 |
| enact | 1 |
| hath | 1 |
| i | 1 |
| i | 1 |
| i' | 1 |
| it | 2 |
| julius | 1 |
| killed | 1 |
| killed | 1 |
| let | 2 |
| me | 1 |
| noble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

# Create postings lists, determine document frequency

| 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 |

# Split the result into dictionary and postings file



# Later in this course

- Index construction: how can we create inverted indexes for large collections?
- How much space do we need for dictionary and index?
- Index compression: how can we efficiently store and process indexes for large collections?
- Ranked retrieval: what does the inverted index look like when we want the "best" answer?

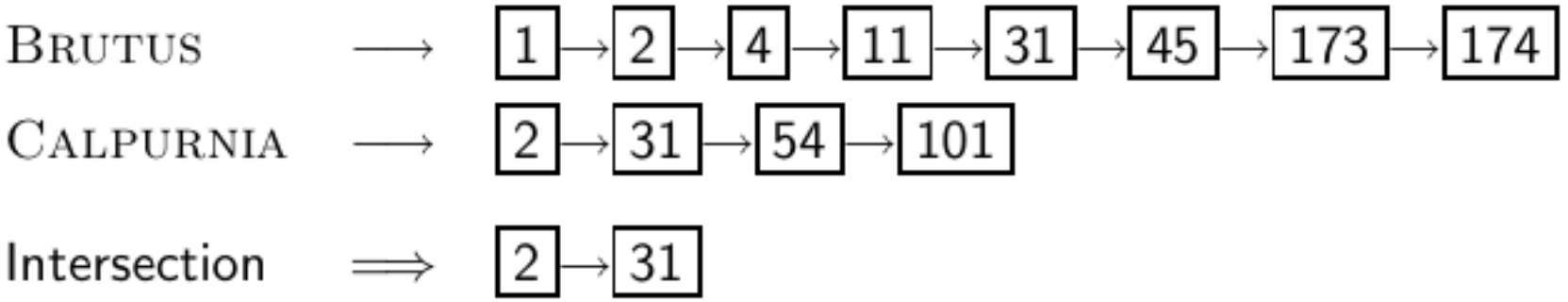
# Outline

- Introduction
- Inverted index
- Processing Boolean queries
- Query optimization

# Simple conjunctive query (two terms)

- Consider the query: BRUTUS AND CALPURNIA
- To find all matching documents using inverted index:
  1. Locate BRUTUS in the dictionary
  2. Retrieve its postings list from the postings file
  3. Locate CALPURNIA in the dictionary
  4. Retrieve its postings list from the postings file
  5. Intersect the two postings lists
  6. Return intersection to user

# Intersecting two posting lists

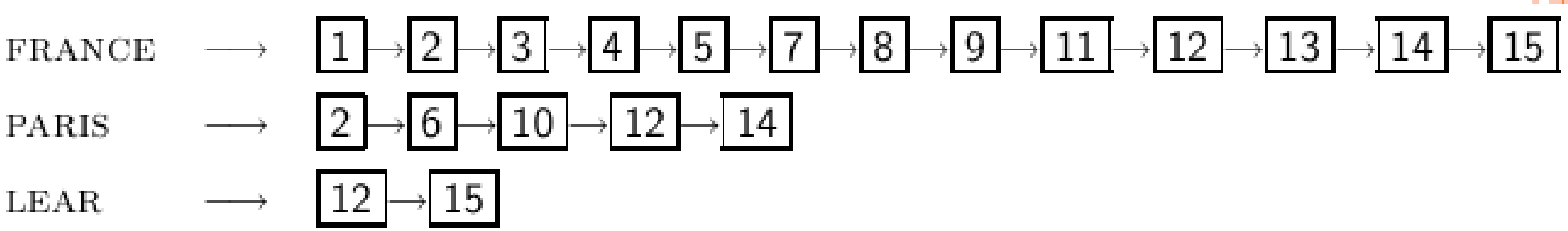



- This is linear in the length of the postings lists.
- Note: This only works if postings lists are sorted.

# Intersecting two posting lists

```
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
```

# Quiz: Query processing




Compute matching docs for

((paris AND NOT france) OR lear)

# Boolean queries

- The Boolean retrieval model can answer any query that is a Boolean expression.
  - Boolean queries are queries that use AND, OR and NOT to join query terms.
  - Views each document as a set of terms.
  - Is precise: Document matches condition or not.
- Primary commercial retrieval tool for 3 decades
- Many professional searchers (e.g., lawyers) still like Boolean queries.
  - You know exactly what you are getting.
- Many search systems you use are also Boolean: spotlight, email, intranet etc.

# Commercially successful Boolean retrieval: Westlaw

- Largest commercial legal search service in terms of the number of paying subscribers
- Over half a million subscribers performing millions of searches a day over tens of terabytes of text data
- The service was started in 1975.
- In 2005, Boolean search (called "Terms and Connectors" by Westlaw) was still the default, and used by a large percentage of users . . .
- . . . although ranked retrieval has been available since 1992.

# Westlaw: Example queries

*Information need*: Information on the legal theories involved in preventing the disclosure of trade secrets by employees formerly employed by a competing company

*Query*: "trade secret" /s disclos! /s prevent /s employe!

*Information need*: Requirements for disabled people to be able to access a workplace
Query: disab! /p access! /s work-site work-place (employment /3 place)

*Information need*: Cases about a host's responsibility for drunk guests
*Query*: host! /p (responsib! liab!) /p (intoxicat! drunk!) /p guest

# Westlaw: Comments

- Proximity operators: /3 = within 3 words, /s = within a sentence, /p = within a paragraph
- Space is disjunction, not conjunction! (This was the default in search pre-Google.)
- Long, precise queries: incrementally developed, not like web search
- Why professional searchers often like Boolean search: precision, transparency, control
- When are Boolean queries the best way of searching? Depends on: information need, searcher, document collection, . . .

# Outline

- Introduction
- Inverted index
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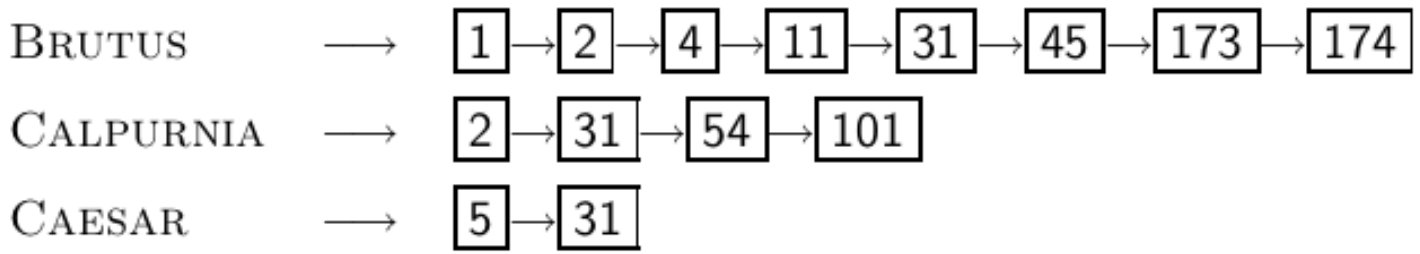
- Query optimization

# Query optimization

- Consider a query that is an **and** of $n$ terms, $n > 2$
- For each of the terms, get its postings list, then **and** them together
- Example query: BRUTUS AND CALPURNIA AND CAESAR
- What is the best order for processing this query?

# Query optimization

- Example query: BRUTUS AND CALPURNIA AND CAESAR
- Simple and effective optimization: Process in order of increasing frequency
- Start with the shortest postings list, then keep cutting further
- In this example, first CAESAR, then CALPURNIA, then BRUTUS



# Optimized intersection algorithm for conjunctive queries

```
INTERSECT(⟨t_1, ..., t_n⟩)
1  terms ← SORTBYINCREASINGFREQUENCY(⟨t_1, ..., t_n⟩)
2  result ← postings(first(terms))
3  terms ← rest(terms)
4  while terms ≠ NIL and result ≠ NIL
5  do result ← INTERSECT(result, postings(first(terms)))
6     terms ← rest(terms)
7  return result
```



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# More general optimization

- Example query: (MADDING OR CROWD) and (IGNOBLE OR STRIFE)
- Get frequencies for all terms
- Estimate the size of each “or” by the sum of its frequencies (conservative)
- Process in increasing order of “or” sizes

# Quiz: Query Processing Order

- Recommend a query processing order for

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

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

# Term Vocabulary & Posting lists

# Outline

- Documents
- Terms
  - General + Non-English
  - English
- Skip pointers
- Phrase queries

# Documents

- Previously: Simple Boolean retrieval system
- Our assumptions were:
  - We know what a document is.
  - We can “machine-read” each document.
- This can be complex in reality.

# Parsing a document

- We need to deal with format and language of each document.
- What format is it in? pdf, word, excel, html etc.
- What language is it in?
- What character set is in use?
- Each of these is a classification problem, which we will study later in this course.
- Alternative: use heuristics
  - machine learning vs. heuristics:
  - Data driven vs. human experience

# Format/Language: Complications

- A single index usually contains terms of several languages.
  - Sometimes a document or its components contain multiple languages/formats.
  - French email with Spanish pdf attachment
- What is the document unit for indexing?
  - A file?
  - An email?
  - An email with 5 attachments?
  - A group of files (ppt or latex in HTML)?
- Bottomline: Answering the question "what is a document?" is not trivial and requires some design decisions.
- Also: XML

# Outline

- Documents
- Terms
  - General + Non-English
  - English
- Skip pointers
- Phrase queries

# Definitions

- Word – A delimited string of characters as it appears in the text.
- Term – A "normalized" word (case, morphology, spelling etc); an equivalence class of words.
- Token – An instance of a word or term occurring in a document.
- Type – The same as a term in most cases: an equivalence class of tokens.

# Normalization

- Need to "normalize" terms in indexed text as well as query terms into the same form.
- Example: We want to match *U.S.A.* and *USA*
- We most commonly implicitly define equivalence classes of terms.
- Alternatively: do asymmetric expansion
  - window → window, windows
  - windows → Windows, windows
  - Windows (no expansion)
- More powerful, but less efficient

- Why don't you want to put *window, Window, windows,* and *Windows* in the same equivalence class?
- Because they have different meanings

# Normalization: Other languages

- Normalization and language detection interact.
- *PETER WILL NICHT MIT.* → MIT = mit

  (*Peter do not want to.*)
- *He got his PhD from MIT.* → MIT ≠ mit

# Recall: Inverted index construction

- Input:


- Output:


- Each token is a candidate for a postings entry.
- What are valid tokens to emit?

# Quiz: Tokens, Words and Terms

*In June, the dog likes to chase the cat in the barn.*

– How many English word tokens are there?

– How many non-English word tokens are there?

– How many terms are there?

# Tokenization problems: One word or two? (or several)

- Hewlett-Packard
- State-of-the-art
- co-education
- the hold-him-back-and-drag-him-away maneuver
- data base
- San Francisco
- Los Angeles-based company
- cheap San Francisco-Los Angeles fares
- York University vs. New York University

# Numbers

- 3/20/91
- 20/3/91
- Mar 20, 1991
- B-52
- 100.2.86.144
- (800) 234-2333
- 800.234.2333
- Older IR systems may not index numbers . . .
- . . . but generally it's a useful feature.

# Chinese: No whitespace

莎拉波娃现在居住在美国东南部的佛罗里达。今年４月９日，莎拉波娃在美国第一大城市纽约度过了１８岁生日。生日派对上，莎拉波娃露出了甜美的微笑。

# Ambiguous segmentation in Chinese


The two characters can be treated as one word meaning ‘monk’ or as a sequence of two words meaning ‘and’ and ‘still’.

# Other cases of "no whitespace"

- Compounds in Dutch, German, Swedish
- Computerlinguistik → Computer + Linguistik
- Lebensversicherungsgesellschaftsangestellter

  → leben + versicherung + gesellschaft + angestellter

  (*life insurance company employee*)
- Inuit: tusaatsiarunnanngittualuujunga (*I can't hear very well.*)
- Many other languages with segmentation difficulties: Finnish, Urdu, . . .

# Japanese

ノーベル平和賞を受賞したワンガリ・マータイさんが名誉会長を務めるＭＯＴＴＡＩＮＡＩキャンペーンの一環として、毎日新聞社とマガジンハウスは「私の、もったいない」を募集します。皆様が日ごろ「もったいない」と感じて実践していることや、それにまつわるエピソードを８００字以内の文章にまとめ、簡単な写真、イラスト、図などを添えて１０月２０日までにお送りください。大賞受賞者には、５０万円相当の旅行券とエコ製品２点の副賞が贈られます。

4 different “alphabets”: Chinese characters, hiragana syllabary for inflectional endings and functional words, katakana syllabary for transcription of foreign words and other uses, and latin. No spaces (as in Chinese). End user can express query  entirely in hiragana!

# Arabic script

كِتَابٌ ⇐ ك ِ ت ا ب ٌ

un b ā t i k

/kitābun/ *‘a book’*

# Arabic script: Bidirectionality

استقلت الجزائر في سنة 1962 بعد 132 عاما من الاحتلال الفرنسي.

← → ← → ← START

'Algeria achieved its independence in 1962 after 132 years of French occupation.'

Bidirectionality is not a problem if text is coded in Unicode.

# Accents and diacritics

- Accents: résumé vs. resume (simple omission of accent)
- Umlauts: Universität vs. Universitaet (substitution with special letter sequence “ae”)
- Most important criterion: How are users likely to write their queries for these words?
- Even in languages that standardly have accents, users often do not type them. (Polish?)

# Case folding

- Reduce all letters to lower case
- Possible exceptions: capitalized words in mid-sentence
- MIT vs. mit
- Fed vs. fed
- It's often best to lowercase everything since users will use lowercase regardless of correct capitalization.

# Stop words

- stop words = extremely common words which would appear to be of little value in helping select documents matching a user need
- Examples: *a, an, and, are, as, at, be, by, for, from, has, he, in, is, it, its, of, on, that, the, to, was, were, will, with*
- Stop word elimination used to be standard in older IR systems.
- But you need stop words for phrase queries, e.g. "King of Denmark"
- Most web search engines index stop words.

# More equivalence classing

- Soundex: IIR 3 (phonetic equivalence, Muller = Mueller)
- Thesauri: IIR 9 (semantic equivalence, car = automobile)

# Lemmatization

- Reduce inflectional/variant forms to base form
- Example: *am, are, is* → *be*
- Example: *car, cars, car's, cars'* → *car*
- Example: *the boy's cars are different colors* → *the boy car be different color*
- Lemmatization implies doing "proper" reduction to dictionary headword form (the lemma).
- Inflectional morphology (*cutting* → *cut)* vs. derivational morphology (*destruction* → *destroy)*

# Stemming

- Definition of stemming: Crude heuristic process that *chops off the ends of words* in the hope of achieving what "principled" lemmatization attempts to do with a lot of linguistic knowledge.
- Language dependent
- Often inflectional and derivational
- Example for derivational: *automate, automatic, automation* all reduce to *automat*

# Porter algorithm

- Most common algorithm for stemming English
- Results suggest that it is at least as good as other stemming options
- Conventions + 5 phases of reductions
- Phases are applied sequentially
- Each phase consists of a set of commands.
  - Example command: Delete final *ement* if what remains is longer than 1 character
  - replacement → replac
  - cement → cement
- Example convention: Of the rules in a compound command, select the one that applies to the longest suffix.

# Porter stemmer: A few rules

| **Rule** | **Example** |
| --- | --- |
| SSES → SS | caresses → caress |
| IES → I | ponies → poni |
| SS → SS | caress → caress |
| S → | cats → cat |

# Three stemmers: A comparison

| | |
|---|---|
| *Sample text:* | Such an analysis can reveal features that are not easily visible from the variations in the individual genes and can lead to a picture of expression that is more biologically transparent and accessible to interpretation |
| *Porter stemmer:* | such an analysi can reveal featur that ar not easili visibl from the variat in the individu gene and can lead to pictur of express that is more biolog transpar and access to interpret |
| *Lovins stemmer:* | such an analys can reve featur that ar not eas vis from th vari in th individu gen and can lead to a pictur of expres that is mor biolog transpar and acces to interpres |
| *Paice stemmer:* | such an analys can rev feat that are not easy vis from the vary in the individ gen and can lead to a pict of express that is mor biolog transp and access to interpret |

# Does stemming improve effectiveness?

- In general, stemming increases effectiveness for some queries, and decreases effectiveness for others.
- Queries where stemming is likely to help: [tartan sweaters], [sightseeing tour san francisco] (equivalence classes: {sweater,sweaters}, {tour,tours})
- Porter Stemmer equivalence class *oper* contains all of *operate operating operates operation operative operatives operational.*
- Queries where stemming hurts: [operational AND research], [operating AND system], [operative AND dentistry]

# Quiz: Stemming

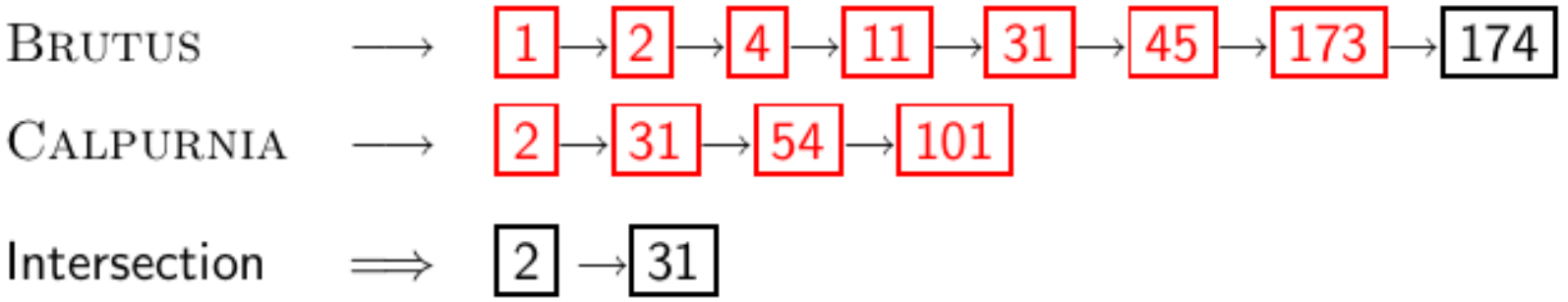
Are the following statements true or false?

1. In a Boolean retrieval system, stemming never lowers precision. (T/F)
2. In a Boolean retrieval system, stemming sometimes lowers recall. (T/F)
3. Stemming increases the size of the vocabulary. (T/F)
4. Stemming is invoked at indexing time but not while processing a query. (T/F)

# Outline

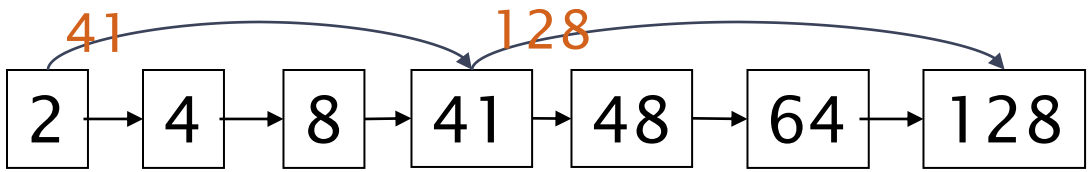
- Documents
- Terms
  - General + Non-English
  - English
- Skip pointers
- Phrase queries

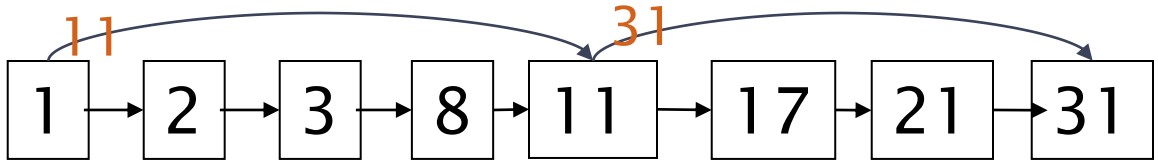
# Recall basic intersection algorithm




- Linear in the length of the postings lists.
- Can we do better?

# Augment postings with skip pointers (at indexing time)



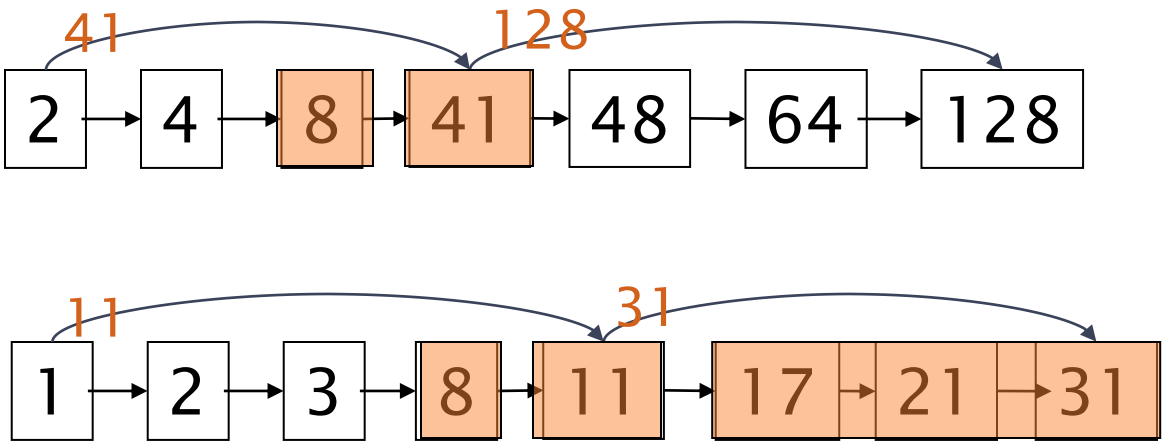




- Why?

  To skip postings that will not feature in the search results.

- How?
- Where do we place skip pointers?

# Query processing with skip pointers




Suppose we've stepped through the lists until we process **8** on each list. We match it and advance.

We then have **41** and **11** on the lower. **11** is smaller.

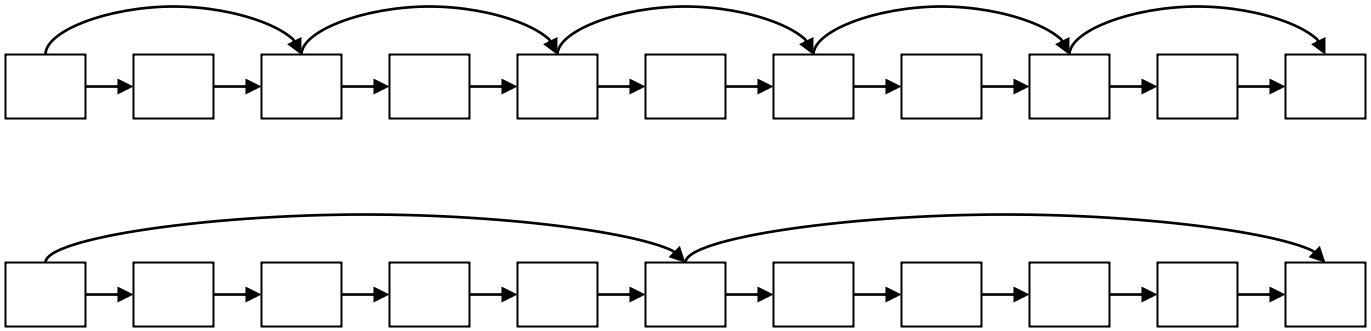
But the skip successor of **11** on the lower list is **31**, so we can skip ahead past the intervening postings.

# Intersection with skip pointers

```
INTERSECTWITHSKIPS(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 if hasSkip(p1) and (docID(skip(p1)) ≤ docID(p2))
 9                     then while hasSkip(p1) and (docID(skip(p1)) ≤ docID(p2))
10                          do p1 ← skip(p1)
11                     else p1 ← next(p1)
12                else if hasSkip(p2) and (docID(skip(p2)) ≤ docID(p1))
13                     then while hasSkip(p2) and (docID(skip(p2)) ≤ docID(p1))
14                          do p2 ← skip(p2)
15                     else p2 ← next(p2)
16  return answer
```

# Where do we place skips?

- Tradeoff:
  - More skips → shorter skip spans ⇒ more likely to skip. But lots of comparisons to skip pointers.
  - Fewer skips → few pointer comparison, but then long skip spans ⇒ few successful skips.



# Where do we place skips? (cont)

- Simple heuristic: for postings list of length *P*, use $\sqrt{P}$ evenly-spaced skip pointers.
- This ignores the distribution of query terms.
- Easy if the index is static; harder in a dynamic environment because of updates.
- How much do skip pointers help?
- They used to help a lot.
- With today's fast CPUs, they don't help that much anymore.