Information Retrieval: Boolean Retrieval

Romi Satria Wahono
romi@romisatriawahono.net
http://romisatriawahono.net
0878-804804-85

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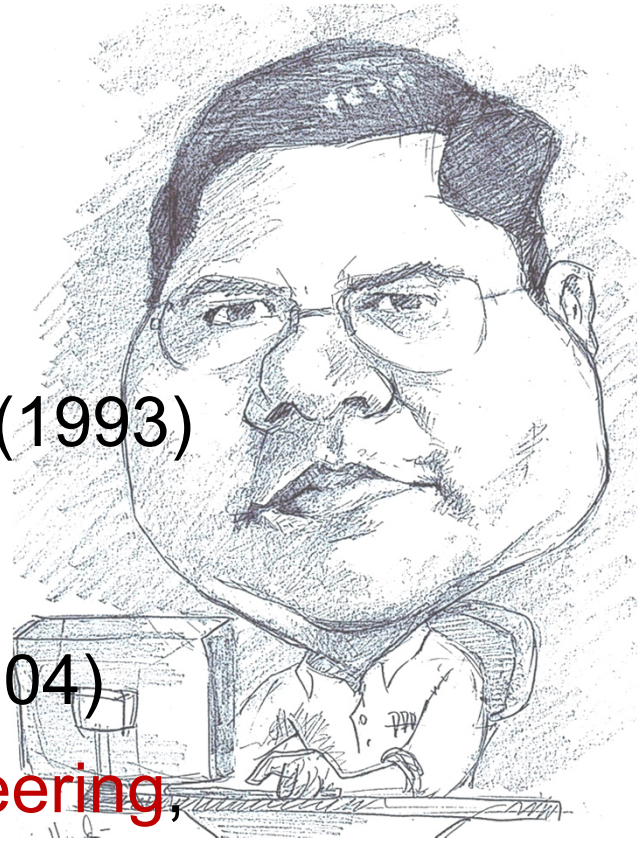
Romi Satria Wahono



- Lahir di Madiun, 2 Oktober 1974
- SD Sompok Semarang (1987)
- SMPN 8 Semarang (1990)
- SMA Taruna Nusantara, Magelang (1993)
- S1, S2 dan S3 (on-leave)
  Department of Computer Sciences
  Saitama University, Japan (1994-2004)
- Core Competence: Software Engineering, Computational Intelligence
- Founder dan Koordinator IlmuKomputer.Com
- CEO PT Brainmatics Cipta Informatika

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BOOLEAN RETRIEVAL

Shakespeare's Collected Works

- 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 is that not the answer? We need more!
  1. Slow (for large corpora) → need to process large
  2. Other operations (e.g., find the word ***Romans*** near ***countrymen***) not feasible → need to allow more flexible matching operations
  3. Without ranked retrieval (best documents to return) → need to allow ranked retrieval

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

Brutus *AND* ***Caesar*** *BUT NOT* ***Calpurnia***

1 if play contains word, 0 otherwise

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

(Brutus) (Caesar) (Not Calpurnia)

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.

Basic Assumptions of Information Retrieval

- Collection: Fixed set of documents
- Goal: Retrieve documents with information that is relevant to the user's information need and helps the user complete a task

How good are the retrieved docs?

- **Precision**: What fraction of the returned results are relevant to the information need?

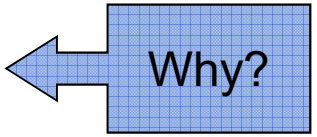
- **Recall**: What fraction of the relevant documents in the collection were returned by the system?

Bigger collections

- Consider *N* = 1 million documents, each with about 1000 words.
- Average 6 bytes/word including spaces and 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?

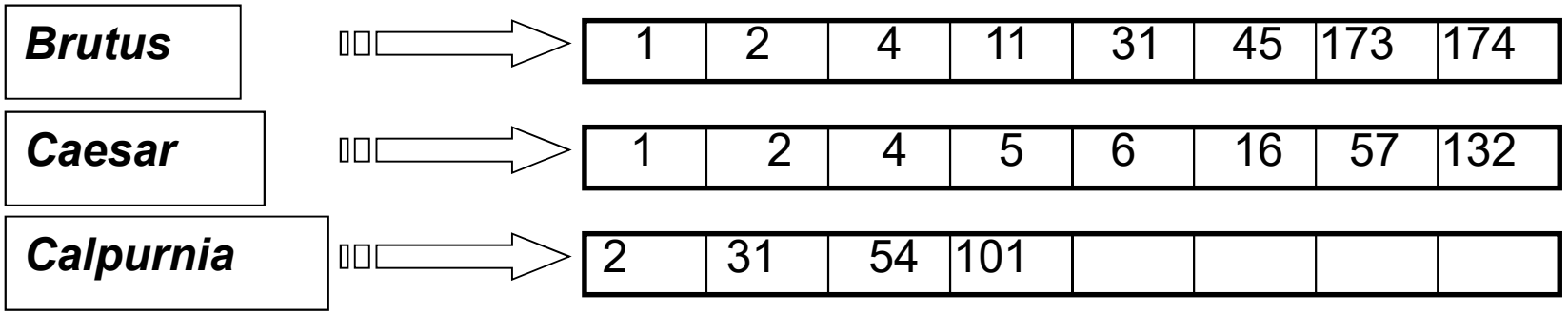


  - We only record the 1 positions

Inverted Index

Inverted Index

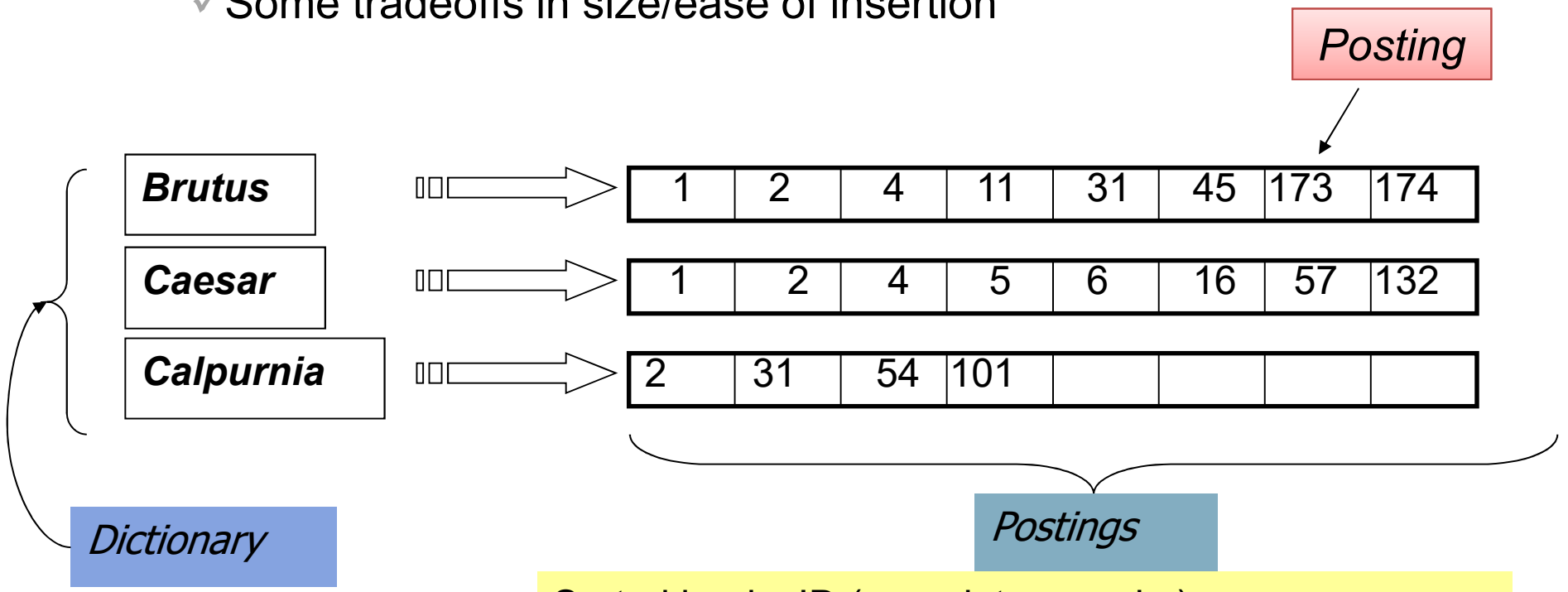
- For each term *t*, we must store a list of all documents that contain *t*
- Identify each by a **docID**, a document serial number
- Can we used fixed-size arrays for this?



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

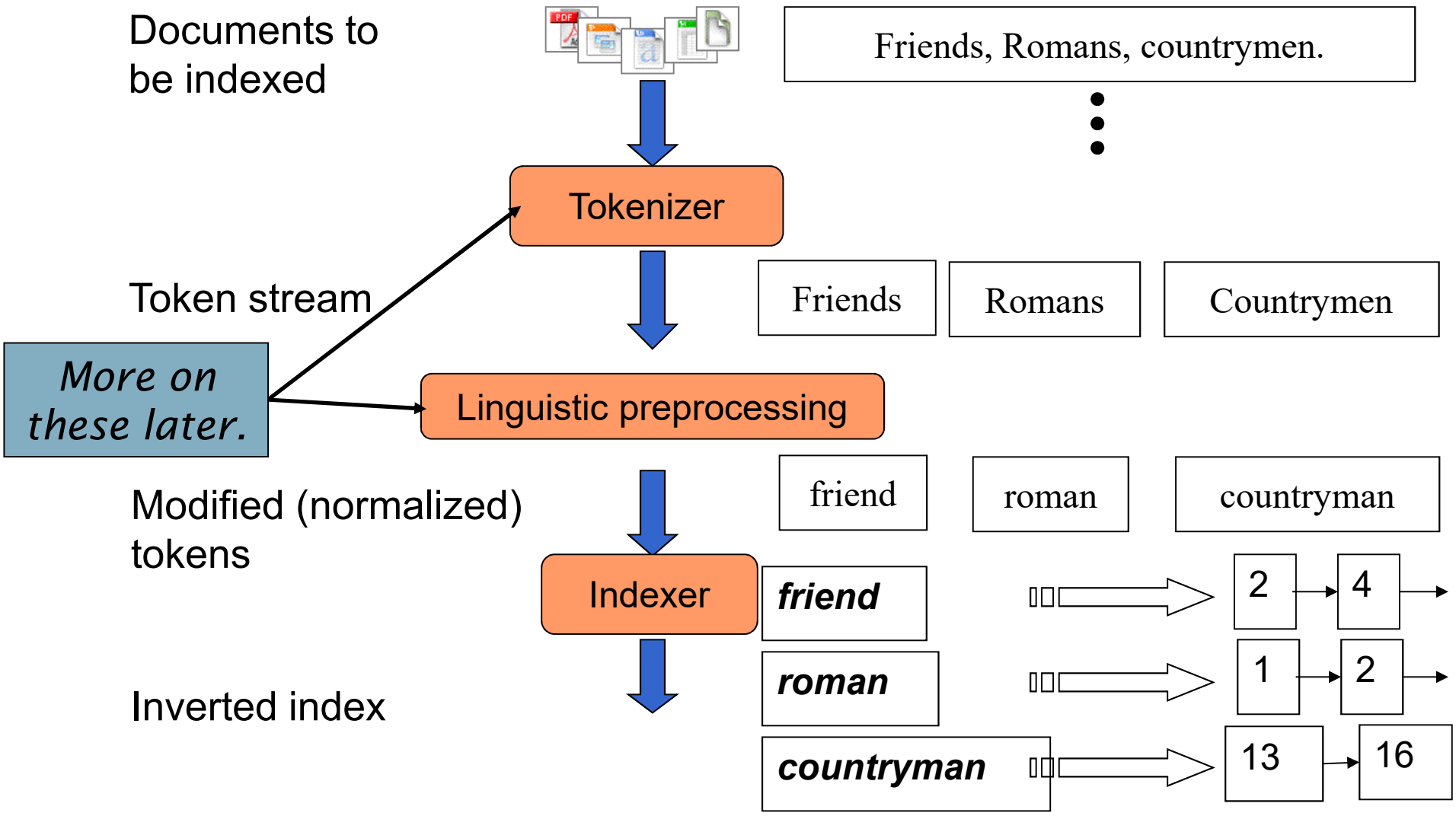
Inverted Index

- 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



Sorted by docID (more later on why).

Inverted Index Construction



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

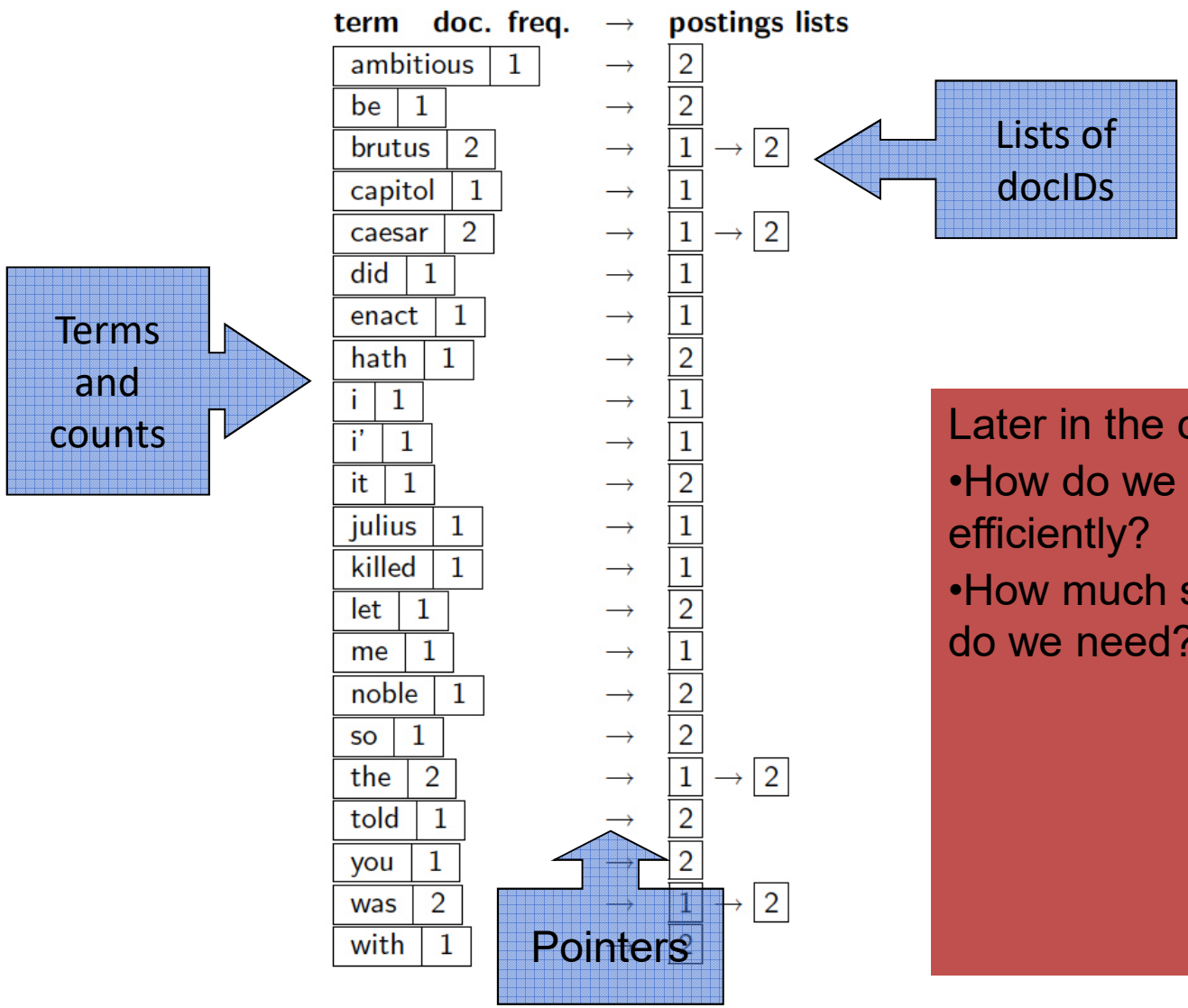
- Multiple term entries in a single document are merged
- Split into Dictionary and Postings
- Document frequency information is added

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

Why frequency?
Will discuss later.

Where Do We Pay in Storage?



Later in the course:

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

The Index We Just Built

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

Exercise: term-document incidence matrix

- Draw the term-document incidence matrix for this document collection

  Doc 1 breakthrough drug for schizophrenia

  Doc 2 new schizophrenia drug

  Doc 3 new approach for treatment of schizophrenia

  Doc 4 new hopes for schizophrenia patients

- Tunjukkan hasil retrieval untuk query boolean: Schizophrenia AND drug

Exercise: Inverted Index

- Draw the inverted index representation for this collection

Doc 1	breakthrough drug for schizophrenia
Doc 2	new schizophrenia drug
Doc 3	new approach for treatment of schizophrenia
Doc 4	new hopes for schizophrenia patients

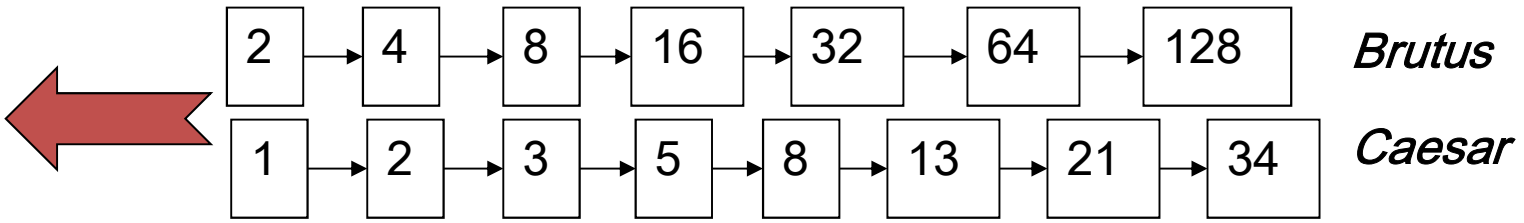
Processing Boolean Queries

Query Processing: AND

- Consider processing the query:

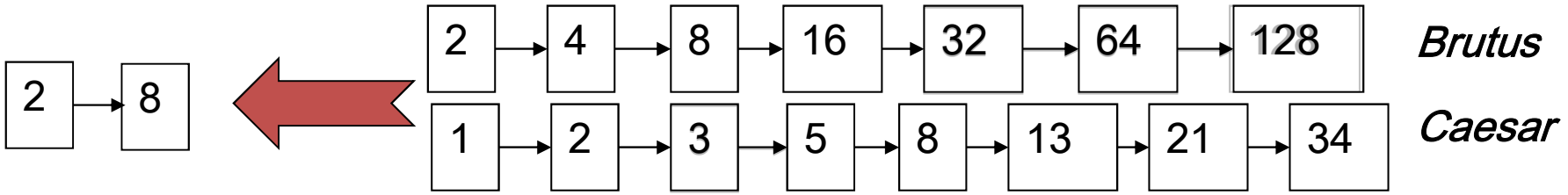
  Brutus *AND* ***Caesar***

  1. Locate ***Brutus*** in the Dictionary
     - ✓ Retrieve its postings.
  2. Locate ***Caesar*** in the Dictionary
     - ✓ Retrieve its postings.
  3. "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.

Intersecting two postings lists (a "merge" algorithm)

```
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
```

Exercise: Query Processing

- For the document collection shown in the following

  Doc 1 breakthrough drug for schizophrenia

  Doc 2 new schizophrenia drug

  Doc 3 new approach for treatment of schizophrenia

  Doc 4 new hopes for schizophrenia patients

- what are the returned results for these queries:

  1. schizophrenia AND drug
  2. for AND NOT(drug OR approach)

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
  - Perhaps the simplest model to build an IR system
- Primary commercial retrieval tool for 3 decades
- Many search systems you still use are Boolean:
  - Email, library catalog, Mac OS X Spotlight

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

What can we achieve?

Merging

What about an arbitrary Boolean formula?

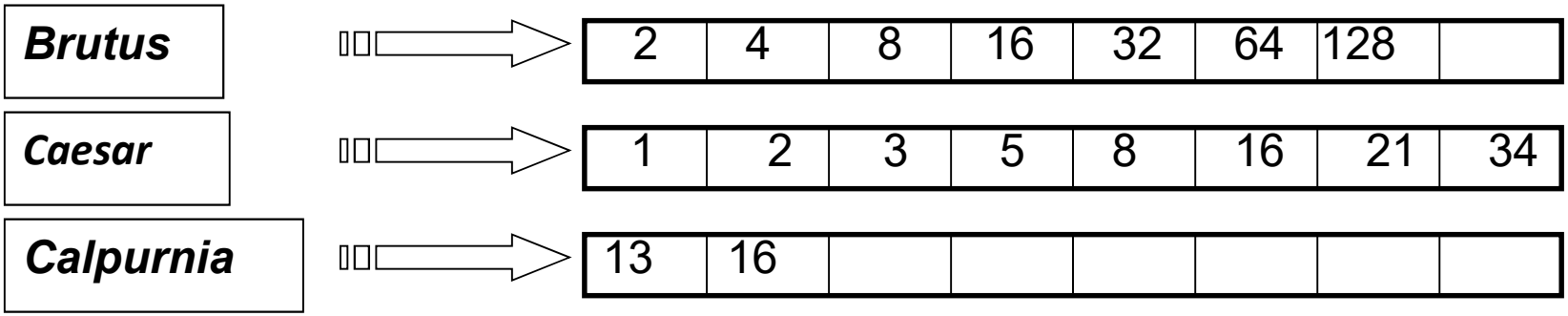
***(Brutus** OR **Caesar)** AND NOT*

(Antony** OR **Cleopatra)

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

Query Optimization

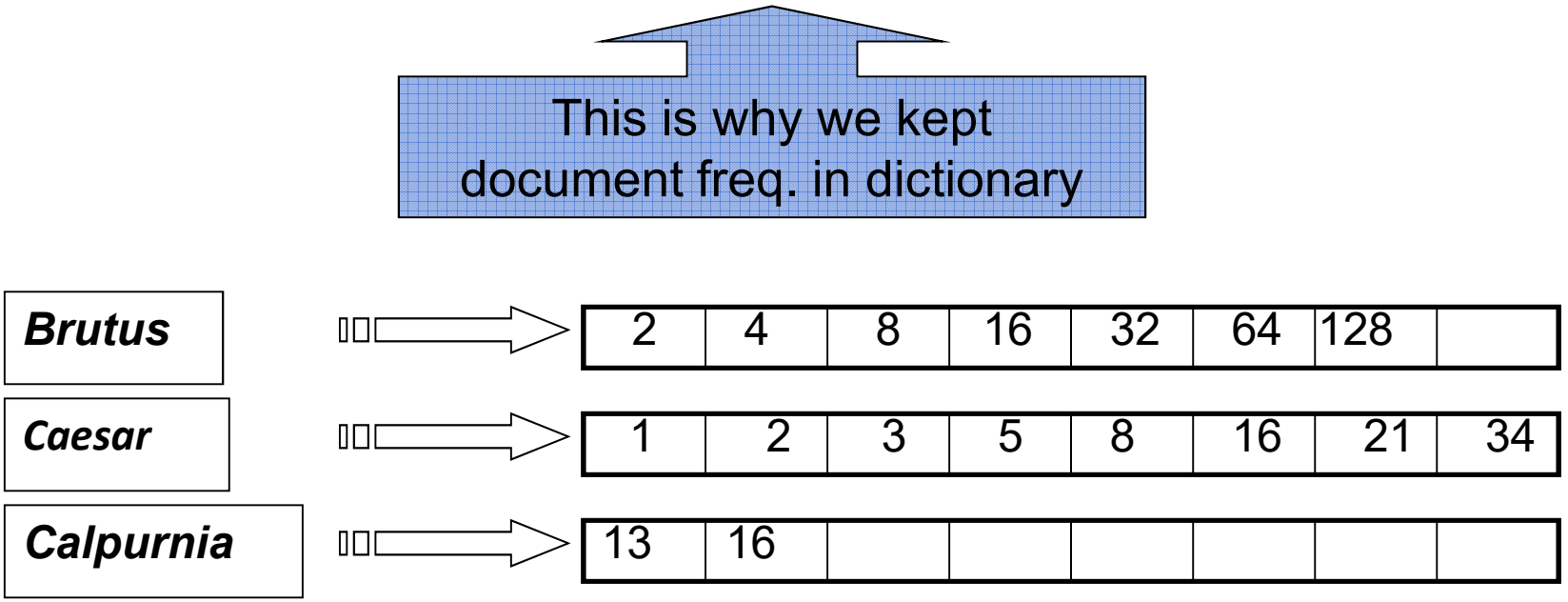
- What is the best order for query processing?
- Consider a query that is an *AND* of *n* terms.
- For each of the *n* terms, get its postings, then *AND* them together.



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 (***Calpurnia*** *AND* ***Brutus)*** *AND* ***Caesar***

More General Optimization

- e.g., *(**madding** OR **crowd**) AND (**ignoble** OR **strife**)*
- Get doc. freq.'s 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.

Exercise: Query Processing Order

- 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

Query processing exercises

- Exercise: 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.

Exercise

- Try the search feature at http://www.rhymezone.com/shakespeare/
- Write down five search features you think it could do better

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