Introduction to

Informa I

Lecture 1: Bool ai

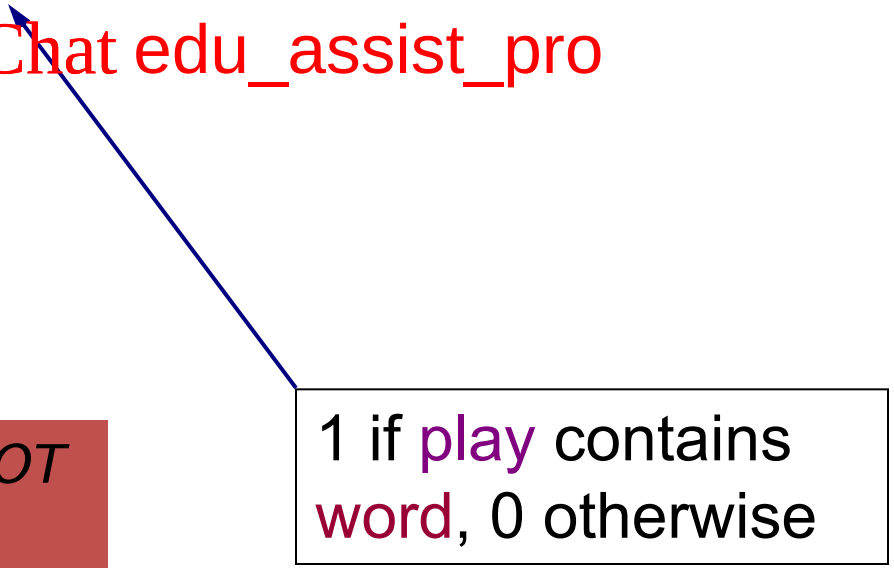
Introduction to Informa

Term-document inc trices

Unstructured data in 1620

- 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,*** t ... aining ***Calpurnia***?
- Why is that not the answer
  - 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 matrices



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* 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

- Antony and Cleopatra, Act III, Scene ii

Agrippa [Aside to DOMITIUS ENOBARBUS]: Why, Enobarbus,
When Antony found Julius ***Caesar*** dead,
He wept
Wh lain.

- Hamlet, Act III, Sce

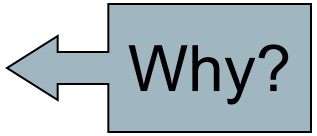
Lord Polonius: I did enact Julius ***Caesar*** I was killed i' the Capitol; ***Brutus*** killed me.

Bigger collections

- Consider *N* = 1 million documents, each with about 1000 words.
- Avg 6 bytes/word including spaces/punctuation
  - 6GB of data i
- Say there are *M* = 500K *dist* 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 bett
  - We only record the 1 positions.



Introduction to

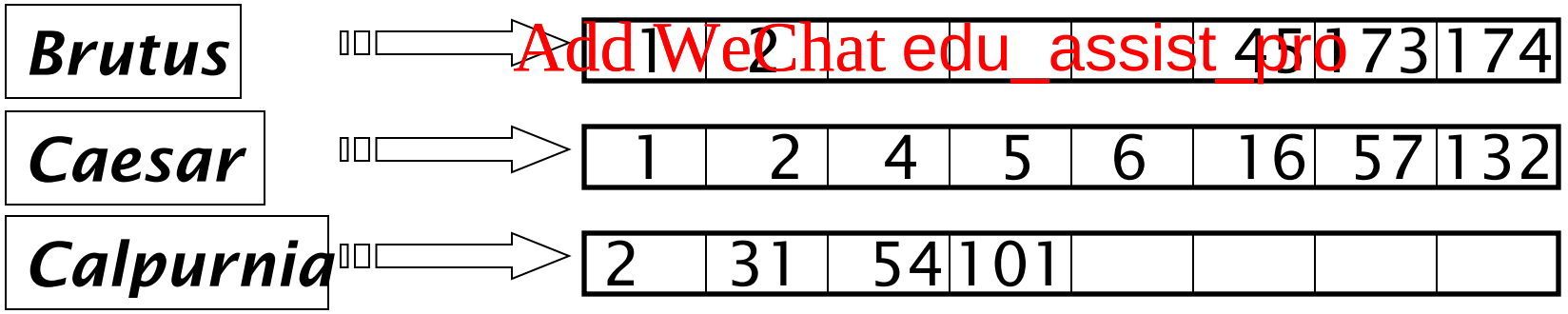
Informa I

The Inverte

The key data structure underlying modern IR

Inverted index

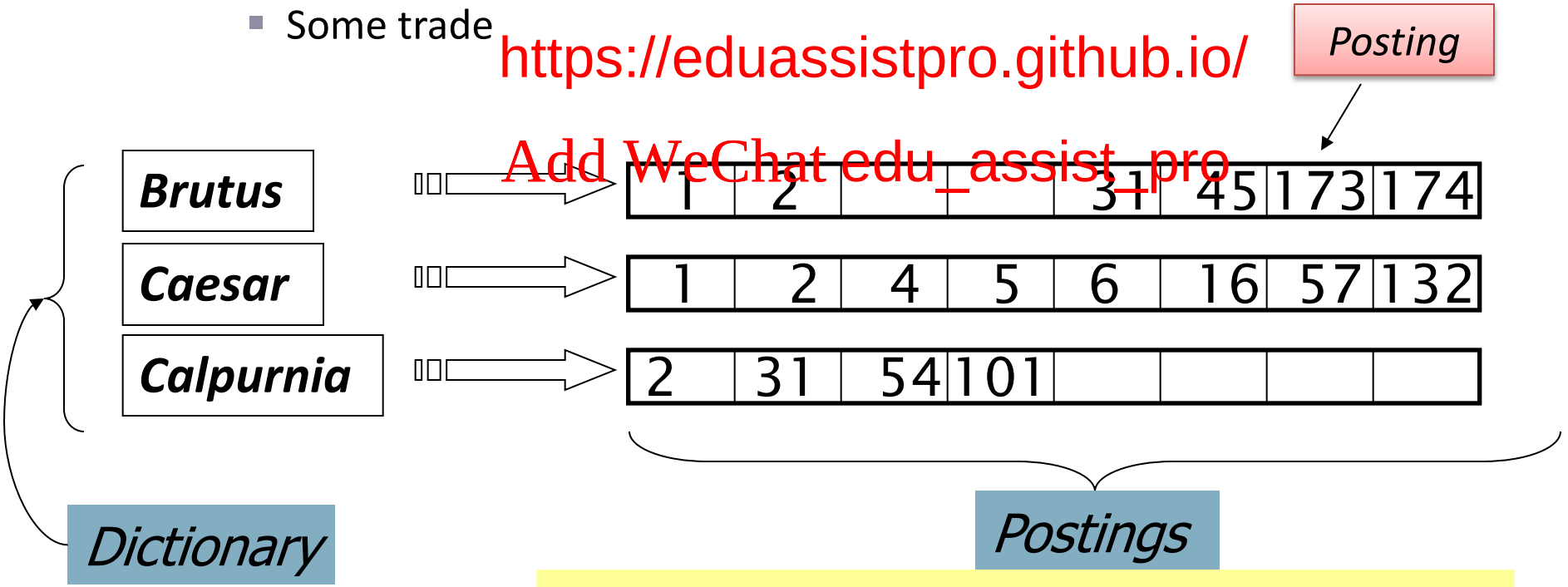
- For each term *t*, we must store a list of all documents that contain *t*.
  - Identify each by a **docID**, a document serial number
- Can we use fi ?



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

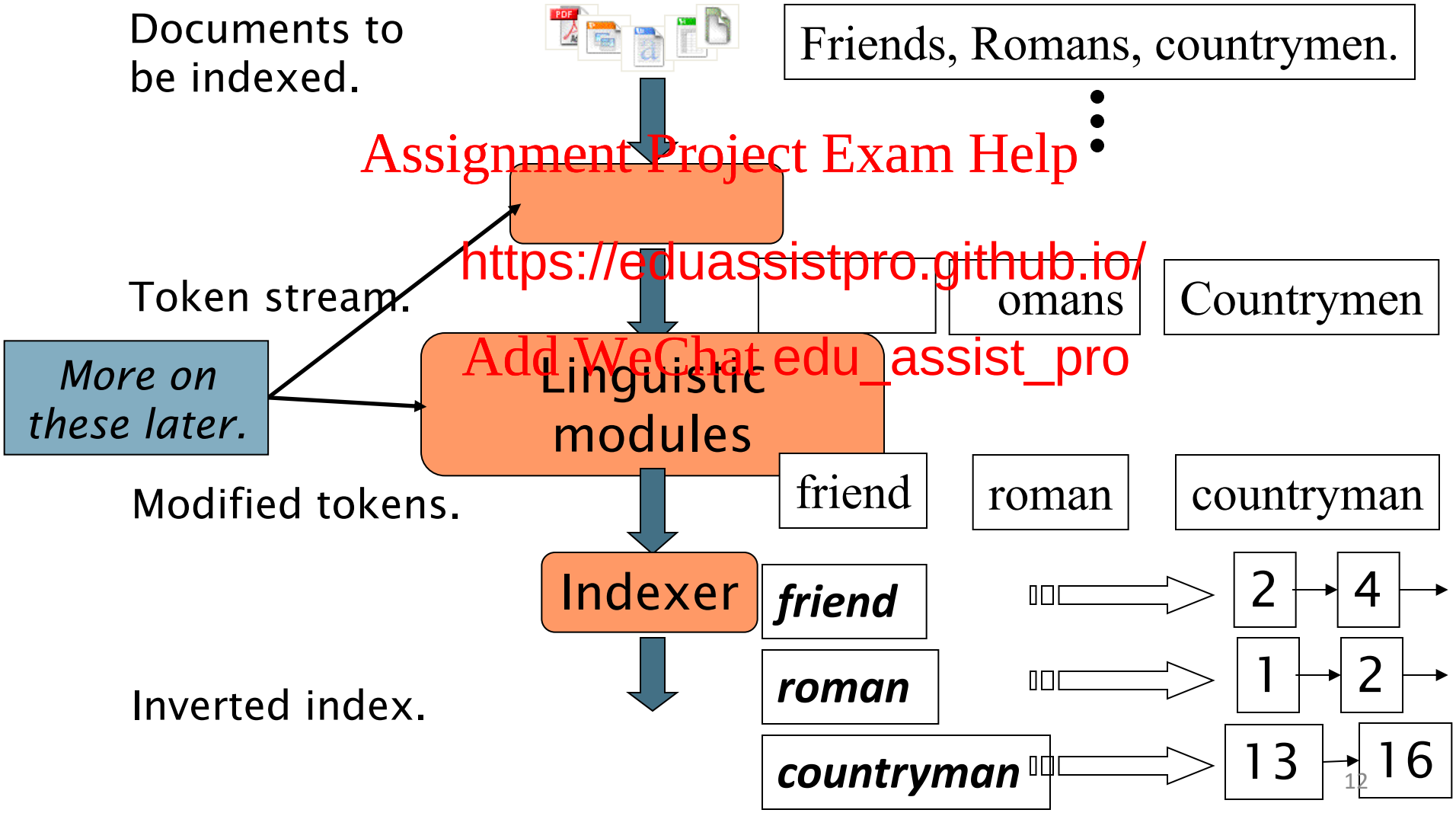
Inverted index

- 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 trade



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.

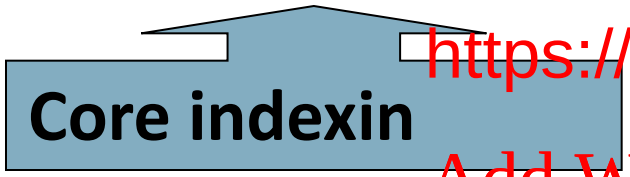
Doc 2

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

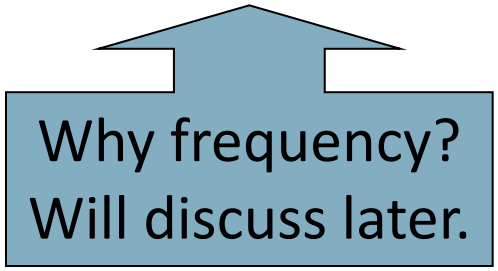
- Sort by terms
  - And then docID



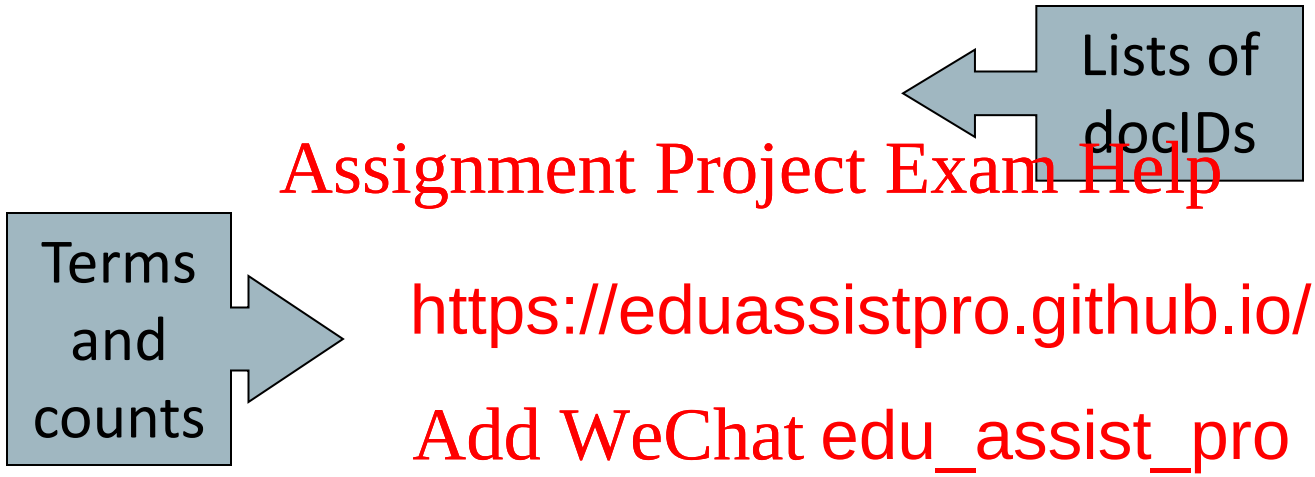
Term	docID
ambitious	2
be	2
brutus	1
brutus	2
capitol	1
caesar	1
caesar	2
caesar	2
did	1
enact	1
hath	1
I	1
I	1
i'	1
it	2
julius	1
killed	1
killed	1
let	2
me	1
noble	2
so	2
the	1
the	2
told	2
you	2
was	1
was	2
with	2

Indexer steps: Dictionary & Postings

- Multiple term entries in a single document are merged.
- Split into Dictio and Postings
- Doc. frequency information is added.



Where do we pay in storage?



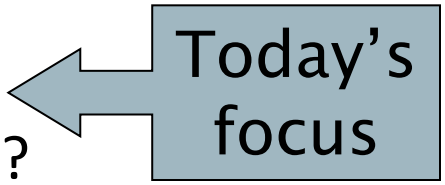
Introduction to

Informa I

Query processing wit ed index

The index we just built

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

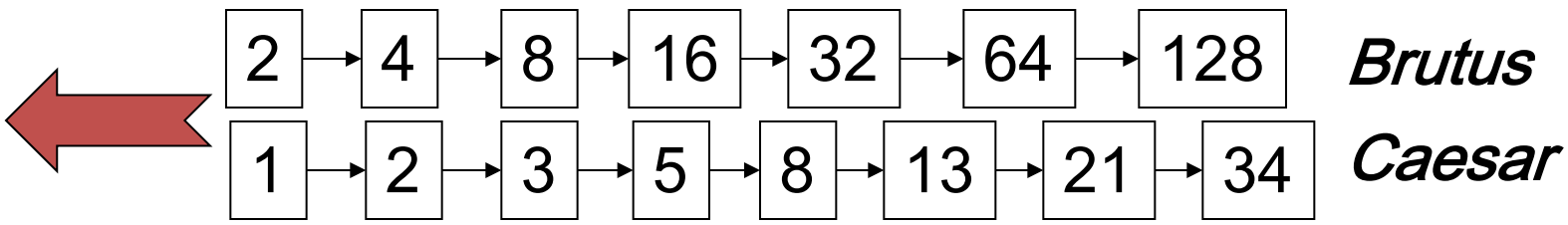


Query processing: AND

- Consider processing the query:

  Brutus *AND* ***Caesar***

  - Locate ***Brutus*** in the Dictionary;
    - Retrieve its
  - Locate *Caesa*
    - 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.

Intersecting two postings lists (a "merge" algorithm)

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
    - Views each document as a s__
    - Is precise: document matcn 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:
  - 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; new federated search added 2010)
- Tens of ter ,000 users
- Majority of users *still* us 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
    - foo! = foo*, /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 a place /employment /3 place)
- Note that SPACE is disjun onjunction!
- 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 N*

Can we still run through the m e $O(x+y)$?

What can we achieve?

Merging

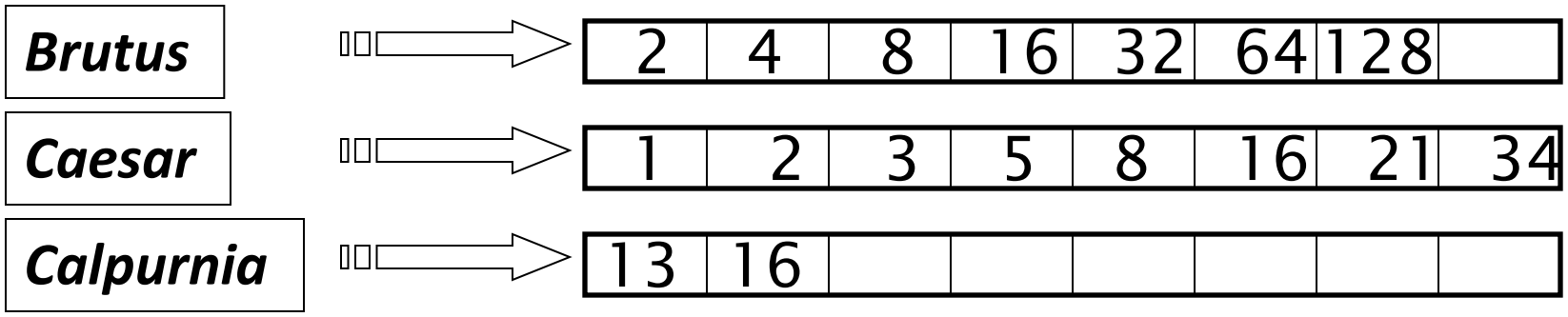
What about an arbitrary Boolean formula?

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

- Can we alway e?
  - Linear in what?
- Can we do better?

Query optimization

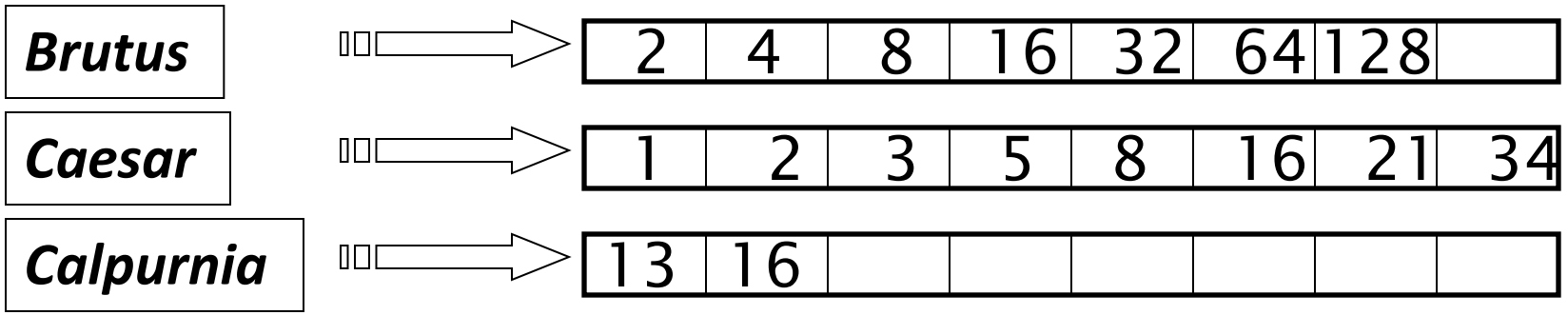
- What is the best order for query processing?
- Consider a query that is an *AND* of *n* terms.
- For each of th ings, then *AND* them to



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

Query optimization example

- Process in order of increasing freq:
  - *start with the 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**) AND (**light** OR **lord**)*
- Get doc. freq
- Estimate the e sum of its doc. freq.'s (conservative
- Process in increasing order of *OR* sizes.

Q: When will the conservative estimate fail?

Exercise

- Recommend a query processing order for

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

Q: Can we merge multiple lists (>2) simultaneously?

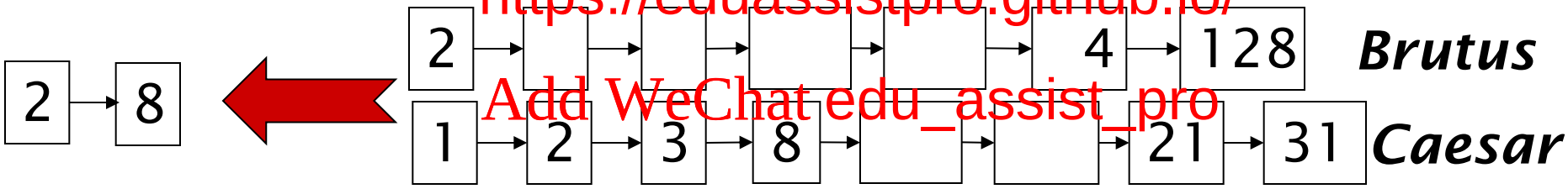
Introduction to

Informa I

Faster postings merges: ters and Skip lists

Recall basic merge

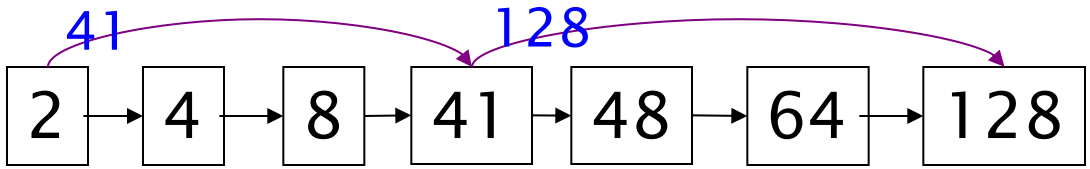
- Walk through the two postings simultaneously, in time linear in the total number of postings entries

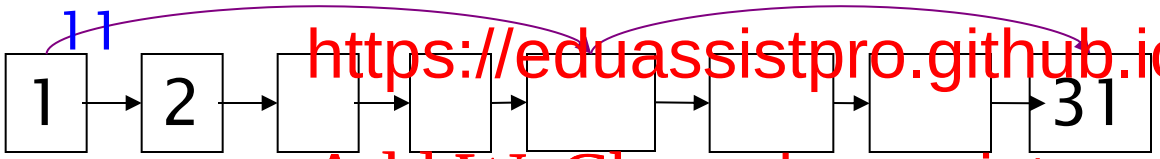


If the list lengths are *m* and *n*, the merge takes O(*m*+*n*) operations.

Can we do better?
Yes (if index isn't changing too fast).

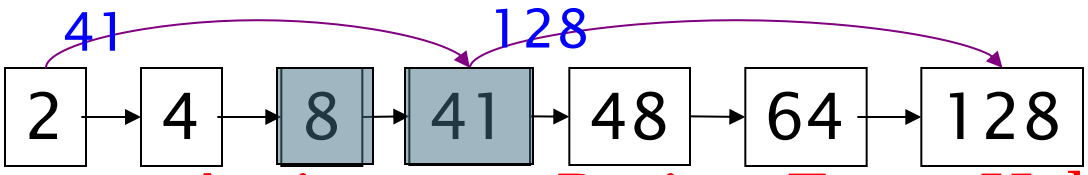
Augment postings with skip pointers (at indexing time)

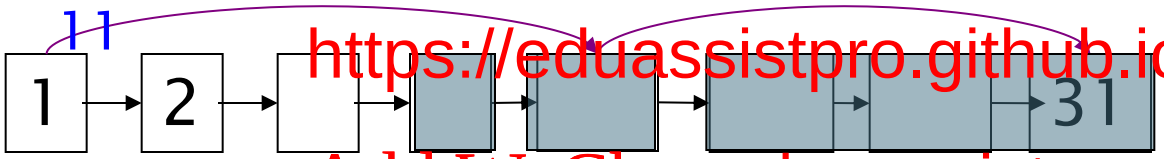




- Why?
- To skip postings that will not figure in the search results.
- How?
- Where do we place skip pointers?

Query processing with skip pointers





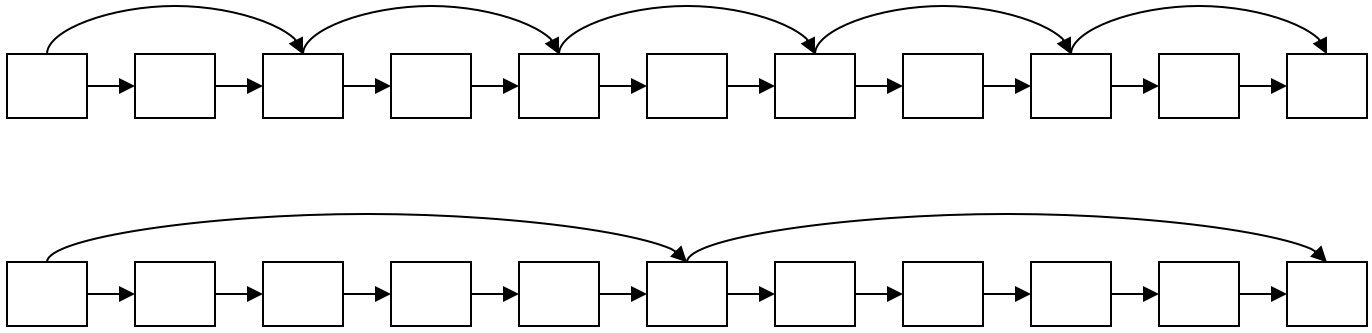
Suppose we've stepped throu until we process **8** on each list. We match it and advance.

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.

Where do we place skips?

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



Placing skips

- Simple heuristic: for postings of length L, use $L^{1/2}$ evenly-spaced skip pointers.
- This ignores the distribution of query terms.
- Easy if the index is relatively static; harder if L keeps changing because of updat

- This definitely used to help; with modern hardware it may not (Bahle et al. 2002) unless you're memory-based
  - The I/O cost of loading a bigger postings list can outweigh the gains from quicker in memory merging!

Introduction to

Informa I

Phrase queries and ndexes

Phrase queries

- Want to be able to answer queries such as "***stanford university***" – as a phrase
- Thus the sentence "*I went to university at Stanford*" is not a match
  - The concept of phrase queri n easily understood by users; one of vanced search" ideas that works
  - Many more queries are *implicit phrase queries*
- For this, it no longer suffices to store only

<*term* : *docs*> entries

Solution 1: Biword indexes

- Index every consecutive pair of terms in the text as a phrase
- For example the text "Friends, Romans, Countrymen" generates the biwords
  - ***friends romans***
  - ***romans countrymen***
- Each of these biwords is now a dictionary term
- Two-word phrase query-processing is now immediate.

Longer phrase queries

- Longer phrases are processed as we did with wild-cards:
- ***stanford university palo alto*** can be broken into the Boolean quer

stanford university *AND* ***univ*** *AND* ***palo alto***

Without the docs, we cannot verify that the docs matching the above Boolean query do contain the phrase.

Can have false positives!

Issues for biword indexes

- False positives, as noted before
- Index blowup due to bigger dictionary
  - Infeasible for more than biwords, big even for them
- Biword indexes are not the solution (for all biwords) but can be part of nd strategy

Solution 2: Positional indexes

- In the postings, store, for each ***term*** the position(s) in which tokens of it appear:

<***term***, number
doc1: position1, position2 … ;
doc2: position1, position2 … ;
etc.>

Positional index example

<*be*: 993427;
1: 7, 18, 33, 72, 86, 231;
2: 3, 149;
4: 17, 191, 29
5: 363, 367, …>

Which of docs 1,2,4,5 could contain "***to be or not to be***"?

- For phrase queries, we use a merge algorithm recursively at the document level
- But we now need to deal with more than just equality

Processing a phrase query

- Extract inverted index entries for each distinct term: ***to, be, or, not.***
- Merge their doc:position lists to enumerate all positions with
  - ***to****:*
    - *2*:1,17,74,222,551; *4*:8,16 3; 7:13,23,191; ...
  - ***be****:*
    - *1*:17,19; *4*:17,191,291,430,434; *5*:14,19,101; ...
- Same general method for proximity searches

Proximity queries

- LIMIT! /3 STATUTE /3 FEDERAL /2 TORT
  - Again, here, /*k* means "within *k* words of".
- Clearly, positional indexes can be used for such queries; biwo
- Exercise: Adapt the linear stings to handle proximity queries. ake it work for any value of *k*?
  - This is a little tricky to do correctly and efficiently
  - **See Figure 2.12 of IIR (Page 39)**
  - There's likely to be a problem on it!

Positional index size

- You can compress position values/offsets: we'll talk about that in lecture 5
- Nevertheless, a positional index expands postings storage *subst*
- Nevertheless, a positional i w standardly used because of the power lness of phrase and proximity queries … whether used explicitly or **implicitly** in a ranking retrieval system.

Positional index size

- Need an entry for **each occurrence**, not just once per document
- Index size depends on average document size

Why?

  - Average web
  - SEC filings, books, even som s … easily 100,000 terms

- Consider a term with frequency 0.1%

Document size	Postings	Positional postings
1000	1	1
100,000	1	100

Rules of thumb

- A positional index is 2–4 as large as a non-positional index
- Positional index size 35–50% of volume of original text
- Caveat: all of this holds for "English-like" languages

Combination schemes

- These two approaches can be profitably combined
  - For particular phrases (***"Michael Jackson", "Britney Spears"***) it erging positional postings lis
    - Even more so for phrases lik
- Williams et al. (2004) evaluate a more sophisticated mixed indexing scheme
  - A typical web query mixture was executed in ¼ of the time of using just a positional index
  - It required 26% more space than having a positional index alone

Resources for today's lecture

- *Introduction to Information Retrieval*, chapter 1
- Shakespeare:
  - http://www.rhymezone.com/shakespeare/
  - Try the neat bra
- *Managing Gigabytes*, chapt
- *Modern Information Retrieval*, chapter 8.2

Resources for today's lecture

- Skip Lists theory: Pugh (1990)
  - Multilevel skip lists give same O(log *n*) efficiency as trees
- H.E. Williams, J. Zobel, and D. Bahle. 2004. "Fast Phrase Querying with Combined Indexes", ACM Transactions on Information Syst
  http://www.seg.rmi thor=4
- D. Bahle, H. Williams, and J. Zobel. Ef querying with an auxiliary index. SIGIR 2002, pp. 215-2