Information Retrieval and Organisation

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Boolean Retrieval

Example IR Problem

- Let's look at a simple IR problem
  - Suppose you own a copy of Shakespeare's Collected Works
  - You are interested in finding out which plays contain the words `Brutus AND Caesar AND NOT Calpurnia`
- Possible solutions:
  - Start reading . . .
  - Use string-matching algorithm (e.g. grep) scanning files
  - For simple queries on small to modest collections (Shakespeare's Collected Works contain not quite a million words) this is OK.

Limits of Scanning

- For many purposes, you need more:
  - Process large collections containing billions or trillions of words quickly
  - Allow for more flexible matching operations, e.g. `Romans NEAR countrymen`
  - Rank answers according to importance (when a large number of documents is returned)
- Let's look at the performance problem first:
  - Solution: do preprocessing

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` does not 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 `Calpurnia`
  - Complement the vector of `Calpurnia`
  - Do a (bitwise) `AND` on the three vectors
  - 110100 `AND` 110111 `AND` 101111 = 100100

Indexing Large Collections

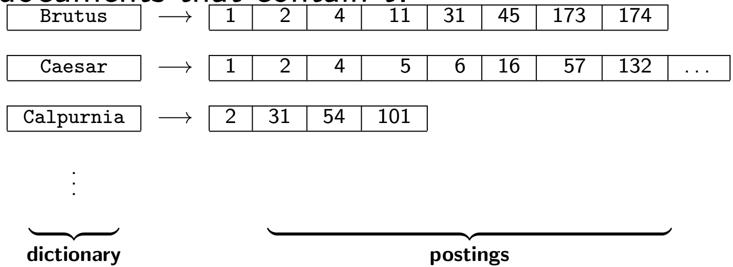
- Consider $N = 10^6$ documents, each with about 1000 tokens
- On average 6 bytes per token, including spaces and punctuation $\Rightarrow$ the size of document collection is about 6 GB
- Assume there are $M = 500{,}000$ distinct terms in the collection

Building Incidence Matrix

- $M = 500{,}000 \times 10^6 =$ half a trillion 0s and 1s.
  - We would use about 60GB to index 6GB of text, which is clearly very inefficient.
- But, wait a minute, the matrix has no more than one billion 1s.
  - The matrix is extremely sparse, i.e. 99.8% is filled with 0s.
- What is a better representations?
  - We only record the 1s.

Inverted Index

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



Brutus ⟶ 1 | 2 | 4 | 11 | 31 | 45 | 173 | 174

Caesar ⟶ 1 | 2 | 4 | 5 | 6 | 16 | 57 | 132 | ...

Calpurnia ⟶ 2 | 31 | 54 | 101

⋮

dictionary

postings

Index Construction

- Collect the documents to be indexed:

  Friends, Romans, countrymen.   So let it be with Caesar   . . .

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

  Friends   Romans   countrymen   So   . . .

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

  friend   roman   countryman   so   . . .

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

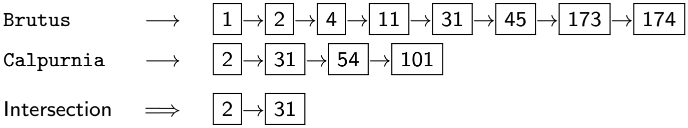
Index Construction

- Later on in this module, we'll talk about optimizing inverted indexes:
  - 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?

Processing Boolean Queries

- Consider the conjunctive 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 Postings Lists



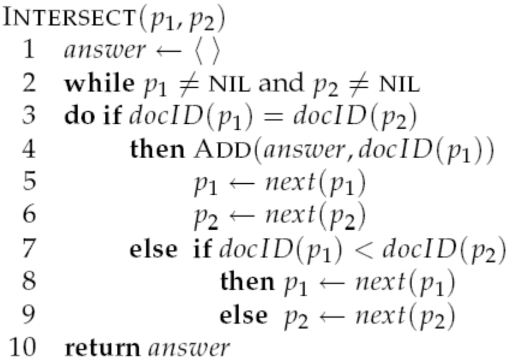
Brutus ⟶ 1 → 2 → 4 → 11 → 31 → 45 → 173 → 174

Calpurnia ⟶ 2 → 31 → 54 → 101

Intersection ⟹ 2 → 31

- Can be done in linear time if postings lists are sorted

Intersecting Postings Lists



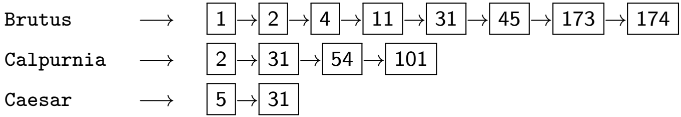
```
INTERSECT$(p_1, p_2)$
answer $\leftarrow \langle\ \rangle$
while $p_1 \neq$ NIL and $p_2 \neq$ NIL
do if $docID(p_1) = docID(p_2)$
      then ADD$(answer, docID(p_1))$
           $p_1 \leftarrow next(p_1)$
           $p_2 \leftarrow next(p_2)$
      else if $docID(p_1) < docID(p_2)$
             then $p_1 \leftarrow next(p_1)$
             else $p_2 \leftarrow next(p_2)$
return answer
```

Mapping Operators to Lists

- The Boolean operators `AND`, `OR`, and `NOT` are evaluated as follows:
  - `term1 AND term2`: intersection of the lists for `term1` and `term2`
  - `term1 OR term2`: union of the lists for `term1` and `term2`
  - `NOT term1`: complement of the list for `term1`

Query Optimization

- What is the best order for query processing?
- 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`



`Brutus` ⟶ 1 → 2 → 4 → 11 → 31 → 45 → 173 → 174

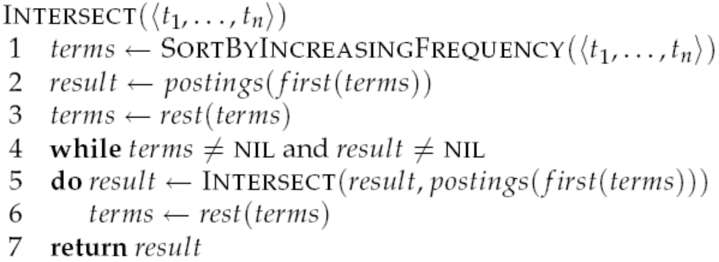
`Calpurnia` ⟶ 2 → 31 → 54 → 101

`Caesar` ⟶ 5 → 31

Query Optimization

- Simple and effective optimization:
  - Process in the 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



```
$\text{INTERSECT}(\langle t_1, \ldots, t_n \rangle)$
$terms \leftarrow \text{SORTBYINCREASINGFREQUENCY}(\langle t_1, \ldots, t_n \rangle)$
$result \leftarrow postings(first(terms))$
$terms \leftarrow rest(terms)$
while $terms \neq$ NIL and $result \neq$ NIL
do $result \leftarrow \text{INTERSECT}(result, postings(first(terms)))$
    $terms \leftarrow rest(terms)$
return $result$
```

Commercial Boolean IR: Westlaw

- Largest commercial legal search service in terms of the number of paying subscribers (www.westlaw.com)
- 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
  - “trade secret” /s disclos! /s prevent /s employe!
- *Information need:* Requirements for disabled people to be able to access a workplace
  - disab! /p access! /s work-site work-place (employment /3 place)
- *Information need:* Cases about a host’s responsibility for drunk guests
  - host! /p (responsib! liab!) /p (intoxicat! drunk!) /p guest

Westlaw Example Queries

- /s = within same sentence
- /p = within same paragraph
- /*n* = within *n* words
- Space is disjunction, not conjunction (This was the default in search pre-Google.)
- & is `AND`
- ! is a trailing wildcard query

Summary

- 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.
  - It 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.
- When are Boolean queries the best way of searching?
  - It depends on: information need, searcher, document collection, . . .