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Text Technologies for Data Science

INFR11145

Indexing

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Lecture Objectives

- <u>Learn</u> about and <u>implement</u>
- Boolean search
- Inverted index
- Positional index

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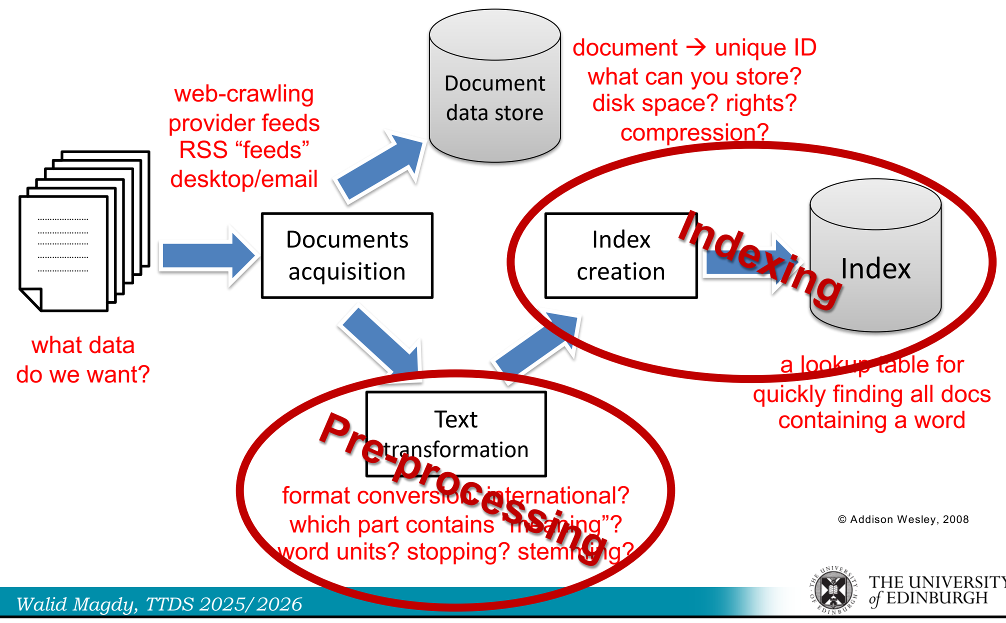
Indexing Process



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Pre-processing output

This is an example sentence of how the pre-processing is applied to text in information retrieval. It includes: Tokenization, Stop Words Removal, and Stemming

exampl sentenc pre process appli text inform retriev includ token stop word remov stem

- Add processed terms to index
- What is "index"?

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Index

- How to match your term in non-linear time?
- Find/Grep:
  Sequential search for term
- Index:
  Find term locations immediately

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Book Index

Index

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Indexing

- Search engines vs PDF find or grep?
  - Infeasible to scan large collection of text for every "search"
  - Find section that has: "UK and Scotland and Money"?!
- Book Index
  - For each word, list of "relevant" pages
  - Find topic in sub-linear time
- IR Index:
  - Data structure for fast finding terms
  - Additional optimisations could be applied

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Document Vectors

- Represent documents as vectors
  - Vector → document, cell → term
  - Values: term frequency or binary (0/1)
  - All documents → collection matrix

he	drink	ink	likes	pink	think	wink	
2	1	0	2	0	0	1	← **D1:** He likes to wink, he likes to drink
1	3	0	1	0	0	0	← **D2:** He likes to drink, and drink, and drink
1	1	1	1	0	1	0	← **D3:** The thing he likes to drink is ink
1	1	1	1	1	0	0	← **D4:** The ink he likes to drink is pink
1	1	1	1	1	0	1	← **D5:** He likes to wink, and drink pink ink

number of occurrence of
a term in a document

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Inverted Index

- Represent terms as vectors
  - Vector → term, cell → document
  - Transpose of the collection matrix
  - Vector: inverted list

he	drink	ink	likes	pink	thing	wink	
2	1	0	2	0	0	1	← **D1:** He likes to wink, he likes to drink
1	3	0	1	0	0	0	← **D2:** He likes to drink, and drink, and drink
1	1	1	1	0	1	0	← **D3:** The thing he likes to drink is ink
1	1	1	1	1	0	0	← **D4:** The ink he likes to drink is pink
1	1	1	1	1	0	1	← **D5:** He likes to wink, and drink pink ink

Boolean Search

- Boolean: exist / not-exist
- Multiword search: logical operators (AND, OR, NOT)
- Example
  - Collection: search Shakespeare's Collected Works
  - Boolean query: Brutus AND Caesar AND NOT Calpurnia
- Build a **Term-Document Incidence Matrix**
  - Which term appears in which document
  - Rows are terms
  - Columns are documents

Collection Matrix

Documents

Terms	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 ***document*** contains ***term***, 0 otherwise

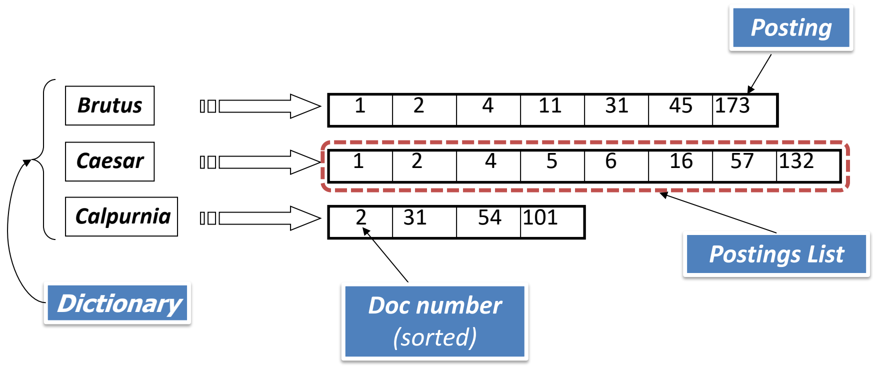
Query: Brutus AND Caesar AND NOT Calpurnia
Apply on rows: **110100** AND **110111** AND !(**010000**) = **100100**

Bigger collections?

- Consider N = 1 million documents, each with about 1000 words.
- n = 1M x 1K = 1B words
  ➔ Heap's law → $v \approx$ 500K
- Matrix size = 500K unique terms x 1M documents = 0.5 trillion 0's and 1's entries!
- If all words appear in many documents
  → max{count(1's)} = N * doc. length = 1B
- Actually, from Zip's law → 250k terms appears once!
- Collection matrix is extremely **sparse**. (*mostly 0's*)

Inverted Index: Sparse representation

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



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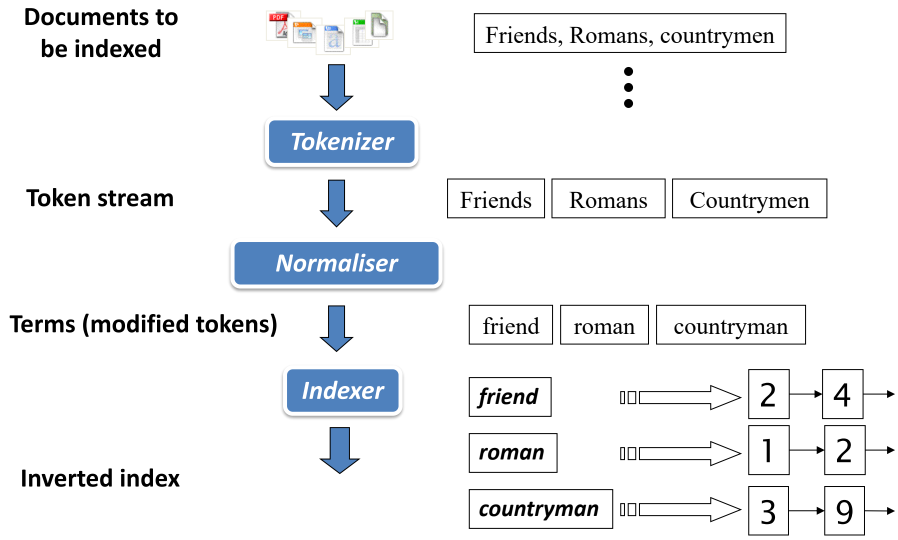
Inverted Index Construction



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Step 1: Term Sequence

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

Sequence of (term, Doc ID) pairs

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

Step 2: Sorting

- **Sort by:**
  - **1) Term**
  - then
  - **2) Doc ID**

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

Sorting

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

Step 3: Posting

1. Multiple term entries in a single document are merged
2. Split into Dictionary and Postings
3. Doc. Frequency (*df*) 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

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Inverted Index: matrix → postings

he	drink	ink	likes	pink	think	wink	
2	1	0	2	0	0	1	← **D1:** He likes to wink, he likes to drink
1	3	0	1	0	0	0	← **D2:** He likes to drink, and drink, and drink
1	1	1	1	0	1	0	← **D3:** The thing he likes to drink is ink
1	1	1	1	1	0	0	← **D4:** The ink he likes to drink is pink
1	1	1	1	1	0	1	← **D5:** He likes to wink, and drink pink ink

he ⇨ 1 2 3 4 5
drink ⇨ 1 2 3 4 5
ink ⇨ 3 4 5
pink ⇨ 4 5
thing ⇨ 3
wink ⇨ 1 5

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Inverted Index: with frequency

- Boolean: term → DocIDs list
- Frequency: term → tuples (DocID,count(term)) lists

he	1:2	2:1	3:1	4:1	5:1
drink	1:1	2:3	3:1	4:1	5:1
ink	3:1	4:1	5:1		
pink	4:1	5:1			
thing	3:1				
wink	1:1	5:1			

appeared in
D2 3 times

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Query Processing

- Find documents matching query {ink **AND** wink}
  1. Load inverted lists for each query word
  2. Merge two postings lists → **Linear merge**
- Linear merge → O(*n*)
  n: total number of posts for all query words

ink	3:1	4:1	5:1
wink	1:1	5:1	

Matches
1: f(0,1)
3: f(1,0)
4: f(1,0)
5: f(1,1)

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Phrase Search

- Find documents matching query “pink ink”
  1. Find document containing both words
  2. Both words has to be a phrase
- Bi-gram Index:

He likes to wink, and drink pink ink → Convert to bigrams

He_likes likes_to to_wink wink_and and_drink drink_pink pink_ink

- Bi-gram Index, issues:
  - Fast, but index size will explode!
  - What about trigram phrases?
  - What about proximity? “ink is pink”

Proximity Index

- Terms positions is embedded to the inv. Index
  - Called proximity/positional index
  - Enables phrase and proximity search
  - Tuples (DocID, term position)

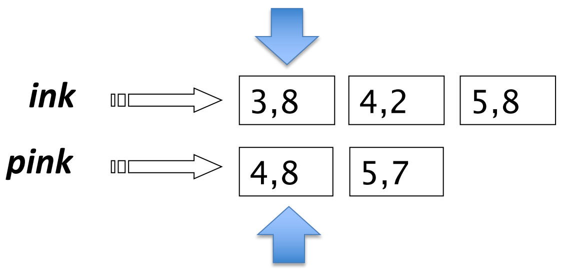
he ⇨	1:2	2:1	3:1	4:1	5:1	
drink ⇨	1:1	2:3	3:1	4:1	5:1	

D1: He likes to wink, he likes to drink
D2: He likes to drink, and drink, and drink
D3: The thing he likes to drink is ink
D4: The ink he likes to drink is pink
D5: He likes to wink, and drink pink ink

he ⇨	1,1	1,5	2,1	3,3	4,3	5,1	
drink ⇨	1,8	2,4	2,6	2,8	3,6	4,5	5,6

Query Processing: Proximity

- Find documents matching query "pink ink"
  1. Use **Linear merge**
  2. Additional step: check terms positions
- **Proximity search**:
  pos(term1) – pos(term2) < |*w*| → #5(pink,ink)



Matches

3: f(1,0) = **0**

4: f(1,1) = ? =
pos(ink) – pos(pink) == 1?

5: f(1,1) = ? =
pos(ink) – pos(pink) == 1?

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Query Processing: Simple implementation

- For each term in query → retrieve posting list
- AND → Intersection (∩) between posting lists
- OR → Union (∪) of posting lists
- NOT → inverse of posting list (all docs not in the list)
  - Usually only combined with AND operator.
- Phrase search → AND + check pos2-pos1 == 1
- Proximity search → AND + check |pos2-pos1| ≤ n

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Proximity search: data structure

- Possible data structure:
  <term: df;
  DocNo: pos1, pos2, pos3
  DocNo: pos1, pos2, pos3
  ……. >
- Example:
  <scotland: 25;
  94: 212
  351: 23,34,1354,1779,1838
  370: 981
  3330: 115
  3334: 121,316
  3532: 59,111,162,265 …>

Practical

Summary

- Document Vector
- Term Vector
- Inverted Index
- Collection Matrix
- Posting
- Proximity Index
- Query Processing → Linear merge

Resources

- Textbook 1: Intro to IR, Chapter 1 & 2.4
- Textbook 2: IR in Practice, Chapter 5
- Lab 2