Information Retrieval

LBAW · Databases and Web Applications
MIEIC 18/19

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DEI, FEUP, U.Porto

Agenda

- Introduction to Information Retrieval
- Search Engines Overview
- Information Retrieval Models
- Retrieval Efficiency
- Retrieval Evaluation
- Full Text Search in PostgreSQL

Introduction

Information Retrieval

- Information Retrieval deals with the representation, storage, organization of, and access to information items

- IR research includes:
  - Document and query modeling, web search, text classification, system architecture, user interfaces, data visualization, filtering

- Early example of *information retrieval systems* –> libraries
  - Manually built indexes and categories.

Historic Highlights

- First developments in the area of Information Retrieval started in the 50s, with pioneers such as Hans Peter Luhn and Eugene Garfield.

- In the 60s, the TF-IDF weighting scheme was developed as a result of work by Karen Spark Jones, Gerard Salton, and others. The probabilistic model was introduced in the 70s and the vector model in the 80s.

- Libraries were among the first institutions to adopt IR systems for retrieving information.

- The emergence of the Web, which has become the largest repository of knowledge in human history, put IR at the center of the stage.

Central Issue

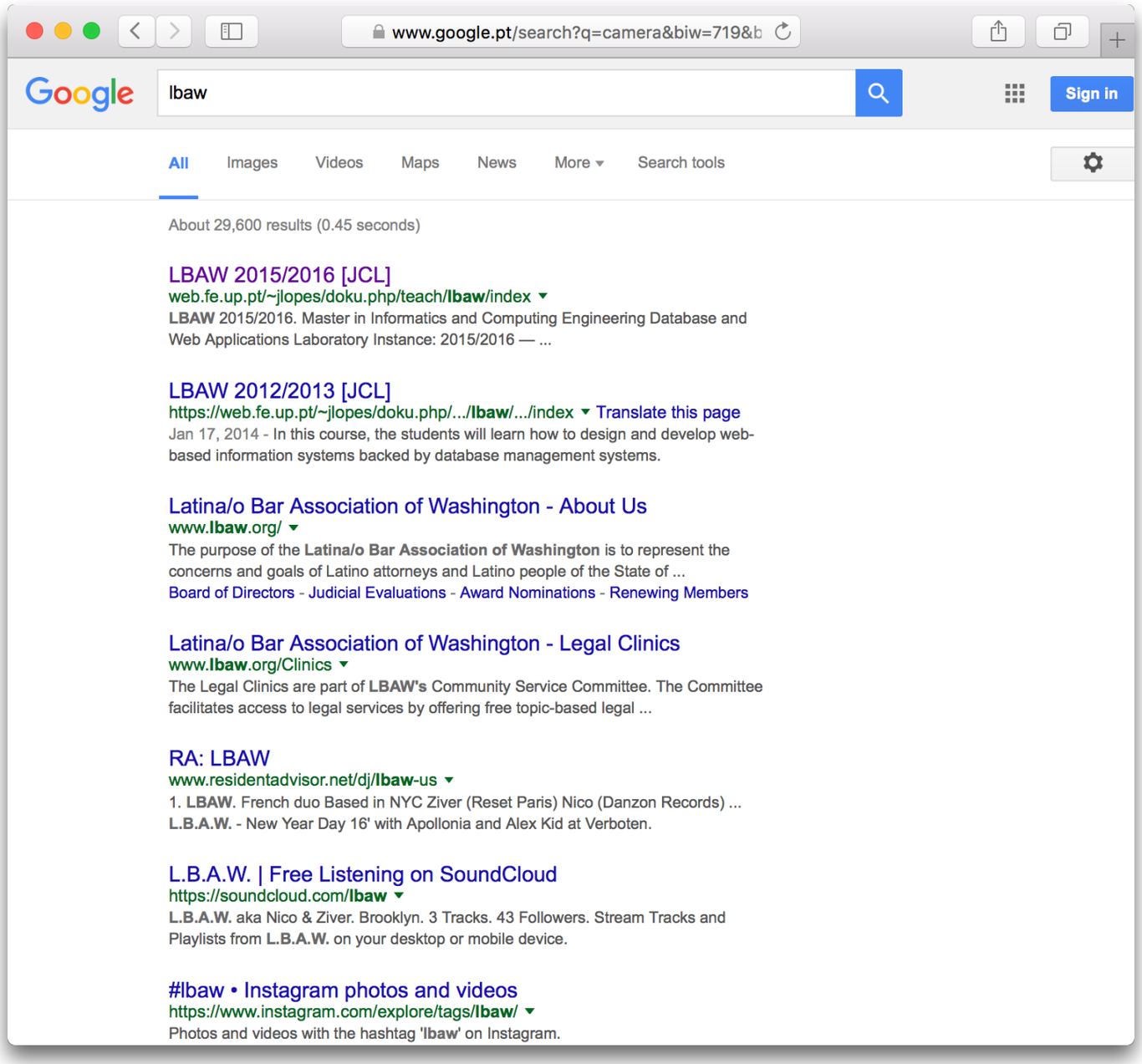
- The IR Problem
  - The key goal of an IR system is to retrieval all items that are relevant to a user query, representing an information need, while retrieving as few non relevant items as possible.

- The central concept in IR is the notion of relevance.

Motivation

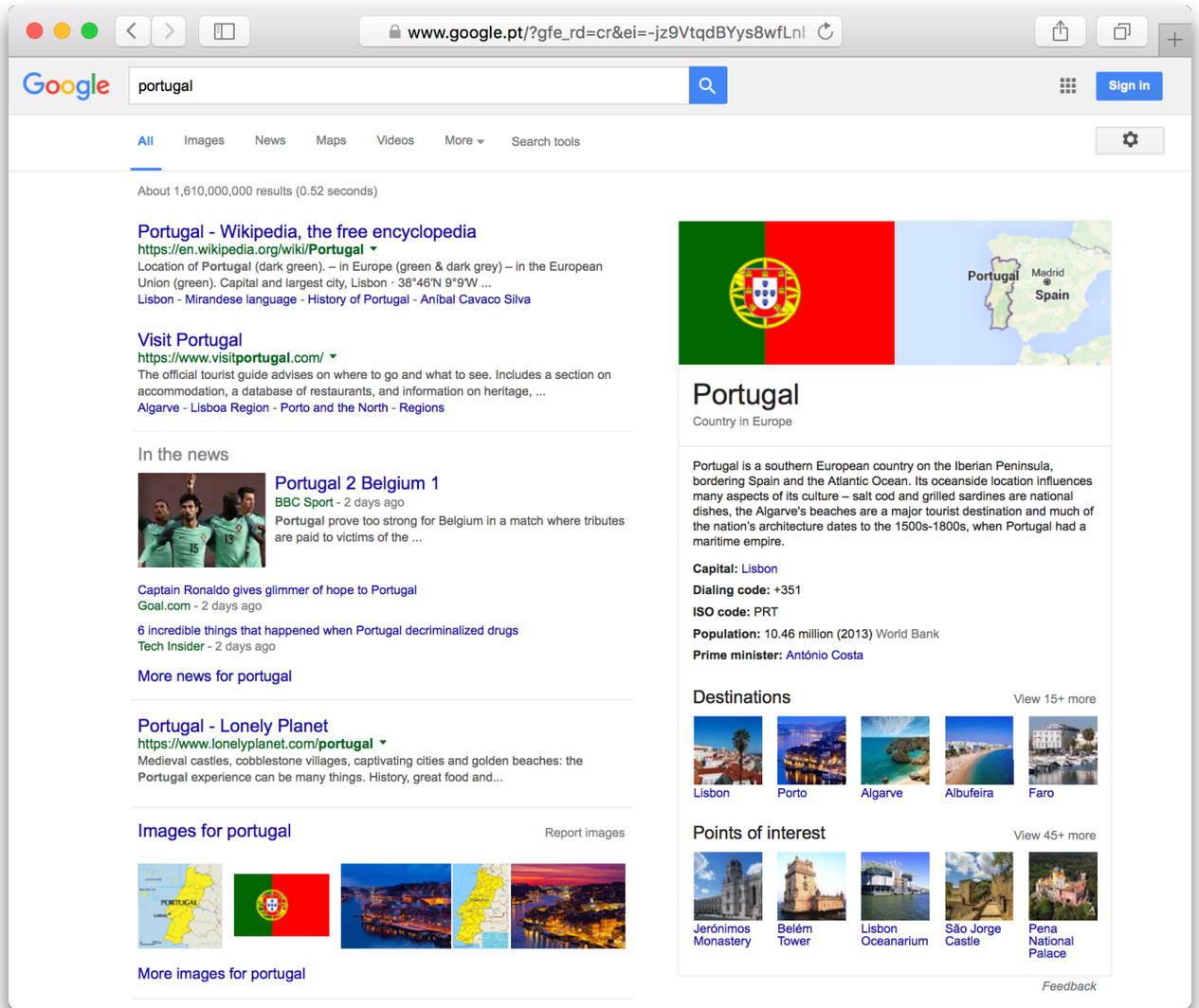
- RDBS provide set-based or data retrieval.
    - SELECT title, year FROM book
      WHERE title LIKE '%introduction%html%';
- **Limitations?**
    - There is no linguistic support (e.g. intro vs. introduction)
    - Difficult to search for multiple keywords (e.g. introduction to html vs. html introduction)
    - Degraded performance when dealing with large number of documents.
    - No ranking of results (e.g. order by relevance)

Web Search System



Trends

- Users expect more than a pointer to a single document for a given information need (e.g. entities, relations).



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University in Porto, Portugal

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Treinador principal: Sérgio Conceição

Arena/Estádio: Estádio do Dragão

Atendimento ao cliente: 22 557 0400

Fundador: António Nicolau d'Almeida

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Escalação

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Titanic

1997 · Drama film/Disaster Film · 3h 30m

7.7/10	74%	88%
IMDb	Metacritic	Rotten Tomatoes

James Cameron's "Titanic" is an epic, action-packed romance set against the ill-fated maiden voyage of the R.M.S. Titanic; the pride and joy of the White Star Line and, at the time, the largest moving object ever built. She was the most luxurious liner of her era -- the "ship of dreams" -- which ult… More

Initial release: November 18, 1997 (London)

Director: James Cameron

Featured song: My Heart Will Go On

Box office: 2.187 billion USD

Awards: Academy Award for Best Picture, more

Critic reviews

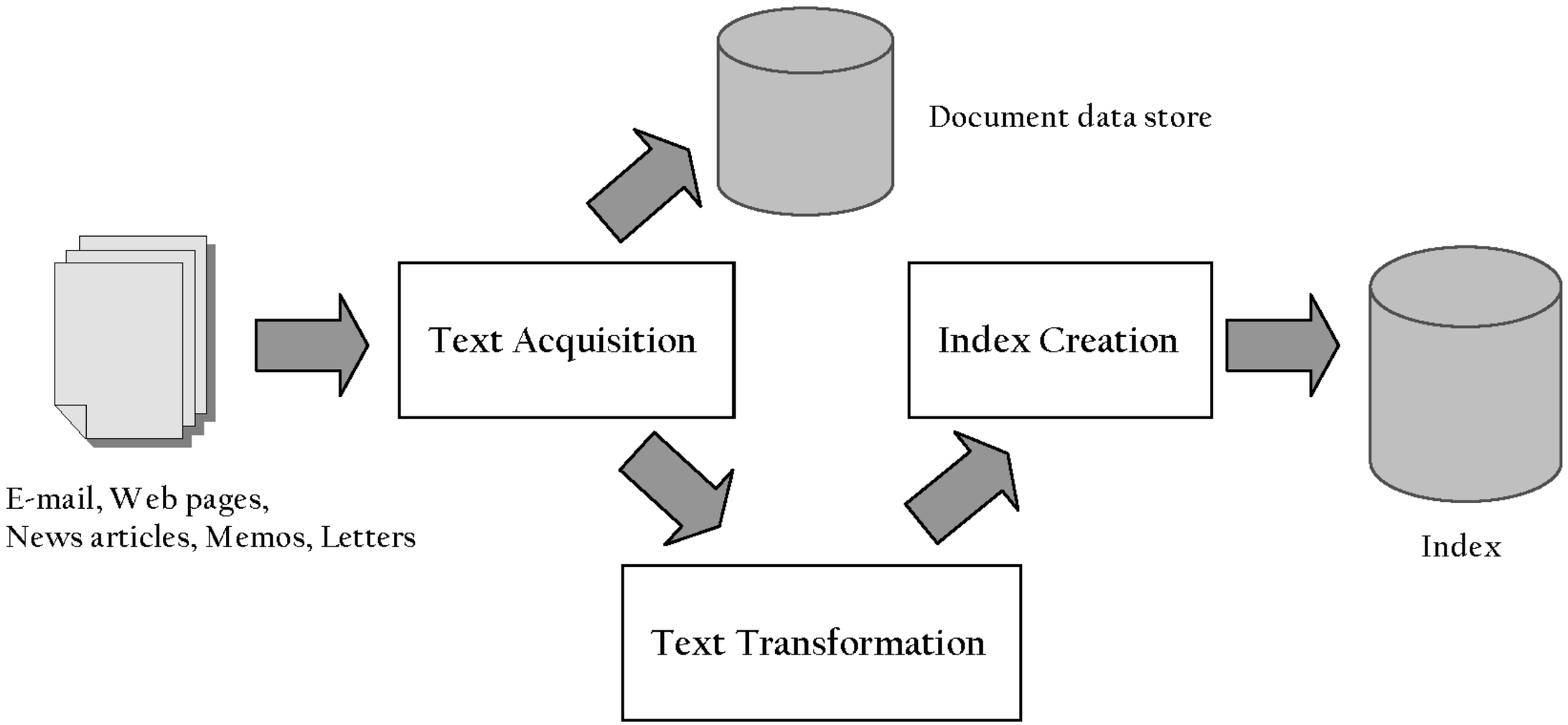
For Cameron, Titanic is an attempt to raise pop entertainment to the level of art. Full review
Peter Travers · Rolling Stone

Search Engines

Search Engine Architecture

- The architecture of search engines can be divided in two main processes
  - **the indexing process** – offline, when collection changes
  - **the querying process** – online, in response to user queries

Indexing Process

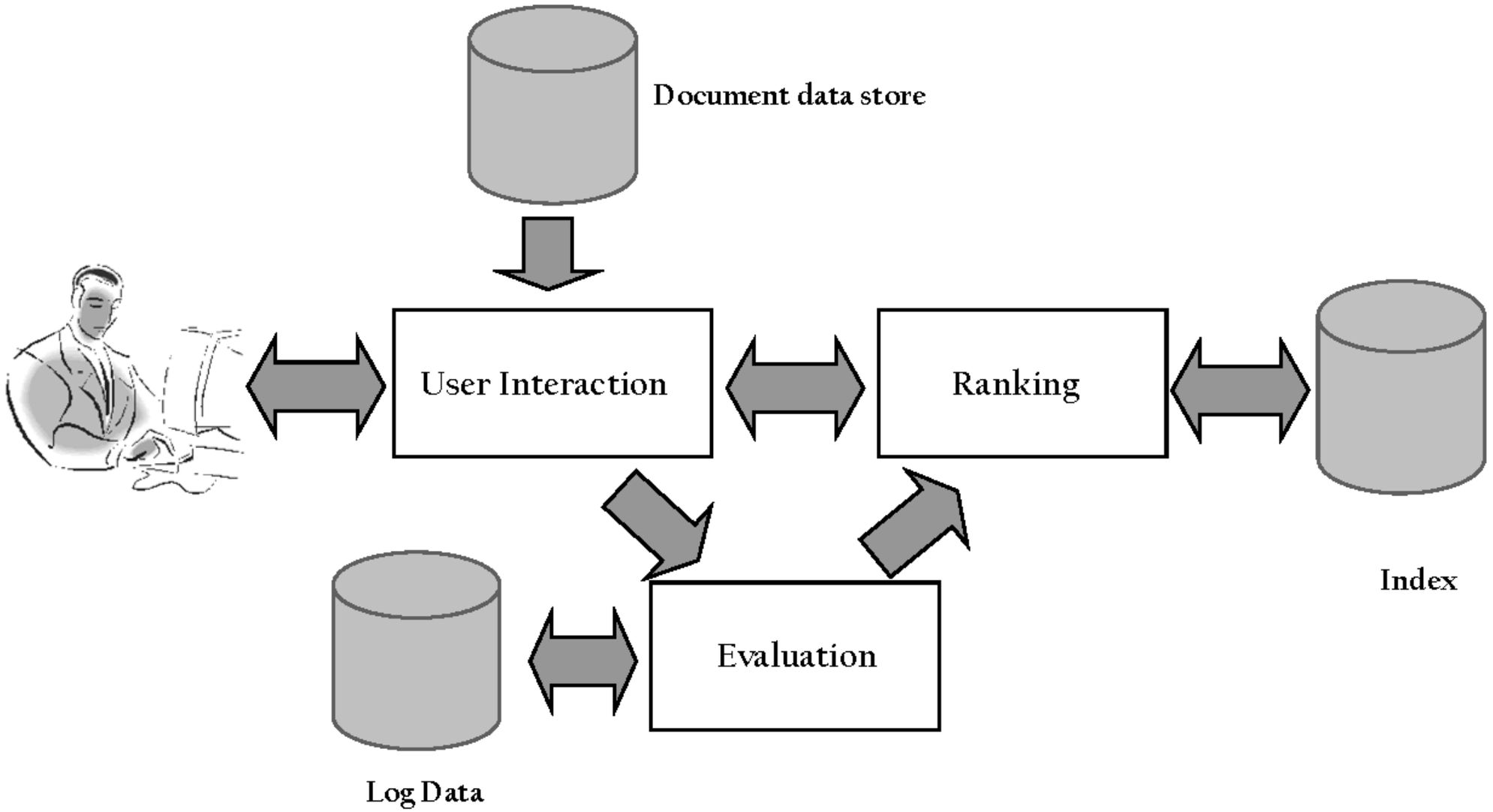


Croft, Metzler, Strohman (2010), Search Engines: Information Retrieval in Practice

Indexing Process

- Text Acquisition
  - identifies (finds) and stores documents for indexing
- Text Transformation
  - transforms documents into index terms or features
- Index Creation
  - takes index terms and creates data structures to support fast searching

Query Process



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Query Process

- User Interaction
  - supports creation and refinement of queries; display of results
- Ranking
  - use query and index to generate ranked list of results
- Evaluation
  - monitors and measures effectiveness and efficiency

Ranking Signals

- Estimating each document relevance for a given user query and context is done using various sources of information, usually called signals.

- **Which signals are used by a search engine?**

  - Keywords in the document.
  - Origin of the document (e.g. up.pt, publico.pt, .gov.pt)
  - References (i.e. links) to the document.
  - Information about the user (e.g. previous searches and clicks, location, network, browser used, device used).
  - Much more …

Ranking Signals

- Web search engines use hundreds of signals, also called features.
- These signals can be divided in two groups
  - static signals that can be computed during the indexing process, e.g. length of document, age of document, number of links to document, etc.
  - query-dependent signals that are only available at query time, e.g. number of query terms, time of day, query terms in document, etc.
- Signals can also be divided according to their source:
  - Document-based, Collection-based, User-based

Information Retrieval Models

Information Retrieval Models

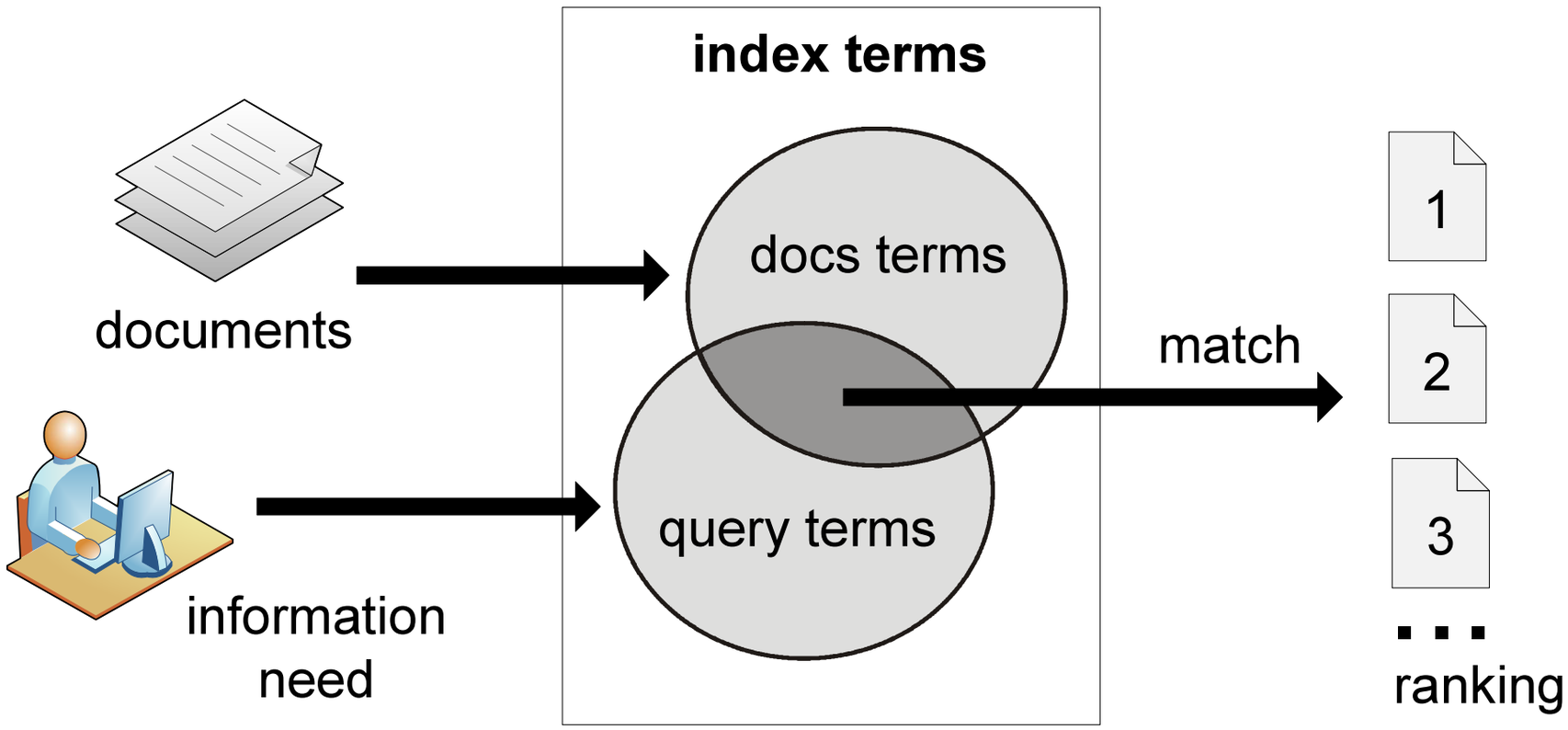
- Information Retrieval modeling is a process aimed at producing a ranking function

- The process consists of two main tasks

  - The conception of a logical framework for representing documents and queries

  - The definition of a ranking function that allows quantifying the similarities among documents and queries.

Information Retrieval Process



The Term-Document Matrix

- The term-document matrix is a basic concept that represents the relation between indexed terms and collection documents.

- Also called incidence matrix.

$$\begin{array}{c} \\ k_1 \\ k_2 \\ k_3 \end{array} \begin{array}{c} \begin{array}{cc} d_1 & d_2 \end{array} \\ \begin{bmatrix} f_{1,1} & f_{1,2} \\ f_{2,1} & f_{2,2} \\ f_{3,1} & f_{3,2} \end{bmatrix} \end{array}$$

where each $f_{i,j}$ element stands for the frequency of term k_i in document d_j

Term Weighting

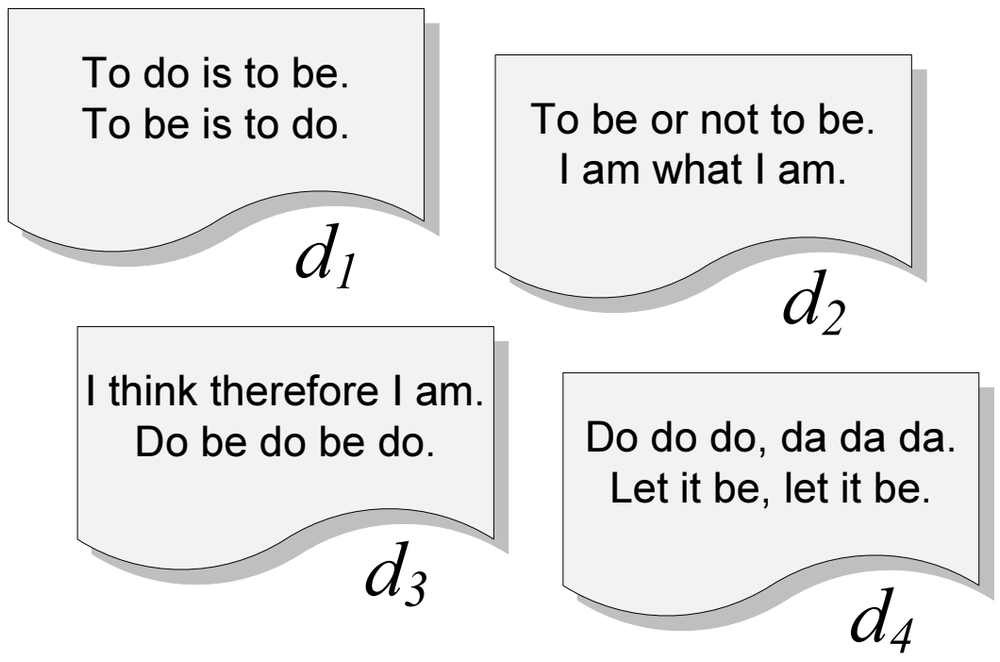
- Terms are not equally useful for describing a document.

- **Term weights** quantify the importance of a given index term for describing the contents of a document.

$$f(do, d_1) = 2$$
$$f(do, d_2) = 0$$
$$f(do, d_3) = 3$$
$$f(do, d_4) = 3$$

$$F(do) = 8$$

$$n(do) = 3$$



Term Frequency

- Term frequency can be used as an estimation of the term importance for a given document.

- However, it can be easily manipulated.

Quasi architecto

Sed ut perspiciatis unde omnis iste natus error sit **flowers** accusantium doloremque laudantium, totam rem aperiam, eaque ipsa quae ab illo **flowers** veritatis et quasi architecto beatae vitae dicta sunt explicabo.

Nemo enim **flowers** voluptatem quia voluptas sit aspernatur aut odit aut fugit, sed quia consequuntur magni dolores eos qui ratione voluptatem sequi nesciunt.

TF("flowers") = 3

Quasi architecto

Sed ut **flowers** unde omnis **flowers** natus error sit **flowers** accusantium **flowers** laudantium, totam rem aperiam, eaque ipsa quae ab illo **flowers** veritatis et quasi **flowers** beatae vitae dicta sunt explicabo.

Nemo enim **flowers** voluptatem quia voluptas sit aspernatur aut **flowers** aut fugit, sed quia **flowers** magni dolores eos qui ratione voluptatem sequi **flowers**.

TF("flowers") = 10

Quasi architecto

flowers ut **flowers flowers** omnis **flowers flowers flowers** sit **flowers flowers flowers flowers**, totam **flowers** aperiam, **flowers** ipsa **flowers** ab **flowers flowers flowers** et quasi **flowers flowers flowers** dicta **flowers**.

flowers enim **flowers flowers** quia **flowers flowers flowers** aut **flowers** aut **flowers**, **flowers** quia **flowers flowers** dolores **flowers** qui **flowers flowers** sequi **flowers**.

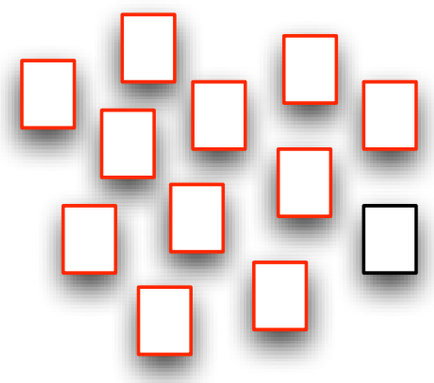
TF("flowers") = ∞

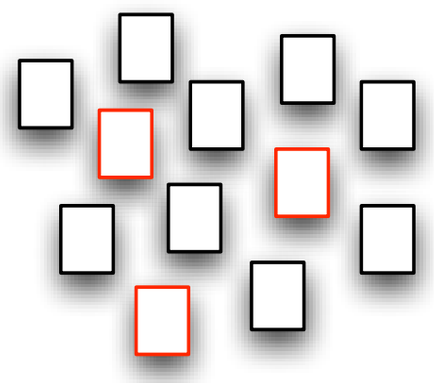
Inverse Document Frequency

- An important, but less intuitive measure, is the inverse document frequency (IDF) of a term.

- Terms that appear in fewer documents of a collection have more discriminative power, thus are given a higher weight. Also referred to as the specificity of a term.

$$IDF(term) = \frac{|Documents\ in\ collection|}{|Documents\ containing\ term|}$$

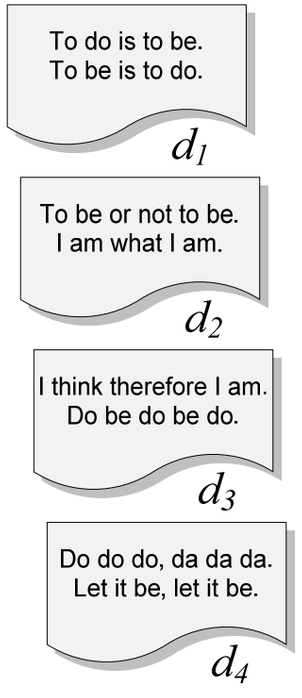




TF-IDF

- The best known term weighting scheme uses weights that combine term frequency with inverse document frequency, known as TF-IDF.

- tf-idf(*term, document, collection*) = tf(*term, document*) x idf(*term, collection*)



		d_1	d_2	d_3	d_4
1	to	3	2	-	-
2	do	0.830	-	1.073	1.073
3	is	4	-	-	-
4	be	-	-	-	-
5	or	-	2	-	-
6	not	-	2	-	-
7	I	-	2	2	-
8	am	-	2	1	-
9	what	-	2	-	-
10	think	-	-	2	-
11	therefore	-	-	2	-
12	da	-	-	-	5.170
13	let	-	-	-	4
14	it	-	-	-	4

Practical Example

Term specificity

- Use Google to estimate the inverse document frequency (idf) (or specificity) of the following terms:
  - [portugal], [technology], [health]
  - Use $idf_k = \log \frac{N}{n_k}$
    - What term do you expect to have a higher idf score? And the lowest?
- Again using Google and the same set of terms, consider the subset of documents in the .pt domain as a collection (filter using [site:pt]).
  - What changes do you expect to the idf scores?

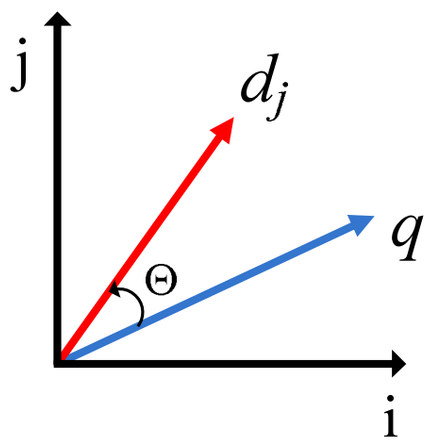
Term specificity [solving]

- **What is Google's index size?**
  - Search for a very common term, e.g. max([the], [and], [is]) ≈ 26B
- **All World Wide Web**
  - idf (portugal) ≈ log (26B / 1.16B) = log (22.42) ≈ 1.35
  - idf (technology) ≈ log (26B / 2.64B) ≈ 0.99
  - idf (health) ≈ log (26B / 3.14B) ≈ 0.92
- **.pt Domain**
  - Update index size of the new sub-collection, [pt site:pt] ≈ 278M
  - idf (portugal) ≈ log (278M / 99,6M) = log (2.79) ≈ 0.44
  - idf (technology) ≈ log (278M / 1.94M) ≈ 2.16
  - idf (health) ≈ log (278M / 8.26M) ≈ 1.53

Vector Model

- Binary weights are too limiting. The vector model proposes a framework in which partial matching is possible.

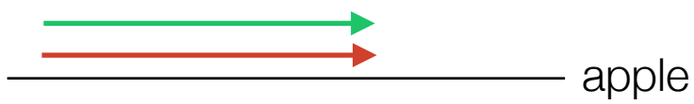
- Documents, and queries, are represented as unary vectors in a n-dimensional space. The similarity between two different documents is obtained using the cosine between these vectors.



$$cos(\theta) = \frac{\vec{d}_j \bullet \vec{q}}{|\vec{d}_j| \times |\vec{q}|}$$

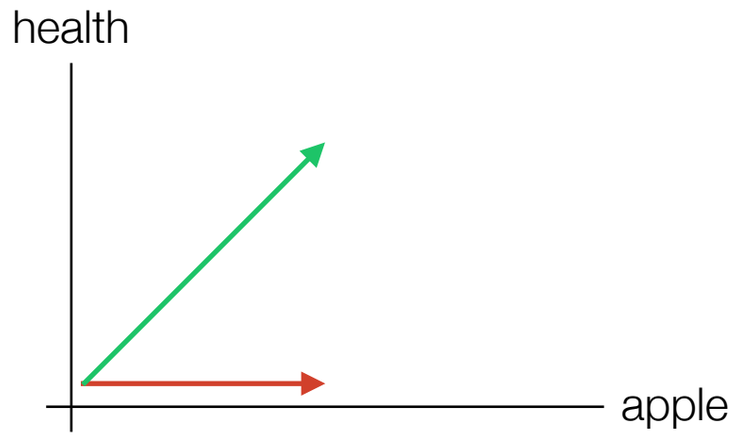
Vector Model Example

- Considering the following two sentences:
  - s1: apples are good for your health
  - s2: apples are fruits the grown in trees
- We can represent these two documents in vector spaces, considering n-dimensions.



1-dimension: apple

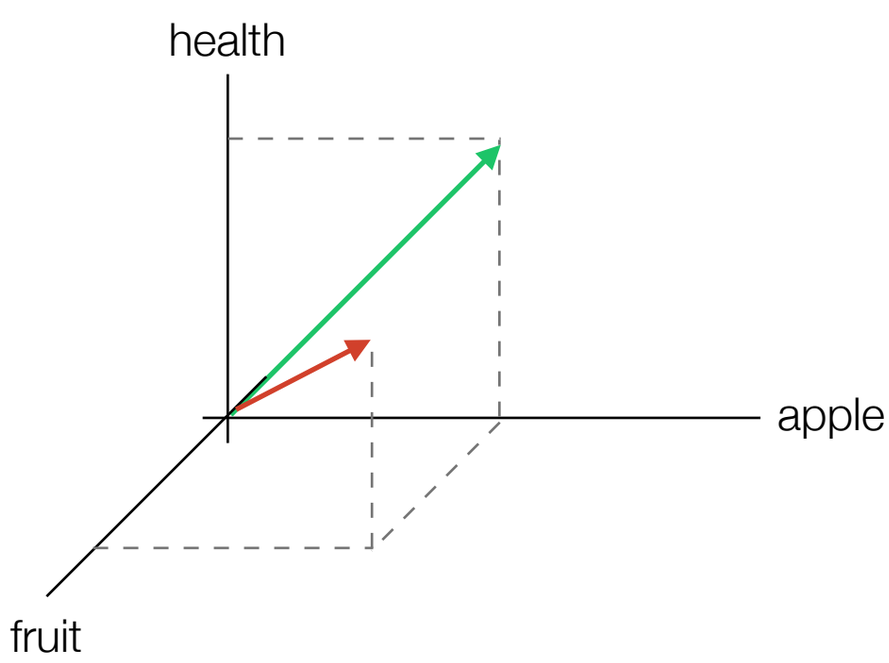
1-dimension: health



2-dimensions: apple, health

Vector Model Example

- Considering the following two sentences:
  - s1: apples are good for your health
  - s2: apples are fruits the grown in trees



3-dimensions: apple, health, fruit

Search Engine Ranking

Link-based Signals

Link-based Signals

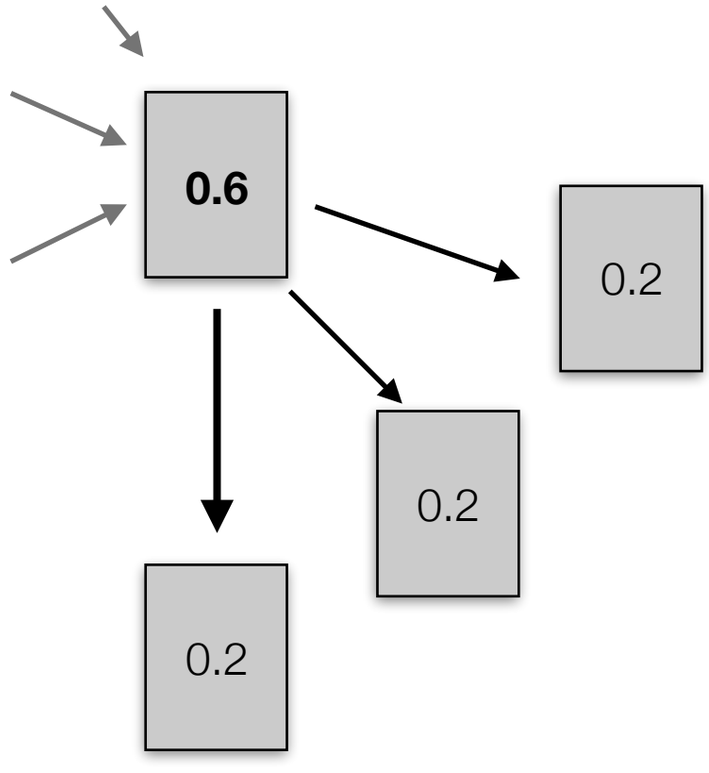
- The web is a directed graph.
- The number of hiperlinks pointing to a given document has be used as a measure of quality of that document.
- Simple approach: use the number of links to a page (i.e. in-degree) as a ranking signal.
- The best known link-based ranking signal is the PageRank, introduced by Google (Larry Page) in their ranking strategy.

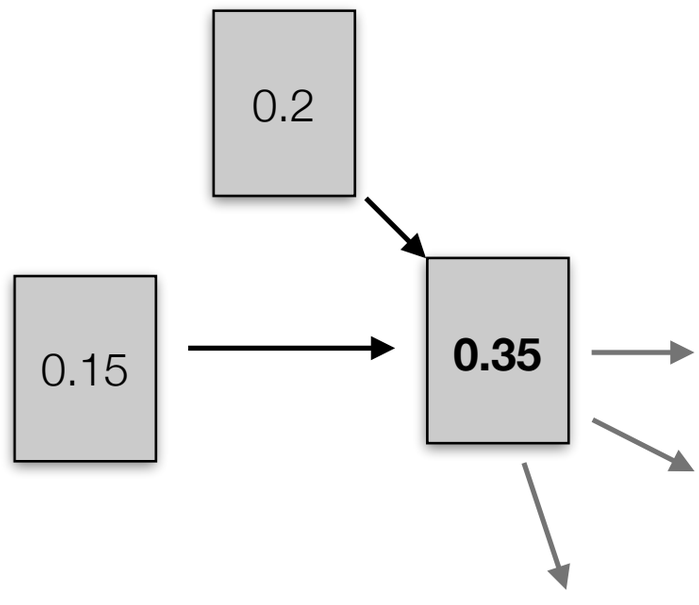
PageRank

- The web is a directed graph.
- The number of hiperlinks pointing to a given document has be used as a measure of quality of that document.
- Simple approach: use the number of links to a page (i.e. in-degree) as a ranking signal.
- The best known link-based ranking signal is the PageRank, developed at Stanford (Larry Page PhD) and used by Google in their ranking strategy. PageRank is a query-independent score.
- A link-based, query-dependent alternative, is the HITS algorithm, developed Jon Kleinberg in 1999. HITS produces two independent scores for each page, an authority score and a hub score.
  - An authority is a page with many citations from hubs.
  - A hub is a page that cites a large number of authorities.

PageRank Example

- PageRank is computed iteratively.
- All nodes (web documents) start with the same initial value, e.g. 1/N.
- The score of each node is distributed to the documents that it links to, until the score of each node converges.





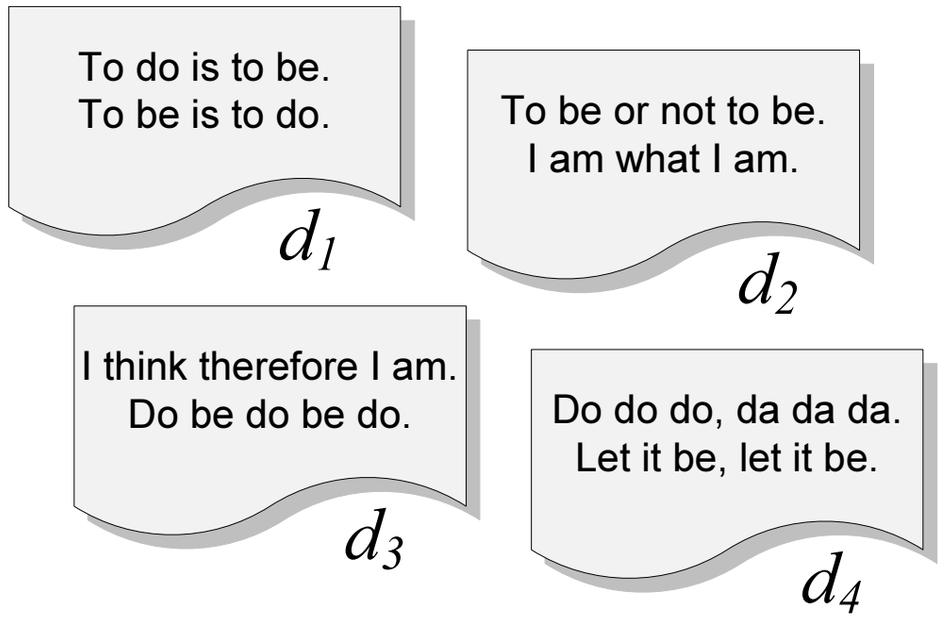
Retrieval Efficiency

Efficiency in Information Retrieval

- The goal is to process user queries with minimal requirements of computational resources.
- The inverted index is a word-based data structure built to speed up access.
- The inverted index structure is composed of two elements: the vocabulary and the occurrences.
  - The vocabulary is the set of all different words
  - For each word the index stores the document which contain that word

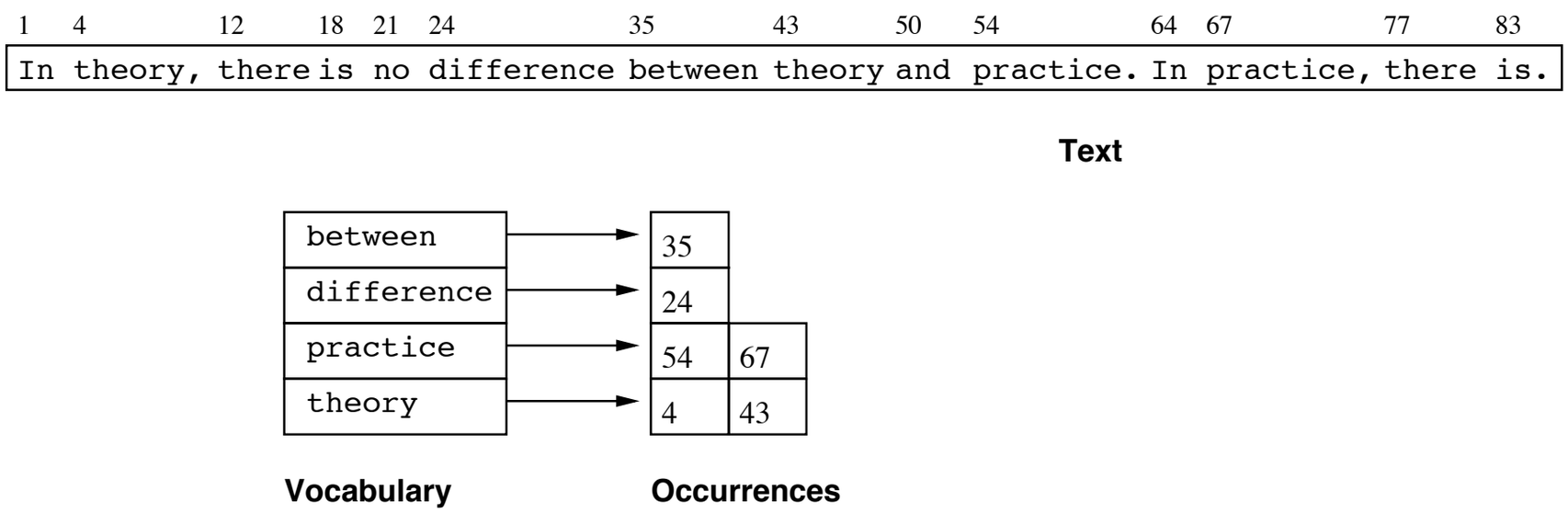
Basic Inverted Index

Vocabulary	n_i	Occurrences as inverted lists
to	2	[1,4],[2,2]
do	3	[1,2],[3,3],[4,3]
is	1	[1,2]
be	4	[1,2],[2,2],[3,2],[4,2]
or	1	[2,1]
not	1	[2,1]
I	2	[2,2],[3,2]
am	2	[2,2],[3,1]
what	1	[2,1]
think	1	[3,1]
therefore	1	[3,1]
da	1	[4,3]
let	1	[4,2]
it	1	[4,2]



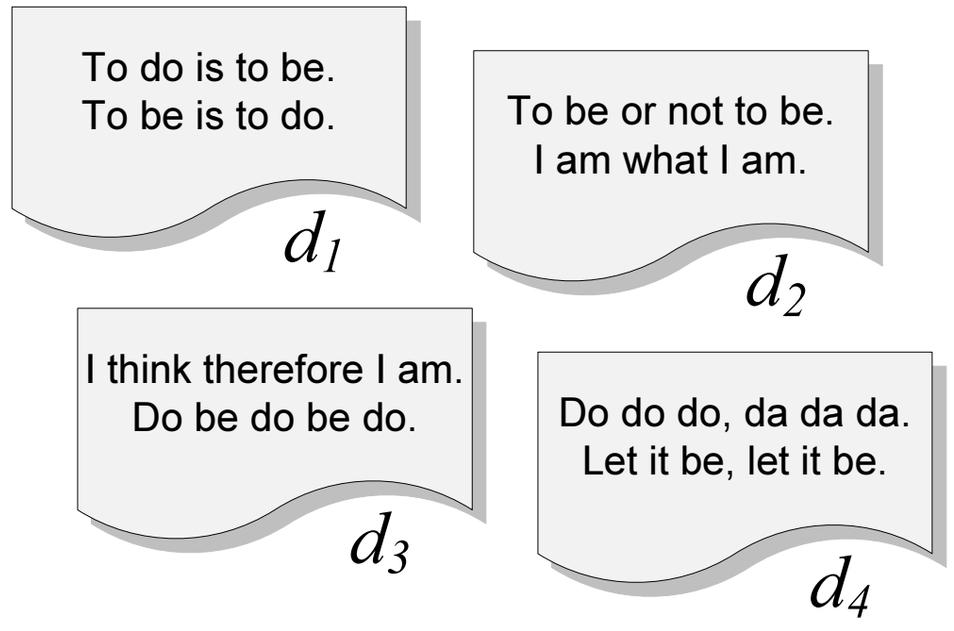
Full Inverted Index

- The basic index is not suitable for answering phrase or proximity queries.
- Hence, we need to add the position of each word in each document to the index.



Full Inverted Index

Vocabulary	n_i	Occurrences as full inverted lists
to	2	[1,4,[1,4,6,9]],[2,2,[1,5]]
do	3	[1,2,[2,10]],[3,3,[6,8,10]],[4,3,[1,2,3]]
is	1	[1,2,[3,8]]
be	4	[1,2,[5,7]],[2,2,[2,6]],[3,2,[7,9]],[4,2,[9,12]]
or	1	[2,1,[3]]
not	1	[2,1,[4]]
I	2	[2,2,[7,10]],[3,2,[1,4]]
am	2	[2,2,[8,11]],[3,1,[5]]
what	1	[2,1,[9]]
think	1	[3,1,[2]]
therefore	1	[3,1,[3]]
da	1	[4,3,[4,5,6]]
let	1	[4,2,[7,10]]
it	1	[4,2,[8,11]]



Retrieval Evaluation

Retrieval Evaluation

- How to evaluate how well the system is responding to users' queries?

- The field of Information Retrieval has a long tradition of measuring and evaluating the performance of retrieval systems. Well-known measures such as Precision and Recall, were proposed in this area.

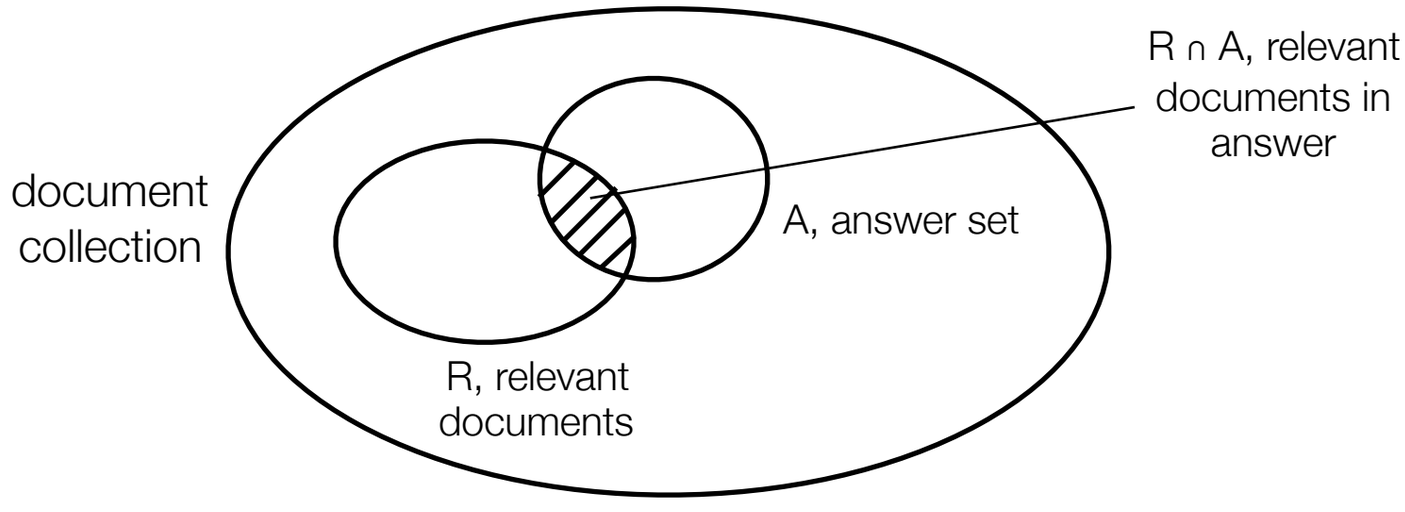
- Retrieval evaluation is a critical component of any modern search system to:
  - Determine how well a system is performing and evaluate changes.
  - Compare the performance of a system with others.

- Challenging, compared to tradicional areas where performance can be measured using objetive metrics such as space, speed, size, etc.

Precision and Recall

- Consider,
  - **R**, set of relevant document in the collection.
  - **A**, set of documents in the retrieved answer.

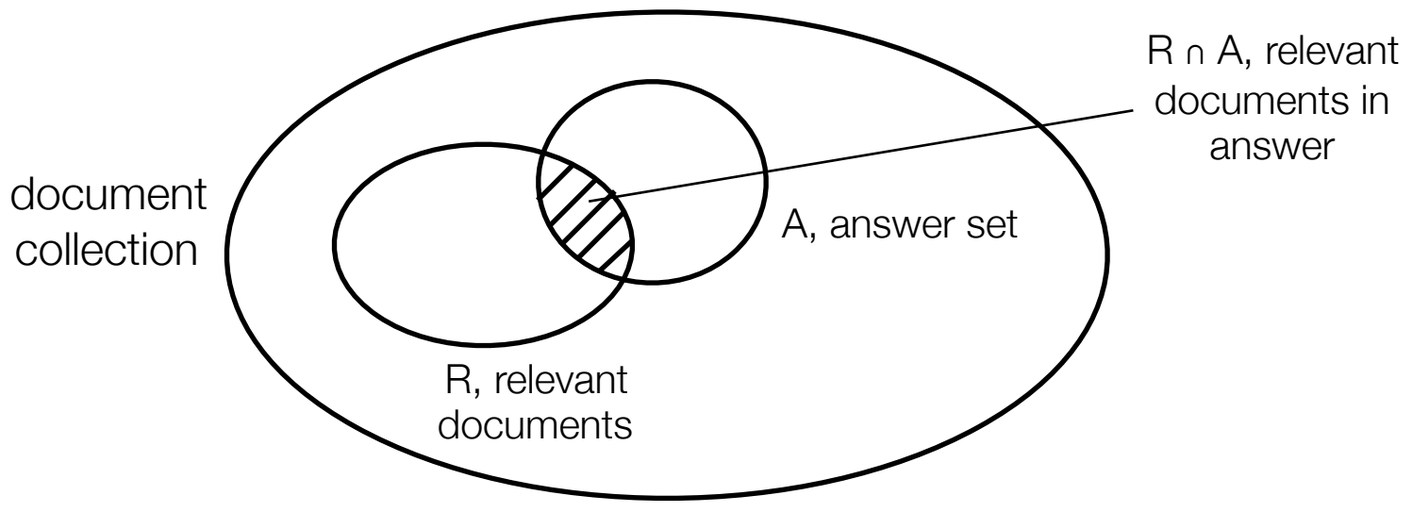
- We can define the two core measures in IR evaluation,
  - **Precision** is the fraction of the retrieved documents that are relevant.
  - **Recall** is the fraction of the relevant documenta that are retrieved.



Precision and Recall

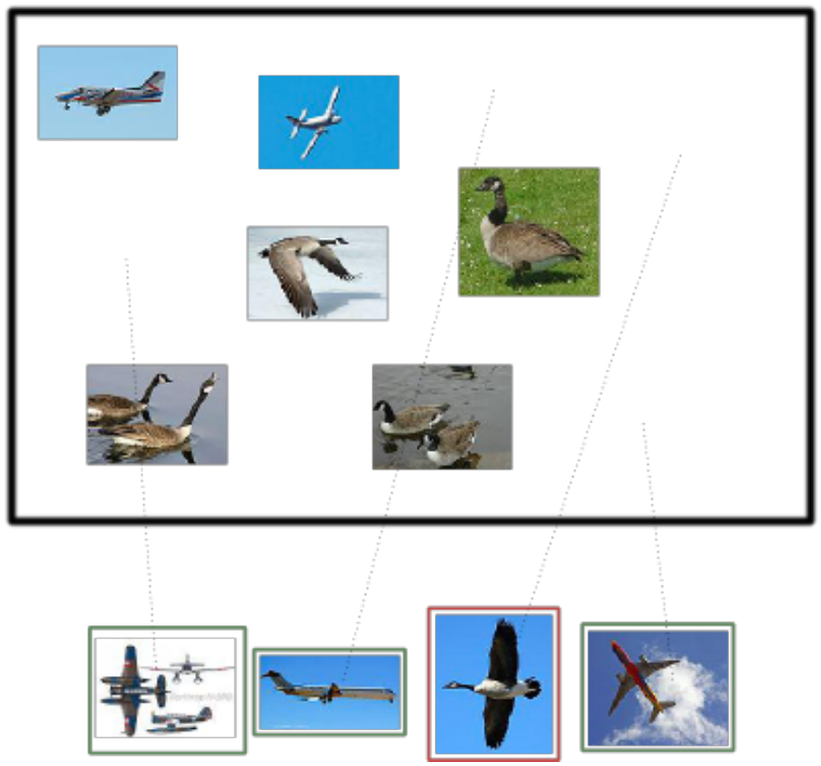
$$Precision = \frac{|R \cap A|}{|A|}$$

$$Recall = \frac{|R \cap A|}{|R|}$$



Precision and Recall Example

- For the following system, calculate precision and recall when searching for [airplane].



	relevant	not
retrieved	3	1
not retrieved	2	4

Precision = 3 / (3 + 1) = 0.75

Recall = 3 / (3 + 2) = 0.6

P@5 and P@10

- P@N measures the precision at the top N results.
- These metrics assume that precision at the top results has the most impact on user experience, e.g. web search.
- Consider the top 10 results returned by two systems ([X] rel and [–] not rel),
  - System #1: [X], [–], [–], [X], [X], [X], [–], [X], [X], [X]
  - System #2: [X], [X], [X], [X], [–], [–], [–], [–], [X], [–]
- System #1, P@5 = 0.6 and P@10 = 0.7
- System #2, P@5 = 0.8 and P@10 = 0.5

Full Text Search in PostgreSQL

Based on PostgreSQL 9.4.6 Documentation, Chapter 12 - Full Text Search.
http://www.postgresql.org/docs/9.4/static/textsearch.html

Parsing Documents

- to_tsvector converts a text to a representation optimized for text search.
- to_tsvector([config regconfig,] document text) returns tsvector
  - `SELECT to_tsvector('english', 'the old lady sailing an old boat in the sea');`
    - `'boat':7 'ladi':3 'old':2,6 'sail':4 'sea':10`
  - `SELECT to_tsvector('portuguese', 'a velha raposa saltou o muro');`
    - `'mur':6 'rapos':3 'salt':4 'velh':2`

Parsing Queries

- to_tsquery and plainto_tsquery convert a query text to a query structure optimized for search.
- `to_tsquery([ config regconfig, ] querytext text) returns tsquery`
  - SELECT plainto_tsquery('english','sail boats');
    - 'sail' & 'boat'
  - SELECT plainto_tsquery('portuguese','o velho barco');
    - 'velh' & 'barc'

Full Text Search

- Full text searching in PostgreSQL is based on the match operator @@, which returns true if a tsvector (document) matches a tsquery (query).
  - `SELECT to_tsvector('portuguese','o velho barco') @@ plainto_tsquery('portuguese','barca');`
    - t
  - SELECT to_tsvector('portuguese','o velho barco') @@ plainto_tsquery('portuguese','carro');
    - f

Searching a Table

- Example table: people(id, name)

- ```
  CREATE TABLE people (
    id SERIAL PRIMARY KEY,
    name TEXT NOT NULL
  );
  ```

- ```
  INSERT INTO people (name) VALUES ('Rui Silva');
  INSERT INTO people (name) VALUES ('Pedro Silva');
  INSERT INTO people (name) VALUES ('Filipa Silva');
  INSERT INTO people (name) VALUES ('Ana Marques');
  INSERT INTO people (name) VALUES ('Ana Pinto');
  INSERT INTO people (name) VALUES ('Fernando Pinto');
  INSERT INTO people (name) VALUES ('Alice Pinto e Pinto');
  ```

Searching a Table

- ```
  SELECT name
  FROM people
  WHERE to_tsvector('portuguese', name) @@
  to_tsquery('portuguese', 'pinto');
  ```

- ```
          name
  ----------------
  Ana Pinto
  Fernando Pinto
  Alice Pinto e Pinto
  ```

- Although these queries will work without an index, most applications will find this approach too slow. Practical use of text searching usually requires creating an index.

Using Indexes

- There are two kinds of indexes that can be used to speed up full text searches.
  - GIN (Generalized Inverted Index) - lossless
  - GiST (Generalized Search Tree) - lossy
- As a rule of thumb, GIN indexes are best for static data because lookups are faster. For dynamic data, GiST indexes are faster to update.

Using GIN Index

- Create a GIN index on the name column.

- ```
  CREATE INDEX people_name_idx ON people
  USING gin(to_tsvector('portuguese', name));
  ```
  ```

Ranking Results

- PostgreSQL provides two predefined ranking functions, which take into account lexical, proximity, and structural information:
  - how often the query terms appear in the document;
  - how close together the terms are in the document;
  - how important is the part of the document where they occur.
- Different applications might require additional information for ranking, e.g., document modification time. The built-in ranking functions are only examples.

Ranking Example

```
SELECT name,
  ts_rank_cd(
    to_tsvector('portuguese', name),
    to_tsquery('portuguese', 'pinto')
  ) AS score
FROM people
ORDER BY score DESC;
```

```
          name          | score
------------------------+-------
Alice Pinto e Pinto |   0.2
Ana Pinto           |   0.1
Fernando Pinto      |   0.1
Rui Silva           |     0
Ana Marques         |     0
Pedro Silva         |     0
Filipa Silva        |     0
```

Obtaining Document Statistics

- The function ts_stat is useful for checking your configuration and for finding stop-word candidates.

- ```
  SELECT *
  FROM ts_stat('
    SELECT to_tsvector(name)
    FROM people
  ');
  ```

- ```
     word    | ndoc | nentry
  -----------+------+--------
   silva     |    3 |      3
   rui       |    1 |      1
   pinto     |    3 |      4
   pedro     |    1 |      1
   marqu     |    1 |      1
   filipa    |    1 |      1
   fernando  |    1 |      1
   e         |    1 |      1
   ana       |    2 |      2
   alic      |    1 |      1
  ```

Search Systems

- Apache Lucene
  https://lucene.apache.org/

- Solr
  https://lucene.apache.org/solr/

- Elasticsearch
  https://www.elastic.co/products/elasticsearch

- Terrier IR Platform
  http://www.terrier.org/

- Xapian
  http://xapian.org/

References

- Christopher D. Manning, Prabhakar Raghavan, and Hinrich Schütze. *Introduction to Information Retrieval*. Cambridge University Press, 2008. [online]

- W. Bruce Croft, Donald Metzler, and Trevor Strohman. *Search Engines: Information Retrieval in Practice*. Addison-Wesley, 2010. [online]

- Ricardo Baeza-Yates, and Berthier Ribeiro-Neto. *Modern Information Retrieval* (2nd Edition). ACM press, 2012.

- PostgreSQL. *PostgreSQL 9.4.6 Documentation, Chapter 12 - Full Text Search*. [online]