Information Retrieval

Databases and Web Applications Laboratory (LBAW)
Bachelor in Informatics Engineering and Computation (L.EIC)

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FEUP · U.Porto

Agenda

➔ Introduction to Information Retrieval

➔ Search Engines Overview

➔ Information Retrieval Models

➔ Retrieval Efficiency

➔ Retrieval Evaluation

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 Spärk 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.

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 a large number of documents.

  ➔ No ranking of results (e.g. order by relevance)

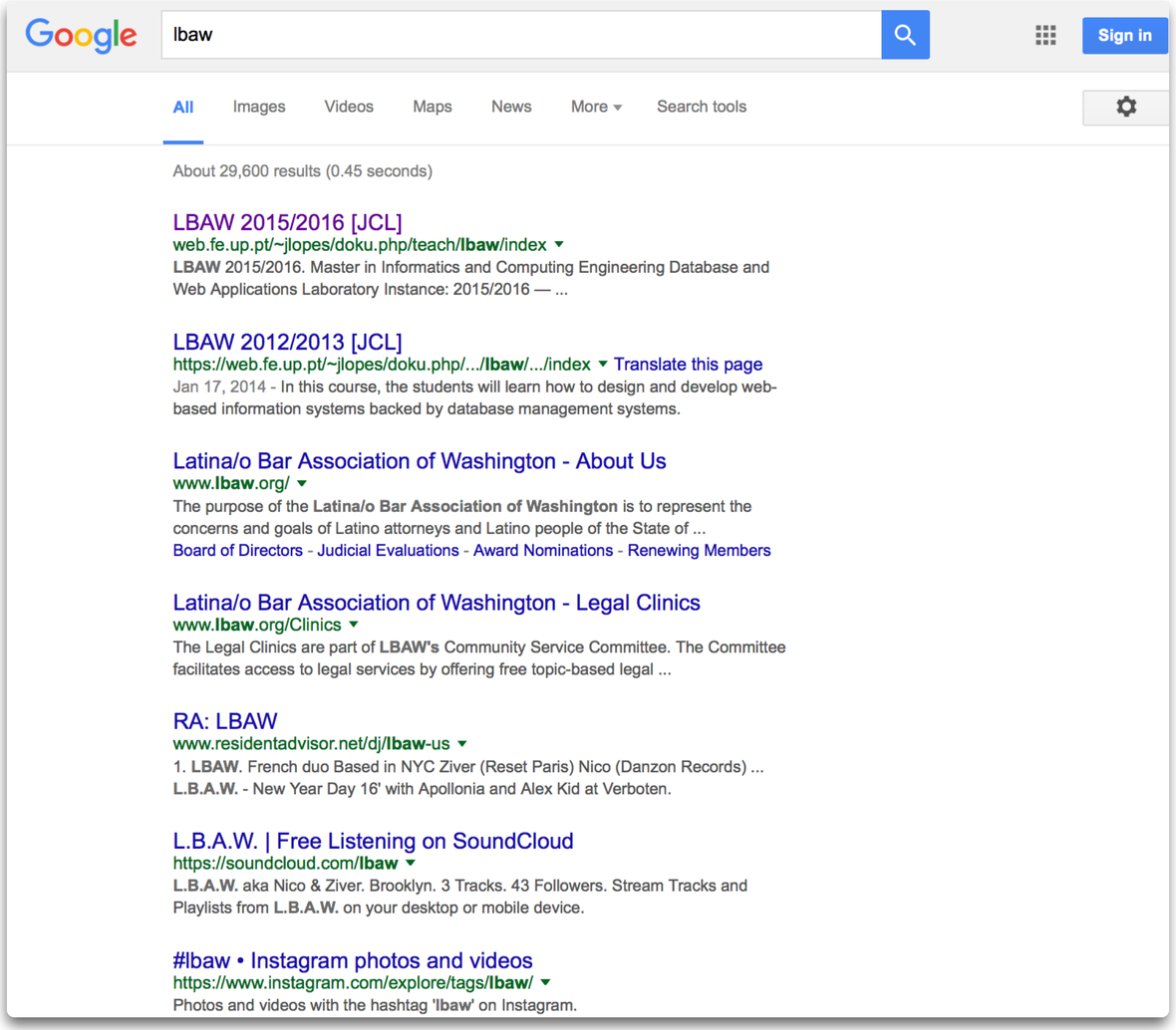
Central Issue

➔ 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.

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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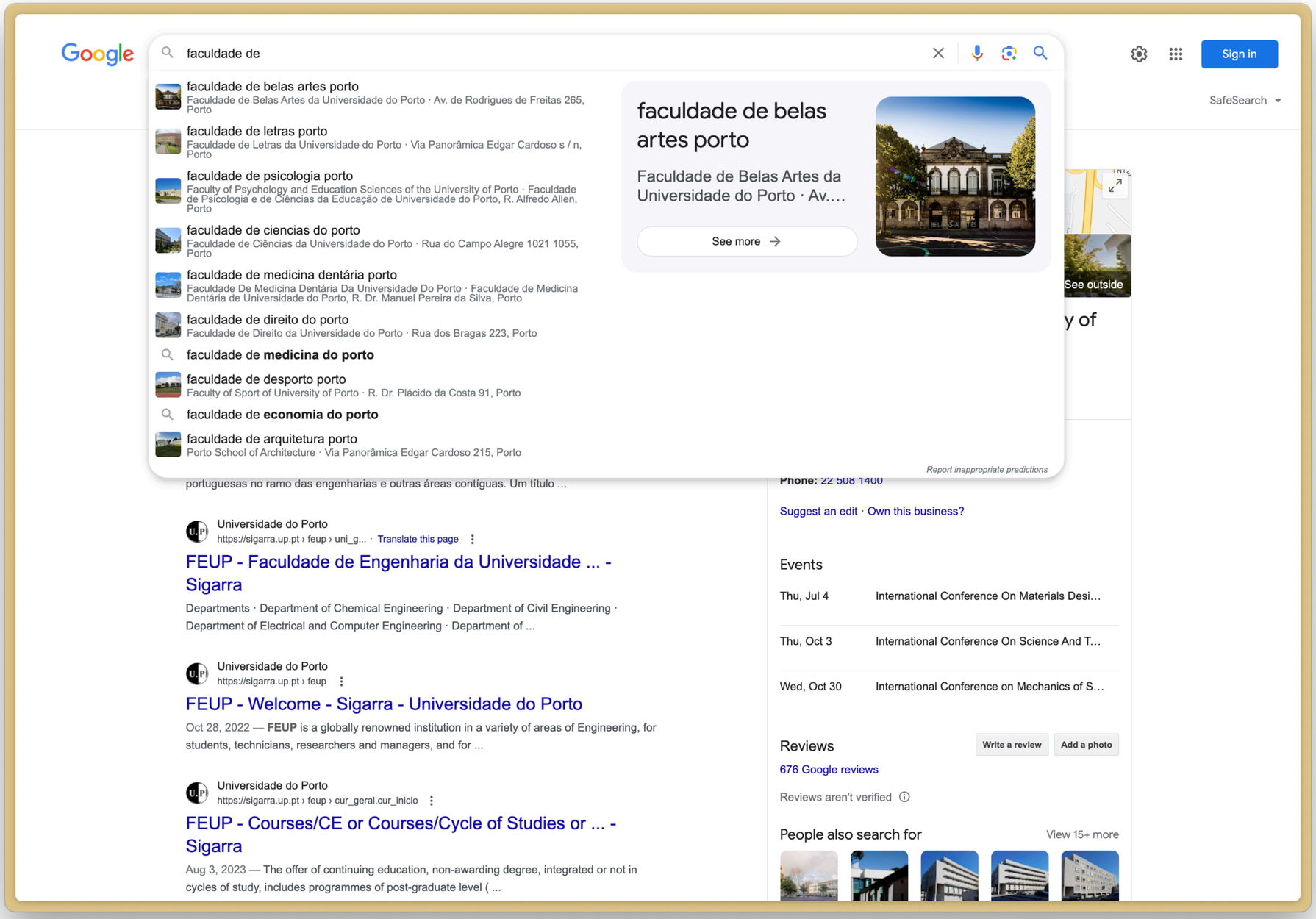
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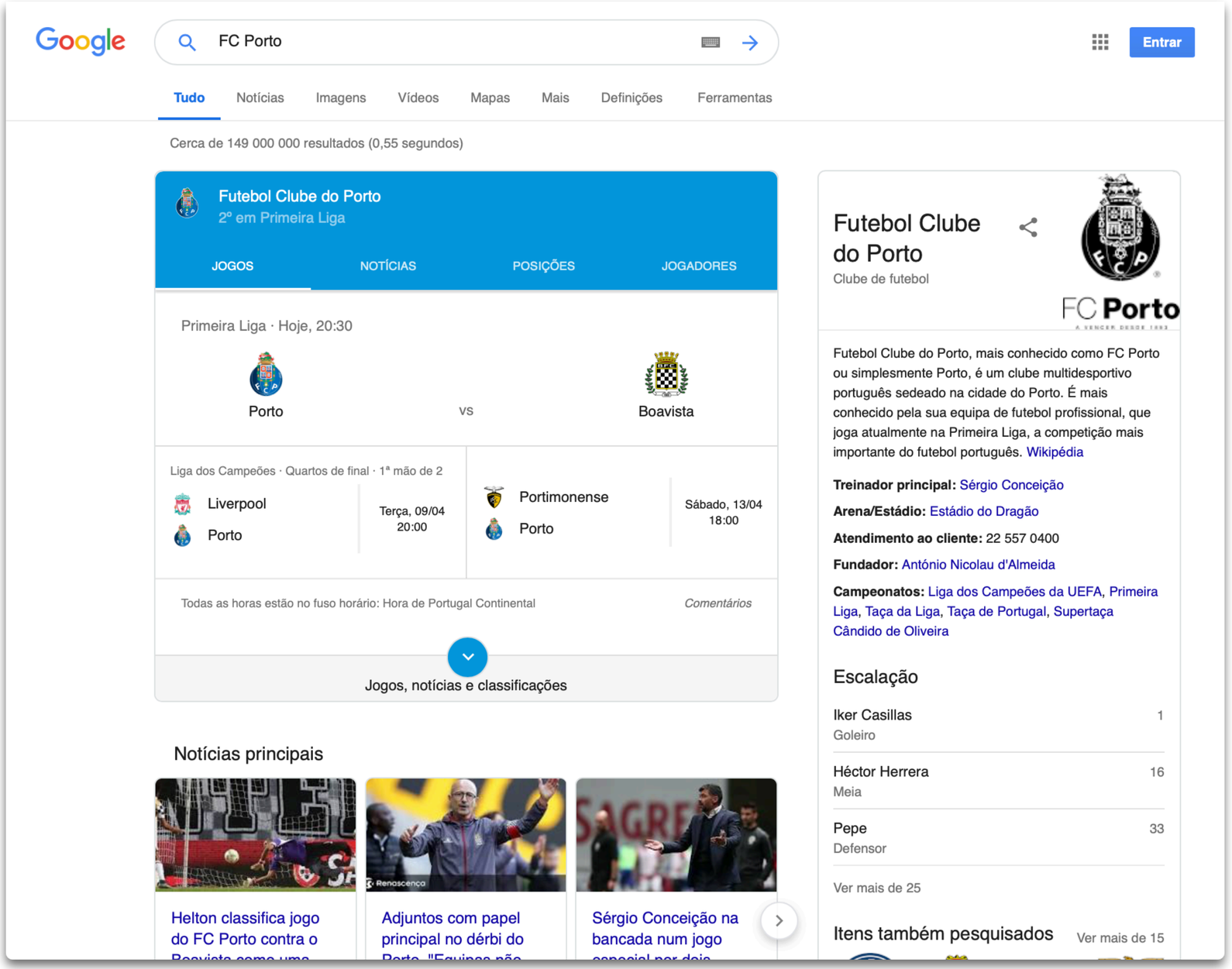
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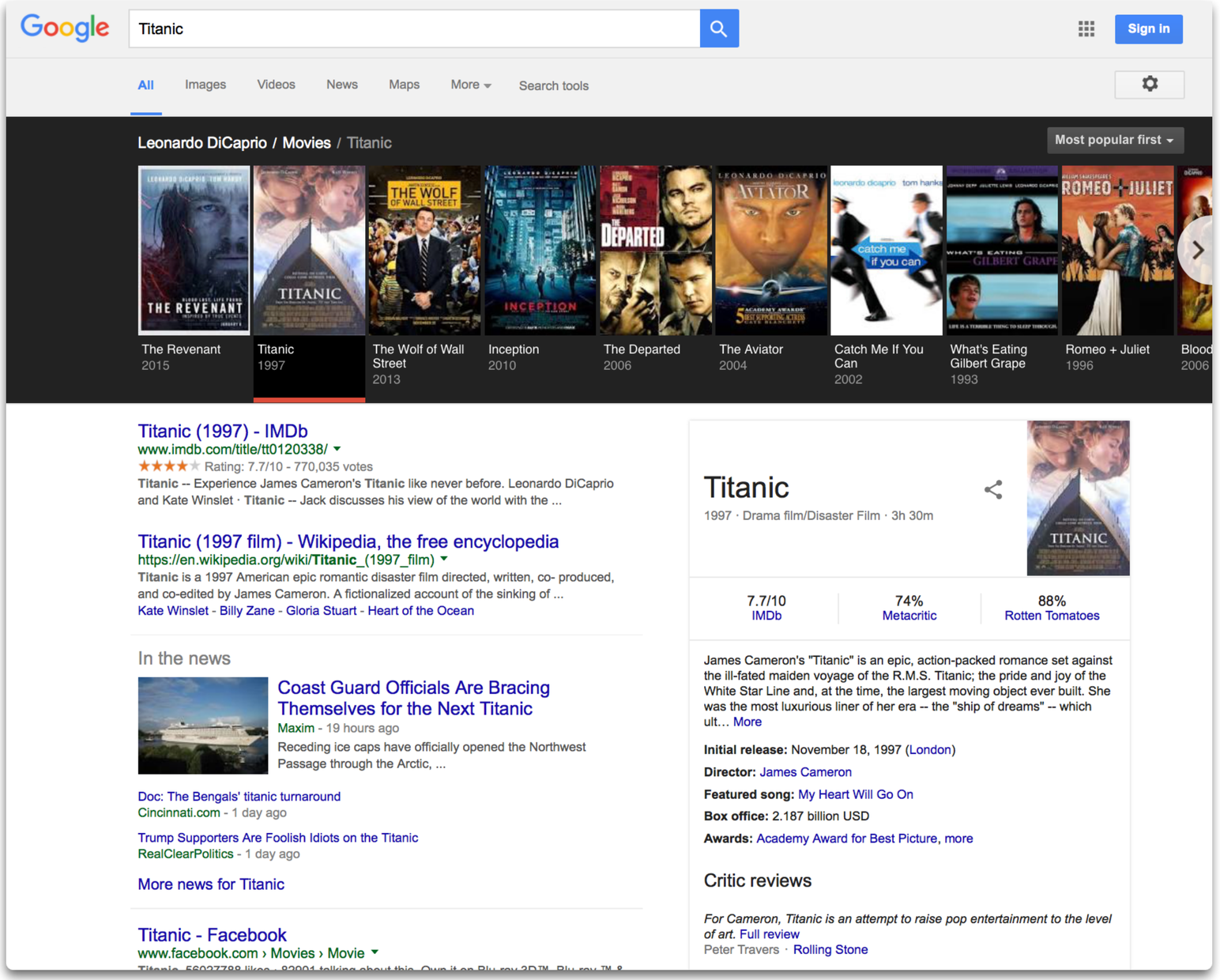
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Initial release: November 18, 1997 (London)
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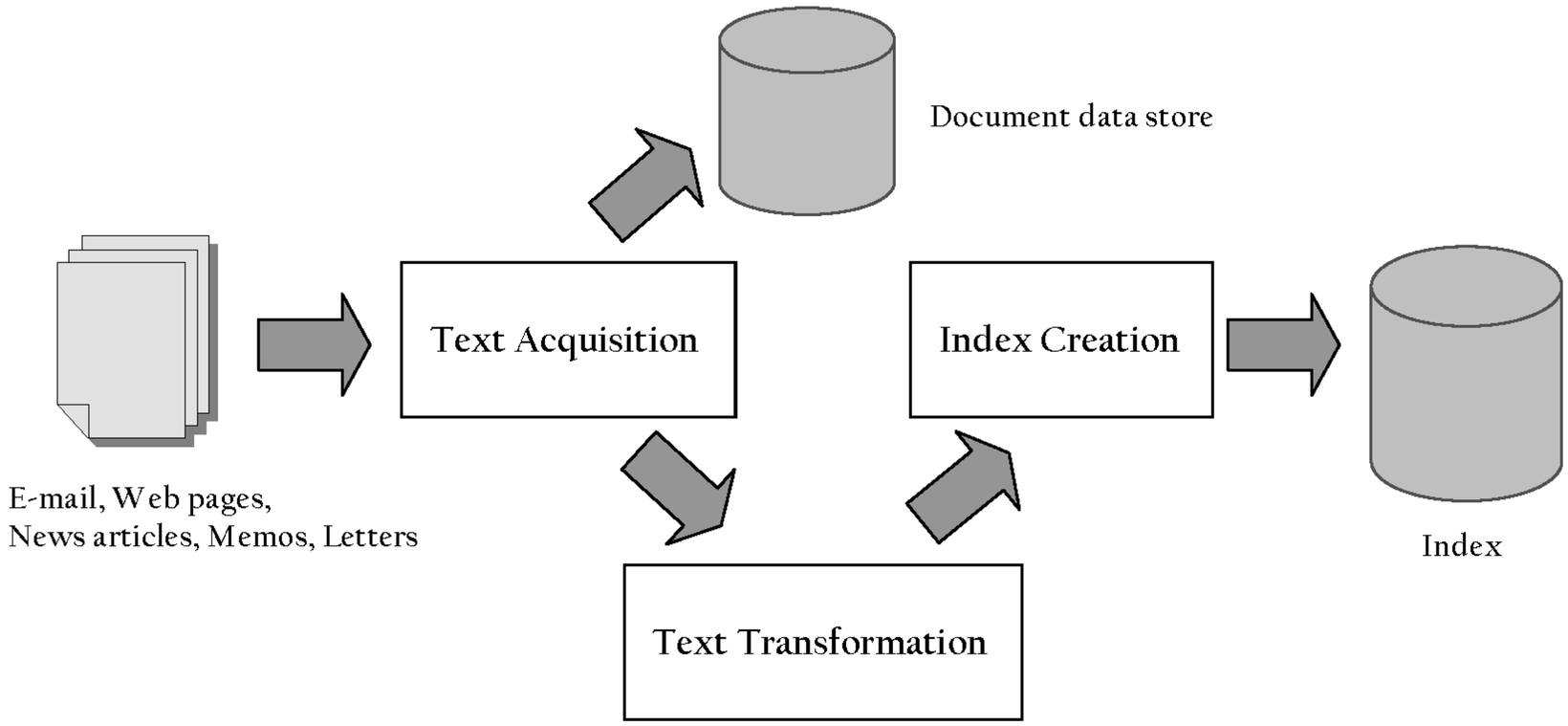
Search Engines

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

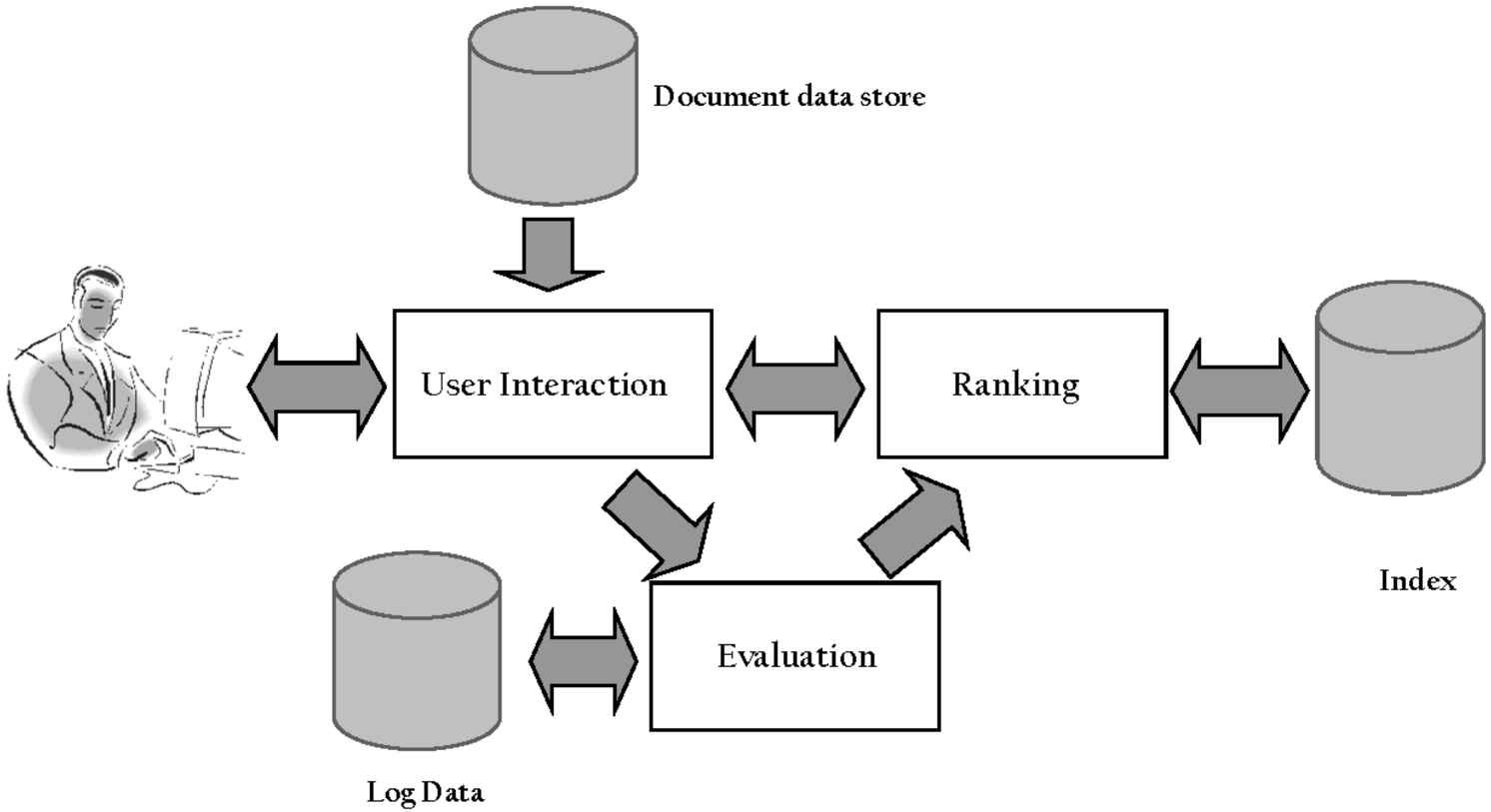
➔ Text Transformation

  ➔ 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

Example of System Architecture

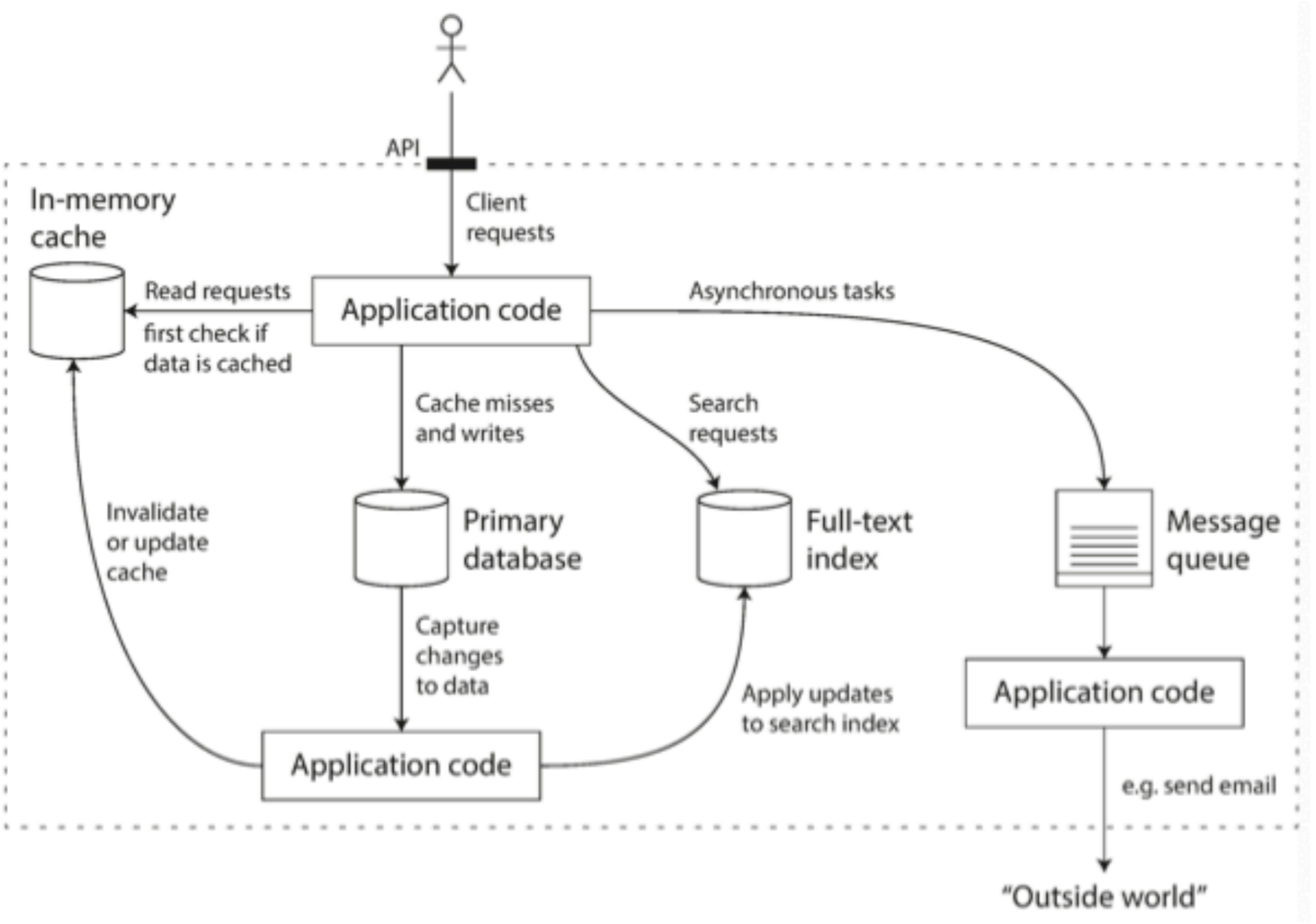


Image from Kleppmann, M. Designing Data-Intensive Applications (2017).

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

Web Ranking Signals

- ➔ Anchor text
- ➔ Domain history
- ➔ HTML Headings
- ➔ HTTPS
- ➔ Backlinks
- ➔ Keyword location / prominence
- ➔ Keyword stuffing (negative signal)
- ➔ Paid links (negative signal)
- ➔ Mobile friendliness
- ➔ Page speed
- ➔ Physical proximity to searcher
- ➔ Click depth
- ➔ User’s search history
- ➔ … many more

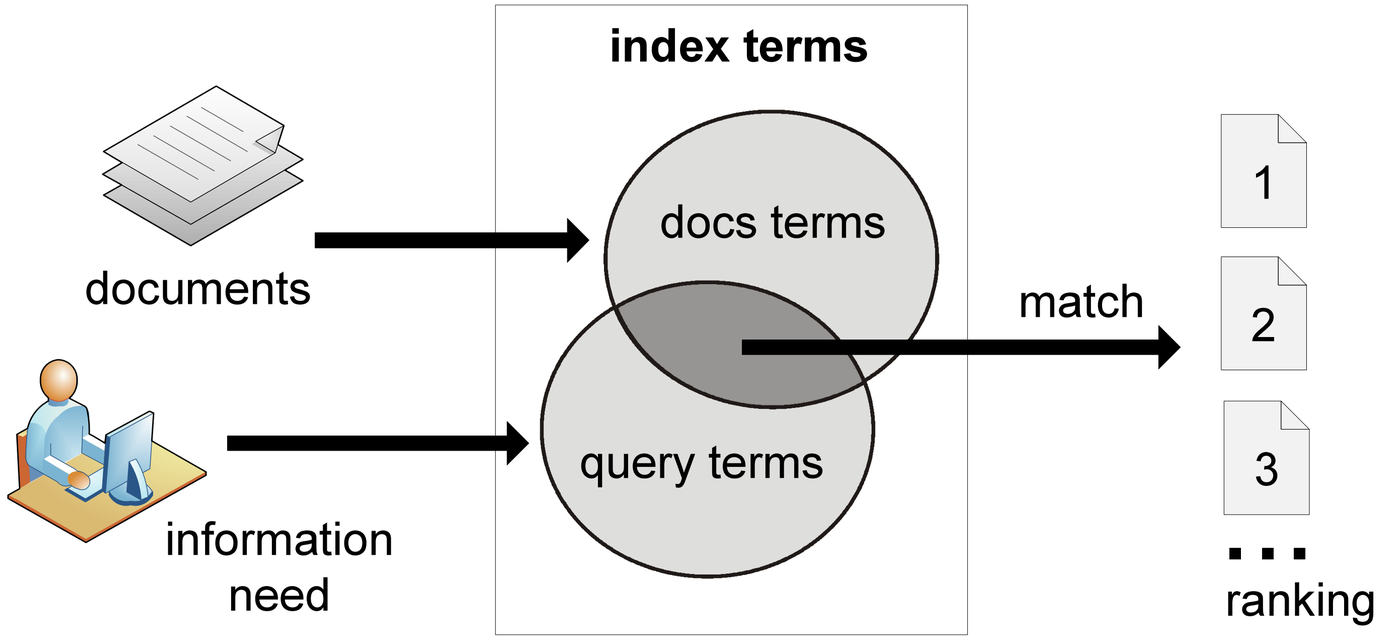
Search Engine Land: Google Ranking Signals (2023) https://searchengineland.com/google-ranking-signals-complete-breakdown-391784

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.

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

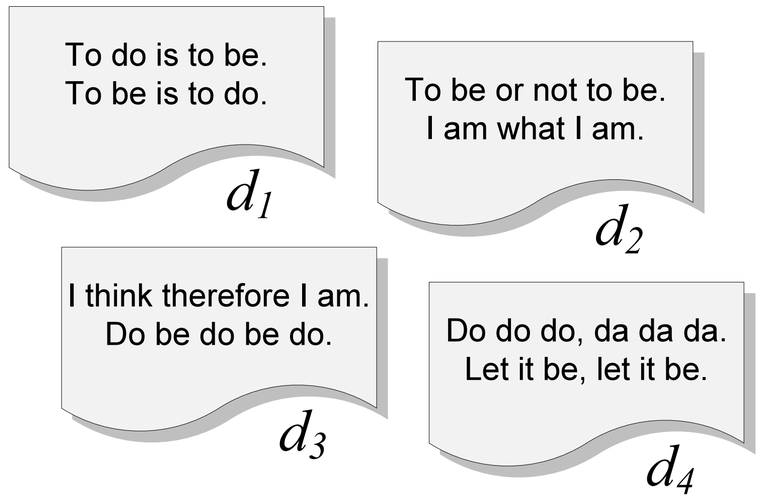
where each $f_{i,j}$ element stands for the frequency of term k_i in document d_j

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.

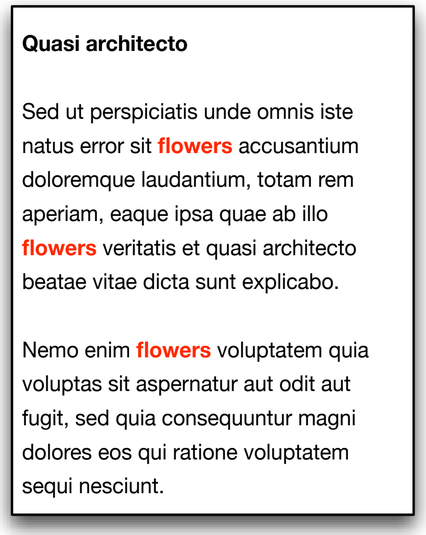
$$f(do, d_1) = 2$$
$$f(do, d_2) = 0$$
$$f(do, d_3) = 3$$
$$f(do, d_4) = 3$$
$$F(do) = 8$$
$$n(do) = 3$$



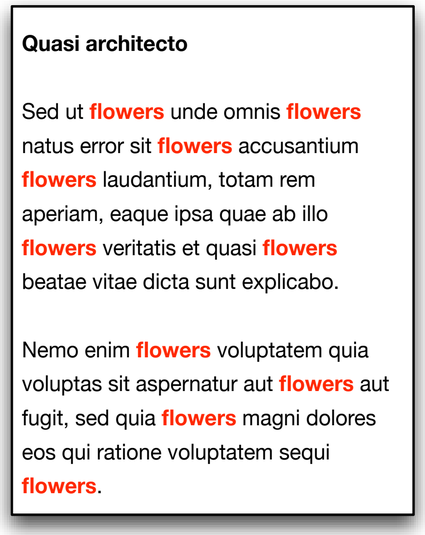
Term Frequency

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

➔ However, it can be easily manipulated.



TF("flowers") = 3



TF("flowers") = 10

TF("flowers") = ∞

Inverse Document Frequency

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

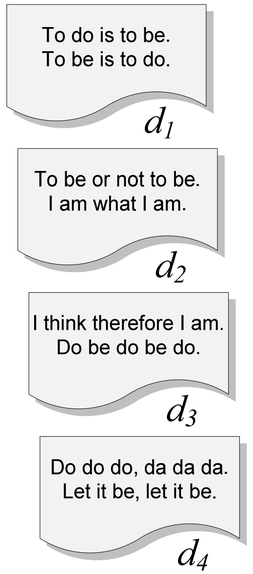
➔ Terms that appear in fewer documents of a collection have more discriminative power, thus are given a higher weight. Also referred to as the specificity of a term.

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

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*)



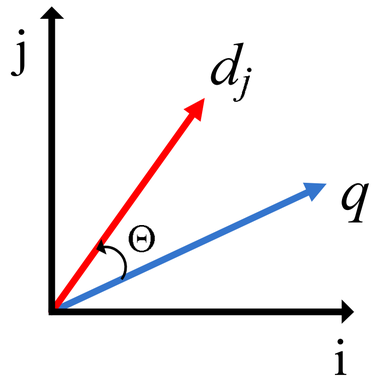
		d_1	d_2	d_3	d_4
1	to	3	2	-	-
2	do	0.830	-	1.073	1.073
3	is	4	-	-	-
4	be	-	-	-	-
5	or	-	2	-	-
6	not	-	2	-	-
7	I	-	2	2	-
8	am	-	2	1	-
9	what	-	2	-	-
10	think	-	-	2	-
11	therefore	-	-	2	-
12	da	-	-	-	5.170
13	let	-	-	-	4
14	it	-	-	-	4

Chap 03: Modeling, Baeza-Yates & Ribeiro-Neto, Modern Information Retrieval, 2nd Edition – p. 43

Vector Space Model

➔ Binary weights are too limiting. The vector space 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:

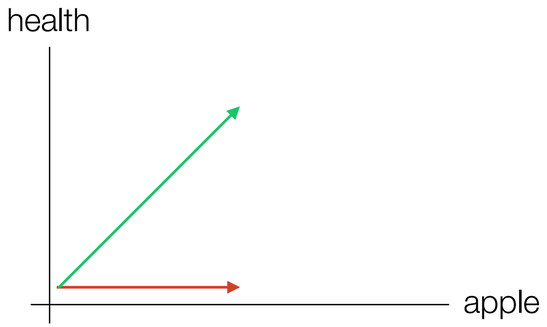
➔ s1: apples are good for your health

➔ s2: apples are fruits that grown on trees

➔ We can represent these two documents in vector spaces, considering n-dimensions.

1-dimension: apple

1-dimension: health

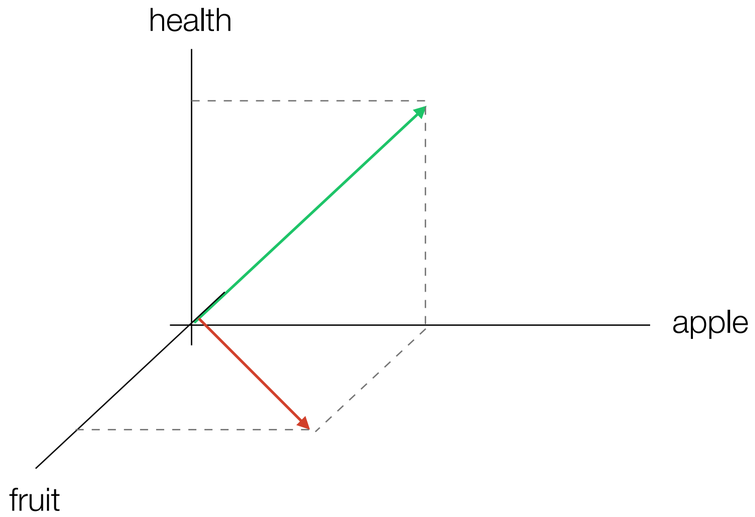


2-dimensions: apple, health

Vector Model Example

➔ Considering the following two sentences:

- ➔ s1: apples are good for your health
- ➔ s2: apples are fruits that grown on trees



3-dimensions: apple, health, fruit

Search Engine Ranking

Link-based Signals

PageRank

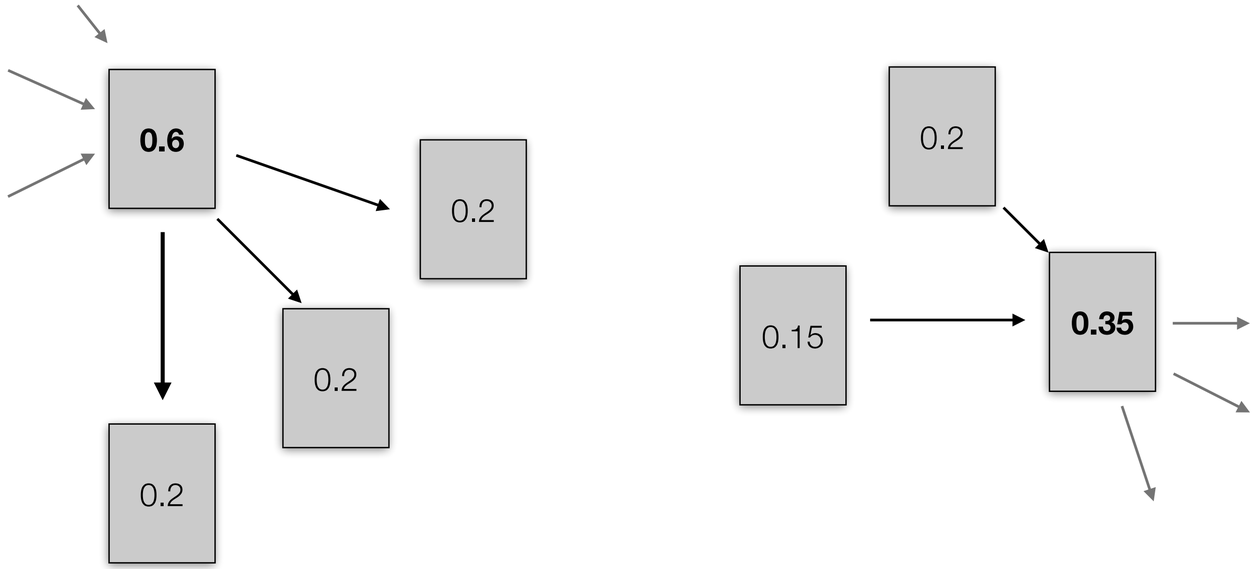
- ➔ The web can be viewed as a directed graph.
- ➔ The number of hyperlinks pointing to a page has been used as a measure of quality of that page.
- ➔ Simple approach: use the number of links to a page (i.e. in-degree) as a ranking signal.
- ➔ The best known link-based ranking signal is the PageRank, developed at Stanford (during Larry Page's 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 by 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.



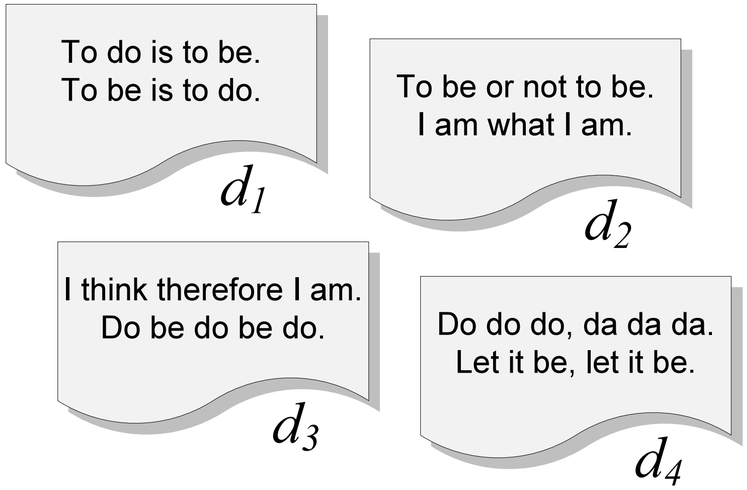
Retrieval Efficiency

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

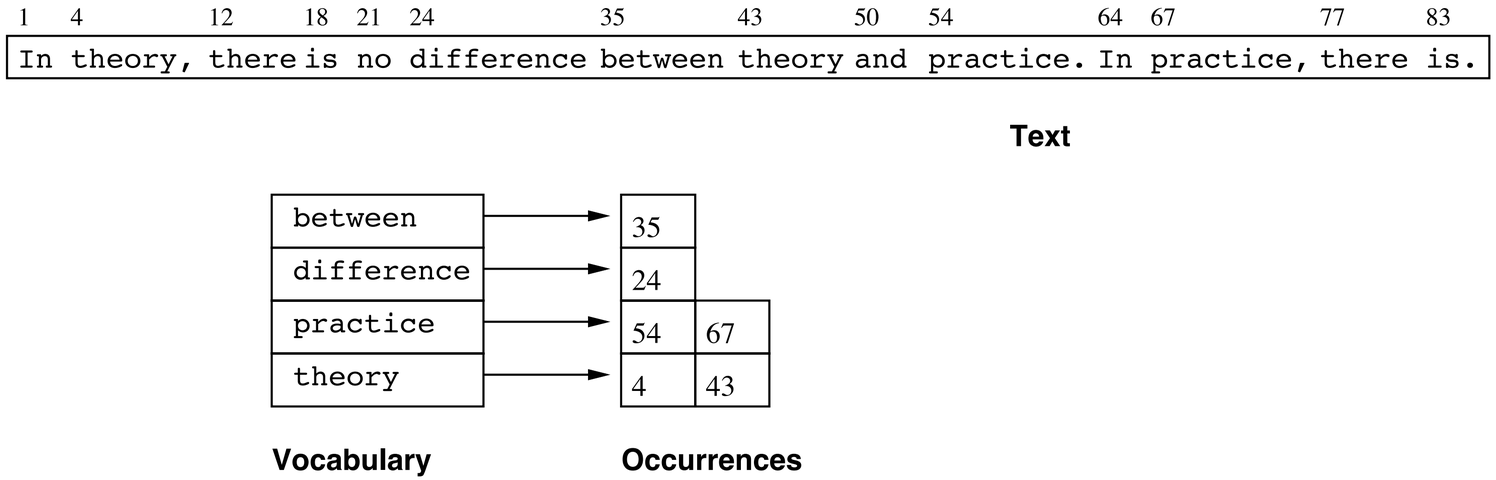
Vocabulary	n_i	Occurrences as inverted lists
to	2	[1,4],[2,2]
do	3	[1,2],[3,3],[4,3]
is	1	[1,2]
be	4	[1,2],[2,2],[3,2],[4,2]
or	1	[2,1]
not	1	[2,1]
I	2	[2,2],[3,2]
am	2	[2,2],[3,1]
what	1	[2,1]
think	1	[3,1]
therefore	1	[3,1]
da	1	[4,3]
let	1	[4,2]
it	1	[4,2]



Full Inverted Index

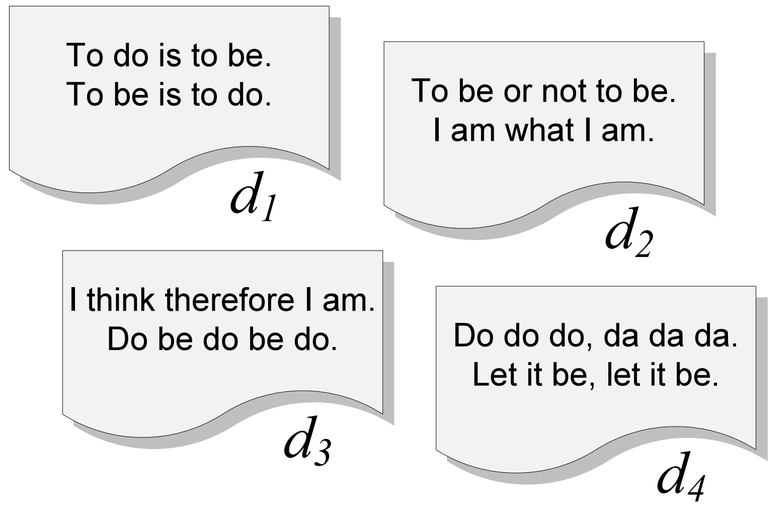
➔ The basic index is not suitable for answering phrase or proximity queries.

➔ 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 traditional areas where performance can be measured using objective metrics such as space, speed, size, etc.

Precision and Recall

➔ Consider,

  ➔ R, set of relevant documents in the collection.

  ➔ A, set of documents in the retrieved answer.

➔ We can define the two core measures in IR evaluation,

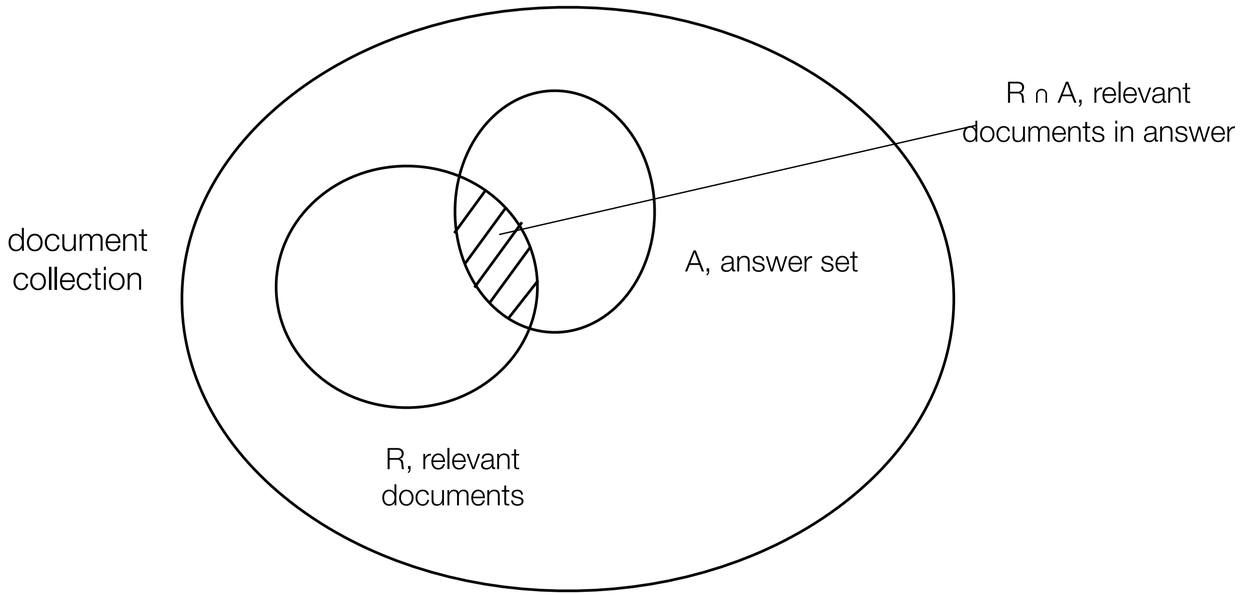
  ➔ Precision is the fraction of the retrieved documents that are relevant.

  ➔ Recall is the fraction of the relevant documents that are retrieved.

Precision and Recall

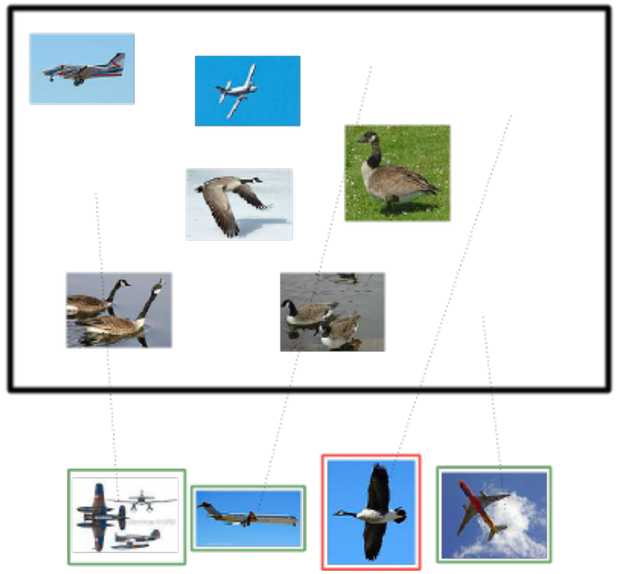
$$Precision = \frac{|R \cap A|}{|A|}$$

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



Precision and Recall Example

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



	relevant	not
retrieved	3	1
not	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 (R relevant and M not relevant),
  - ➔ System #1: R N N R R R N R R R
  - ➔ System #2: R R R R N N N N R N
  - ➔ System #1, P@5 = 0.6 and P@10 = 0.7
  - ➔ System #2, P@5 = 0.8 and P@10 = 0.5

Search Systems

- Apache Lucene
  https://lucene.apache.org
- Solr
  https://solr.apache.org
- Elasticsearch
  https://www.elastic.co/products/elasticsearch
- OpenSearch
  https://opensearch.org/
- Terrier IR Platform
  http://www.terrier.org
- Lemur Project
  https://www.lemurproject.org

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➔ 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 17 Documentation, Chapter 12 - Full Text Search*. [online]