Information Retrieval

LBAW · Databases and Web Applications
MIEIC 20/21

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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.

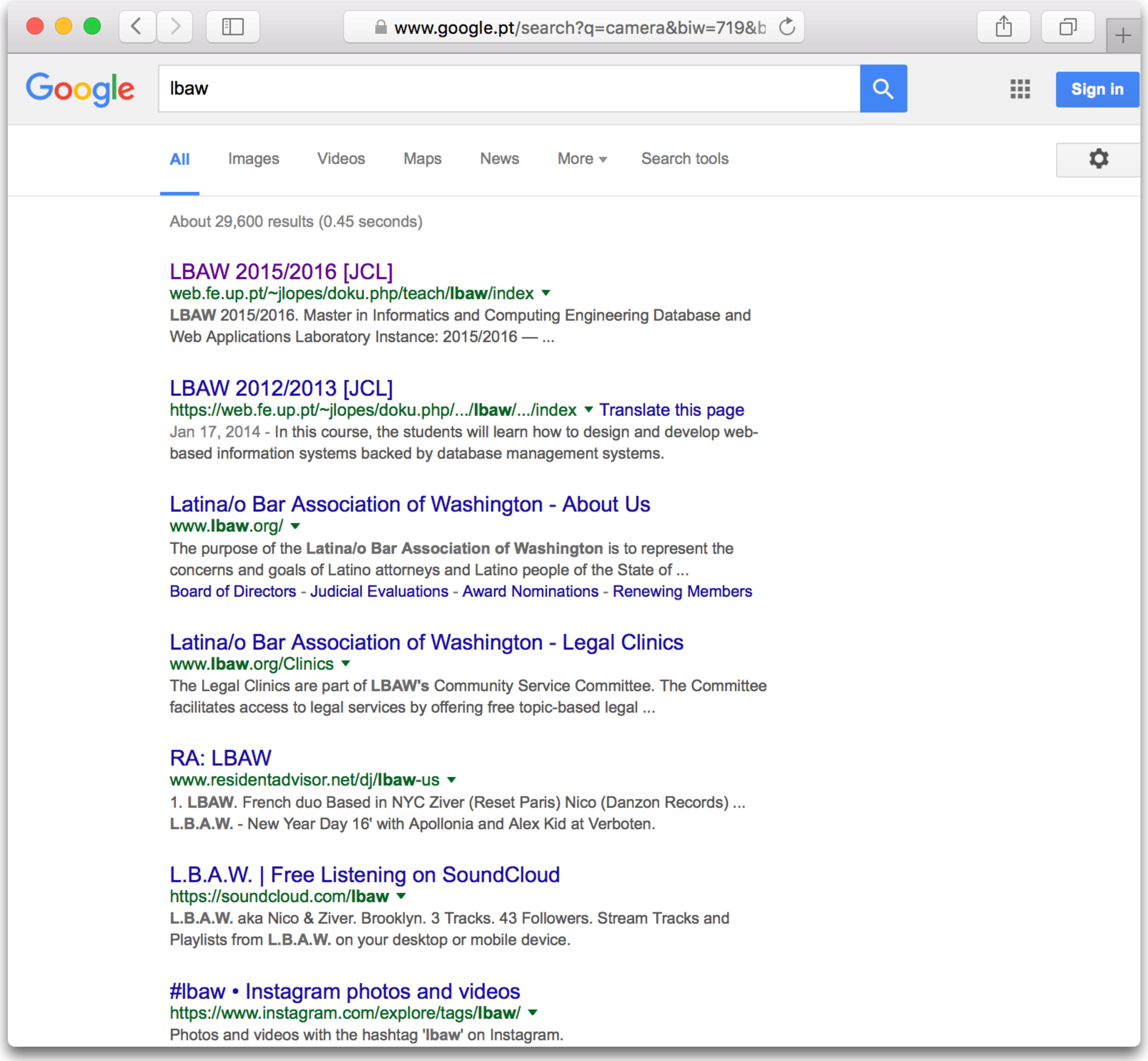
Central Issue

- ➔ 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

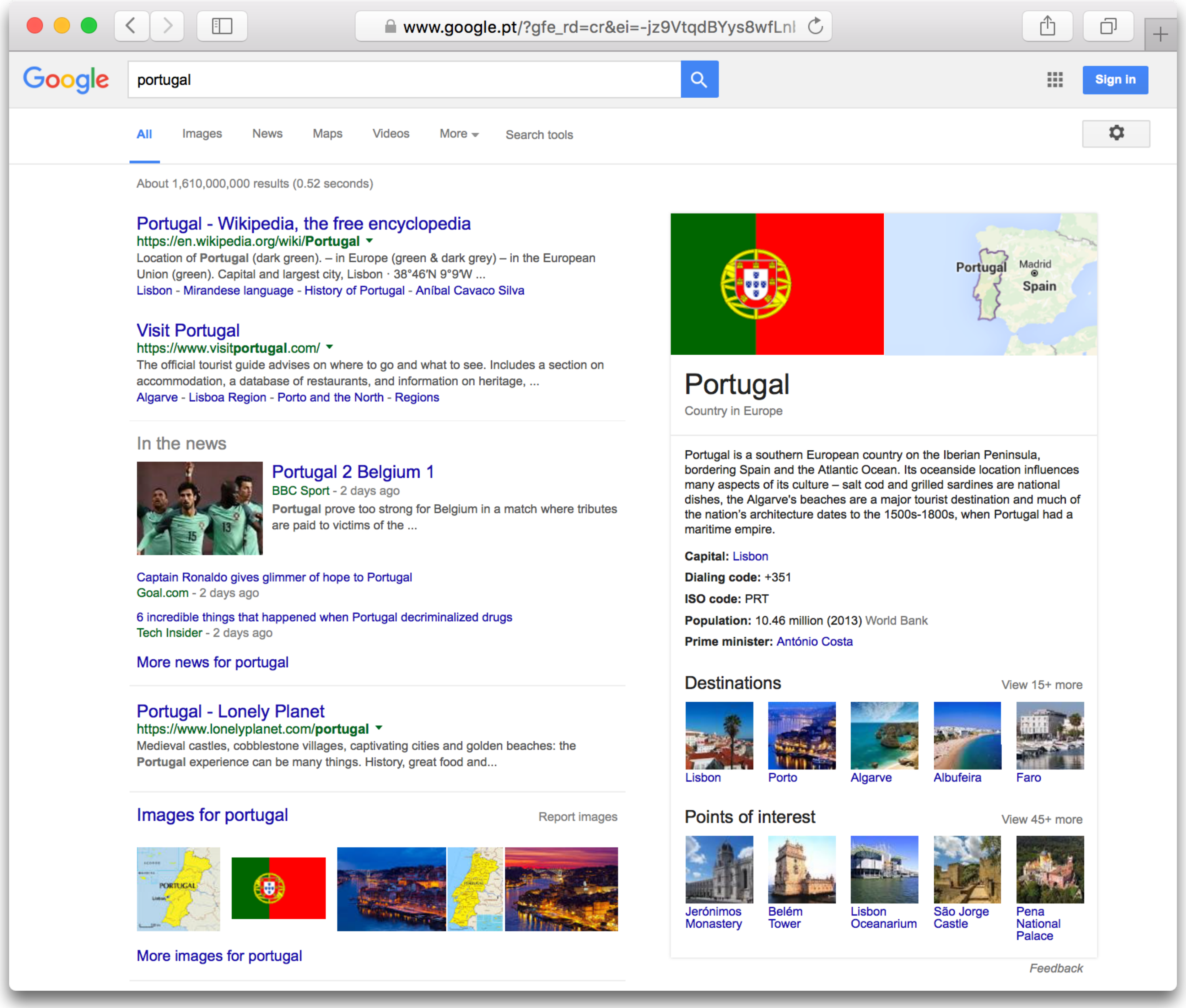
- ➔ RDBS provide set-based or data retrieval.
  - ➔ SELECT title, year FROM book
    WHERE title LIKE '%introduction%html%';
- ➔ **Limitations?**
  - ➔ There is no linguistic support (e.g. intro vs. introduction)
  - ➔ Difficult to search for multiple keywords (e.g. introduction to html vs. html introduction)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

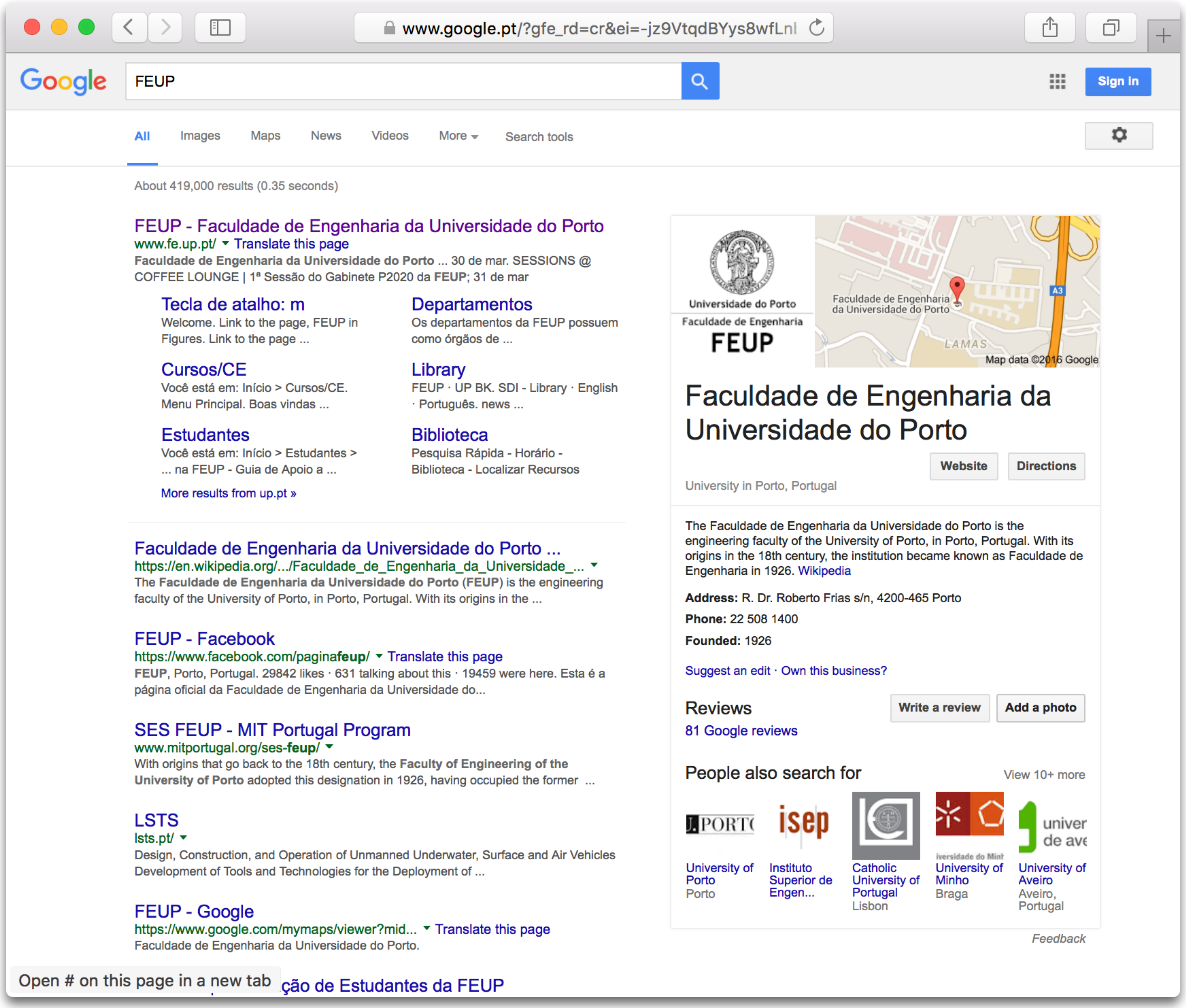
Web Search System



Trends

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

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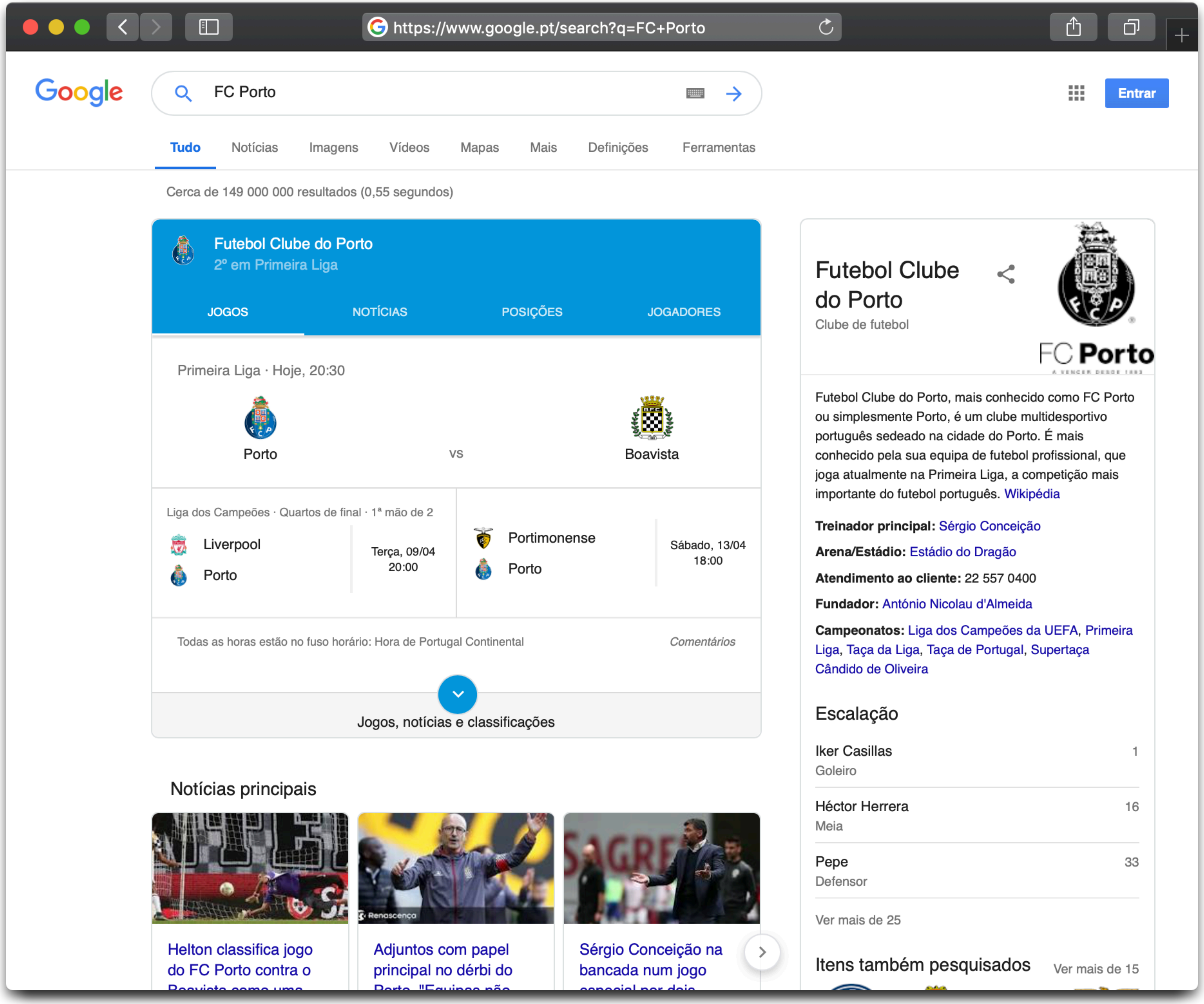
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Terça, 09/04
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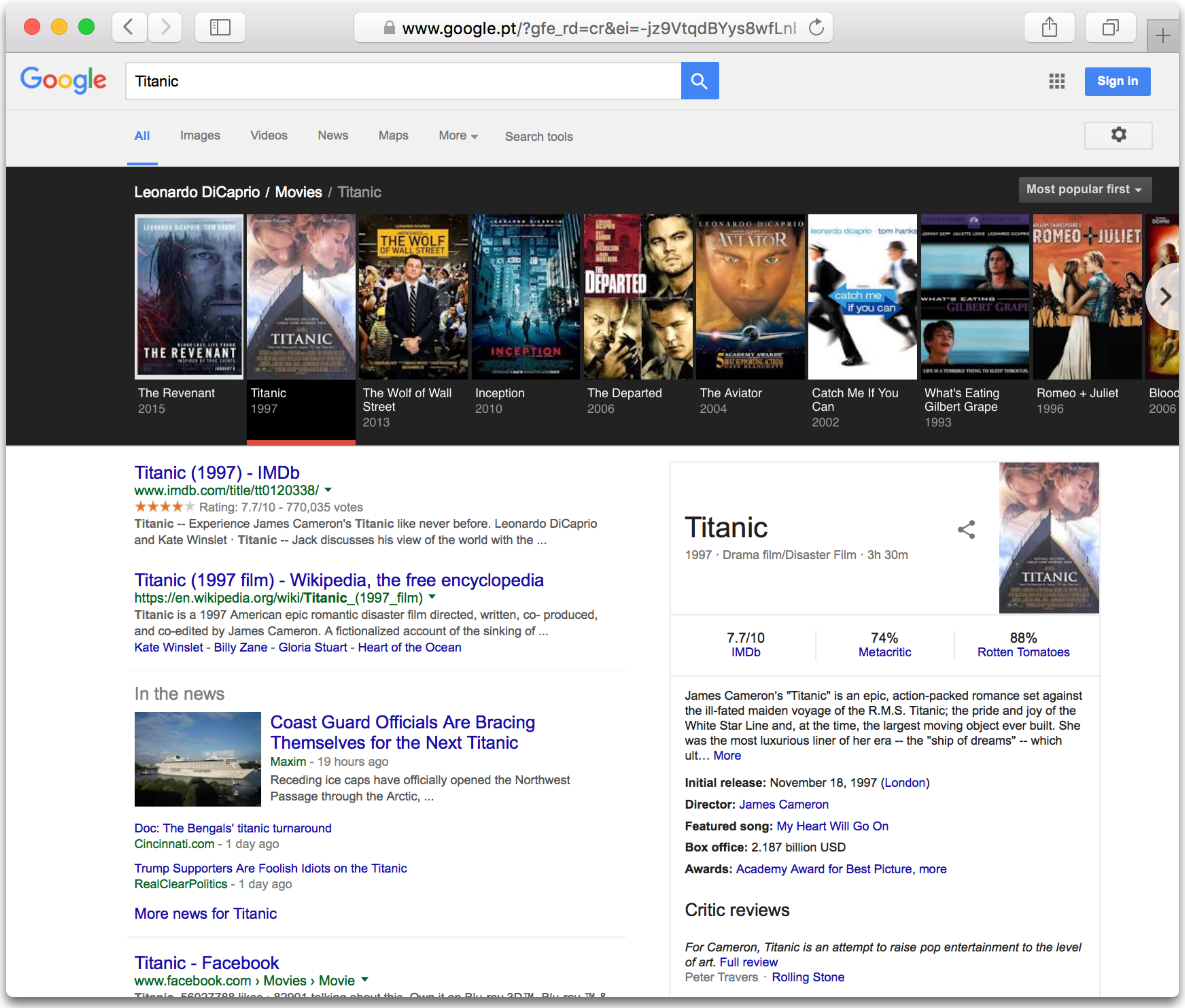

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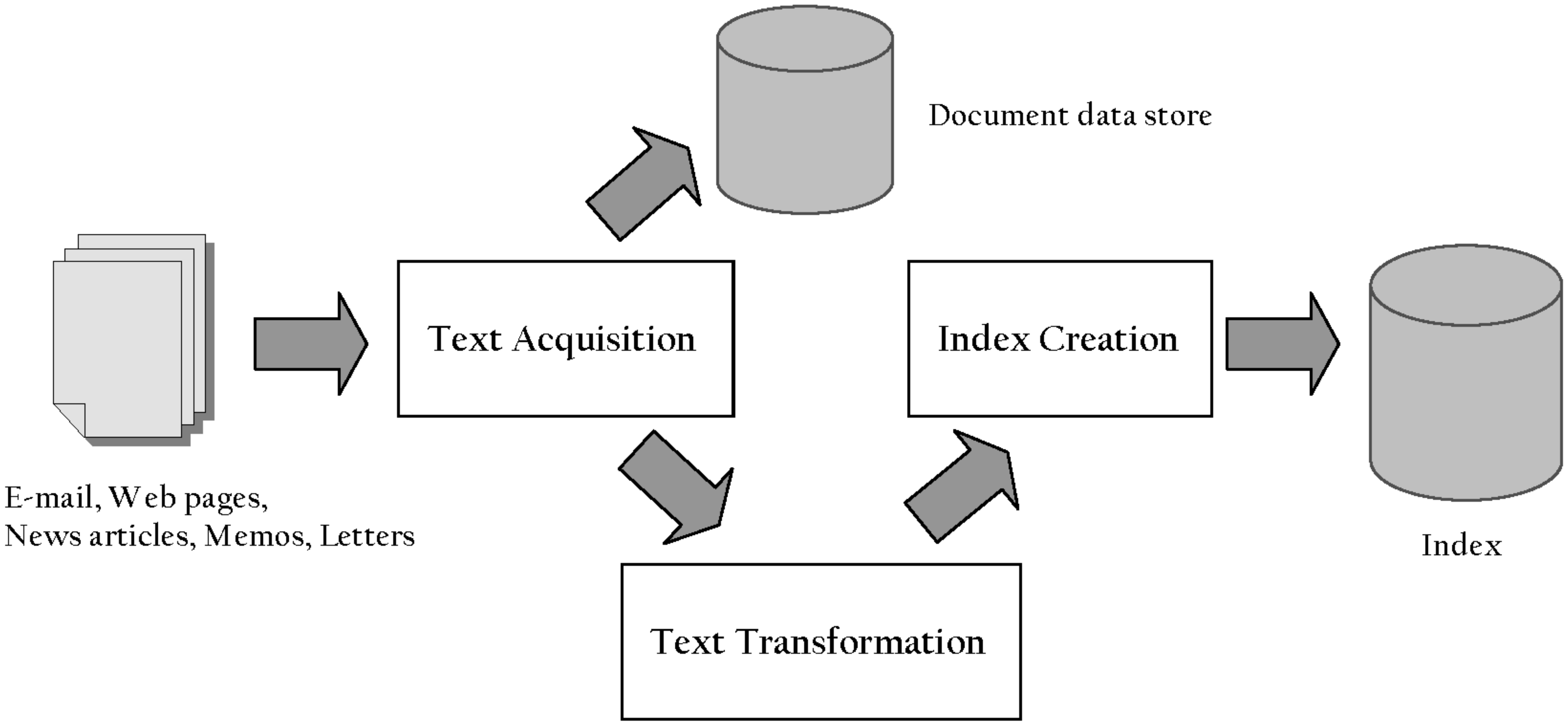
James Cameron's "Titanic" is an epic, action-packed romance set against the ill-fated maiden voyage of the R.M.S. Titanic; the pride and joy of the White Star Line and, at the time, the largest moving object ever built. She was the most luxurious liner of her era -- the "ship of dreams" -- which ult...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

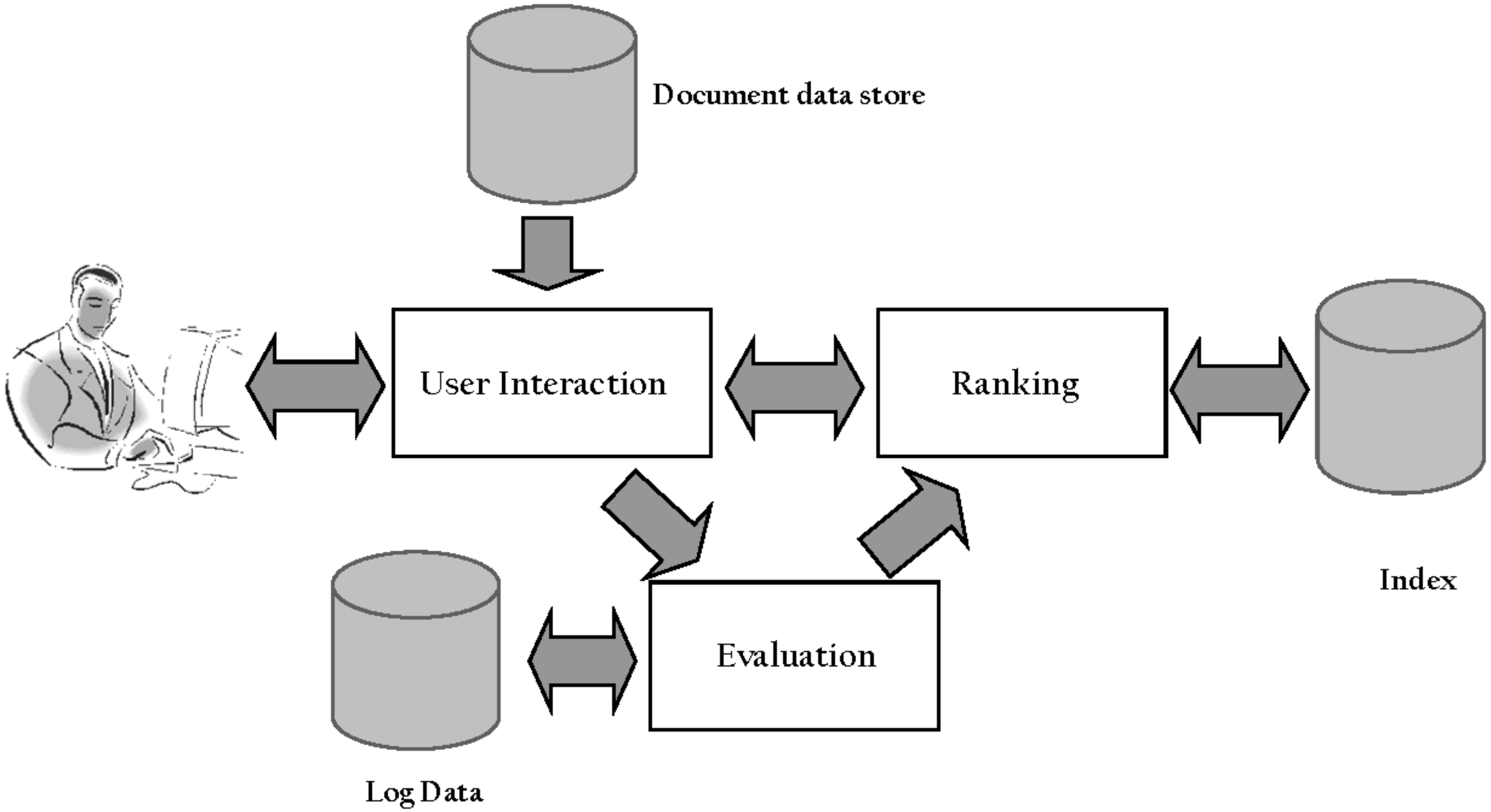


Croft, Metzler, Strohman (2010), Search Engines: Information Retrieval in Practice

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

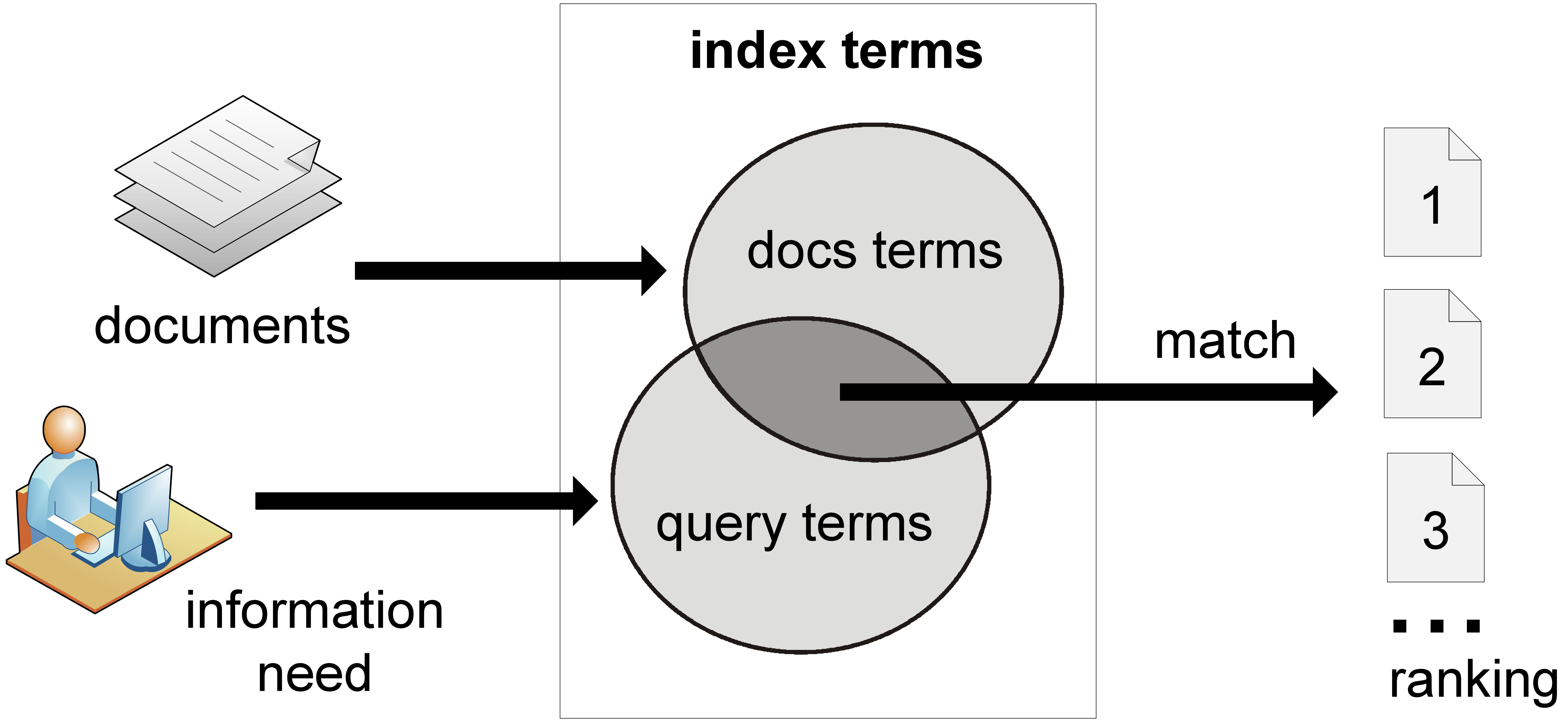
- ➔ Web search engines use hundreds of signals, also called features.
- ➔ These signals can be divided in two groups
  - ➔ static signals that can be computed during the indexing process, e.g. length of document, age of document, number of links to document, etc.
  - ➔ query-dependent signals that are 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



Chap 03: Modeling, Baeza-Yates & Ribeiro-Neto, Modern Information Retrieval, 2nd Edition – p. 4

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.

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

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

Chap 03: Modeling, Baeza-Yates & Ribeiro-Neto, Modern Information Retrieval, 2nd Edition – p. 13

Term Weighting

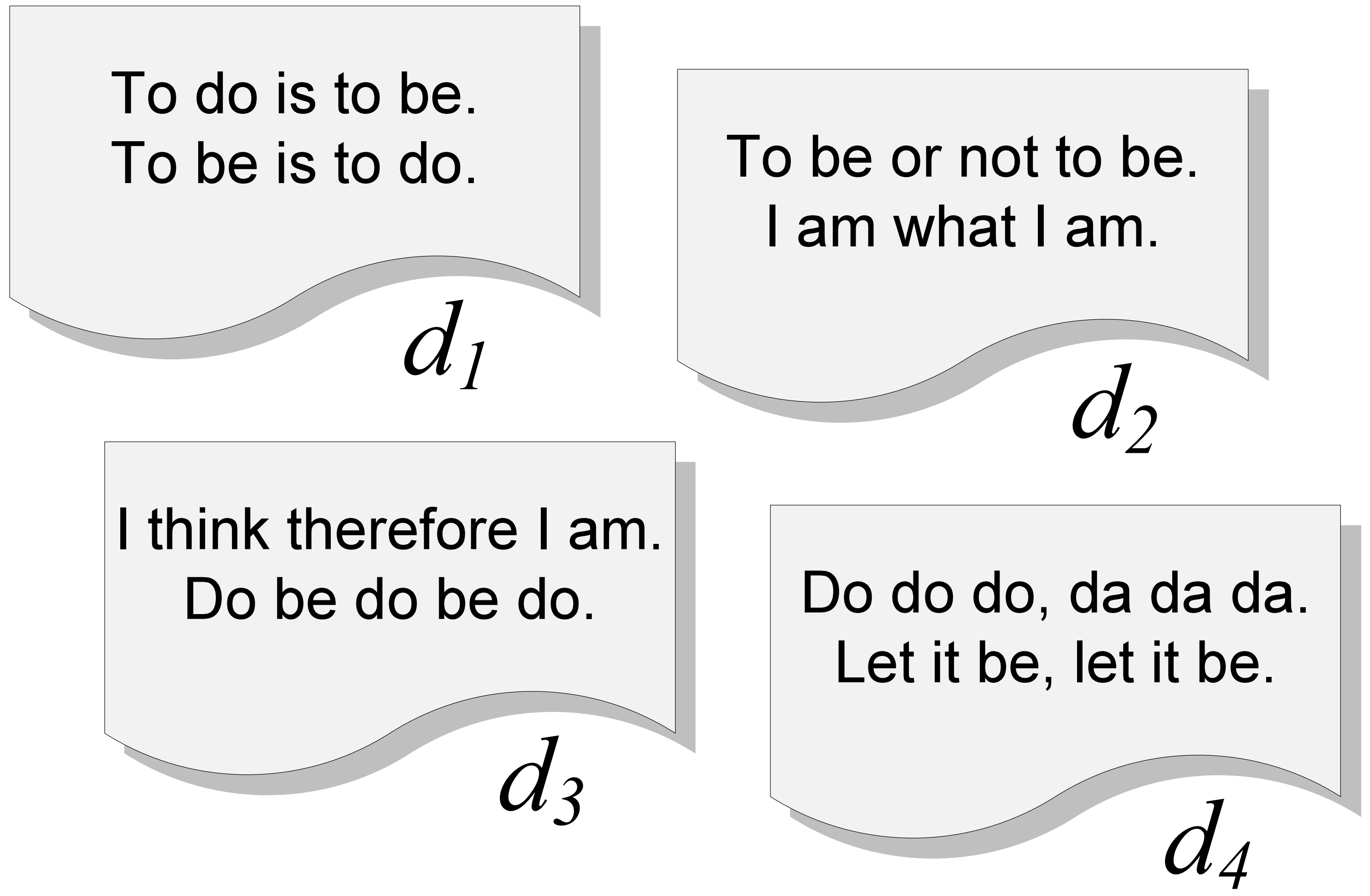
➔ Terms are not equally useful for describing a document.

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

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

$$F(do) = 8$$

$$n(do) = 3$$



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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

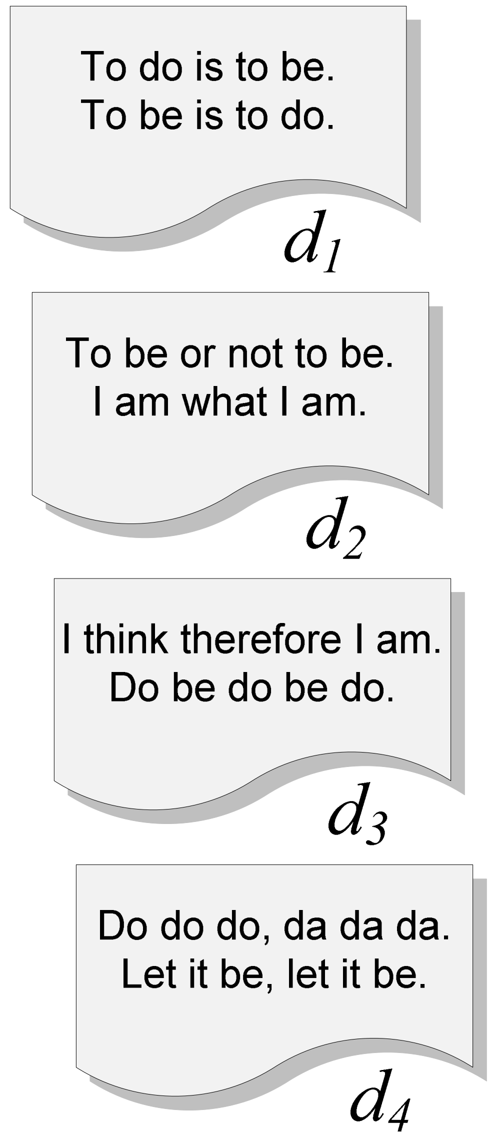
- An important, but less intuitive measure, is the inverse document frequency (IDF) of a term.
- Terms that appear in fewer documents of a collection have more discriminative power, thus are given a higher weight. Also referred to as the specificity of a term.

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

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*)



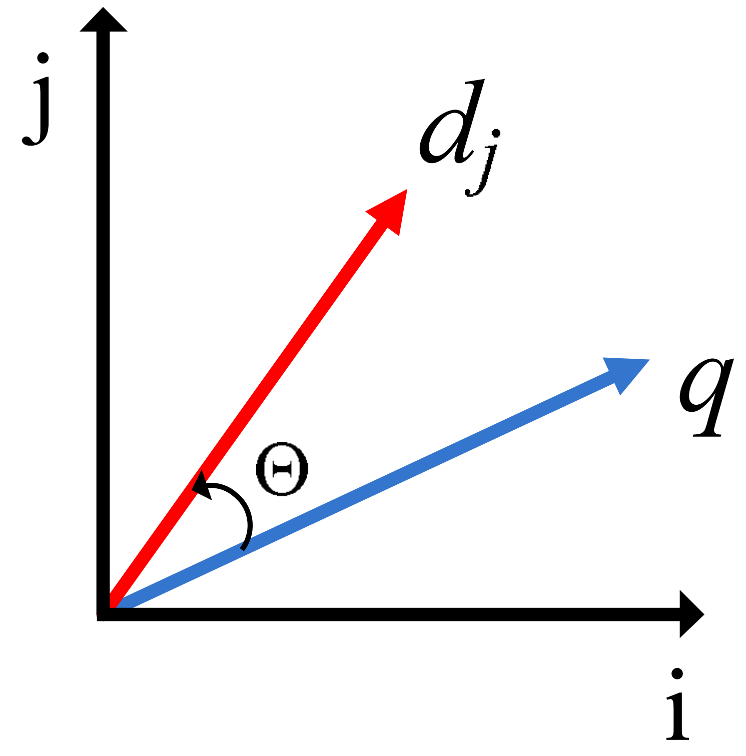
		d_1	d_2	d_3	d_4
1	to	3	2	-	-
2	do	0.830	-	1.073	1.073
3	is	4	-	-	-
4	be	-	-	-	-
5	or	-	2	-	-
6	not	-	2	-	-
7	I	-	2	2	-
8	am	-	2	1	-
9	what	-	2	-	-
10	think	-	-	2	-
11	therefore	-	-	2	-
12	da	-	-	-	5.170
13	let	-	-	-	4
14	it	-	-	-	4

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.



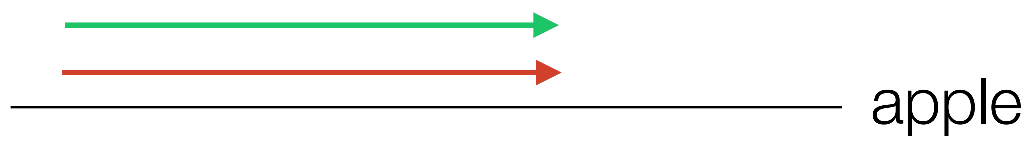
$$cos(\theta) = \frac{\vec{d_j} \bullet \vec{q}}{|\vec{d_j}| \times |\vec{q}|}$$

Vector Model Example

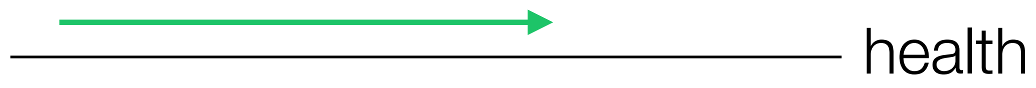
➔ Considering the following two sentences:

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

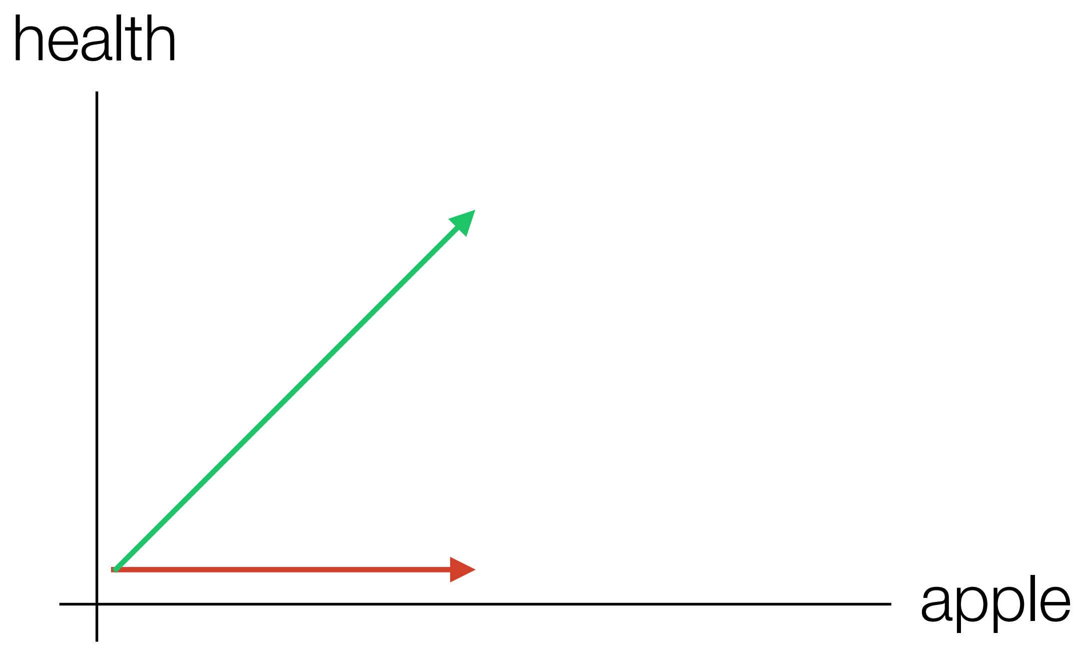
➔ We can represent these two documents in vector spaces, considering n-dimensions.



1-dimension: apple



1-dimension: health

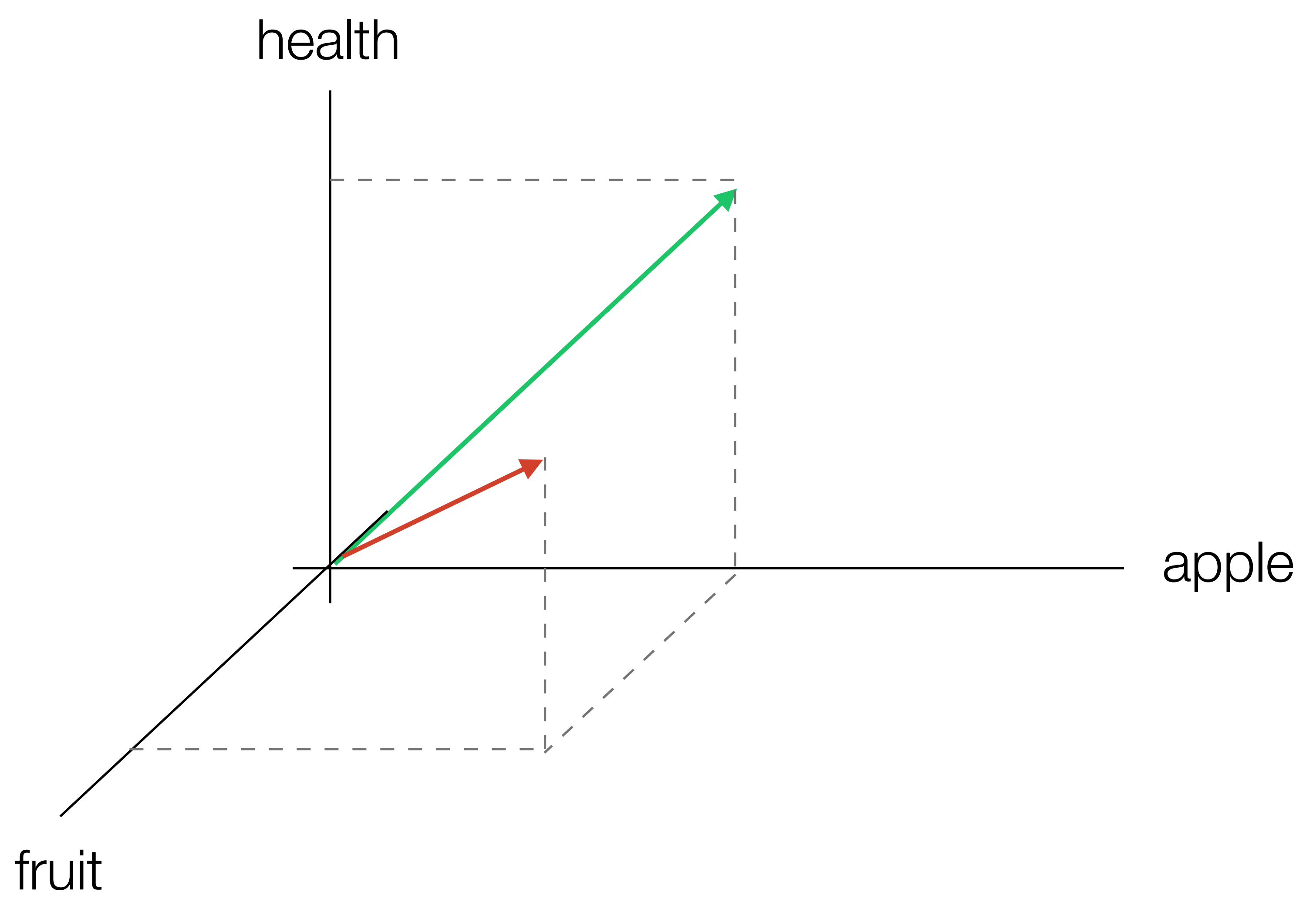


2-dimensions: apple, health

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

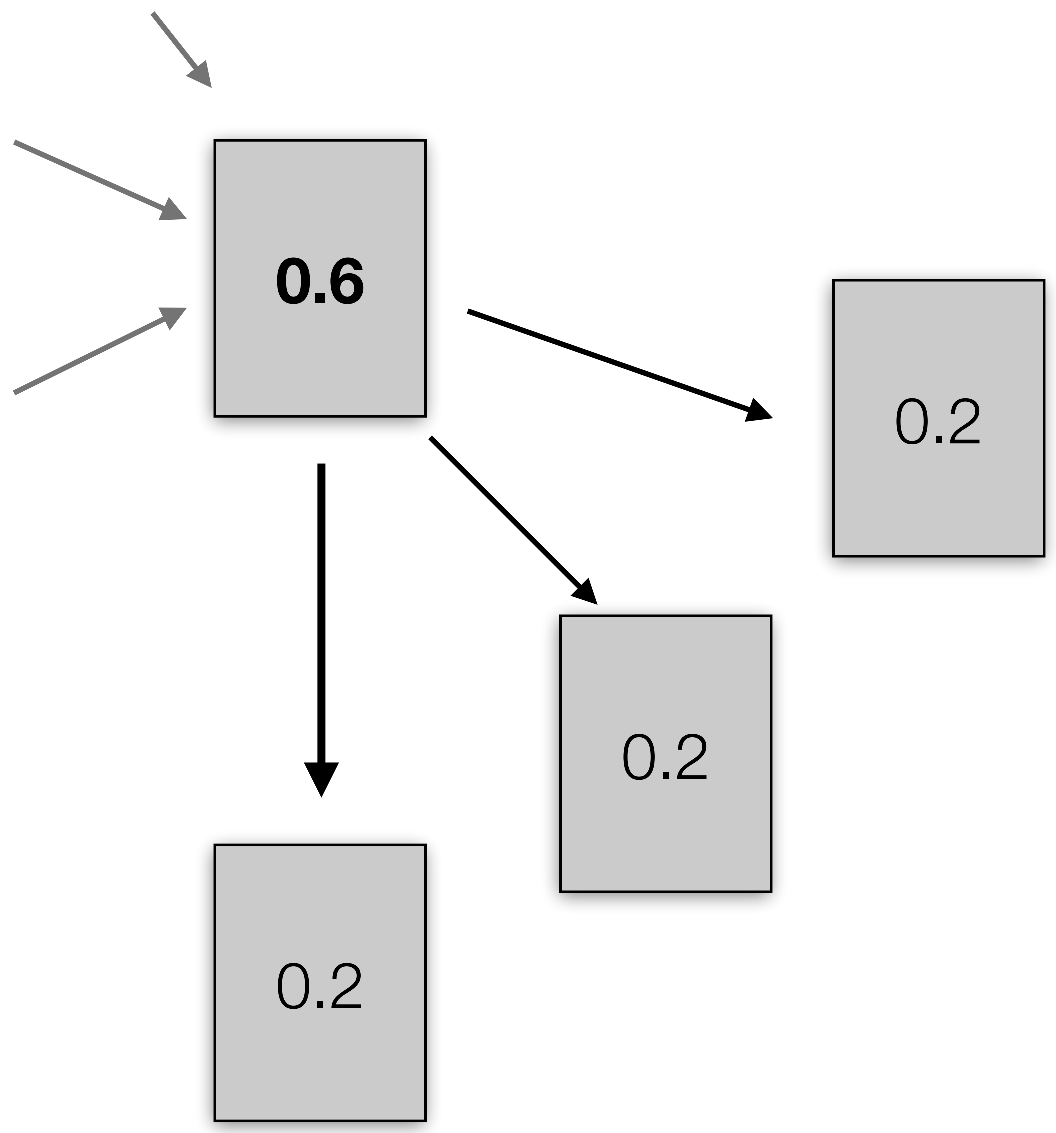
Link-based Signals

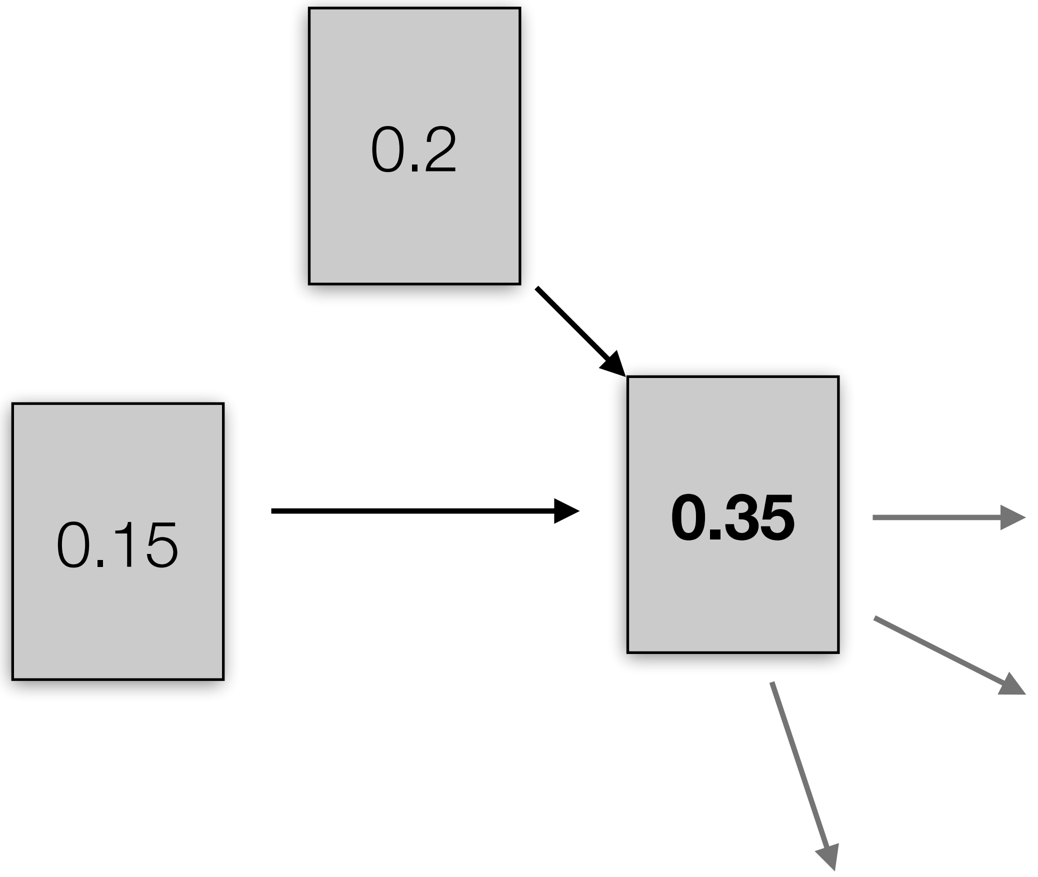
PageRank

- ➔ The web is a directed graph.
- ➔ The hyperlinks pointing to a given 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.





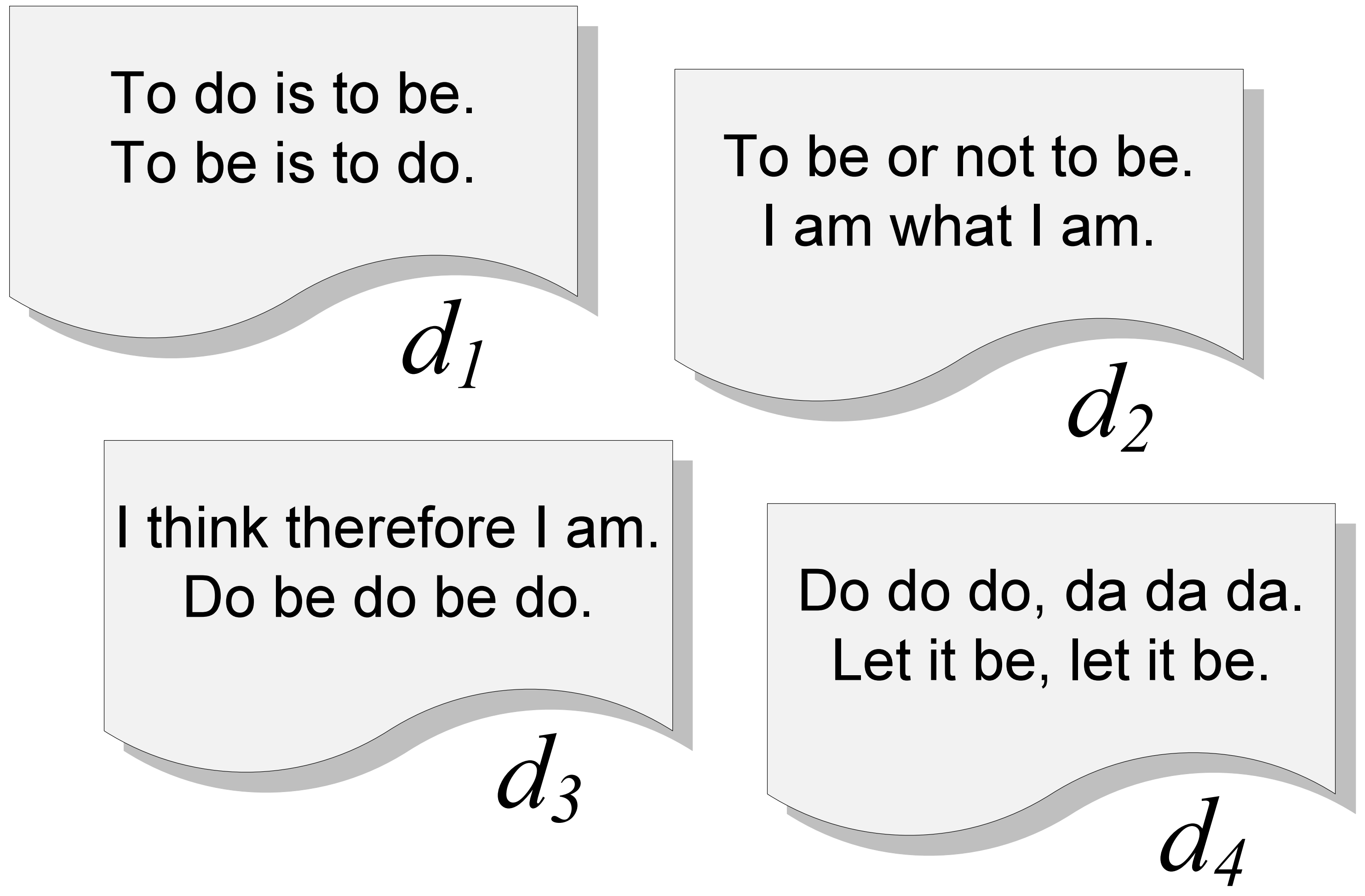
Retrieval Efficiency

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

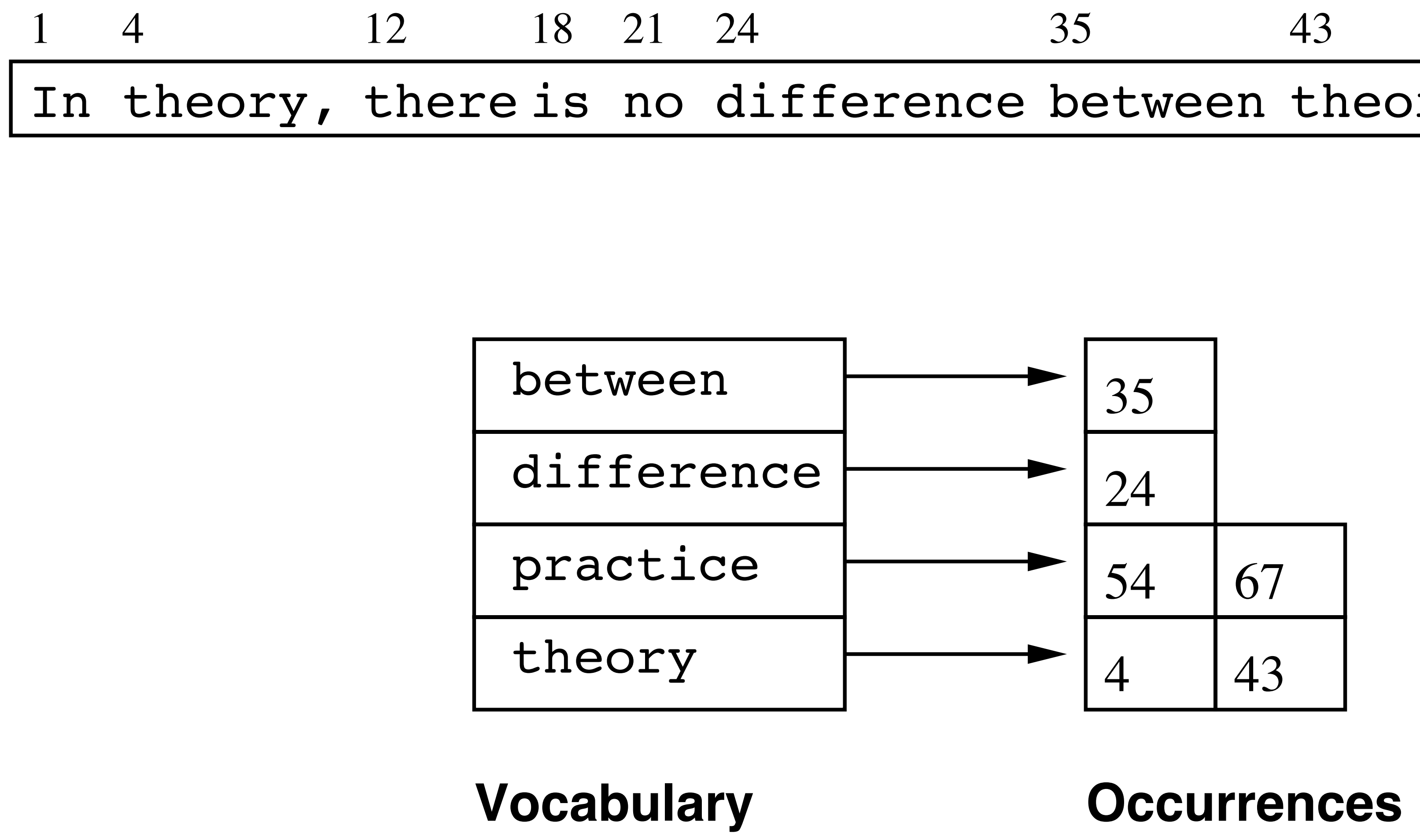
Vocabulary	n_i	Occurrences as inverted lists
to	2	[1,4],[2,2]
do	3	[1,2],[3,3],[4,3]
is	1	[1,2]
be	4	[1,2],[2,2],[3,2],[4,2]
or	1	[2,1]
not	1	[2,1]
I	2	[2,2],[3,2]
am	2	[2,2],[3,1]
what	1	[2,1]
think	1	[3,1]
therefore	1	[3,1]
da	1	[4,3]
let	1	[4,2]
it	1	[4,2]



Full Inverted Index

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

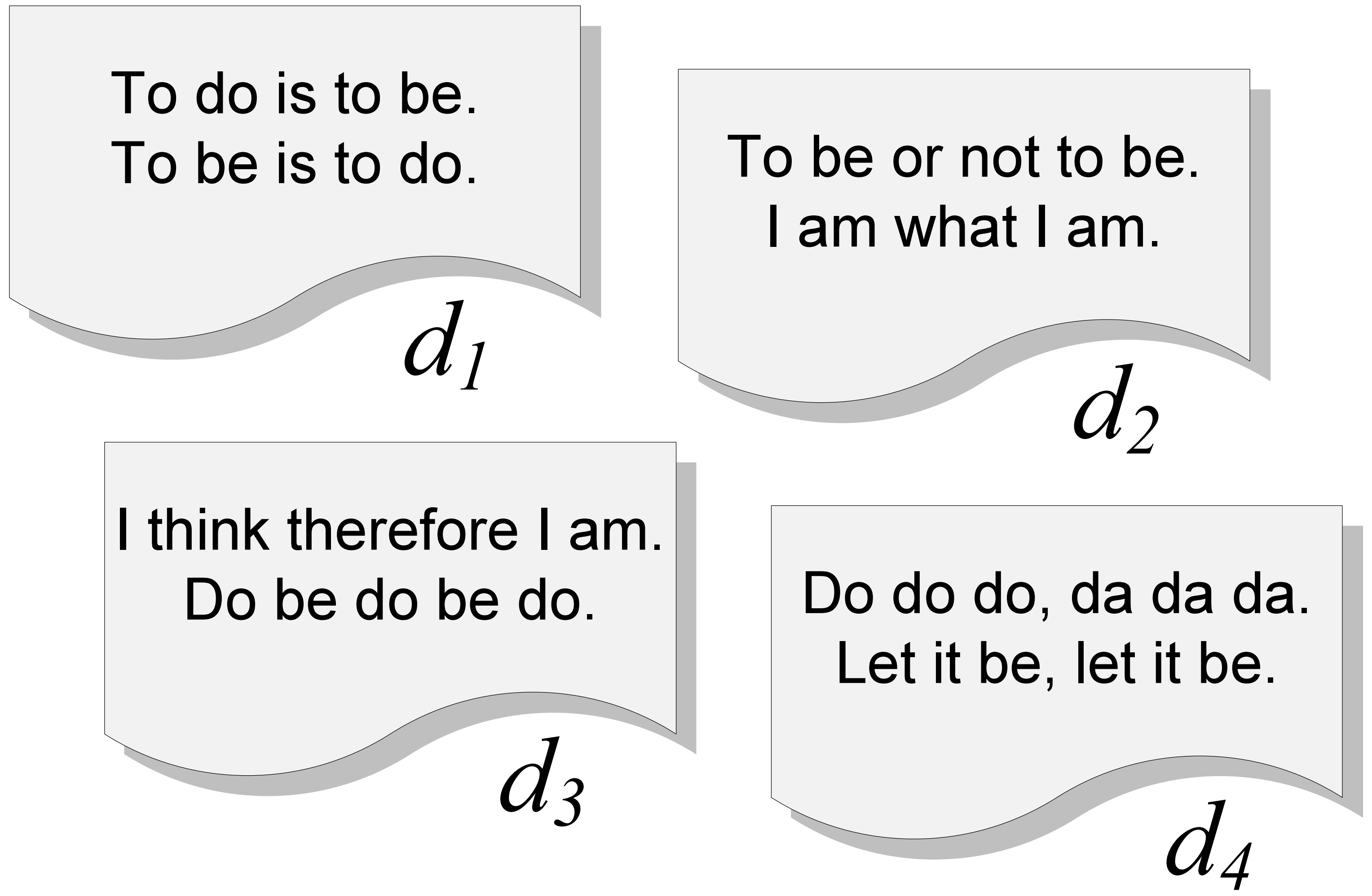
➔ Hence, we need to add the position of each word in each document to the index.



Indexing and Searching, Modern Information Retrieval, Addison Wesley, 2010 – p. 11

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.

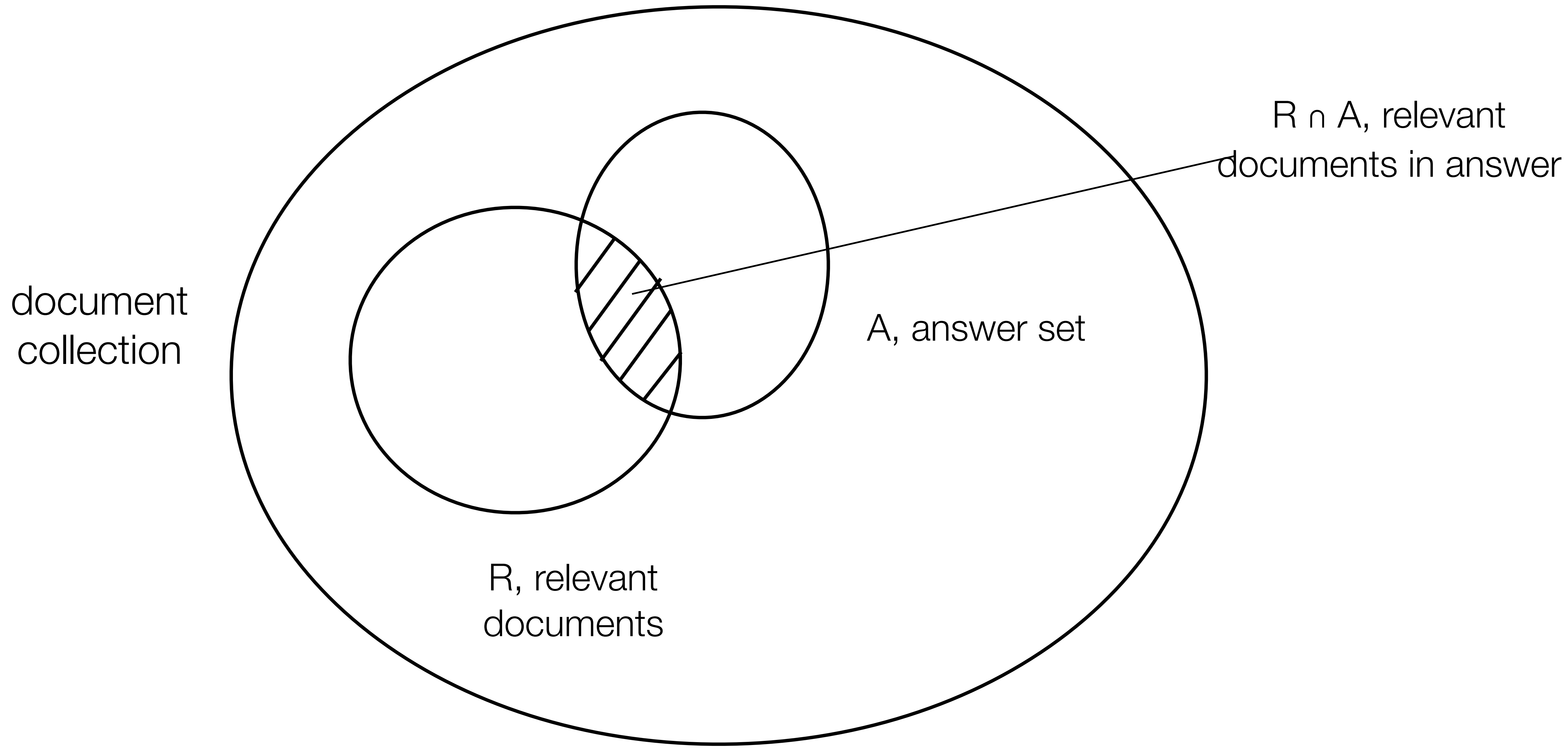
Precision and Recall

- Consider,
  - R, set of relevant 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

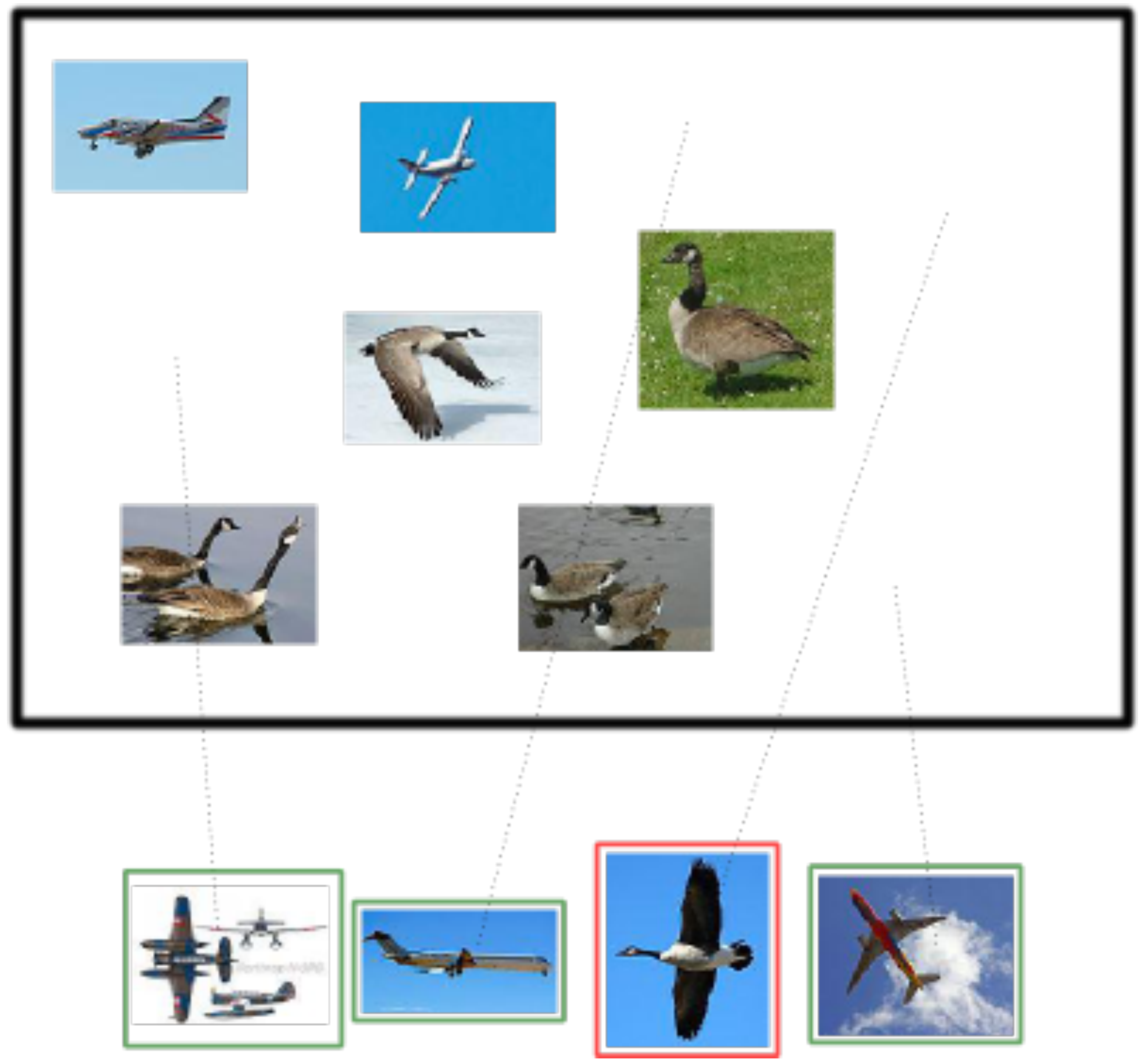
$$Precision = \frac{|R \cap A|}{|A|}$$

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



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 ([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://solr.apache.org

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

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

➔ Lemur Project
https://www.lemurproject.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 13 Documentation, Chapter 12 - Full Text Search*. [online]