# Chapter 6: Information Retrieval and Web Search

Dr. Mehmet S. Aktaş

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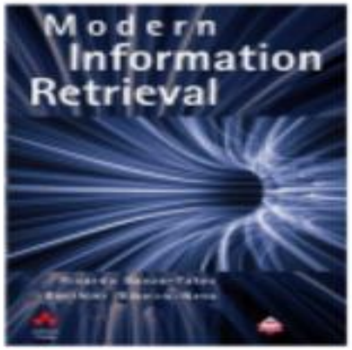
# Introduction

- Text mining refers to data mining using text documents as data.
- Most text mining tasks use Information Retrieval (IR) methods to pre-process text documents.
- These methods are quite different from traditional data pre-processing methods used for relational tables.
- Web search also has its root in IR.

# Information Retrieval (IR)

- Conceptually, IR is the study of finding needed information. I.e., IR helps users find information that matches their information needs.
  - Expressed as queries
- Historically, IR is about document retrieval, emphasizing document as the basic unit.
  - Finding documents relevant to user queries
- Technically, IR studies the acquisition, organization, storage, retrieval, and distribution of information.

# What is Information Retrieval (IR)?




IR: Part of computer science which studies the **retrieval of information (not data)** from a collection of **written documents.** The retrieved documents aim at satisfying a **user information need** usually expressed in **natural language.**

- **Documents, unstructured, text, large**
- **Information need**
- **Store, search, find**
- **The World Wide Web?**
- **Relational databases?**



http://www.ifis.cs.tu-bs.de/teaching/ss-11/irws

# DIKW

- **Data:** Raw web pages
- **Information:** Result of query
- **Knowledge:** Result of processing query result by user
- **Wisdom:** Synthesis of many such actions by a set of users

- One possible classification of steps in process

# Information Retrieval vs. Databases

| Information retrieval | Data retrieval |
|---|---|
| Retrieve all objects **relevant** to some **information need** | Retrieve all objects satisfying some **clearly defined conditions** |
| Find all documents about the **topic** "semantic web"! | **SELECT** id **FROM** document **WHERE** title **LIKE** '%semantic web%' |
| Result **list** | **Well-defined** result **set** |


```
[selke@tbdb ~]$ db2 "SELECT id FROM document WHERE title L
IKE '%semantic web%' FETCH FIRST 3 ROWS ONLY"

ID
--------------------
               45489
             9635899
               98556

  3 record(s) selected.
```



http://www.ifis.cs.tu-bs.de/teaching/ss-11/irws

# Web Search

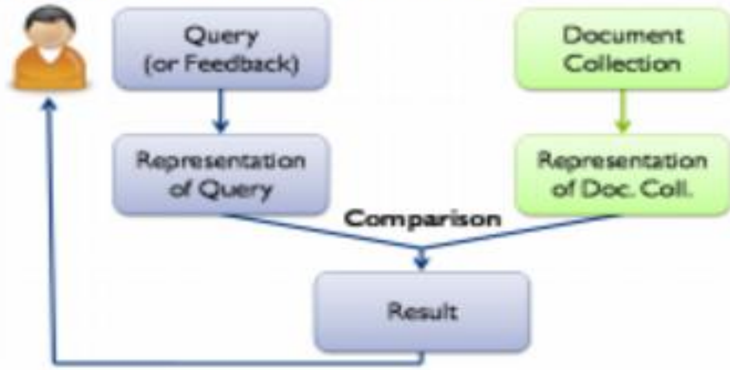
- Very similar to information retrieval
- Main differences:
  - **Links** between Web pages can be exploited
  - **Collecting,** storing, and **updating** documents is more difficult
  - Usually, the **number of users** is very large
  - **Spam** is a problem



http://www.ifis.cs.tu-bs.de/teaching/ss-11/irws

# IR Models

- Any IR system is based on an **IR model**
- The model defines …
  - … a **query language,**
  - … an internal **representation of queries,**
  - … an internal **representation of documents,**
  - … a **ranking function** which associates a real number with each query–document pair.
- Optional: A mechanism for **relevance feedback**



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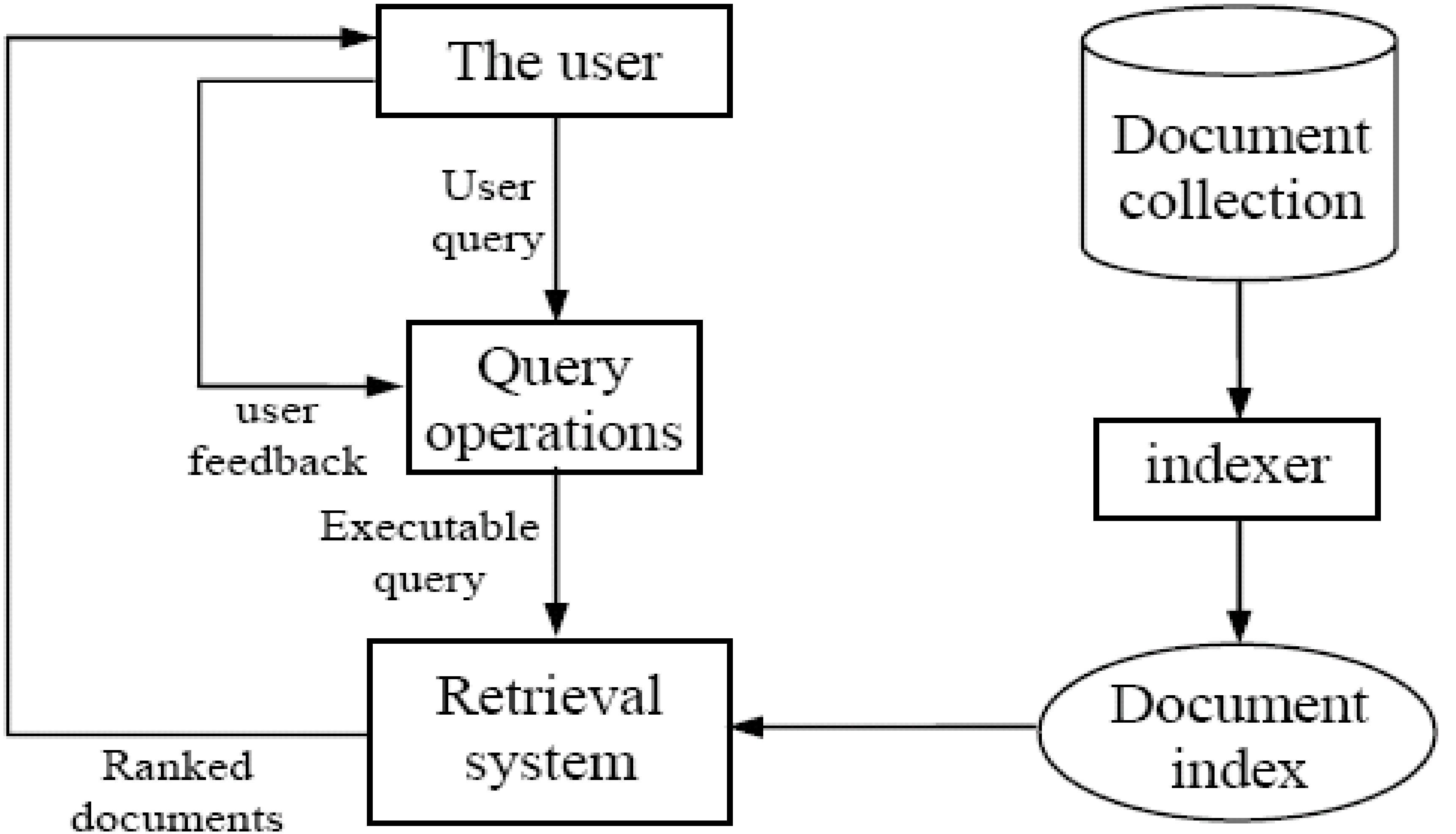
# IR architecture



# IR queries

- Keyword queries
- Boolean queries (using AND, OR, NOT)
- Phrase queries
- Proximity queries
- Full document queries
- Natural language questions

# Information retrieval models

- An IR model governs how a document and a query are represented and how the relevance of a document to a user query is defined.
- Main models:
  - Boolean model
  - Vector space model
  - Statistical language model
  - etc

# Boolean model

- Each document or query is treated as a **"bag" of words** or **terms**. Word sequence is not considered.
- Given a collection of documents $D$, let $V = \{t_1, t_2, ..., t_{|V|}\}$ be the set of distinctive words/terms in the collection. $V$ is called the vocabulary.
- A weight $w_{ij} > 0$ is associated with each term $t_i$ of a document $\mathbf{d}_j \in D$. For a term that does not appear in document $\mathbf{d}_j$, $w_{ij} = 0$.

$$\mathbf{d}_j = (w_{1j}, w_{2j}, ..., w_{|V|j}),$$

# Boolean model (contd)

- Query terms are combined logically using the Boolean operators **AND**, **OR**, and **NOT.**
  - E.g., ((*data* AND *mining*) AND (NOT *text*))
- Retrieval
  - Given a Boolean query, the system retrieves every document that makes the query logically true.
  - Called **exact match**.
- The retrieval results are usually quite poor because term frequency is not considered.

# Vector space model

- Documents are also treated as a "bag" of words or terms.
- Each document is represented as a vector.
- However, the term weights are no longer 0 or 1. Each term weight is computed based on some variations of TF or TF-IDF scheme.

- Term Frequency (TF) Scheme: The weight of a term $t_i$ in document $\mathbf{d}_j$ is the number of times that $t_i$ appears in $\mathbf{d}_j$, denoted by $f_{ij}$. Normalization may also be applied.

# TF-IDF term weighting scheme

- The most well known weighting scheme
  - TF: still **term frequency**
  - IDF: **inverse document frequency**.

  *N*: total number of docs

  $df_i$: the number of docs that $t_i$ appears.
- The final TF-IDF term weight is:

$$tf_{ij} = \frac{f_{ij}}{\max\{f_{1j}, f_{2j}, \ldots, f_{|V|j}\}}$$

$$idf_i = \log \frac{N}{df_i}$$

$$w_{ij} = tf_{ij} \times idf_i.$$

# Retrieval in vector space model

- Query **q** is represented in the same way or slightly differently.
- Relevance of $\mathbf{d}_i$ to **q**: Compare the similarity of query **q** and document $\mathbf{d}_i$.
- Cosine similarity (the cosine of the angle between the two vectors)

$$cosine(\mathbf{d}_j, \mathbf{q}) = \frac{\langle \mathbf{d}_j \bullet \mathbf{q} \rangle}{\| \mathbf{d}_j \| \times \| \mathbf{q} \|} = \frac{\sum_{i=1}^{|V|} w_{ij} \times w_{iq}}{\sqrt{\sum_{i=1}^{|V|} w_{ij}^2} \times \sqrt{\sum_{i=1}^{|V|} w_{iq}^2}}$$

- Cosine is also commonly used in text clustering

# An Example

- A document space is defined by three terms:
  - hardware,  software, users
  - the vocabulary
- A set of documents are defined as:
  - A1=(1, 0, 0),  A2=(0, 1, 0),  A3=(0, 0, 1)
  - A4=(1, 1, 0),  A5=(1, 0, 1),  A6=(0, 1, 1)
  - A7=(1, 1, 1)  A8=(1, 0, 1).  A9=(0, 1, 1)
- If the Query is "hardware and software"
- what documents should be retrieved?

# An Example (cont.)

- In Boolean query matching:
  - document A4, A7 will be retrieved ("AND")
  - retrieved: A1, A2, A4, A5, A6, A7, A8, A9 ("OR")
- In similarity matching (cosine):
  - q=(1, 1, 0)
  - S(q, A1)=0.71, S(q, A2)=0.71, S(q, A3)=0
  - S(q, A4)=1, S(q, A5)=0.5, S(q, A6)=0.5
  - S(q, A7)=0.82, S(q, A8)=0.5, S(q, A9)=0.5
  - Document retrieved set (with ranking)=
    - {A4, A7, A1, A2, A5, A6, A8, A9}

# Okapi relevance method

- Another way to assess the degree of relevance is to directly compute a relevance score for each document to the query.
- The **Okapi** method and its variations are popular techniques in this setting.

The Okapi relevance score of a document $d_j$ for a query $q$ is:

$$okapi(d_j, q) = \sum_{t_i \in q, d_j} \ln \frac{N - df_i + 0.5}{df_i + 0.5} \times \frac{(k_1 + 1) f_{ij}}{k_1 (1 - b + b \frac{dl_j}{avdl}) + f_{ij}} \times \frac{(k_2 + 1) f_{iq}}{k_2 + f_{iq}},$$

where $k_1$ (between 1.0-2.0), $b$ (usually 0.75) and $k_2$ (between 1-1000)

# Relevance feedback

- Relevance feedback is one of the techniques for improving retrieval effectiveness. The steps:
  - the user first identifies some relevant ($D_r$) and irrelevant documents ($D_{ir}$) in the initial list of retrieved documents
  - the system expands the query **q** by extracting some additional terms from the sample relevant and irrelevant documents to produce $\mathbf{q}_e$
  - Perform a second round of retrieval.
- Rocchio method ($\alpha$, $\beta$ and $\gamma$ are parameters)

$$\mathbf{q}_e = \alpha\mathbf{q} + \frac{\beta}{|D_r|}\sum_{\mathbf{d}_r \in D_r}\mathbf{d}_r - \frac{\gamma}{|D_{ir}|}\sum_{\mathbf{d}_{ir} \in D_{ir}}\mathbf{d}_{ir}$$

# Text pre-processing

- Word (term) extraction: easy
- Stopwords removal
- Stemming
- Frequency counts and computing TF-IDF term weights.

# Stopwords removal

- Many of the most frequently used words in English are useless in IR and text mining – these words are called *stop words*.
  - the, of, and, to, ….
  - Typically about 400 to 500 such words
  - For an application, an additional domain specific stopwords list may be constructed
- Why do we need to remove stopwords?
  - Reduce indexing (or data) file size
    - stopwords accounts 20-30% of total word counts.
  - Improve efficiency and effectiveness
    - stopwords are not useful for searching or text mining
    - they may also confuse the retrieval system.

# Stemming

- Techniques used to find out the root/stem of a word. E.g.,

| | |
|---|---|
| user | engineering |
| users | engineered |
| used | engineer |
| using | |

- stem: use engineer

**Usefulness:**

- improving effectiveness of IR and text mining
  - matching similar words
  - Mainly improve recall
- reducing indexing size
  - combing words with same roots may reduce indexing size as much as 40-50%.

# Basic stemming methods

Using a set of rules. E.g.,

- remove ending
  - if a word ends with a consonant other than s, followed by an s, then delete s.
  - if a word ends in es, drop the s.
  - if a word ends in ing, delete the ing unless the remaining word consists only of one letter or of th.
  - If a word ends with ed, preceded by a consonant, delete the ed unless this leaves only a single letter.
  - ......
- transform words
  - if a word ends with "ies" but not "eies" or "aies" then "ies --> y."

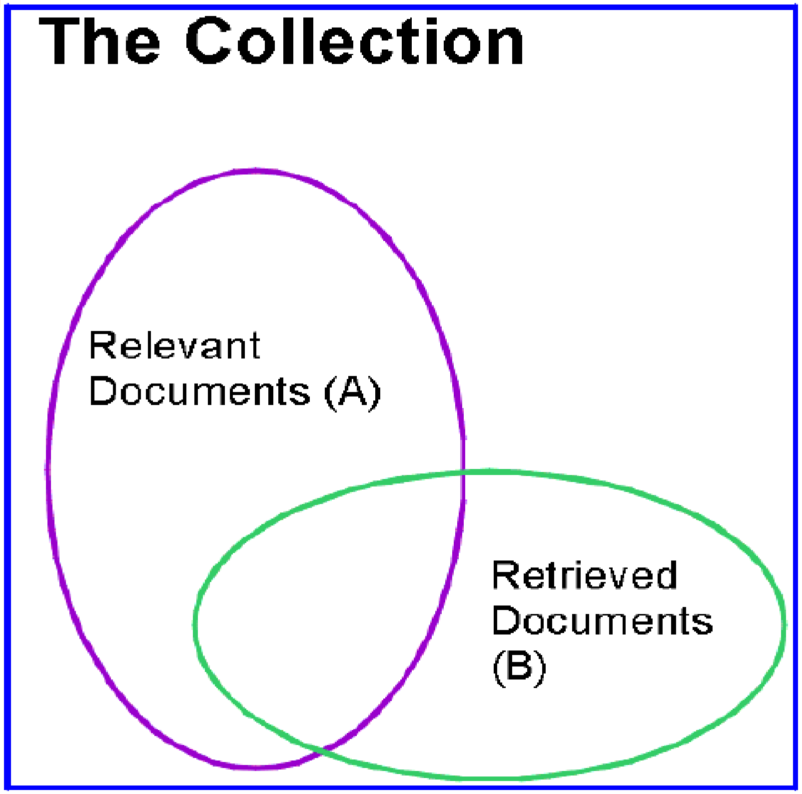
# Frequency counts + TF-IDF

- Counts the number of times a word occurred in a document.
  - Using occurrence frequencies to indicate relative importance of a word in a document.
    - if a word appears often in a document, the document likely "deals with" subjects related to the word.
- Counts the number of documents in the collection that contains each word
- TF-IDF can be computed.

# Evaluation: Precision and Recall

- Given a query:
  - Are all retrieved documents relevant?
  - Have all the relevant documents been retrieved?
- Measures for system performance:
  - The first question is about the precision of the search
  - The second is about the completeness (recall) of the search.

## "Classic" Information Retrieval




- Given a query, the system retrieves a set B of documents
- Every retrieved document is either relevant or irrelevant to the query

Quality metrics:

- ***Recall*** : $(A \cap B) / A$
- ***Precision*** : $(A \cap B) / B$



http://webcourse.cs.technion.ac.il/236375/Winter2013-2014/ho/WCFiles/lec1-intro.pdf

# Recall and Precision on the Web

- Relevance of document to queries is not binary – there are many shades of gray
- Broad-topic queries:
  - abundance problem
  - Precision is the dominating factor: users mostly satisfied with a few good results (a few *authoritative* pages)
- Narrow-topic queries:
  - Find a needle in an enormous haystack
  - Recall demands engines cover significant portions of the Web
- Common measure: precision@10
- Nowadays larger emphasis on *diversity*
  - Positive recall for many aspects of the query



http://webcourse.cs.technion.ac.il/236375/Winter2013-2014/ho/WCFiles/lec1-intro.pdf

# Precision-recall curve

**Example 2:** Following Example 1, we obtain the interpolated precisions at all 11 recall levels in the table of Fig. 6.4. The precision-recall curve is shown on the right.

| $i$ | $p(r_i)$ | $r_i$ |
|---|---|---|
| 0 | 100% | 0% |
| 1 | 100% | 10% |
| 2 | 100% | 20% |
| 3 | 100% | 30% |
| 4 | 80% | 40% |
| 5 | 80% | 50% |
| 6 | 71% | 60% |
| 7 | 70% | 70% |
| 8 | 70% | 80% |
| 9 | 62% | 90% |
| 10 | 62% | 100% |

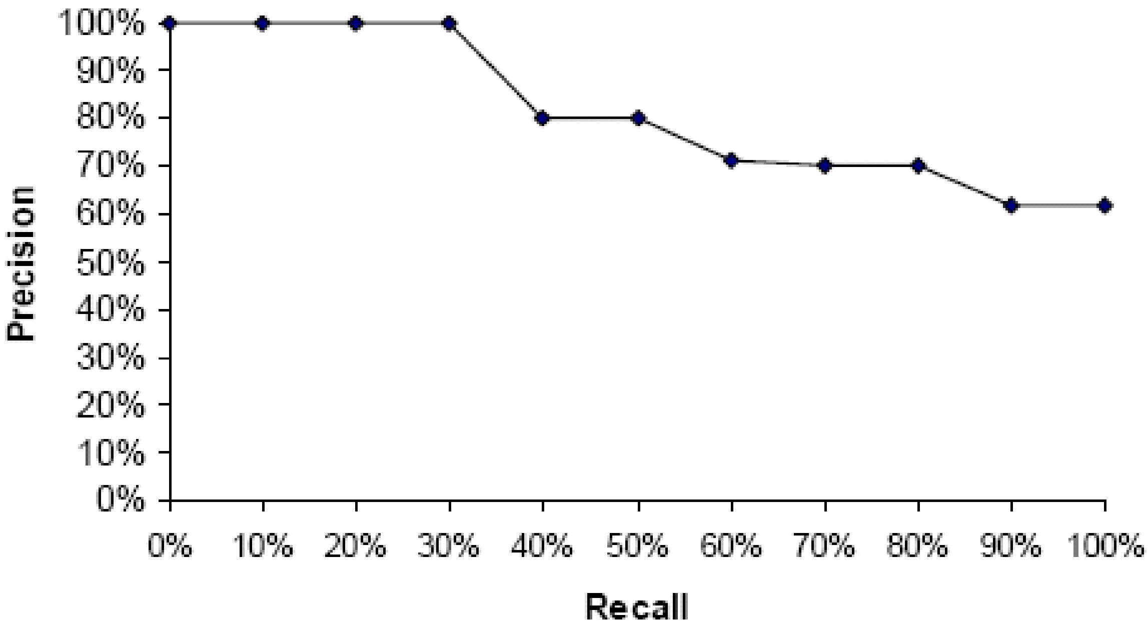



**Fig. 6.4.** The precision-recall curve ■

# Compare different retrieval algorithms

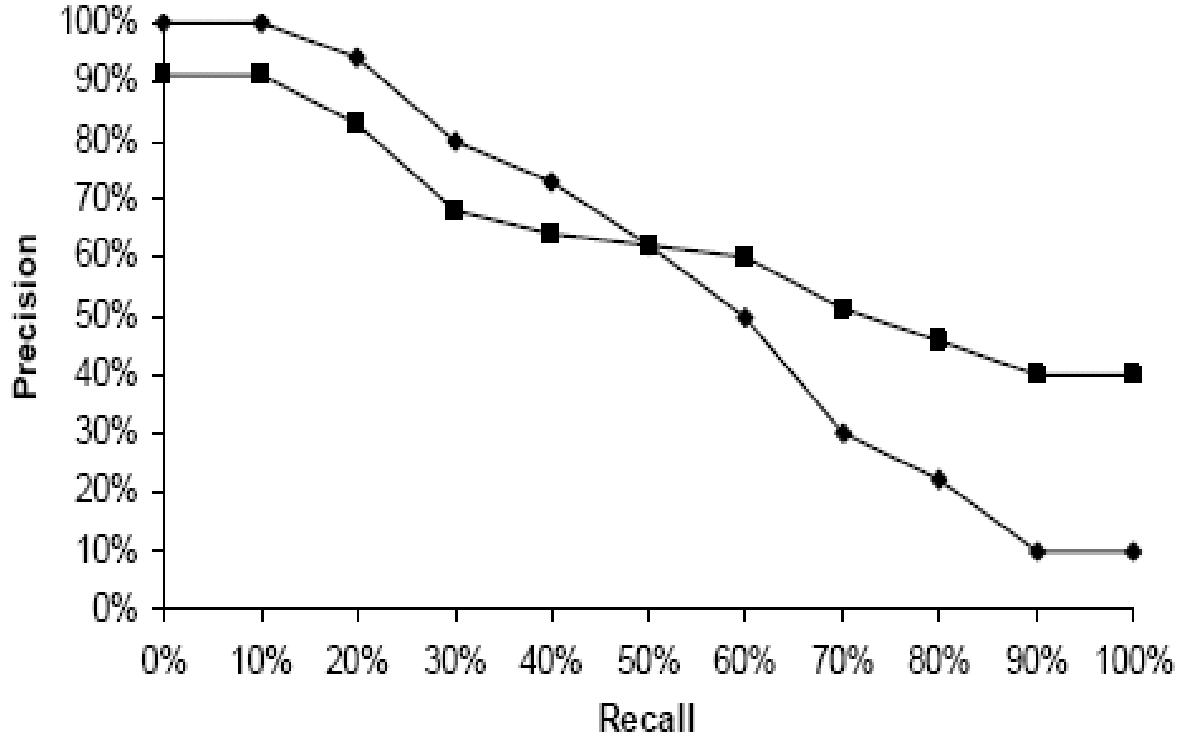



**Fig. 6.5.** Comparison of two retrieval algorithms based on their precision-recall curves

# Compare with multiple queries

- Compute the average precision at each recall level.

$$\overline{p}(r_i) = \frac{1}{|Q|} \sum_{j=1}^{|Q|} p_j(r_i), \qquad (22)$$

where $Q$ is the set of all queries and $p_j(r_i)$ is the precision of query $j$ at the recall level $r_i$. Using the average precision at each recall level, we can also draw a precision-recall curve.

- Draw precision recall curves

# Rank precision

- Compute the precision values at some selected rank positions.
- Mainly used in Web search evaluation.
- For a Web search engine, we can compute precisions for the top 5, 10, 15, 20, 25 and 30 returned pages
  - as the user seldom looks at more than 30 pages.
- Recall is not very meaningful in Web search.
  - Why?

# Web Search as a huge IR system

- A Web crawler (robot) crawls the Web to collect all the pages.
- Servers establish a huge inverted indexing database and other indexing databases
- At query (search) time, search engines conduct different types of vector query matching.

# Inverted index

- The inverted index of a document collection is basically a data structure that
  - attaches each distinctive term with a list of all documents that contains the term.
- Thus, in retrieval, it takes constant time to
  - find the documents that contains a query term.
  - multiple query terms are also easy handle as we will see soon.

# An example

**Example 3:** We have three documents of $id_1$, $id_2$, and $id_3$:

$id_1$: Web mining is useful.
1 2 3 4

$id_2$: Usage mining applications.
1 2 3

$id_3$: Web structure mining studies the Web hyperlink structure.
1 2 3 4 5 6 7 8

| | |
|---|---|
| Applications: | $id_2$ |
| Hyperlink: | $id_3$ |
| Mining: | $id_1$, $id_2$, $id_3$ |
| Structure: | $id_3$ |
| Studies: | $id_3$ |
| Usage: | $id_2$ |
| Useful: | $id_1$ |
| Web: | $id_1$, $id_3$ |

(A)

| | |
|---|---|
| Applications: | $\langle id_2, 1, [3]\rangle$ |
| Hyperlink: | $\langle id_3, 1, [7]\rangle$ |
| Mining: | $\langle id_1, 1, [2]\rangle$, $\langle id_2, 1, [2]\rangle$, $\langle id_3, 1, [3]\rangle$ |
| Structure: | $\langle id_3, 2, [2, 8]\rangle$ |
| Studies: | $\langle id_3, 1, [4]\rangle$ |
| Usage: | $\langle id_2, 1, [1]\rangle$ |
| Useful: | $\langle id_1, 1, [4]\rangle$ |
| Web: | $\langle id_1, 1, [1]\rangle$, $\langle id_3, 2, [1, 6]\rangle$ |

(B)

**Fig. 6.7.** Two inverted indices: a simple version and a more complex version

# Search using inverted index

Given a query **q**, search has the following steps:

- Step 1 (**vocabulary search**): find each term/word in **q** in the inverted index.
- Step 2 (**results merging)**: Merge results to find documents that contain all or some of the words/terms in **q**.
- Step 3 (**Rank score computation**): To rank the resulting documents/pages, using,
  - content-based ranking
  - link-based ranking

# Different search engines

- The real differences among different search engines are
  - their index weighting schemes
    - Including location of terms, e.g., title, body, emphasized words, etc.
  - their query processing methods (e.g., query classification, expansion, etc)
  - their ranking algorithms
  - Few of these are published by any of the search engine companies. They are tightly guarded secrets.

# Summary

- We only give a VERY brief introduction to IR. There are a large number of other topics, e.g.,
  - Statistical language model
  - Latent semantic indexing (LSI and SVD).
  - (read an IR book or take an IR course)
- Many other interesting topics are not covered, e.g.,
  - Web search
    - Index compression
    - Ranking: combining contents and hyperlinks
  - Web page pre-processing
  - Combining multiple rankings and meta search
  - Web spamming
- Want to know more? Read the textbook