Preliminaries: Information Retrieval

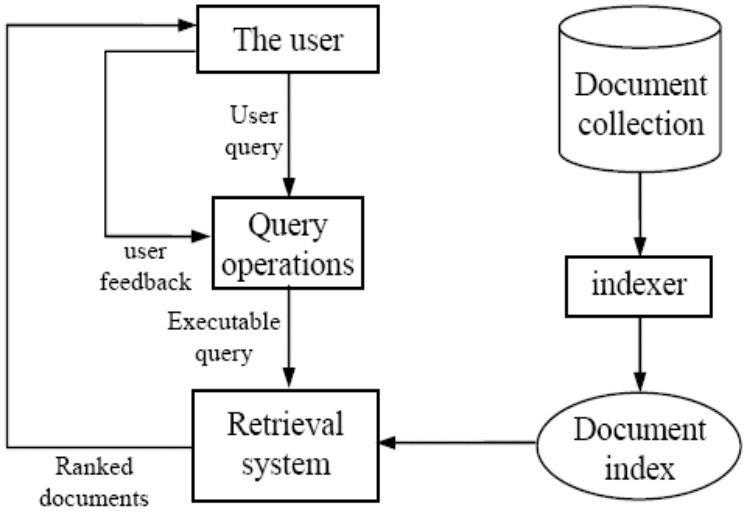
Introduction

- 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.

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
  - 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: weight is Boolean

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:

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

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

$$H(X) = -\sum_{i=1}^{n} p(x_i) \log_b p(x_i)$$

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

Retrieval in vector space model

- Query **q** is represented in the same way
- Relevance of $\mathbf{d}_j$ to **q**: Compare the similarity of query **q** and document $\mathbf{d}_j$.
- 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.

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

df: document frequency, dl: document length

k1, b, k2: parameters in ranges (1,2), ~0.75, (1,1000), respectively

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 (α, β and γ 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

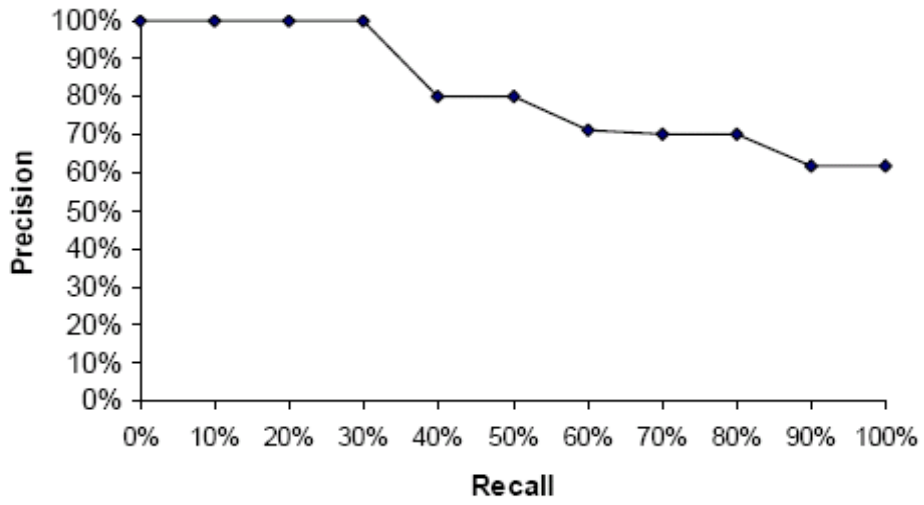
Using a set of rules. E.g., Porter Stemmer

- 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."

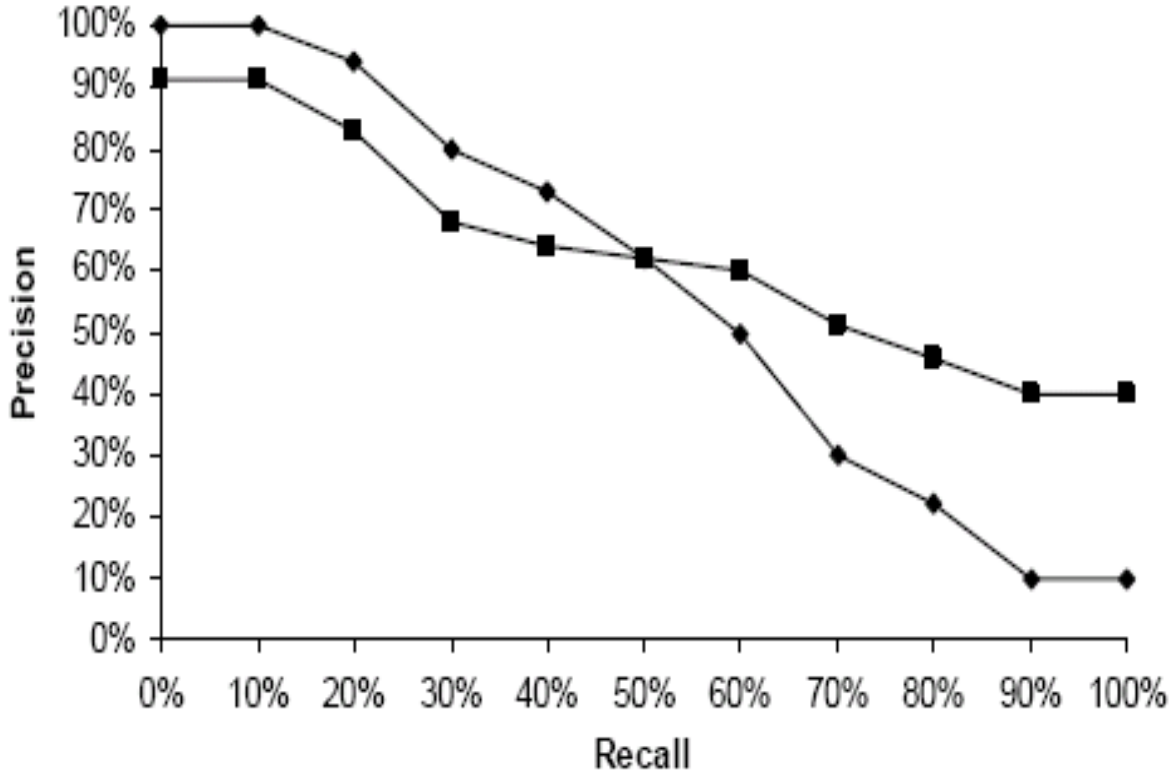
Evaluation: Precision and Recall

- 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.

Precision-recall curve



Compare different retrieval algorithms

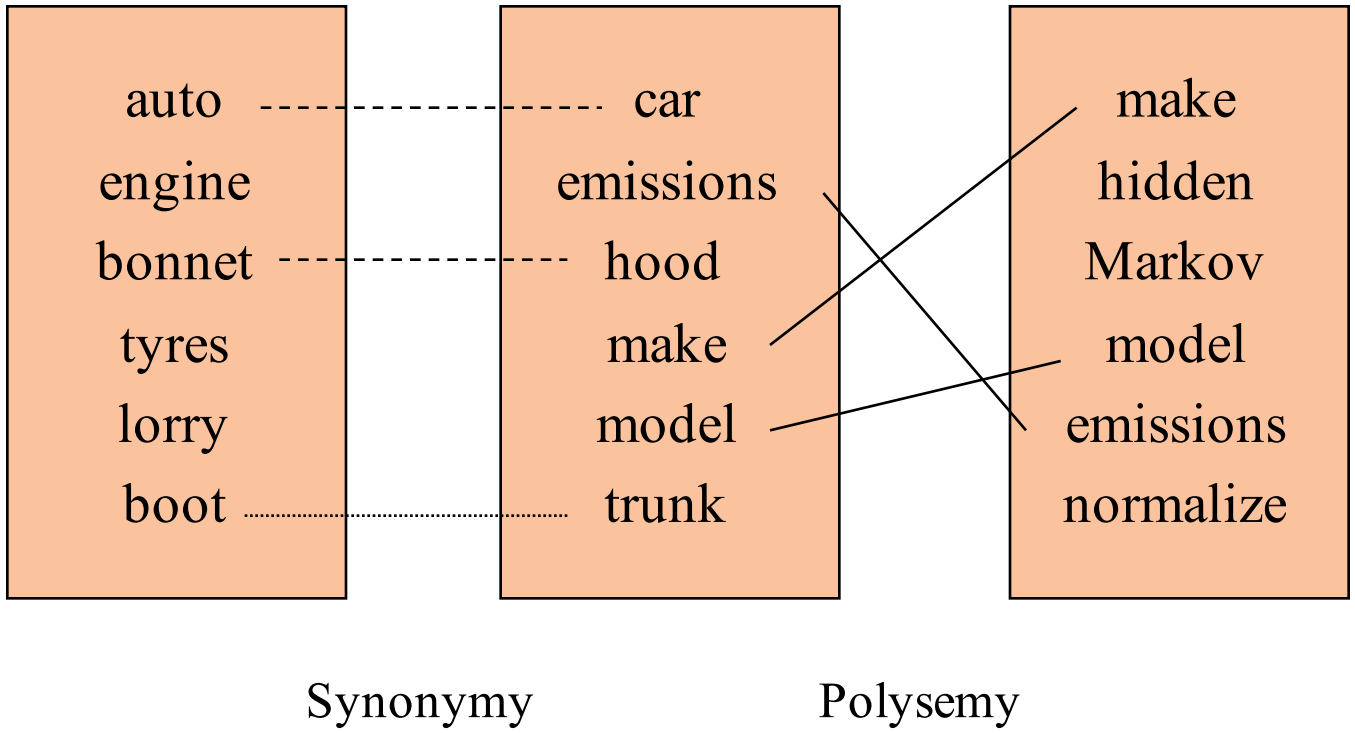


Rank precision

- 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?

The Problem

- Example: Vector Space Model
  - (from Lillian Lee)



Example

Technical Memo Titles

c1: *Human* machine *interface* for ABC *computer* applications

c2: A *survey* of *user* opinion of *computer system response time*

c3: The *EPS user interface* management *system*

c4: *System* and *human system* engineering testing of *EPS*

c5: Relation of *user* perceived *response time* to error measurement

m1: The generation of random, binary, ordered *trees*

m2: The intersection *graph* of paths in *trees*

m3: *Graph minors* IV: Widths of *trees* and well-quasi-ordering

m4: *Graph minors*: A *survey*

Term-by-Document Matrix

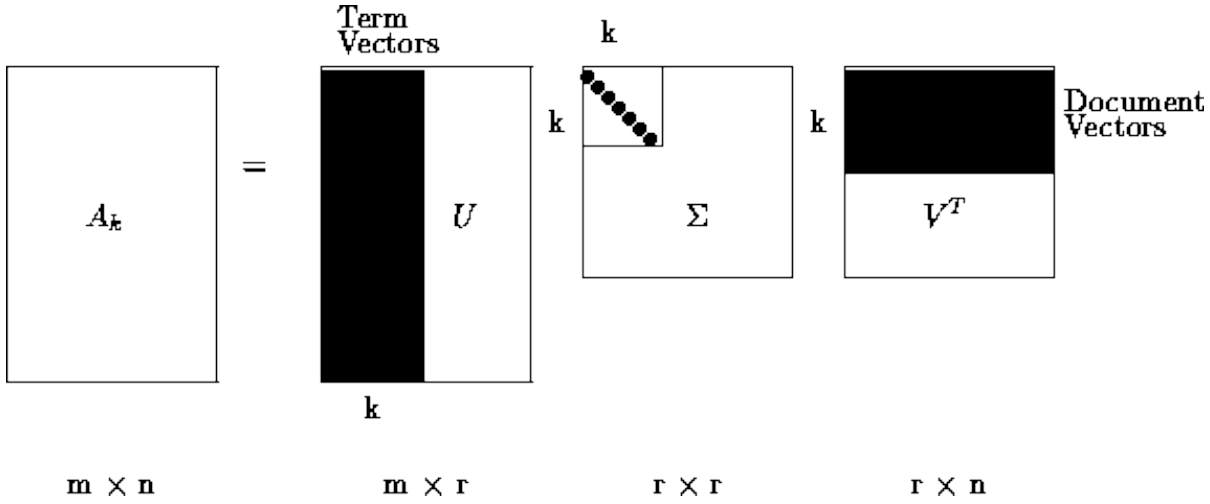
	c1	c2	c3	c4	c5	m1	m2	m3	m4
human	1	0	0	1	0	0	0	0	0
interface	1	0	1	0	0	0	0	0	0
computer	1	1	0	0	0	0	0	0	0
user	0	1	1	0	1	0	0	0	0
system	0	1	1	2	0	0	0	0	0
response	0	1	0	0	1	0	0	0	0
time	0	1	0	0	1	0	0	0	0
EPS	0	0	1	1	0	0	0	0	0
survey	0	1	0	0	0	0	0	0	1
trees	0	0	0	0	0	1	1	1	0
graph	0	0	0	0	0	0	1	1	1
minors	0	0	0	0	0	0	0	1	1

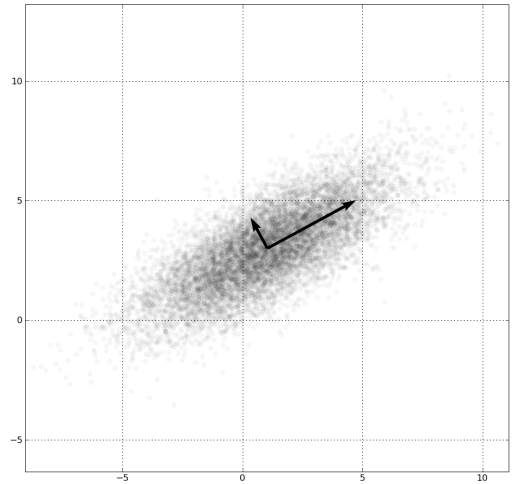
-.38

-.29

Deerwester, S.,Dumais, S.T., Landauer, T.K.,Furnas, G.W. and Harshman, R.A. (1990). "Indexing by latent semantic analysis." *Journal of the Society for Information Science, 41(6)*, 391-407.

Singular Value Decomposition





Rank-2 Truncated Matrix

	c1	c2	c3	c4	c5	m1	m2	m3	m4
human	0.16	0.40	0.38	0.47	0.18	-0.05	-0.12	-0.16	-0.09
interface	0.14	0.37	0.33	0.40	0.16	-0.03	-0.07	-0.10	-0.04
computer	0.15	0.51	0.36	0.41	0.24	0.02	0.06	0.09	0.12
user	0.26	0.84	0.61	0.70	0.39	0.03	0.08	0.12	0.19
system	0.45	1.23	1.05	1.27	0.56	-0.07	-0.15	-0.21	-0.05
response	0.16	0.58	0.38	0.42	0.28	0.06	0.13	0.19	0.22
time	0.16	0.58	0.38	0.42	0.28	0.06	0.13	0.19	0.22
EPS	0.22	0.55	0.51	0.63	0.24	-0.07	-0.14	-0.20	-0.11
survey	0.10	0.53	0.23	0.21	0.27	0.14	0.31	0.44	0.42
trees	-0.06	0.23	-0.14	-0.27	0.14	0.24	0.55	0.77	0.66
graph	-0.06	0.34	-0.15	-0.30	0.20	0.31	0.69	0.98	0.85
minors	-0.04	0.25	-0.10	-0.21	0.15	0.22	0.50	0.71	0.62

+.94

-.83

Rank-2 Truncated Matrix

	c1	*c2*	*c3*	*c4*	*c5*	*m1*	*m2*	*m3*
c2	-0.19							
c3	0.00	0.00						
c4	0.00	0.00	0.47					
c5	-0.33	0.58	0.00	-0.31				
m1	-0.17	-0.30	-0.21	-0.16	-0.17			
m2	-0.26	-0.45	-0.32	-0.24	-0.26	0.67		
m3	-0.33	-0.58	-0.41	-0.31	-0.33	0.52	0.77	
m4	-0.33	-0.19	-0.41	-0.31	-0.33	-0.17	0.26	0.56

0.02	
-0.30	0.44

c2	0.91							
c3	1.00	0.91						
c4	1.00	0.88	1.00					
c5	0.85	0.99	0.85	0.81				
m1	-0.85	-0.56	-0.85	-0.88	-0.45			
m2	-0.85	-0.56	-0.85	-0.88	-0.44	1.00		
m3	-0.85	-0.56	-0.85	-0.88	-0.44	1.00	1.00	
m4	-0.81	-0.50	-0.81	-0.84	-0.37	1.00	1.00	1.00

0.92	
-0.72	1.00

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

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

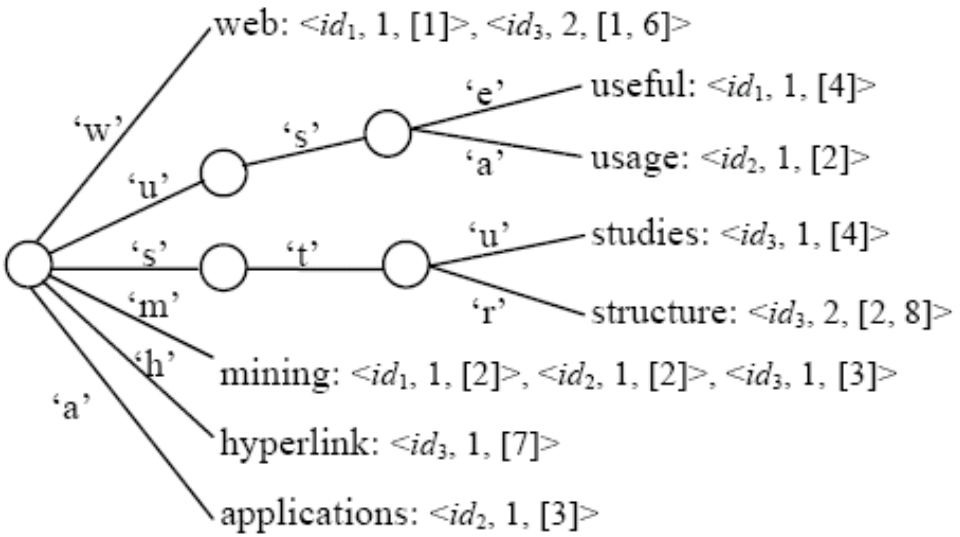
Applications:	id_2
Hyperlink:	id_3
Mining:	id_1, id_2, id_3
Structure:	id_3
Studies:	id_3
Usage:	id_2
Useful:	id_1
Web:	id_1, id_3

(A)

Applications:	<id_2, 1, [3]>
Hyperlink:	<id_3, 1, [7]>
Mining:	<id_1, 1, [2]>, <id_2, 1, [2]>, <id_3, 1, [3]>
Structure:	<id_3, 2, [2, 8]>
Studies:	<id_3, 1, [4]>
Usage:	<id_2, 1, [1]>
Useful:	<id_1, 1, [4]>
Web:	<id_1, 1, [1]>, <id_3, 2, [1, 6]>

(B)

Index construction



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.

Page Rank