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Chapter 3 - Text

Management and Retrieval

Literature:
Baeza-Yates, R.; Ribeiro-Neto, B.: *Modern Information Retrieval*.
Addison-Wesley, Harlow, England. 1999

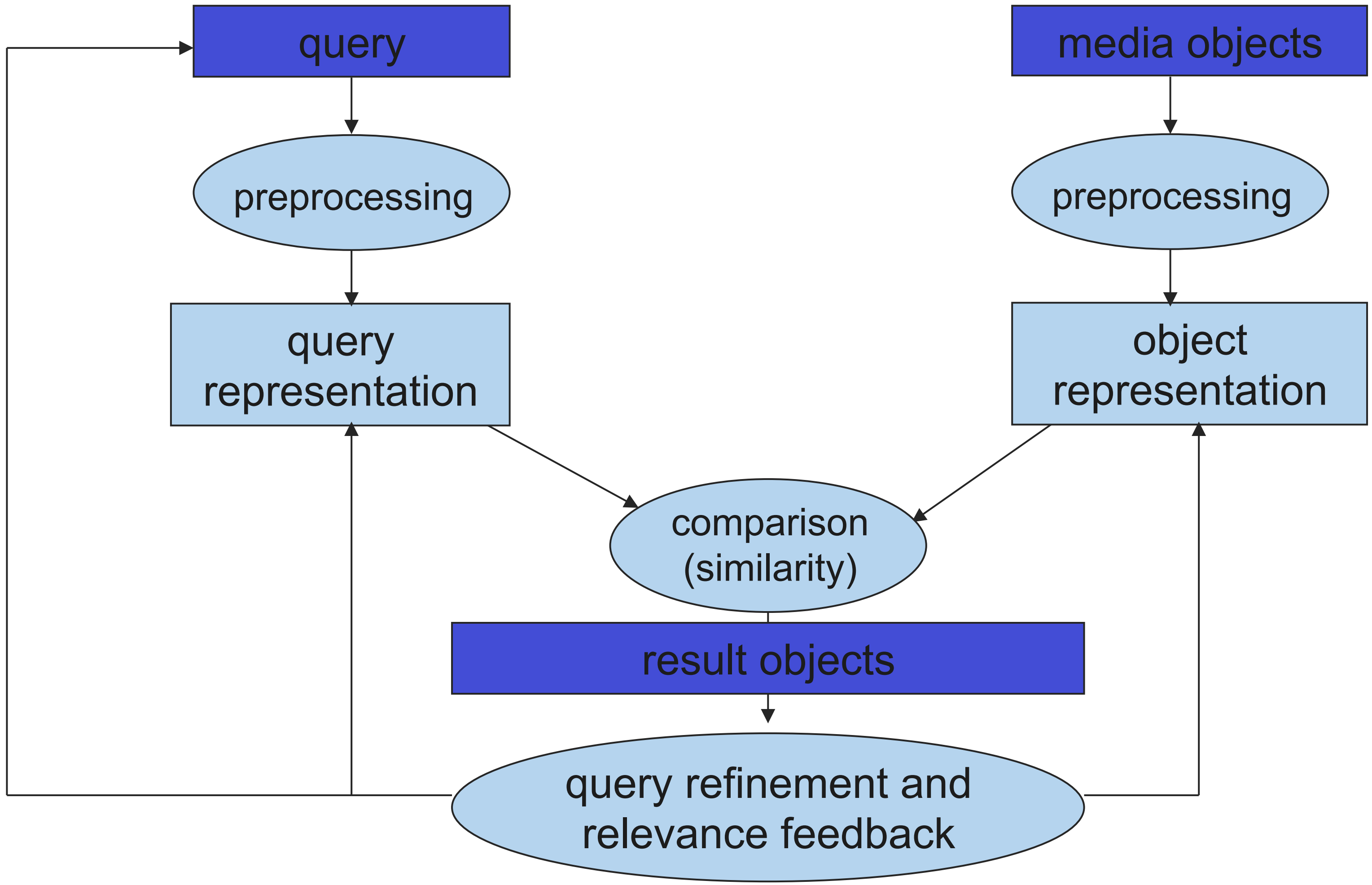
Outline

- Text as a media object
- Text/Information retrieval models
  - boolean model
  - fuzzy set model
  - vector model
- Relevance feedback
- Retrieval evaluation
  - relevance, precision, recall
- Query languages
  - keyword-based
  - pattern matching
- Document preprocessing
- Indexing and Searching

Text

- Raw data
  - sequence of characters (letters, digits, special characters) of variable length, printable
- Registration data
  - character set (ISO Latin-1, Unicode, Kanji)
  - # of bits/character (8, 16, …)
  - character encoding (ASCII, EBCDIC, UTF-8, UTF-16)
  - length of text, or end-of-text character (0x0)
  - length of line, or end-of-line character (<LF>, <RET>)
- Descriptive data
  - structural information, e.g.
    - chapter (nr, heading)
    - section (nr, chapter-nr, position, length)
  - content information (keywords, abstract, …)
- Operations
  - read: determine length, substring, position of a subsequence
  - write: concatenate, replace

Information Retrieval Process



Traditional Information Retrieval Models

- Based on index terms as a means for internal document representation
  - restricted form: keyword (usually a noun) with a meaning of its own
  - general form: any word appearing in a document in a collection of documents
- Fundamental assumption: semantics of a document (and user information need) can be expressed through a set of index terms
  - but not completely – a lot of semantics is "lost" in the process
  - matching of documents and queries is imprecise
- Central problem: predicting which documents are relevant, and which not
- An information retrieval model
  - refines the internal document/query representation
  - defines comparison function (ranking function) for two documents, or a document and a query to determine relevance of documents
- Classic models, developed originally for text retrieval
  - boolean, vector, probabilistic
  - extensions, variations

Basic Concepts

- Document collection
  - contains a set of text documents
  - scope of a retrieval operation, which returns relevant documents
- Index term
  - helps describe the main theme of a document
- Term weight
  - numerical value
  - describes the importance of an index term in describing a specific document
  - (or describes the importance of a query term for the user information need)
- Index term vocabulary
  - set of all index terms used to describe the documents in a collection/system

Boolean Model

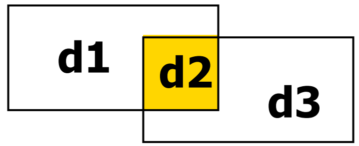
- Simple retrieval model based on set theory and boolean algebra
  - received a lot of attention in the early IR years
  - incorporated in a lot of early commercial IR systems
- Internal document representation: a set of index terms
  - term weights are binary
- Comparison function only considers presence/absence of query keyword in the document
- Query
  - index term
  - combination of index terms using boolean operators
    AND (set intersection)
    OR (set union)
    NOT (set complement)

Boolean Model – Example

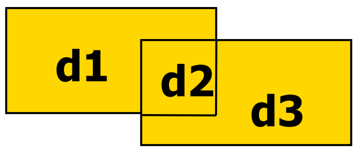
- Vocabulary: {digital library content management multimedia database}
- Documents
  - d1: {digital library multimedia}
  - d2: {digital library content management}
  - d3: {content management multimedia database}
- Queries and results

library *content*

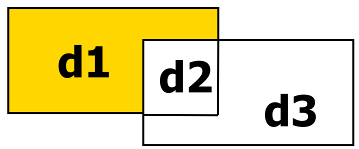
library AND *content*



library OR *content*



library AND NOT *content*



Additional Operators

- BUT
  - motivation: 'NOT content' retrieves all documents that do not contain "content"
  - may be the whole document collection
  - negation is often restricted to the BUT operation (equivalent to AND NOT)
- OF – construct
  - search for documents that contain m out of n (m < n) terms
  - example: 2 OF (content, library, multimedia)
  - equivalent to a more complex boolean expression
    (content AND library) OR (content AND multimedia) OR (library AND multimedia)

Query Processing Steps

- Query normalization in disjunctive normal form (DNF) or conjunctive normal form (CNF)
  - query: content AND ((digital AND library) OR multimedia)
  - DNF: (content AND digital AND library) OR (content AND multimedia)
  - CNF: content AND (digital OR multimedia) AND (library OR multimedia)
- Query evaluation
  - every term determines a set of documents described by the term
  - complex query: determine result using the set operations that correspond to the operators
  - DNF will help reduce size of intermediate results (first intersection, then union)

Problems With Boolean Model

- Exact model based on binary weights
  - strong data retrieval "flavor" (instead of IR)
  - search is too precise, no notion of similarity considered
- Query result
  - all result documents are considered equally relevant
    - no ranking
    - complete presentation/inspection of result required
  - depending on the query, result is often found to be
    - too large
    - too small (empty)
- Boolean query operators
  - are considered unnatural, too difficult to use by most end-users
  - confusion with the colloquial semantics of "and", "or", "not"

Possible Improvements

- Attempt to address the "exact model" problem
  - introduce different levels of relevance
    - turn "AND" into "OR" and
    - present results based on the number of terms matched by the document
  - example: library AND content -> library OR content
    - first return documents containing both terms (d2)
    - then those containing any of the terms (d1, d3)
- Attempt to address the query result (size) problem using faceted query
  - two-level search
    1. formulate query and refine it based on named (previous) queries and result set size
    2. retrieve final query result
  - example:

▪ content	returns	Q1: 5276
Q1 AND management	returns	Q2: 17
▪ display Q2	returns	17 result documents

Fuzzy Set Model

- Alternative set-theoretic model that extends boolean retrieval with "fuzziness"
  - Generalizes the boolean operators
  - Fuzziness introduces a gradual association of documents with terms
- Based on fuzzy set theory

  Definition:
  A fuzzy subset A of a universe of discourse U is characterized by a membership function $\mu_A : U \rightarrow [0, 1]$ which associates with each element u of U a number $\mu_A(u)$ in the interval [0, 1].

- Fuzzy Sets in Information Retrieval
  - universe is the document collection
  - term t defines a fuzzy subset
  - membership function $\mu_t(d)$
    - 0 for no relevance
    - 1 for maximal relevance
    - value between 0 and 1 for gradual relevance

Membership Function (1)

- Numerous approaches for determining membership values
- Example: term-term correlation matrix (Ogawa, Morita & Kobayashi)
  - defines correlation $c_{i,j}$ of any pair of terms t_i and t_j in the vocabulary
    - rows correspond to term t_i, columns to term t_j
    - n_i - #docs containing t_i, n_j - #docs containing t_j
    - $n_{i,j}$ - #docs containing both t_i and t_j

$$c_{i,j} = \frac{n_{i,j}}{n_i + n_j - n_{i,j}}$$

- Example:
  - d1: {digital library multimedia}
  - d2: {digital library content management}
  - d3: {content management multimedia database}

correlation	digital	library	content	management	multimedia	database
digital	1	1	0.33	0.33	0.33	0
library	1	1	0.33	0.33	0.33	0
content	0.33	0.33	1	1	0.33	0.5
management	0.33	0.33	1	1	0.33	0.5
multimedia	0.33	0.33	0.33	0.33	1	0.5
database	0	0	0.5	0.5	0.5	1

Membership Function (2)

correlation	digital	library	content	management	multimedia	database
digital	1	1	0.33	0.33	0.33	0
library	1	1	0.33	0.33	0.33	0
content	0.33	0.33	1	1	0.33	0.5
management	0.33	0.33	1	1	0.33	0.5
multimedia	0.33	0.33	0.33	0.33	1	0.5
database	0	0	0.5	0.5	0.5	1

- Membership based on term-term correlation matrix
  - membership degree for term t_i and document d_j
    - 1, if the index term is contained in the document
    - ~1, if a term closely related to the index term is contained

$$\mu_{t_i}(d_j) = 1 - \prod_{t_k \in d_j} (1 - c_{i,k})$$

- Example:
  - d1: {digital library multimedia}
    - e.g., content: 1 – (0.66 x 0.66 x 0.66) ≈ 0.7
    - e.g., database: 1 – (1 x 1 x 0.5) = 0.5
  - d2: {digital library content management}
  - d3: {content management multimedia database}

membership	d1	d2	d3
digital	1	1	0.7
library	1	1	0.7
content	0.7	1	1
management	0.7	1	1
multimedia	1	0.8	1
database	0.5	0.75	1

Fuzzy Set Model – Operations

- Standard operations on fuzzy sets
  - every document is (to some degree) a member of each fuzzy set
    - the usual set operator semantics is not applicable
  - standard operators determine a new membership value

    AND (conjunction): $\mu_{A \cap B}(u) = \min(\mu_A(u), \mu_B(u))$

    OR (disjunction): $\mu_{A \cup B}(u) = \max(\mu_A(u), \mu_B(u))$

    NOT (negation): $\mu_{\neg A}(u) = 1 - \mu_A(u)$
- Example

μ	**d1**	**d2**	**d3**
content	0,7	1	1
database	0,5	0,75	1
content ∩ database	0,5	0,75	1
content ∪ database	0,7	1	1
¬ content	0,3	0	0

Query Processing Steps

- Queries and query processing
  - query is transformed into DNF
  - every query term determines a fuzzy set
  - application of fuzzy set operators on fuzzy sets
  - result: documents sorted by descending membership values
- Limiting the size of the retrieval result
  - result consists of all documents (complete universe)
  - reduce result size using
    - threshold for membership value
    - fixed result set size

Vector Model

- Addresses limitations of the boolean model (i.e., binary weights) by assigning non-binary weights to index terms in queries and documents
- Assumption: vocublary (set of terms) used for queries and as document descriptors
- Approach
  - vocabulary consisting of N terms
  - document $D_i = (T_{i1}, T_{i2}, ..., T_{ik}, ..., T_{iN})$, T_{ik} weight of term k in document i
  - query $Q_j = (Q_{j1}, Q_{j2}, ..., Q_{jk}, ..., Q_{jN})$, Q_{jk} weight of term k in query j
  - both document and query are interpreted as N-dimensional vectors in the vector space defined by the set of terms
  - similarity of document D_i and query Q_j is defined as the correlation of the two vectors
  - cosine similarity quantifies the correlation using the cosine of the angle between vectors

$$sim_{\cos}(D_i, Q_j) = \frac{D_i \bullet Q_j}{|D_i| \times |Q_j|} = \frac{\sum_{k=1}^{N} T_{i,k} \times Q_{j,k}}{\sqrt{\sum_{k=1}^{N} T_{i,k}^2} \times \sqrt{\sum_{k=1}^{N} Q_{j,k}^2}}$$

Calculating Index Term Weights

- TFIDF (term frequency/inverse document frequency) method
  - Determines a weight $w_D(t)$ for each term t of a document D based on
    - its frequency in the document (term frequency, $tf_D(t)$) and
    - the inverse of its frequency in all documents (inverse document frequency, idf(t))
  - Basic weight formula: $w_D(t) = tf_D(t) \cdot idf(t)$
- Idea:
  - terms occurring more frequently in the document D have a higher weight because they help characterize the document D
  - terms occurring in almost every document receive a lower weight because they don't help to distinguish document D from the other documents
- Many different approaches to calculate $tf_D(t)$ and idf(t)
  - e.g., with $n_{D,x}$ being the number of occurrences of term x in document D, T being the set of all terms in D, N being the total number of documents, and N_t being the number of documents that contain term t (at least once):

$$tf_D(t) = \frac{n_{D,t}}{\max_{i \in T}(n_{D,i})} \qquad idf_D(t) = \log \frac{N}{N_t}$$

Vector Model - Summary

- Very popular method
- Requires fixed set of numerical properties (e.g., term weights) per document
- Problems:
  - terms are assumed to be independent from each other (i.e., not correlated), which is unrealistic
  - doesn't work well for large term vocabularies, large documents
  - query is a vector, there are no boolean operators
    - possible combination with fuzzy set model to introduce boolean operators

Relevance Feedback

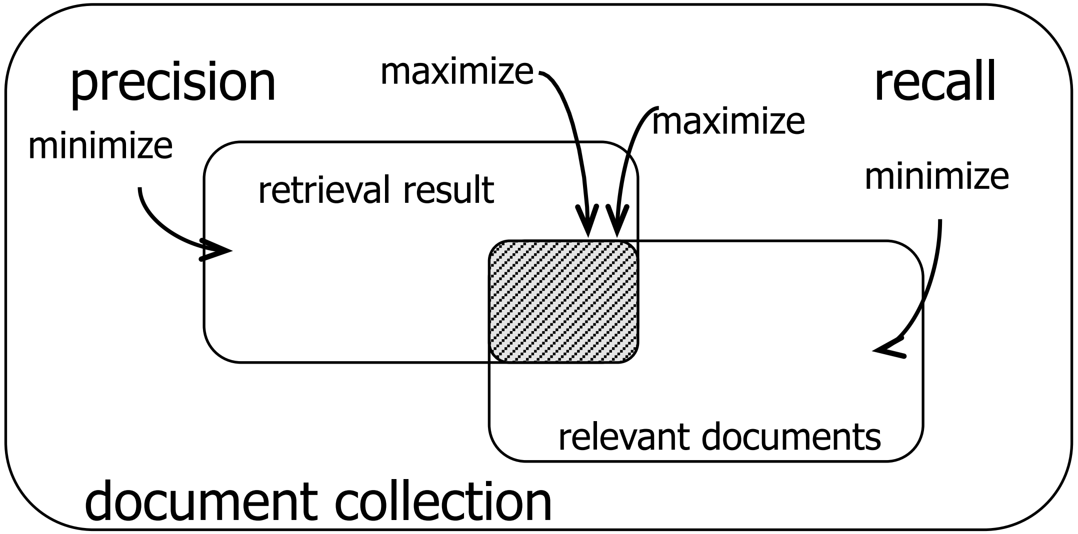
- End-user marks returned documents as relevant or irrelevant
- Query modification
  - terms present in documents marked as relevant are added to the query, or their weights are increased
  - terms present in documents marked as irrelevant are removed from the query, or their weights are decreased
  - improves retrieval quality, but only for the current user
  - Example (for vector model)

$$Q^{(i+1)} = \alpha Q^{(i)} + \frac{\beta}{|Rel|} \sum_{d \in Rel} d - \frac{\gamma}{|NonRel|} \sum_{d \in NonRel} d$$

- Document modification
  - query terms not present in the document are added as descriptors with an initial weight
  - query terms present in relevant documents receive an increase for the document descriptors
  - document descriptor weight is reduced for descriptors which are not query terms (because document was found without the term)
  - positive effects if similar queries follow, effects questionable for other queries

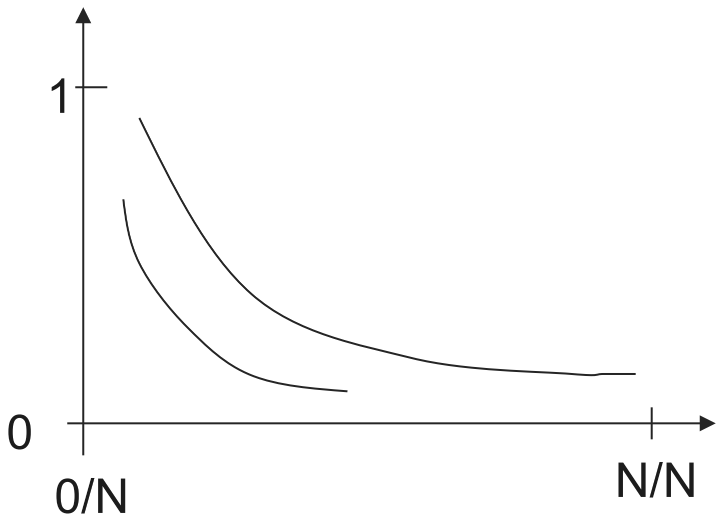
Retrieval Evaluation

- Response time
- Relevance
  - Recall: fraction of relevant documents which has been retrieved
    - recall = #relevant results / #all relevant documents
  - Precision: fraction of retrieved documents which is relevant
    - precision = #relevant results / #result documents
- Contradictory goals
  - maximize precision
  - maximize recall
- Retrieval engine needs to find compromise
- Problem: determining all relevant documents
  - requires inspection of document collection
  - benchmark on small test database



Retrieval Evaluation (2)

- Precision-Recall-Graph:

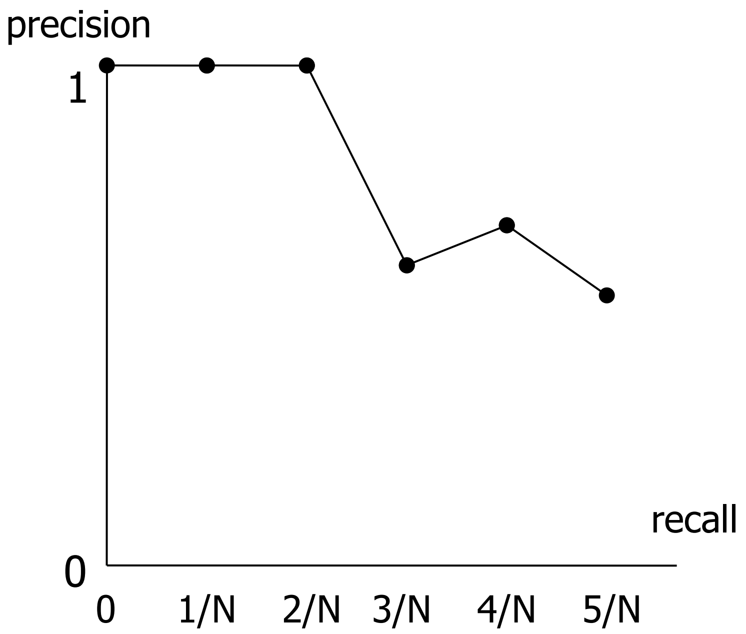


  - determines precision for increasing recall numbers
  - needs to be determined for a large, representative set of queries
    - aggregated into average precision-recall figures

Retrieval Evaluation (3)

- Example:
  - Result: R, R, I, I, R, R, I, I, R, I

#results	R/I	recall	precision
1	R	1/N	1/1
2	R	2/N	2/2
3	I	2/N	2/3
4	I	2/N	2/4
5	R	3/N	3/5
6	R	4/N	4/6
7	I	4/N	4/7
8	I	4/N	4/8
9	R	5/N	5/9
10	I	5/N	5/10



Query Languages

- Different types of queries possible
  - largely dependent on the underlying information retrieval model
- Keyword-based querying
  - single-word
  - context-based
  - boolean
  - natural language
- Pattern matching

Keyword-Based Querying

- Single-word queries
  - ask for documents containing one (or more) words
  - example
    "content", "management"
- Context queries: searching for words "near" other words
  - phrase search: find a sequence of words
    - example
      "content management"
      does <u>not</u> match "content and multimedia database management"
    - considers a 'normalized' phrase representation
      - number of separator/whitespace characters in the text is ignored
    - usually does not consider "uninteresting" words (stopwords)
      - previous query could match "content and management"
  - proximity search: find a set of words with a maximum distance from each other
    - distance: characters, words, sentences, paragraphs
    - examples
      "content" IN SAME SENTENCE AS "management"
      "content" NEAR "management" WITHIN 3 WORDS

Keyword-Based Querying (2)

- Boolean queries
  - involve boolean operators (AND, OR, NOT) – see previous discussion in this chapter
- Natural language queries
  - query is an enumeration of words
  - ranking may consider
    - number of words matched by the document
    - proximity of words appearing in the document vs. those in the query
- General option: query term expansion
  - to cover linguistic variations (see discussion of stemming later in this chapter), or
  - by introducing synonyms, broader terms, narrower terms (using a thesaurus)

Pattern Matching

- Retrieval of pieces of text that match a specified pattern
  - pattern: set of syntactic features that have to occur in a text segment
  - search for all documents containing a text segment that matches the pattern
- Types of patterns
  - word – string of characters
  - prefix/suffix – beginning/end of a text word
  - substring – string appearing within a text word
  - range – pair of string defining a lexical range
    - example: ["content" "continent"] will also match "context"
  - allowing errors – word with error threshold matches "similar" words
    - Edit-distance functions, e.g. Levenshtein distance:
      Count the number of edit operations (insert, modify, delete) to turn string a into string b
    - Example:

      ```
      kitten
      sitting
      ```

      ➨ 2 replacements, 1 insertion LevenshteinDist("kitten","sitting") = 3
    - Weighting of operations possible (e.g. replace more expensive than delete)
    - Normalization to interval [0,1] by dividing result through max(length(String A), length(string B))

Pattern Matching (2)

- Types of patterns (cont.)
  - wildcard characters
    - ., +, * match a single, at least one, any number of arbitrary characters in a word
  - regular expressions: general pattern built by simple strings
  - extended patterns
    - subsets of regular expressions
    - expressed with a simpler syntax
    - examples
      - wildcard characters (see above)
      - case-insensitive matching

operator	meaning
.	any character
A*	any number of As
A+	one or more As
A?	single A or nothing
[a-d]	any of a, b, c, or d
(a)	matches expression a
a | b	either a or b

Document Preprocessing

- Goal: produce internal logical document representation
  - set of descriptors, index terms for each document
- Manual preprocessing
  - classification (hierarchical, facetted)
  - indexing
    - words contained in the document
    - words not contained in the document
      - using thesaurus
    - descriptor attributes (aspects, roles)
      - example: name:carpenter vs. profession:carpenter
    - descriptor weights
- Automatic preprocessing
  - assign index terms based on the text content of the document
  - goal: improve retrieval quality
  - involves various types of operations on the text
    - successive transformations of text into index terms

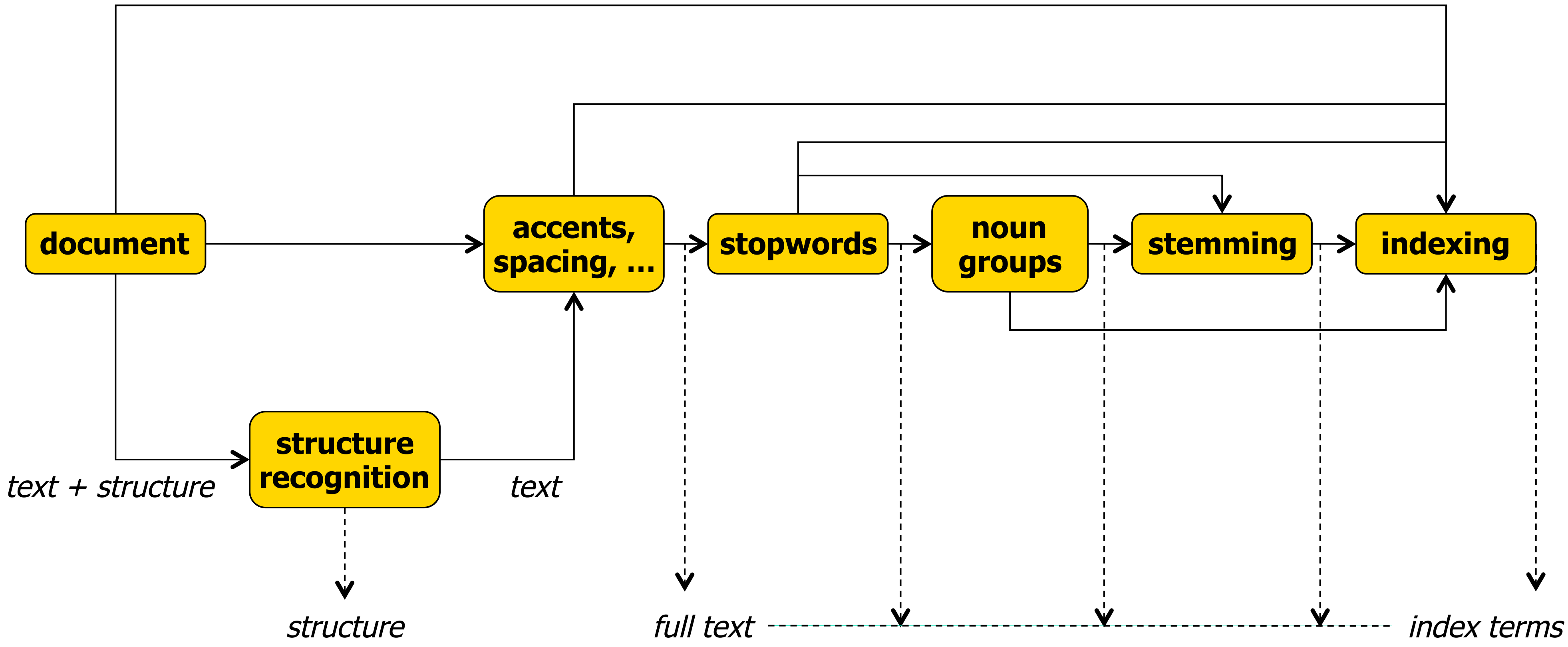
Preprocessing Operations

- Lexical analysis
  - treat digits, hyphens, punctuation marks, case of letters to produce a sequence of words
- Stopword elimination
  - filter out words with very low discrimination values (i.e., unsuitable for retrieval)
- Stemming
  - reduce words to their word stems (e.g., remove prefixes, suffixes, inflections) to allow for syntactic variations of query terms
- Index term selection
  - select words that carry more "semantics"
  - usually based on the syntactic nature (e.g., only nouns)

and also

- Construction of term categorization structures (thesaurus), extracting document text structure

Phases of Text Preprocessing



Lexical Analysis

- Converts a stream of characters into a sequence of words
  - problem: identification of words in the text
- Subtasks
  - recognition of whitespace characters as word separators
  - treatment of numbers
    - numbers alone are usually too vague without a surrounding context, can be disregarded
      - example: "2008" could be a year, phone number, PIN, …
    - but maybe "510B.C." or "0631 205 3275" are useful index terms
      - advanced lexical analysis to recognize and normalize specific kinds of numbers
  - hyphenated words
    - break up into words? - "state-of-the-art" vs "state of the art"
    - don't break up - "B-52", "cutting-edge", …
  - removing punctuation marks
    - o.k. for "text, image, audio …", "510B.C."
    - but not for "x.id" (vs. "xid") in program code
  - converting to upper/lower case for normalization
    - what about "TED" vs. "Ted", "OR" vs. "or", …

Stopword Elimination

- Stopword: word that appears too frequently in the document collection (e.g., >80%) to be of any discriminative use
  - don't contribute to the retrieval task, can be eliminated
  - articles, prepositions, conjunctions are likely candidates
  - might also include adjectives, adverbs, verbs
- Additional benefit: reduces the size of the indexing structure
- Possible problems
  - reduction of precision
    - "War and Peace" vs. "war or peace", "war, peace"
  - reduction of recall
    - "To be or not to be" cannot be found

Stemming & Index Term Selection

- Stemming
  - stem: portion of a word left after removal of affixes (pre-/suffixes)
    - example: "connect" for "connected", "connecting", "connection", "connections"
  - reduces variants of the same root word to a common concept
  - different strategies, such as table lookup or affix removal algorithms
    - Porter algorithm: rules for stripping off suffixes
- Index term selection
  - full text representation adopts all words
  - more selective approaches
    - eliminate verbs, adjectives, adverbs, … (see stopword elimination)
    - identify noun groups as index terms
      - example: "database management system", "computer science", "digital library"

Text Mining

- Discover knowledge (high-level information) in unstructured text for metadata creation
  - patterns
  - relationships
- Uses techniques from
  - data mining
  - natural language processing
  - machine learning

Text Mining Operations

- Feature Extraction
  - identifies facts and relations in the text
    - distinguish person, place, organization, etc. for noun phrases
  - uses dictionaries, linguistic patterns (part of speech tagging)
- Categorization
  - classifies documents into predefined categories
  - thesaurus-based approach
    - categories are determined based on frequencies of domain-specific terms
  - machine-learning approach
    - categorizer is trained with (pre-categorized) sample documents
    - statistically analyzes linguistic patterns (word frequencies, lexical affinities)
    - builds statistical signatures for the categories
    - uses the signatures to classify new documents

Text Mining Operations (2)

- Clustering
  - groups together related documents into clusters
    - based on a similarity measure
      - may utilize lexical affinities, extracted features
    - done without predefined categories
  - variations
    - hierarchical
    - binary relational (flat)
    - fuzzy
- Summarization
  - reduces text while still keeping its key meaning
  - based on input parameters
    - number of sentences, percentage of original text to extract
  - result contains the most important sentences

Linear/Sequential Searching

- Text documents are stored in one or multiple files
  - search by scanning the text sequentially, "before" preprocessing
    - also called "online search"
- Type of search: pattern matching
- Performance time proportional to length of document (collection)
  - numerous algorithms
- Appropriate only for small document collections
  - but may be the only option if
    - text collection changes too frequently
      - indexing is done periodically, index doesn't reflect current state
    - indexing is too expensive

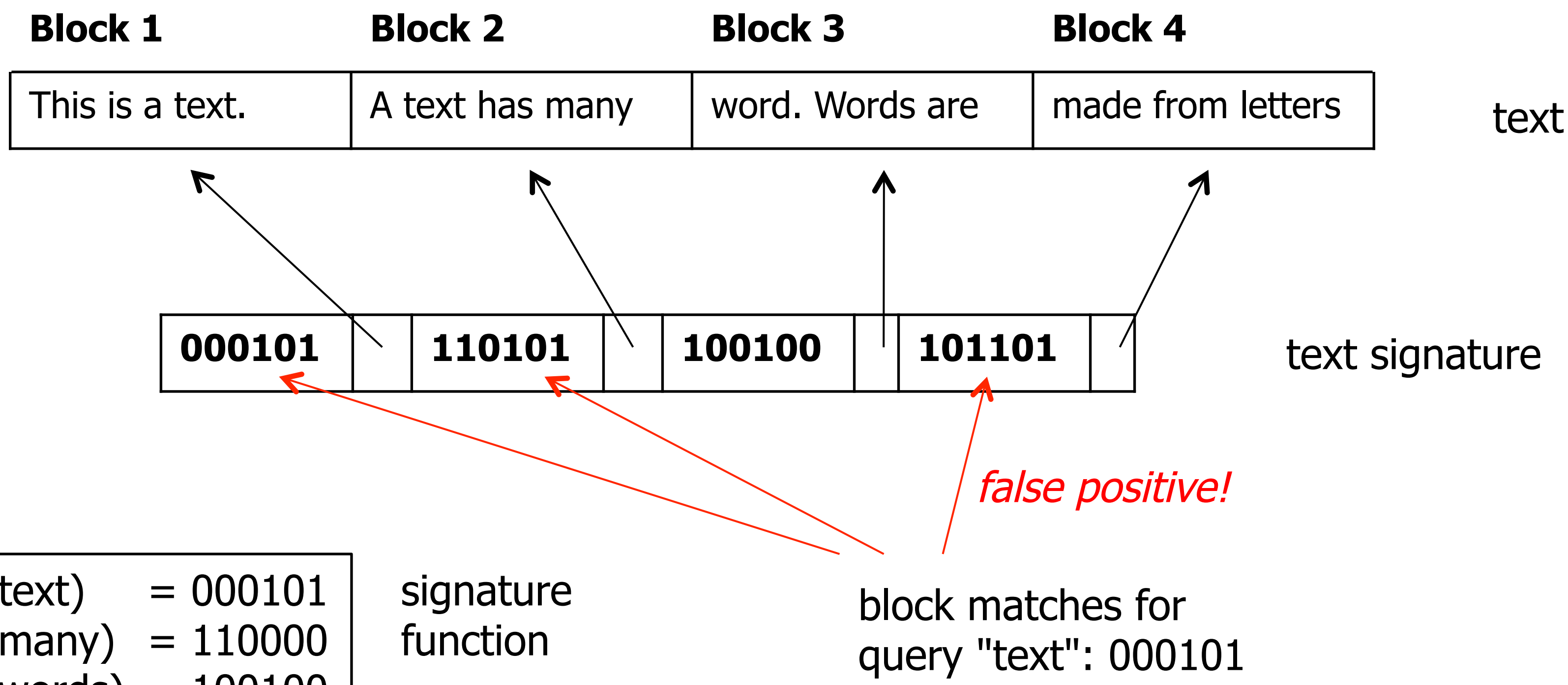
Signature Files

- Word-oriented index structure based on hashing
  - hash function (signature) maps words to bitmaps of length *B*
  - text is divided into blocks with *b* words each
  - a bitmap of length *B* is assigned to each block (plus a pointer to each block)
    - block bitmap is computed by bitwise OR-ing of the word bitmaps for all words in the block
  - idea: a word can only be present in the block, if the bits that are set in the word bitmap are also set in the block bitmap
- False positives
  - query word bitmap and block bitmap match, but the word doesn't appear in the block
  - probability for false positives depends on proportion *b / B*
    - tradeoff: overhead vs. false positives probability

Signature Files - Search

- Single keyword queries
  - determine signature value of query term, find matching block bitmaps
    - with q = bitmap of query term, B_i = bitmap of block i, find all blocks with q AND $B_i = q$
  - additional sequential search on block is required for determining word match
- Phrase queries
  - determine bitwise OR of bitmaps for all words in the phrase
  - allows to find blocks (potentially) containing all the words
  - need to have blocks overlap to account for phrase words on block boundaries

Signature Files - Example



h(text) = 000101
h(many) = 110000
h(words) = 100100
h(made) = 001100
h(letters) = 100001

signature function

Inverted Files

- Word-oriented index
  - lists for each index term the identifiers of documents to which the keyword was assigned
  - includes additional information about the word occurrence (position in the document) and term weights
- Entry (row in the inverted file)
  - (term: (doc-id-1 pos-1 … pos-n weight) …)
  - pos: paragraph-no, sentence-no, word-no, character-no
- Search
  - search for individual terms in the index
    - phrase and proximity queries need to be split up
  - retrieve the occurrences
  - manipulate the occurrences
    - resolve phrases, proximity, boolean operators (list union/intersection/difference)
- Search steps can be supported by appropriate access structures (B-trees, …)

Inverted files/indexes are the best foundation for text retrieval in practice

Inverted Files - Example

text

```
1    6  9 11    17 19   24  28   33      40    46  50   55   60
This is a text. A text has many words. Words are made from letters.
```

inverted file

vocabulary	*occurrences*
letters	60 …
made	50 …
many	28 …
text	11, 19 …
words	33, 40 …

Summary

- Text as a media object
- Text retrieval - main problems
  - imprecise search
  - similarity, relevance of text documents
- Text/Information retrieval models defines internal document model, similarity rank
  - boolean model, fuzzy set model, vector model
- Relevance feedback uses user input to improve retrieval quality
  - adjusts query and/or document representation
- Retrieval evaluation based on notions of relevance, precision, recall
- Query languages
  - keyword-based (keyword, phrase, boolean operators, natural language queries)
  - pattern matching (simple patterns, error tolerance, regular expressions)
- Document preprocessing produces logical internal document representation
  - lexical analysis, stopword elimination, stemming, index term selection
- Text Mining operations extract higher-level information
  - feature extraction, categorization, clustering, summarization
- Indexing and Searching for text
  - sequential search, signature files, inverted files/indexes