Digital Libraries

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What's all about?

Digital Libraries

Any attempt to define what a digital library is or is not will either be too vague or too restrictive

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It is rather an environment to bring together collections, services, and people in support of the full life cycle of creation, dissemination, use, and preservation of data, information, and knowledge.

Santa Fe Workshop

- defined by function not by technology
- involve many domains of research, development, and service
- are characterized by integration of heterogeneous sources, services, traditions, and technologies, many of them involving humans and their way to deal with information

This course will cover some of these aspects

Content / Objects of a DL

Examples

- *Document Like Object (DLO)* (Dublin Core)
- *data, information, and knowledge* (Santa Fe Workshop)
- *article, book, web page, data item, video clip, map, drawing, photo, advertisement, animation*, ... (Winograd)
- *text, images, sound, movies, video, software, animations*
- Specific collections: chemistry, biology, geography, software ...

Possible Definition:

Self contained information objects that
– are collected for a relevant group of users
– over a period of time and
– can be anticipated by these users in the form in which they are presented by the DL system.

Services

Integrated management for

- **Content based access**: search / filter / browse / explore
- **Presentation of samples of objects**: show / filter / cluster / evaluate
- **Presentation of single objects**: display / deliver / abstracting / extracting
- **Authentication**: control originality / control references / copy detection / find citations
- **Access control**: copyright / billing / restrict access to specific groups (decency)
- **Communication**: comment / annotate / evaluate / discuss / contact author

adaptive to: language / problem considered / knowledge & education / technical & physical restrictions / time & money

Aspects of Content

- **Diversity**: topic / format / quality / access methods
- **Quality / Originality**: integrity / reviewing / control of authorship
- **Commercial Aspects**: Copyright / billing / responsibilities / warranties
- **Internal Representation**: formats / metadata / ways of storage
- **Distributed storage**: dynamics of collections / merging / mediation / description of collections
- **Archiving**: security / media life-span / hardware availability / format conversion / definition of archival object

Content of the Course

Part 1: Information Retrieval (Reginald Ferber)

- What's all about
- History
- Different kinds of information systems
- Boolean retrieval
- Stemming
- Classifications
- Thesauri
- Vector space model
- Evaluation of IR systems
- TREC
- Recent developments

Part 2: Inelligent Access to Digital Libraries (Ulrich Thiel)

Part 3: Document Models and Applications / XML and related standards (Karl Aberer)

- Basic XML architecture
- History of XML
- Application Examples
- XML Syntax and Document Type Definitions
- XSL - Layout for XML Documents
- XLink and Xpointer - Links in XML
- RDF - Metadata for XML
- Programming in XML
- XML Tools

Part 4: Data management for documents (Peter Fankhauser)

- Database technology and the Web
- Database architectures for the Web
- Access mechanisms to databases in the Web
- Storage of structured documents
- Indexing for documents
- Document query languages
- Document query processing

Part 5: Applications (Kostas Tzeras)

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Information Retrieval

Introduction

- The amount of digital data is increasing world wide
- More people get access to networks like the Internet

⟶ These data are only useful, if people know
- how to find them
- what they mean
- how to use them

Examples of Information Needs

Find a phone number

Users of the information service in general know

- what kind of information they look for
- where they find the information
- what a telephone is good for
- how to use it
- which person they want to call

Users assume that the number given is correct.

Service is organized by a central data base

Browse the WWW

- No specific purpose given
- defining aspects: protocols HTTP & HTML
- no central organization and responsibility
- few mandatory procedures
- developing style of interaction
- divers motivations of users:
  - looking for scientific information
  - participating in specific interest groups
  - banking
  - planning holidays
  - entertainment
  - shopping
  - no clear goal

⟶ many possibilities to start with

⟶ difficult to search for specific content

⟶ users have to understand / learn services

⟶ hard to judge if the information found is complete

⟶ hard to judge if the information found is correct

A Bit of History

The task to identify and organize documents or knowledge is neither new nor restricted to digital material.

There are long traditions in science and libraries to

- collect documents
- assess and evaluate their content
- organize and preserve them
- give people access to them

Last 40 years:
many computer based systems to organize the access to scientific documents.

But these systems have been build for well defined and homogeneous

- collections
- domains and
- users

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These conditions change. Now systems have to adapt to

- divers types of documents and services
- heterogeneous content
- heterogeneous user groups
- distributed servers
- heterogeneous social and technical conditions

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Different Kinds of Information Systems

To give a feeling for the topic

- diverse types of information
- diverse methods to handle it
- diverse motivations of users

will be discussed in the following examples

Searching for Scientific Documents

Methods

- ask an expert
- look for a book on the topic
- follow citations and references
- use a bibliography, an abstracting service, or a bibliographic database specific to the domain
- look in the web
  - by browsing
  - using search engines

Characteristics and Problems

- *ask an expert*
  - problem to find someone
  - gives the state of knowledge and the view of the respective person
  - chance to discuss and elaborate the information need
- *look for a book on the topic*
  - textbooks are slow: new fields are covered only after a while
  - conference proceedings do not offer a systematic introduction to a domain
  - selection criteria for proceedings are not only governed by content
- *follow citations and references*
  - citations my be limited to a specific view
  - in general only the title of a reference is know; its often unclear, what the content is about.
  - citations are only "backward" in time
  - sometimes it is difficult and time consuming to obtain the referenced material
- *use a bibliography, an abstracting service, or a bibliographic database specific to the domain*
  - bibliographies use complex structures for content organization like classifications. Users have to be familiar with these systems
  - bibliographic databases are expensive and sometimes complex to use. Access is restricted to customers
  - systems offer in general only references to documents

- *look in the web*
  - link pages in the web are often provided by single persons
    —> similar problems like asking an expert.
    But:
    only limited interaction and personal communication
  - no established standards of citation
  - little control of quality and correctness
  - many pages are no longer maintained
  - search engines are limited by many factors
    - no uniform structure of documents
    - formats other than HTML
    - "for sale" material
    - material provided from databases

Example of a Search in a Scientific Database

Information need:
Retrieval systems for multimedia objects especially for images

Database INSPEC contains documents that describe articles and books:

- bibliographic data
- abstract
- classification codes
- key terms

Generate a query:

`RETRIEVAL SYSTEMS and MULTIMEDIA and IMAGES`

The (Boolean) retrieval system selects all documents that contain all the three terms.

There are three hits for January to June 1995:
– "Image Engine: an object-oriented multimedia database for storing, retrieving and sharing medical images and text",
– "Multimedia information retrieval using knowledge in encyclopedia texts",
– "Images database management system: a 'server-client producer' system on a local network and on the Internet"

Figure 1: A document from INSPEC

```
INSPEC XXXXXXXXX
Doc Type:     Journal Paper
Title:        Images database management system: a 'server-client
              producer' system on a local network and on the Internet
Authors:      Ageron, P.; Besson, F.; Desfarges, P.
Affiliation:  Univ. Lumiere, Lyon, France
Journal:      Computer Networks and ISDN Systems
              Vol: 26  Iss: suppl., no.2-3  p. S101-6
              Date: 1994
              Country of Publication: Netherlands
              ISSN: 0169-7552  CODEN: CNISE9
              CCC: 0169-7552/94/$07.00
Language:     English
Treatment:    Practical
Abstract:     Lumiere University offers a full range of arts and social
  sciences. The research resources are very large and are specialized
  in politics, economics, finance, arts and archeology. As soon as the
  first network services were available, researchers tried to find
  information on the network about digitised photo management and
  everything about multimedia communication. The 'Images Database
  Management System' program tries to manage all information about
  digitised images: to give somebody access to, to modify and work on
  images and to export images into other information retrieval systems.
  This application program is based on a special definition of an
  'entity'. This is a physical entity (Photo CD) or a folder or
  directory. It may also be a book, if images are reproduced from a
  document. These entities are named CDphoto, folder or book while
...
  Network like WAIS, WWW, or GOPHER and hope to place this tool at the
  Internet's users' disposal. (0 Refs.)
Classification: C6160S (Spatial and pictorial databases); C6130M
  (Multimedia); C5620L (Local area networks); C6150N (Distributed
  systems software); C5620W (Other computer networks)
Thesaurus: Client-server systems; File servers; Internet; Local area
  networks; Multimedia communication; Multimedia computing; Visual
  databases
Free Terms: Images database management system; Server-client producer
  system; Local network; Internet; Digitised photo management;
  Multimedia communication; Information retrieval systems; Photo CD;
  Text information; SUN servers; OS Macintosh; HyperCard; JPEG Format;
  Communication protocol; Unix directories; GIF format
```

Different queries produce different result sets:

```
RETRIEVAL and MULTIMEDIA and IMAGE$
```

results in 35 hits including:
– “PhotoFile: a digital library for image retrieval”,
– “Spatial knowledge representation and retrieval in 3–D image databases”,
– “Multimedia retrieval technology”,
– “A WWW interface to the OMNIS/Myriad literature retrieval engine”,
– “Problems of content-based retrieval in image databases”,

It is not obvious that these documents are less adequate to the problem than those of the first query.

Figure 2: Number of documents found in INSPEC with different queries for the time interval January – June 1995

Query	Number of documents found
RETRIEVAL SYSTEMS and MULTIMEDIA and IMAGES	3
RETRIEVAL SYSTEMS and MULTIMEDIA and IMAGE$	5
RETRIEVAL and MULTIMEDIA and IMAGE$	35
RETRIEVAL and MULTIMEDIA	148
RETRIEVAL or MULTIMEDIA	2559
RETRIEVAL or MULTIMEDIA or IMAGE$	9364

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Data Retrieval

Data retrieval is characterized by strongly structured data.

Objects are described by tuples of attribute values, that have a well defined (and simple) type like

- boolean (false / true)
- limited sets of strings
- numbers

These types allow easy comparisons like

- same / different
- =, <, >, ...
- Hamming distance (number of different characters in two strings)

Tuples are selected according to these comparison operations.

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Figure 3: Database entries

	m^2	Kalt-miete	Zimmer	Bal-kon	Ort	Stock-werk	Heizung
A	64	820	3 ZKB	n	Kranich-stein	13	zentral
B	78	1200	4 ZKB	j	Bes-sungen	2	Gaseta-ge
C	86	1475	3 ZKB	j	Martins-viertel	4	zentral Fussbo-den
D	102	580	3	n	Wiebels-bach	EG	Ofen
E	36	680	2 ZKB	j	DA-Ost	3	Nacht-speicher
F	34	640	3 ZKB	n	Arheilgen	EG	Oel
G	38	590	1,5 ZB	j	Gries-heim	2	zentral
H	87	890	4 ZKB	n	Heimstät-tensied-lung	3	zentral

However, to find data sets for a specific information need, it is necessary to know the semantics of the entries.

To select a “good” data set
— additional domain knowledge and
— elaborated optimization procedures
are necessary.

Hypertext Systems

The WWW offers hypertext functionality on the Internet

Organizations like

- universities,
- corporations
- cities
- societies

as well as single persons offer Information on “web sites” beginning with a “homepage”

$\longrightarrow$ information has to be structured “around” the homepage

$\longrightarrow$ often hierarchial structures are used

$\longrightarrow$ it has to be possible to find any information using a “path” that starts at the homepage

$\longrightarrow$ users must be enabled to decide on every step in that path which way to go

Example

Homepage of Darmstadt: six buttons:

- Städtische Einrichtungen
- Kunst & Kultur
- Zu Gast in Darmstadt
- Darmstädter Leben
- Wirtschaft
- Darmstadt aktuell

informations on hotels:
–> “Zu Gast in Darmstadt”, leading to
–> “Hotels und Restaurants”,
–> “Hotels in der Innenstadt”
–> a list of hotels, some of them with their own homepages.

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For information on parks it is not clear which link to follow.

- “Städtische Einrichtungen” offers a long list of links to offices including “Gartenamt”, but there only the office hours can be found.
- “Darmstädter Leben” offers a link to “Sport und Freizeit” but only a very general notice about the “nice parks”
- ”Zu Gast in Darmstadt” offers a link to “Virtueller Stadtrundgang”. This virtual walk through the city includes pages on the various parks in Darmstadt.

General observations:
Hypertext systems have to keep the balance between
— clear structure according to one specific view and
— massive linking bearing the danger that people feel lost in hyperspace.

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Expert Systems

Expert systems give answers to specific questions

Example: travel planning

- clearly structured questions
- many conditions
- many divers answers
- in many divers forms

To find a train connection from A to B

- find possible lines
- evaluate connections according to specific conditions
- select the best one according to
  - distance
  - time needed
  - price
  - convenience (number of change)
- (select and) generate presentation format

$\longrightarrow$ Information provided is no longer a fixed object but generated from a suitable knowledge base.

$\longrightarrow$ knowledge has to be provided in suitable form to be handled by the system

Management Information Systems

– Management information systems
– decision support systems
– data warehouse
– intranet
are defined by the functionality they provide:

- uniform and controlled access to documents and information in an institution
- selection of and access to vital information for the management
- descriptions of various alternative action plans
- predictive descriptions for future developments

Specific Systems for Specific Domains

Specific domains have specific

- problems and needs
- ways to structure information
- specific data formats to search in

Examples:

- Geographic Information systems
- Chemistry
- Biology
- Mathematics / Physics

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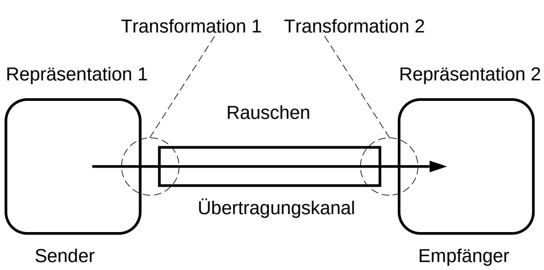
Knowledge Representations and Retrieval Models

Models of Communication and Interaction

Transfer of Information

Figure 4: Basic Scheme of Information Transfer



Information is available at the sender in a specific format. To transport it through the channel it has to be transformed into an appropriate format. At the receiver side it has to be transformed into an adequate format.

- Errors occurring in the channel can be detected if not every pattern that the channel supplies is “legal”
- If the distance between patterns is large enough corrupted messages can be recovered by inferring what pattern was sent based on the pattern received.

  Example:
  typing errors are detected because:
  - the resulting string is no word
  - the resulting chain of words is no sentence
  - the resulting sentence makes no sense

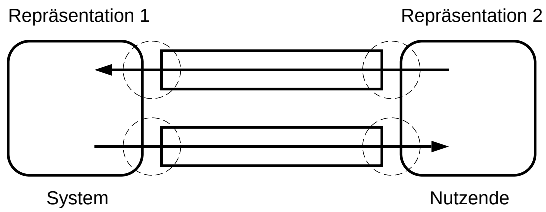
  Critical:

  - names: little knowledge about allowed patterns
  - numbers: Every sequence of digits is a number.
    Solution: writing numbers as words

Dialogues

Simple solution: Add one channel

Figure 5: Simple Dialog Scheme

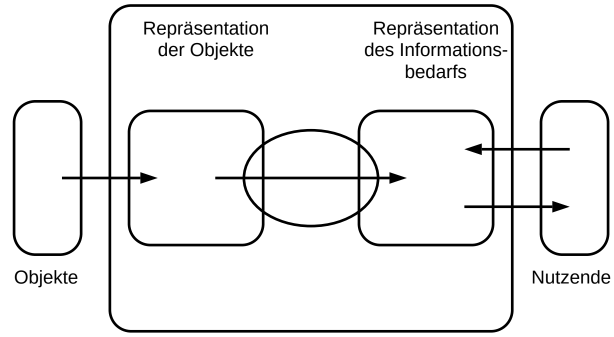


The easiest way to model a dialogue: Add one channel

But:
It is useful to include representations of both sides
— representation of the objects
— representation of the users information need.

—> allows to better support and control dialogues
and searches, by
— additional knowledge bases,
— changing existing queries,
— use of representations of objects to optimize queries.

Figure 6: Basic Scheme of an Information system



Objects and information need of users are represented within the model of IR. The information channels are replaced by a more complex interaction and comparison mechanism

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Boolean Retrieval

Boolean retrieval is still the most popular retrieval model

Advantages:

- easy to understand why a document was found
- easy to implement

Problems:

- difficult to formulate advanced queries
- difficult to understand which documents were **not** found
- no ranking of results
- based on strings of characters
- adequate for language?

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The Boolean Model

Idea:

- describe documents by attributes
- use set operations for retrieval

Attributes

D: set of documents,
T: set of values.

A function

$t : D \rightarrow T,\ t(d) = t_i$

is called an **attribute**.

$$D_{t,t_i} = t^{-1}(\{t_i\}) = \{d \in D \mid t(d) = \ t_i\}$$

is the set of documents in which the attribute t takes the value $t_i \in T$.

Queries

Queries are constructed using **attribute – value pairs** like $q = (t, t_1)$.

For this **simple query** the result set is $D_q := D_{t,t_i}$

Complex queries are constructed by combining queries with the operators **AND** and **OR** as well as the use of the operator **NOT**:

(t, t_1) AND (s, s_1): intersection $D_{t,t_1} \cap D_{s,s_1}$ of result sets,

(t, t_1) OR (s, s_1): disjunction $D_{t,t_1} \cup D_{s,s_1}$ of result sets

NOT (t, t_1): complement $D \setminus D_{t,t_1}$ of a result set.

NOT is used together with AND: it excludes documents with a specific attribute value.

These operations can be applied as well to result sets of complex queries:
—> complex descriptions of sets of documents.

Boolean Text Retrieval

Attributes: occurrence of a term in a document or in a specific part of a document

A term is defined as a sequence of characters with well defined boundaries.

Example:
The reference Database document has various fields:

- Title
- Authors
- Journal
- Abstract
- Thesaurus
- Free Terms

Boolean queries are formulated using field names and terms.
Examples:
— author=smith,
— author: smith,
— smith in author
— ...

Attribute $TI_x : D \rightarrow \{0, 1\}$: Term x appears in Title

Attribute $AU_x : D \rightarrow \{0, 1\}$: Term x appears in Author

Attribute-value-pair for boolean search: $(TI_x, true)$

Result set:

$$D_{TI_x,true} = TI_x^{-1}(\{true\}) = \{d \in D \mid Title\ of\ d\ contains\ x\}$$

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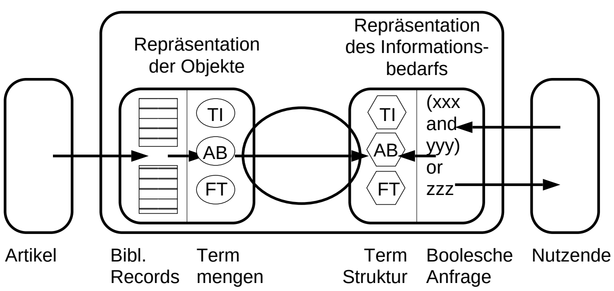
Figure 7: Model of a Text-based Boolean Information Retrieval Systems



Objects are described in intellectually generated documents. These documents are again represented as sets of terms in different fields.

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Implementation

Boolean retrieval systems are in general implemented using inverted files:
for each term occurring in a collection the documents it appears in are listed.

—> fast access

—> storage overhead.

Controlled Vocabulary

List of all terms that can be used in a search

Construction:

- define rules for the decomposition of text into words: define word boundaries, treatment of hyphens, dashes, numbers, ...
- define a list of **stop words** to be excluded from the vocabulary: Very frequent words like articles, prepositions, “and”, “of”, ... that are not useful to characterize content, but would enlarge the inverted list.
- define rules to exclude further words like roman numbers, single characters, ...
- all remaining words are used as terms of the controlled vocabulary

Construction of an inverted list

In principle an inverted list can be constructed as follows:

- decompose each document of the collection into terms according to the rules for the controlled vocabulary
- add the document number an the location within the document to these terms (-> “terms within location list”)
- sort these pairs alphabetically according to the terms
- for pairs with the same term construct a list of document numbers
- concatenate the single lists of documents to a file and construct a list of the terms containing pointers to the starting points of the respective lists in that file

In practice more sophisticated methods for construction and more elaborated access structures can be used

(See for example:

Frakes Baeza-Yates 1992,

Harman, Baeza-Yates, Fox and Lee 1992,

Fox and Lee (1991 described in Frakes Baeza-Yates 1992).

Processing of a query

- decompose the query into terms
- for each term use the inverted list to get the list of documents
- construct new lists of documents according to the operators connecting the terms until one single list remains
- show the number of documents in this final list
- get the documents of the list if the user requests them.

Further Features

Most Boolean retrieval systems offer further features:

- comparison operators (< >) for numbers (years)
- search for composed “terms” (groups of several words)
- distance functions (allow at most / exactly n terms between term a and term b)
- expansion of truncation –> set of terms matching a given pattern.

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Strings, Terms, Concepts

Terms have been defined as strings that obey a number of rules based on character patterns

But: the words of a language are used to describe contents.

Their “meaning” defines important relations, that cannot always been mapped using patterns of characters

Figure 8: Truncations that do not only exclude animals (from Ferber, Wettler, Rapp 1995)

```
 3  273 FIND CT D Vertebrates
 4   24 FIND CT D Invertebrates
 5  346 FIND ALL Animal$
 6 2981 FIND ALL [Cat$;Dog$;Pidgeon$;Monkey$;
             Rat$;Dog$;Mouse;Mice;Rabbit$]
 7 3264 FIND 3 TO 6
 8   15 FIND 2 NOT 7
```

There are several approaches to use the meaning of words in IR. They can be characterized by two different methods:

- to represent and process language in such a way that similarities are used
- to restrict the means of description in such a way, that the built-in structures of the descriptions represent the similarities.

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Stemming

Assumption:
morphological variants of a word share the basic meaning.

Various grades of reduction:

- reduce to basic form of the same type (noun, verb, ...)
- reduce to stems conflating various types

Effects for IR:

- smaller inverted lists (if done at indexing time)
- generalization of meaning

Figure 9: Various depths of reduction (from Kuhlen 1977, p. 58)

Formale Grundform	*Textwörter*	*Lexikalische Grundform*	*Stamm-form*
ABSORB	ABSORB	ABSORB	ABSORB
	ABSORBED		
	ABSORBING		
	ABSORBS		
	ABSORBER	ABSORBER	
	ABSORBERS		
ABSORBAB	ABSORBABLE	ABSORBABLE	
	ABSORBABLY		
ABSORBANC	ABSORBANCE	ABSORBANCE	
	ABSORBANCES		
	ABSORBANCY	ABSORBANCY	
	ABSORBANCIES		
ABSORBENT	ABSORBENT	ABSORBENT	
	ABSORBENTS		
	ABSORBENTLY		
ABSORPTION	ABSORPTION	ABSORPTION	
	ABSORPTIONS		
ABSORPTIV	ABSORBTIVELY	ABSORPTIVE	
	ABSORBTIVE		

Replacement Rules

Approach:
scan word endings for specific patterns and replace these patterns.

⟶ fast algorithm

⟶ few resources needed

⟶ no need to "know" words or stems

Evaluation (according to Kuhlen 1977):

- For a text with 72 000 different words ("types") it can be expected with a probability of 0.95 that the error rate will be less than 0.005
- For the same corpus the reduction rates can be expected between 13 % (lexikographische Grundform) and 27.3 % (stemming)

Figure 10: Some of the Rules of the Kuhlen Algorithm

No	**Suffix**	**Replace**	**Condition**
1	IES	Y	
2	*xy*ES	*xy*	*xy* = *k*O, CH, SH, SS, ZZ or *x*X
3	*xy*S	*xy*	*xy* = *xk*, xE, *v*Y, *v*O, OA or EA
4	IES'	Y	
5	*x*ES'	*x*	
6	*x*S'	*x*	
7	*x*'S	*x*	
8	*x*'	*x*	
9	*xy*ING	*xy*	*xy* = *kk*, *xv*, *x*X
10	*xy*ING	*xy*E	*xy* = *vk*
11	IED	Y	
12	*xy*ED	*xy*	*xy* = *kk*, *xv*, *x*X
13	*xy*ED	*xy*E	*xy* = *vk*

The first column gives the pattern at the end of the word, the second the pattern that replaces it, if the condition in column three is satisfied. Capital letters stand for letters as they are found in the string. Lowercase x and y denote arbitrary but fixed letters, v denotes an arbitrary vowel, k an arbitrary consonant. For each rule there is a list of exceptions. The rules are applied top down until one matches

Figure 11: Application of the Kuhlen Rules

wordform:	Forms	generated	using	the	specified	rules
rule no.:	3	13	10	-	11	3
basic form:	Form	generate	use	the	specify	rule

Lexicon Based Approaches

Problems of replacement rules

- provide no morphological information
- do not resolve ambiguities
- problematic to use in languages with strong changes especially
  - with prefixes ("**ge**laufen")
  - if the stem is changed ("Fluß" "Flüsse")
  - with many irregular forms
  - complicated (or irregular) rules for the separation of prefixes

Examples:

"er brachte den Brief mit" not "er mitbrachte den Brief"

"er überbrachte den Brief" not: "er brachte den Brief über".

Separated prefixes may change the meaning of a word:

"Professorin Mayer schlug ihren Assistenten
(für die Stelle vor)"

Some of these problems can be approached with lexicon based systems.

Idea:

- for each stem store the information necessary to construct every morphological form.
- for a given word try to find all stems that allow to construct the word as a morphological form
- offer all information available for that word (type of word, morphological form, meaning?)
- offer all possible stems of a word

Example:
"Morphy" (Lezius 1995) uses the following steps to analyze a given string. It stops if a step is successful:

- check a small list of known high frequency forms for the string
- check the lexicon of stems for the string, removing recursively the last character. While checking change also the last "Umlaut" to its basic vowel and replace "ß" by "ss". Check all stems to find ambiguous forms.
- Check for composites: Beginning at the end of the word identify recursively the longest part that can be constructed based on the lexicon. If the string can be decomposed into known parts in this way, assume that it is a composite.

Figure 12: Morphological Analysis of "Flüssen" according to Lezius (1995)

Remove:	-	n	en	sen	...
normal	Flüssen-	Flüsse-n	Flüss-en	Flüs-sen	...
Umlaut	Flussen-	Flusse-n	Fluss-en	Flus-sen	...
ß/ss	Flüßen-	Flüße-n	Flüß-en	Flü-ßen	...
both	Flußen-	Fluße-n	**Fluß**-en	Flu-ßen	...

Classifications

Used to organize the objects of a domain into disjoint sets of related or similar objects.

Especially useful for physical objects:

- a book in a library has to have a unique place
- a picture in an exhibition is shown in only one place

Definition: Classification

*Let D be a set of objects. A system of non empty, pair-wise disjoint subsets $K_1, K_2, ..., K_n$ with $D = K_1 \cup K_2 \cup ... \cup K_n$, $K_i \cap K_j = \emptyset \; \forall i, j \in \{1, ..., n\},\; i \neq j$ is called a classification of D into **classes** $K_1, K_2, ..., K_n$.*

*A sequence of such systems is called a **strongly hierarchical classification system** if for each pair of a class from a system and its successor the class of the successor system is either a subset of its predecessor class or disjoint to it. This means that each class is divided into subclasses in the successor system.*

Hierarchical classification systems yield tree structures with varying levels of generalization

Besides strongly hierarchical classification system there are systems with weaker hierarchies, allowing an object to be in several classes or to have several generalizations.

Example:
The seat of a car may be seen
– as a sitting device or
– as part of a car.

Dewey Decimal Classification (DDC)

Hierarchical classification system to organize all areas of knowledge.

The number of subclasses of a single class is restricted to 10 in each level of generalization.

Melvil Dewey (1851–1931): 1876 first edition.

Figure 13: Top level classes of the DDC (according to http://www.oclc.org/oclc/fp/about/ddc21sm1.htm)

0	Generalities
1	Philosophy & psychology
2	Religion
3	Social sciences
4	Language
5	Natural sciences & mathematics
6	Technology (Applied sciences)
7	The arts, Fine and decorative arts
8	Literature & rethoric
9	Geography & history

Figure 14: Level 2 classes of the DDC (according to http://www.oclc.org/oclc/fp/about/ddc21sm2.htm)

51	Mathematics
52	Astronomy & allied sciences
53	Physics
54	Chemistry & allied sciences
55	Earth sciences
56	Paleontology Paleozoology
57	Life sciences biology
58	Plants
59	Animals

Figure 15: A path through the International Decimal Classification IDC (according to Manecke 1997)

5	Mathematik. Naturwissenschaften
53	Physik
539	Physikalischer Aufbau der Materie
539.1	Kernphysik. Atomphysik. Molekülphysik
539.17	Kernreaktionen
539.172	Individuelle Kernreaktionen
539.172.1	Kernreaktionen durch Atomkerne
539.172.13	Kernreaktionen durch Deuteronen

Hierarchical classifications are build before objects (instances) are classified (**pre-coordinated**)
–> little flexibility for new developments,
–> little expressive power.

Means to add more expressiveness:
Add information that is not specific to a class using suffixes to the code of a class:

860=20: “Spanish and Portuguese literatures in English language” (860: Spanish and Portuguese literatures)

622.33(493): coal mining in Belgium (622.33: coal mining)

(Examples adapted from Manecke, 1997)

This allows to construct a suitable classification code when a object is classified (**post-coordination**).

Thesauri

A thesaurus describes
— words or terms of a specific domain / vocabulary and
— the relations between these words or terms.

Relations are not restricted to hierarchical relations. Examples are:

- synonym
- antonym
- related word
- more general term
- more specific term

Further a thesaurus may define one or several meanings of a word.

In an IR system a thesaurus has an additional role: It defines a **controlled vocabulary** as subset of all words in the thesaurus that is used to index documents.

Formal definition of indexing with a controlled vocabulary T: An attribute

$$t : D \rightarrow \mathfrak{P}(T)$$

is defined, that has the (set of subsets of the) controlled vocabulary as its range (set of values).

The controlled vocabulary contains exactly one **descriptor** for each set of mutually synonymous words.

All other words of a “synonym set” have a “USE” relation pointing to this descriptor.
—> for indexing and retrieval an unique term is used for each subset of synonyms.

The definition of the “synonym” relation controls how many details can be represented by means of a thesaurus.

The controlled vocabulary is structured hierarchically by the “more general” and “more specific” relations.

These relations can be used to make queries more general and more specific.

Thesaurus construction

To construct a thesaurus intellectually the following steps can be taken (c.f. Burkart 1997)

- definition of the overall properties: domain, specificity, type of language, size.
- selection of sources for words: ask users and experts, books and journals from the domain, other thesauri.
- terminology control: define the “synonym sets” for the thesaurus. This step determines how detailed the thesaurus will be, what can be distinguished and what cannot. Steps are:
  - collect synonyms and similar terms that are not to be distinguished as well as variations of a term with respect to spelling, abbreviations, styles, foreign words, regional dialects
  - distinguish meanings of ambiguous words: construct separate descriptors for each meaning of a string using unique synonyms, suffixes, scope notes.
  - control of composites: those that are too specific can be broken up into their (less specific) components.
- term relations: define relations between the “synonym sets” defined in the previous step. These relations include hierarchical relations and non hierarchical relations.

Vector Space Model

Boolean retrieval is based on set operations with terms or attribute values represented by strings.

In the last chapter it was discussed what “terms” or attributes can look like.

This chapter introduces more flexible use of such terms by weighting their influence according to their importance.

The Model

Representation of a document or a query: vector $\in \mathbb{R}^n$

—> Methods from the vector space can be used like:

- metric (-> distance, similarity)
- calculus

Definition: Vector Space Model of IR:

*Let $D = \{d_1, ..., d_m\}$ be a set of documents and $A = \{A_1, ..., A_n\}$ be a set of attributes. A **document vector** $w_i = (w_{i,1}, ..., w_{i,n}) \in \mathbb{R}^n$ for $d_i \in D$ is defined by a set of **weights** $\{w_{i,k} \in \mathbb{R},\ k = 1, ..., n\}$. In the same way a **query vector** $q = (q_1, ..., q_n) \in \mathbb{R}^n$ is defined for a query.*

*If further a similarity measure $s : \mathbb{R}^n \times \mathbb{R}^n \to \mathbb{R}$ is given that assigns a real value to every pair of vectors, the whole system is called a **vector space model of IR**.*

Text retrieval attributes: occurrence of terms

Weight $w_{i,k} \in \mathbb{R}$:
importance of term $t_k \in T$ for $d_i \in D$

Weight $q_k \in \mathbb{R}$:
importance of term $t_k \in T$ for the query.

The document vector could in general as well be defined directly by real valued attributes: $A_k : D \to \mathbb{R}$

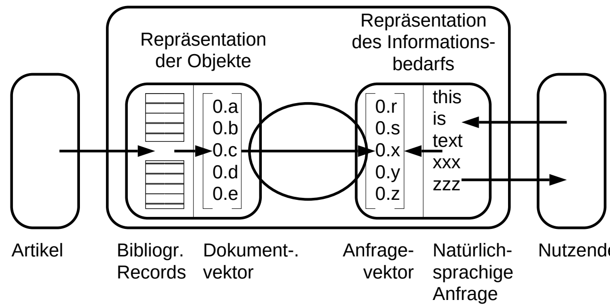
For simplicity reasons and to be consistent with most of the literature we will assume for the future $w_{i,k} = A_k(d_i)$:

The similarity measure can be used to

— compare document and query vectors

—> find the most similar documents for a query.

Figure 16: Vektor Space Model of Text Retrieval



Relation to Boolean Retrieval

Attributes: $A_i : D \to \{0, 1\}$

$$A_i(d) = \begin{cases} 1 & if\ t_i\ occurs\ in\ d \\ 0 & otherwise \end{cases}$$

Query $q = (q_1, ..., q_n)$

$$q_i = \begin{cases} 1 & if\ t_i\ occurs\ in\ the\ query \\ 0 & otherwise \end{cases}$$

If all terms in the query are connected by AND:
a document is in the result set, if

$$A_i(d) = 1\ \forall i \in \{1, ..., n\}\ with\ q_i = 1$$

If all terms are connected by OR:
a document is in the result set, if

$$\exists\ i \in \{1, ..., n\}\ with\ q_i = A_i(d) = 1$$

This result can be expressed using the inner product of two vectors:

Definition: Inner Product:

For $w_i = (w_{i,1}, ..., w_{i,n}) \in \mathbb{R}^n$ and $q = (q_1, ..., q_n) \in \mathbb{R}^n$ the inner product is defined as

$$w_i \cdot q = \sum_{k=1}^{n} w_{i,k} q_k$$

Hence the inner product is a similarity measure $\mathbb{R}^n \times \mathbb{R}^n \to \mathbb{R}$

For vectors containing only 0 and 1 the inner product counts the number of positions in which both vectors have a 1.

If all terms in the query are connected by AND:
a document is in the result set, if

$$w_i \cdot q = \sum q_i$$

If all terms are connected by OR:
a document is in the result set, if

$$w_i \cdot q \geq 1$$

$\longrightarrow$ ANDed queries select only those documents that are most similar to the query

$\longrightarrow$ ORed queries select all documents that have a similarity larger than zero

$\longrightarrow$ the similarity can be used to deliver a ranked list of documents

Term Weighting

Document vectors have been invented to give terms weights according to their importance for a document.

Issues are:

- ability to describe the content of a document
- ability distinguish the document from other documents

Methods:

- Intellectual weighting
- automated weighting

Intellectual methods are expensive and not very reliable.

Two kinds of influence can be distinguished in weighting methods:

— local or context sensitive influences and

— global or context insensitive influences

Local Weighting Strategies

Term frequency

Number of appearances of a term in a document.

Rationale:
the main topic of a document should cover most of its text. In this text important terms should be used frequently.

Method:

$$w_{i,j} = h(i,j)$$

$$w_{i,j} = \frac{h(i,j)}{1 + h(i,j)}$$

$$w_{i,j} = K + (1-K)\frac{h(i,j)}{\max\limits_{l \in \{1,\ldots n\}} h(i,l)} \;\; if\ h(i,j) > 0$$

with $h(i,j)$ denoting the frequency of term t_j in document d_i and $K \in [0,1]$

Using document structure

Terms can be weighted according to the part of document they occur in.

Terms from the
— title or the
— free keyword section
should be more important than terms from the body of an article.

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Word Frequencies in Language

Zipfs Law

For a text corpus C let

$W(C)$ *be the set of words occurring in* C

$h(w)$ *denote the frequency of the word* $w \in W(C)$ *in the corpus.*

$r(w)$ *denote the rank of* $w \in W(C)$ *if the words are ranked according to decreasing frequencies.*

It holds

$$r(w) \cdot h(w) \sim c \;=\; \textit{constant}\ \forall w \in W(C)$$

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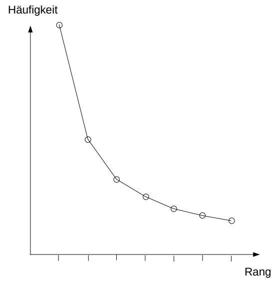
Figure 17: Zipfs Law applied to the Brown- and LOB-Korpus

Rank	Frequency	R*f/100000	Term
1	138323	1.3832	the
2	72159	1.4432	of
3	56750	1.7025	and
4	52941	2.1176	to
5	46523	2.3262	a
6	42603	2.5562	in
7	22177	1.5524	that
8	21210	1.6968	is
9	20501	1.8451	was
10	19587	1.9587	it
100	2043	2.0430	years
500	394	1.9700	program
1000	207	2.0700	jones
2000	105	2.1000	granted
3000	67	2.0100	agencies
4000	47	1.8800	embassy
5000	36	1.8000	vale
10000	14	1.4000	poisoning
12034	11	1.3237	yell

```
Minimum: 1.24982
Maximum:  2.55618
Mean:     1.697
Variance: 0.077
Standard deviation: 0.277
```

Figure 18: Qualitative View of Zipfs Law

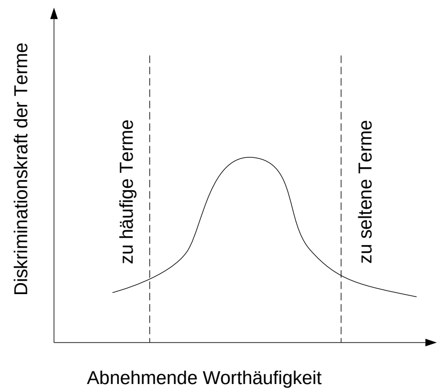


Global Weighting Strategies

Most global strategies use term statistics to determine the usefulness of terms for retrieval:

- very frequent terms tend to appear in many documents
  —> not well suited to select specific documents
- very rare terms tend to appear in only very few documents
  —> not well suited to find all relevant documents.

Figure 19: Discrimination Power vs. Frequency (from Salton & McGill 1983)



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Inverted document frequency

To handle the frequent terms:
—> give terms that occur in many documents low weights.

document frequency $d(j)$ of term t_j =
number of documents a term occurs in.

Method:
Inverted document frequency (IDF);

$$idf(j) = \frac{1}{d(j)}$$

or related forms:

$$w_{i,j} = \ln\left(\frac{m}{d(j)}\right)$$

$$w_{i,j} = \ln\left(\frac{m - d(j)}{d(j)}\right)$$

where m denotes again the total number of documents in the collection.

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Global and local strategies can be combined:

$$\frac{h(i,j)}{d(j)}$$

$$\widetilde{w_{i,j}} = \frac{1}{2}\left(1 + \frac{h(i,j)}{\max\limits_{k\in\{1,\ldots,n\}}\{h(i,k)\}}\right)\ln\left(\frac{m}{d(j)}\right)$$

respectively the normalized version:

$$w_{i,j} = \frac{\widetilde{w_{i,j}}}{\sqrt{\sum_{k=1}^{n}\widetilde{w_{i,k}}^2}}$$

Relevance Feedback (Rocchio)

Weights for queries:
— global methods
— local methods are not applicable (queries are too short).

In dialogue settings:
use documents found to construct a new query:

The user is asked to give **relevance judgements** for the documents in a result set $D_q = \{d_1, ..., d_n\}$.

Two subsets:
$R = \{d_1^+, ..., d_r^+\}$, the set of documents judged relevant
$U = \{d_1^-, ..., d_u^-\}$, the set of documents judged not relevant.

A new query vector is constructed based on the document vectors v_d:

$$q' = \alpha q + \beta \left(\frac{1}{r} \sum_{d \in R} v_d \right) - \gamma \left(\frac{1}{u} \sum_{d \in U} v_d \right)$$

with real parameters α, β, and γ.

The SMART System

— one of the best known vector space IR systems.

— developed for about 30 years by Gerard Salton and his co-workers at Cornell University.

— is rather an experimental framework than a single system.

— uses automated indexing and relevance feedback among other features.

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Automated Indexing

as described in Salton and McGill (1983)

- Decompose the text into words
- remove stop words
- use a replacement rule based stemmer to generate terms
- these terms are weighted or replaced according to the following steps:
  - for terms with medium document frequency use a weighting scheme like

    $$w_{i,k} = \frac{h(i,k)}{d(k)}$$

    or the one given before
  - terms with very high document frequencies are replaced by term pairs built with the other terms in a neighborhood of given size. Weights are constructed based on the frequencies of the two terms of a pair.
  - terms with very low document frequencies are replaced by more general terms from a thesaurus or by groups of related terms

Similarity Measures

Inner Product

— sums the products of the vector entries.

— vectors with many non zero entries have a higher probability to achieve high values.

— vectors with larger entries get higher values

—> longer documents have a higher probability to get high similarity values.

This leads to weak experimental results.

Cosine Measure

$$cos(w_i, q) = \frac{\sum_{k=1}^{n} w_{i,k} q_k}{\sqrt{\sum_{k=1}^{n} w_{i,k}^2} \sqrt{\sum_{k=1}^{n} q_k^2}}$$

— is an attempt to avoid the problems of the inner product

— takes values between -1 and 1.

— is insensitive to the length of the vectors

— can be interpreted as the inner product of the normalized vectors

$$\frac{w_i}{\sqrt{\sum_{k=1}^{n} w_{i,k}^2}} \quad \text{and} \quad \frac{q}{\sqrt{\sum_{k=1}^{n} q_k^2}}$$

— documents are most similar if their vectors have the same directions

Other Similarity Measures

Pseudo cosine:

$$s_p(w_i, q) = \frac{\sum_{k=1}^{n} w_{i,k} q_k}{\left(\sum_{k=1}^{n} w_{i,k}\right)\left(\sum_{k=1}^{n} q_k\right)}$$

Dice:

$$s_d(w_i, q) = \frac{2 \sum_{k=1}^{n} w_{i,k} q_k}{\sum_{k=1}^{n} w_{i,k} + \sum_{k=1}^{n} q_k}$$

Overlap:

$$s_o(w_i, q) = \frac{\sum_{k=1}^{n} \min\left(w_{i,k}, q_k\right)}{\min\left(\sum_{k=1}^{n} w_{i,k}, \sum_{k=1}^{n} q_k\right)}$$

Jaccard:

$$s_J(w_i, q) = \frac{\sum_{k=1}^{n} w_{i,k} q_k}{\sum_{k=1}^{n} w_{i,k} + \sum_{k=1}^{n} q_k - \sum_{k=1}^{n} w_{i,k} q_k}$$

A description of these measures is given in Jones and Furnas (1987).

Evaluation of IR Systems

Determine how useful a system or a specific method within a system is to solve the information problems of users.

A sound experimental evaluation would need representative samples of
— problems and
— users.

Many influencing factors:

- collection characteristics (selection strategies, document formats, ...)
- indexing and representation formats (manual indexing, use of a controlled vocabulary, classifications, ...)
- search methods and tools
- presentation of results
- interaction strategies and interface design

Such an approach is not feasible.

—> most evaluations are restricted to a limited but central sub task.

Given:

- a collection of documents
- a set of queries
- for each query the subset of relevant documents

Goal:
find as many relevant documents as possible.

Measures

Definition: Relevance

Let $D = \{d_1, ..., d_m\}$ be a set of documents and Q a set of queries. The relevance of a document d_i for a query q is defined by a relation

$$r : D \times Q \to U$$

where U denotes a set of “relevance values” in most cases being $U = \{0, 1\}$.

—> Relevance depends only on the query and the document.

Other influences like
— the documents already seen or
— the knowledge of the user
cannot be taken into account.

Definition: Precision and Recall

Let $D = \{d_1, ..., d_m\}$ be a set of documents, and D_q be the sub set of documents found in D for the query $q \in Q$. Let further $R_q = \{d \in D \mid r(d,q) = 1\}$ denote the set of documents relevant for q.

$$P(q, D) := \frac{\mid D_q \cap R_q \mid}{\mid D_q \mid}$$

*is called **Precision** and*

$$R(q, D) := \frac{\mid D_q \cap R_q \mid}{\mid R_q \mid}$$

***Recall** of the result set D_q*

Precision:
fraction of relevant documents within the retrieved documents,

Recall:
fraction of relevant documents that were retrieved.

Best values for precision:
all retrieved documents are relevant,

Best values for recall:
all relevant documents were retrieved.

Extreme values:
— one single relevant document: precision = 1;
— All documents: recall = 1.

Precision and recall are antagonistic:
small result set from a specific query
—> high precision and low recall;

large result set from a general query:
—> low precision an high recall.

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Mean Precision and Recall values can be calculated for a set of queries in two ways: user oriented

$$P_u(D) := \frac{1}{N} \sum_{i=1}^{N} \frac{\mid D_{q_i} \cap R_{q_i} \mid}{\mid D_{q_i} \mid}$$

$$R_u(D) := \frac{1}{N} \sum_{i=1}^{N} \frac{\mid D_{q_i} \cap R_{q_i} \mid}{\mid R_{q_i} \mid}$$

or system oriented

$$P_s(D) := \frac{\sum_{i=1}^{N} \mid D_{q_i} \cap R_{q_i} \mid}{\sum_{i=1}^{N} \mid D_{q_i} \mid}$$

$$R_s(D) := \frac{\sum_{i=1}^{N} \mid D_{q_i} \cap R_{q_i} \mid}{\sum_{i=1}^{N} \mid R_{q_i} \mid}$$

To compare two systems:
Only if one has higher values for Precision and Recall, it is “better” than the other.

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In case of ranked result sets this antagonism can be displayed:

Definition: Precision-Recall-Diagram

Let $D_q = (d_{s_1}, ..., d_{s_k})$ be a completely ordered result set and $R_q = \{d \in D \mid r(d,q) = 1\}$ the set of relevant documents for the query q. Let further $(d_{t_1}, ..., d_{t_l})$ be the intersection $D_q \cap R_q$ ordered according to D_q. The sequence $(R_i(q,D), P_i(q,D))_{i=1,...,l}$ with

$$R_i(q, D) := \frac{\mid (d_{t_1}, ..., d_{t_i}) \mid}{\mid R_q \mid}$$

and

$$P_i(q, D) := \frac{\mid (d_{t_1}, ..., d_{t_i}) \mid}{\mid (d_{s_1}, ..., d_{s_j}) \mid}$$

*with $d_{s_j} = d_{t_i}$ is called the **Precision-Recall-Diagram** of q.*

It can be displayed by points in the square $[0,1]^2$.

Figure 20: A Precision Recall Diagram

R: relevant document
U: document that is not relevant.

RURRURRRUU URRURRRUUU URUUUURUUU UUUUURUUUU
RURUUUUURU UUURUUUURU UUUUURUUUU UUUUURUUUU
UUUUUUUURU UUUUUUUURU UUUUUUUURU UUUUUUUUUU
UUUUURUUUU UUUUUUURUU UUUUUURUUU UUUUUUURUU
UUUUUUUUUU RUUUUUUUUU UUUUURUUU UU...

The sequence $(R_i(q,D), P_i(q,D))_{i=1,\dots,30}$ looks like this:

$$\left(\frac{1}{30},\frac{1}{1}\right),\left(\frac{2}{30},\frac{2}{3}\right),\left(\frac{3}{30},\frac{3}{4}\right),\left(\frac{4}{30},\frac{4}{6}\right),\left(\frac{5}{30},\frac{5}{7}\right)$$

$$\left(\frac{6}{30},\frac{6}{8}\right),\left(\frac{7}{30},\frac{7}{12}\right),\left(\frac{8}{30},\frac{8}{13}\right),\left(\frac{9}{30},\frac{9}{15}\right),\left(\frac{10}{30},\frac{10}{16}\right)$$

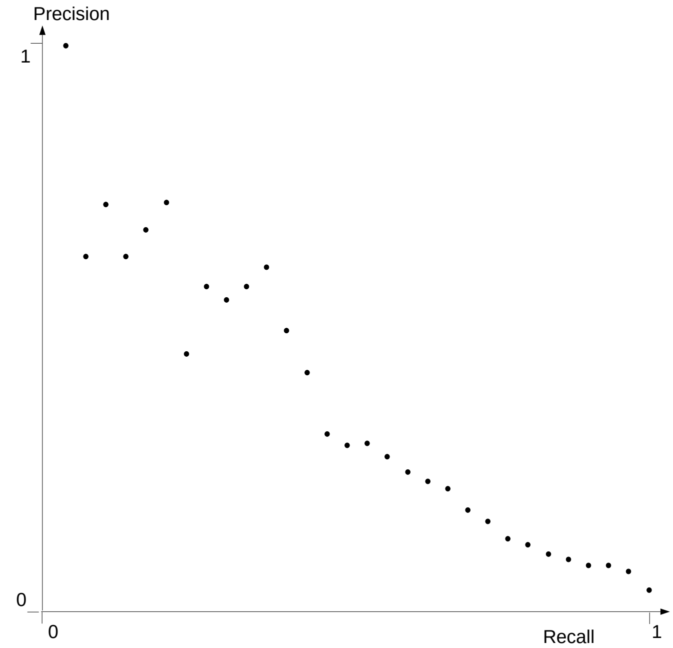
$$\left(\frac{11}{30},\frac{11}{17}\right),\left(\frac{12}{30},\frac{12}{22}\right),\left(\frac{13}{30},\frac{13}{27}\right),\left(\frac{14}{30},\frac{14}{36}\right),\left(\frac{15}{30},\frac{15}{41}\right)$$

$$\left(\frac{16}{30},\frac{16}{43}\right),\left(\frac{17}{30},\frac{17}{49}\right),\left(\frac{18}{30},\frac{18}{54}\right),\left(\frac{19}{30},\frac{19}{59}\right),\left(\frac{20}{30},\frac{20}{66}\right)$$

$$\left(\frac{21}{30},\frac{21}{76}\right),\left(\frac{22}{30},\frac{22}{89}\right),\left(\frac{23}{30},\frac{23}{99}\right),\left(\frac{24}{30},\frac{24}{109}\right),\left(\frac{25}{30},\frac{25}{126}\right)$$

$$\left(\frac{26}{30},\frac{26}{138}\right),\left(\frac{27}{30},\frac{27}{147}\right),\left(\frac{28}{30},\frac{28}{158}\right),\left(\frac{29}{30},\frac{29}{171}\right),\left(\frac{30}{30},\frac{30}{187}\right)$$

Figure 21: Precision – Recall – Diagram Displayed in the Plane



Comparing two systems:
A system is "better" if its precision values are higher at all recall levels.

One dimensional comparison of systems with ranked results:

- Mean precision values at fixed recall levels
- Break even point: Value where Recall=Precision (not always uniquely defined!)

Test Collections

The relevance relation cannot be generated automatically.

It has to be determined by humans knowing the domain.

—> for every query all documents of a collection have to be inspected.

—> this is very expensive.

Therefor collections with queries and relevance data that had once been generated were often reused.

Figure 22: Test Collections (according to Griffiths Luckhurst & Willett 1986 and Dumais, 1991)

Name	Domain	Content	4. Documents	5. Terms / Doc.	6. Queries	7. Terms / Query	8. Rel./ Query
Keen	Librarianship, Information Science	title, Index-terms (manual)	800	9,8	63	10,3	14,9
Cranfield	Aerodynamics	Index-terms (manual)	1400	28,7	225	8,0	7,2
Evans	INSPEC	title	2542	6,6	39	27,5	23,1
Harding*	INSPEC	title, abstracts	2472	36,3	65	32,4	22,6
LISA**	Library and Information Abstracts Database 1982	title, abstracts	6004	39,7	35	16,5	10.8
INSPEC	INSPEC	title, abstracts	12684	36,0	77	17,9	33,0
UCKIS	Chemical Abstract Service	title	27361	6,7	182	7,4	58,9***

MED	Biomedicine	(title?) abstracts	1033	50	30	10	23
CISI	Library , Information Science	(title?) abstracts	1460	45	35	8	50
TIME	World news (Time Magazine)	articles	425	190	83	8	4
ADI	Library science	abstracts	82	16	35	5	5

Columns: 4 number of documents; 5: mean number of terms in a document; 6: number of queries; 7: mean number of queries; 8: mean number of relevant documents per query.

Advantages
— available
— offer comparable test conditions.

Problems:

- the collections are small compared to real collections
- it is often not clear how they were generated
- some collections are quite old
- only few collections have full texts
- different collections yield differing results for the same systems
- systems can be optimized for a single collection
- collections might be selected for evaluation that yield best results.

The TREC Experiments

Since 1992: Seven Text REtrieval Conferences (http://trec.nist.gov/).

Goal:
— to encourage research in information retrieval
— by providing a large test collection,
— uniform scoring procedures, and
— a forum for organizations interested in comparing their results.

Material provided for preparation:

- training data: 2 Gigabyte of text (> 1 mio docs)
- training queries (topics)
- relevance judgements for the queries.

Material provided for testing:

- collection of new documents (˜ 1 GB of text)
- 50 new queries

Participants can adapt their systems to the material provided for preparation.

With the new material for testing two tasks are given:

- Ad hoc: search the old collection with new queries
- Routing: distribute the new documents according to the old topics (queries)

Participants provide ranked lists of 1000 hits per topic.

Evaluation is done centrally at NIST.

Measures are
— Precision Recall Diagrams and the
— mean precision over a fixed set of recall values.

Relevance Judgements

Relevance judgements: pooling method

Top 100 documents of all lists for a query form a "document pool".

This pool is checked for relevant documents by an expert.

—> reduces the number of documents to be checked.

Assumption:
most relevant documents are ranked within the top 100 documents by at least one of the retrieval systems.

realistic only for a large number of participating systems.

The quality of the pooling method was tested in TREC 3:

1. pool with 100 top ranked documents
2. pool with the 200 top ranked documents

— first pool on average 146 relevant documents
— second pool on average 196 relevant documents

—> a remarkable number of relevant documents was missed.

—> overestimation of recall
—> underestimation of precision.

Figure 23: Size of Document Pools Used for Relevance Assessment (from 1995–WWW, 1996–WWW)

	Adhoc			Routing		
	max. possible	actual	relevant	max. possible	actual	relevant
TREC-1	3300	1279 (39%)	277 (22%)	2200	1067 (49%)	371 (35%)
TREC-2	4000	1106 (28%)	210 (19%)	4000	1466 (37%)	210 (14%)
TREC-3 100	2700	1005 (37%)	146 (15%)	2300	703 (31%)	146 (21%)
TREC-3 200	5400	1946 (28%)	196 (10%)	4600	1333 (35%)	187 (14%)
TREC-4	4000	1345 (34%)	115 (8.5%)	2600	930 (35%)	131 (14%)

Tracks

Beginning with TREC 5 several sub tasks (called tracks) have been included in the TREC experiments:

- the **Confusion** track uses documents degraded by optical character recognition (OCR)
- the **Database Merging** track uses several collections. Problems are: selection of appropriate databases and merging of ranked result sets from various collections
- in the **Filtering** track participants have to deliver unordered result sets. A specific cost function is used for evaluation.
- in the **Interactive** track real user interaction is allowed
- the **Multilingual** track uses documents in other languages than English
- in the **Cross Lingual** track documents in one language are being searched with a query in a different language
- the **NLP** track is dedicated to systems using natural language processing techniques

Advanced Vector Space Systems

The first two TREC experiments were mainly used to adapt the systems to the large amount of data.

In TREC 3 and 4 several ideas and methods were used by several systems.

Pseudo Relevance Feedback

Idea:
use documents found in a first run to enhance the query for a second run.

Aassumption:
top ranked documents are likely to be relevant.

Most systems used only a limited number of terms occurring most frequently in the top ranked documents.

SMART:

After a first query operation the top 30 documents were used for feedback.
– All terms from these documents were ordered according to their frequency in the top 30 documents.
– the 500 most frequent terms were selected,
– the 30 document vectors were restricted to these 500 terms
– and added to the query vector according to the Rocchio formula with parameters (8, 8, 0).

Pseudo Relevance Feedback was quite successful

Pairs of Terms

Many systems used pairs of terms for indexing.

Idea:
pairs should be more specific then single terms.

SMART allowed in TREC 3 term pairs for indexing if they occurred in more than 25 documents.

In pseudo relevance feedback the 10 most frequent term pairs were used in the same way as the 500 most frequent single terms.

"INQUERY"
– extracted "phrases" of two or three words from a large sub collection and
– added the most similar phrases to the query.

Term pairs have only little or no positive effect.

In TREC 4 several systems reduced the number of pairs used in their queries.

Passage Retrieval

Methods that divide documents in
— blocks or
— overlapping windows of fixed or limited size
to calculate similarities and to do pseudo relevance feedback.

Idea:
— within longer documents specific topics are dealt with in subsections.
— Similarity measures that are based on subsections of documents should easier find these topics.

SMART:
documents were divided into overlapping blocks of 200 terms.

The similarity measure was defined as follows:

$$s(w_i, q) = w_i \cdot q \left(1 + 2 \frac{\max_{b \in B_d} (b \cdot q)}{\max_{b \in B_D} (b \cdot q)} \right)$$

B_d: vectors of blocks of the document $d \in D$.
B_D: vectors generated from all Blocks/ from documents of D

The use of passage retrieval did in general not yield the expected success.

Similarity Measures

Many groups tried to optimize their similarity measures.

Often these measures are very complicated using many parameters.

Two basic methods

Adapted Cosine

The cosine is insensitive to the length of the document.

For TREC 3:
— the relative frequencies to be judged relevant and
— the relative frequency to get a high ranking by the cosine similarity measure
were compared.
—> short documents are ranked too high compared to the relevance judgement
—> long documents are ranked to low compared to the relevant judgement.

The similarity measure was changed in such a way that these differences vanished (for details see: Singhal, Buckley & Mitra 1996)

Robertsons-Spark Jones Formula

This formula uses relevance feedback data in a different way to determine a query vector:

$$v_k = \ln \frac{(R(q,k)+0.5)/(R(q)-R(q,k)+0.5)}{(d(k)-R(q,k)+0.5)/(N-d(k)-R(q)+R(q,k)+0.5)}$$

with

N being the number of documents in the collection,

$R(q)$ the number of documents judged relevant for q

$d(k)$ the number of documents that contain term t_k

$R(q,k)$ the number of relevant documents that contain term t_k

Distinguishes the documents according to two criteria:
— If a document contains term t_k,
— if it is judged relevant for the query.

Nominator:
relevant documents comparing those containing the term with those that do not.

Denominator:
similar comparison for the documents that are not relevant.

Figure 24: Number of Documents Classified According to the two Criteria

	contains term	does not contain term
relevant	$R(q,k)$	$R(q)-R(q,k)$
not relevant	$d(k)-R(q,k)$	$N-d(k)-R(q)+R(q,k)$

$\longrightarrow$ a term that occurs in most relevant documents and does occur in few non relevant documents gets a high value for the nominator and a low value for the denominator,
—> high weight

$\longrightarrow$ If the term also occurs in many non relevant documents the denominator will increase
—> smaller weight.

$\longrightarrow$ If the term is contained in only a few relevant documents but in many non-relevant documents the nominator will be small and the denominator will be big
—> small weight.

Advanced Models

Inference Networks

An inference network consists of

- a directed graph with
  - nodes representing content (assertions) and
  - edges representing relations (dependencies) between nodes;
- nodes
  - can take an activation value (between 0 and 1)
  - have a function that takes the activation of nodes connected by an edge as input to compute a new activation value.
- To generate a new pattern of activity values, the function of all nodes are applied in parallel.
- This can be repeated until the patterns do no longer change.

Turtle and Croft (1990, 1991) use a network consisting of two parts.

The "document network":

- a document layer
- a layer of text representations
- a layer of concept representations

Edges are leading from one layer to the next one.

The document network is determined by the documents of the collection.

The layers represent various levels of abstraction.

All paths are starting at the document nodes and lead to the concept nodes.

Query network:
— connected to the concept representations
— may consist of several layers.
— All paths lead to a single node, that represents the importance of a document for the specified query.

To obtain this value
— the node of the document is activated
— this activation is propagated through the network
— until it reaches the last node of the query network.

During this propagation several paths of "evidence" contribute to the final value.

Actual implementation in INQUERY:
— much simpler.
— consists of one layer representing terms,
—> vector space model with a sophisticated similarity measure
—> implemented by an inverted list.

Co-occurrence Based Methods

The weighting strategies for terms in a document vector are applied to single words.

Dependencies between words were not taken into account for the selection of index or query terms.

But the occurrences of a term in a document is not independent of the occurrence of other terms in the same document.

These dependencies can be used to select index and query terms.

The associative model assumes:
meanings of terms occurring together in documents are related.

This principle is old:

> *"objects once experienced together tend to become associated in the imagination, so that when any one of them is thought of, the others are likely to be thought of also"*

(James, 1890, Vol 1, page 561)

Figure 25: Associations Automatically Generated from the Lob– and the Brown Corpus Using Co-occurrences of Terms

tax:	fruit:	sin:
income: 71.81	eggs: 56.69	crime: 107.11
fiscal: 66.96	meat: 56.69	doctrine: 98.31
taxes: 61.99	foods: 55.09	morality: 92.00
profits: 56.67	fresh: 54.99	adam: 87.57
revenue: 56.35	seed: 52.16	christ: 57.57
sales: 42.85	sugar: 42.99	jesus: 54.83
reduction: 41.33	milk: 40.12	suffering: 52.18
file: 39.18	meal: 32.20	flesh: 50.89
paying: 35.93	tree: 31.55	original: 47.89
payments: 32.81	believes: 31.42	born: 45.49
collection: 31.20	soft: 31.30	burden: 39.32
towns: 30.29	tea: 30.09	consequently: 36.19
estimated: 29.64	expenditure: 29.98	heaven: 36.19
finance: 29.06	wine: 29.64	god: 35.91
net: 28.81	fish: 26.98	creation: 34.78
uniform: 27.23	breakfast: 26.89	requires: 34.35
corporation: 26.70	containing: 26.08	grace: 30.84
purchase: 26.37	eat: 25.82	death: 30.78
spending: 25.13	referred: 25.08	moral: 30.70
excess: 24.21	parks: 23.29	darkness: 30.16

Use of similarities between terms based on their co-occurrence to

- model human associations and memory
- construct associative thesauri based on the similarity of terms
- use these thesauri for automated indexing
- use these thesauri for query expansion

Similarities can be gained from the so called **Term-Document-Matrix**

$$W = \{w_{i,j}\}_{i=1,\dots,m;\, j=1,\dots,n}$$

The $n \times n$-matrix $W^t \cdot W$ is called the **Term-Term-Matrix**.

Entries:
inner products of vectors composed of the weights that the respective term is given in the documents of the collection;

—> similarity value for the two terms.

Associative Indexing and Query Expansion

Experiment:
co-occurrence data for automated indexing

- A corpus of bibliographic records intellectually indexed with the OECD thesaurus

- used to extract similarities between
— the words of the titles and
— descriptors of the thesaurus.

Two sets of records were kept aside:
— one to optimize the parameters of the system,
— the other to test it.

The word - descriptor similarities were used to predict the intelectually given descriptors of the test records.

Cross Language Retrieval

"Parallel" corpus in two different languages can be used to search for documents in one language using a query formulated in the other language:

documents with the same content are used to compute similarity values between the terms of the two languages.

These similarities are used to expand the query with terms of the other language.

These new terms can be used to search in the collection.

Sheridan and Ballerini (1996):
93 229 Italian news stories

indexed by
— time,
— location,
— content category (out of 50 possible classes).

From the German service of the same agency 10 293 articles with the same indexing.

Based on these pairs of identically indexed articles
— the similarity values for the occurring terms were computed
— and used to expand German queries.

The results were compared with results obtained with intelectually generated translations of the queries.

Figure 26: Results of the Study on Cross Language Retrieval Using Similarity Measures Generated from Parallel Corpora. (from Sheridan and Ballerini, 1996)

		Relevant Docs Found	Mean Precision
Cross Lingual:	Number of Query Terms		
	10	525	0.212
	25	694	0.278
	50	638	0.275
Italian only:	Stemming		
	no	488	0.231
	yes	898	0.527

Meta Data

Information about documents like:
— bibliographic data,
— classifications,
— access information
are not really part of the document.

—> **Meta Data**.

The destinction between data and Meta Data is fuzzy.

Meta Data can be
— included in documents encoded in appropriate structured formats like SGML,
— can be provided separately like (reference databases or by web search engines).

Meta Data should be machine readable.

There are many complex formats for various domains and types of documents.

The diversity and complexity of these make it difficult to handle them in a uniform way.

Dublin Core

The "Dublin Core" initiative is an approach to unify the storage of Meta Data for digital document like objects.

It is named after the first meeting in Dublin (Ohio) in 1995.

It proposes a set of elements to describe a digital document that is

- simple and intuitive enough such that non specialists can use it
- general and flexible enough such that it can cover many domains
- powerful enough such that also elaborated descriptions can be included

To accomplish these goals a number of principles where set up for the elements:

- The Dublin Core element set is **extensible**: new elements for specific documents can be added
- all elements are **optional**: there are no mandatory elements
- all elements are **repeatable** within a description
- all elements are **modifiable**: attributes can specify how the content should be interpreted. This means that existing formats and content description systems can be used within Dublin Core.

A description of the initiative and the proposed 15 elements can be found at http://purl.oclc.org/dc.

Systems using Dublin Core should adhere to these principles.

This means:
— be able to ignore elements and attributes they do not know.

It does not mean:
to be able to use all information provided.

References

Burkhart, M. (1997). Thesaurus. In *Grundlagen der praktischen Information und Dokumentation*. München: K. G. Saur, ch. B 6, 160-179.

Dumais, S. T. (1991). Improving the retrieval of information from external sources. *Behavior Research Methods, Instruments, & Computers 23*(2), 229-236.

Ferber, R. (1997). Automated indexing with thesaurus descriptors: A co-occurrence based approach to multilingual retrieval. In *Research and Advanced Technology for Digital Libraries. First European Conference (ECDL'97). Proceeding* (1997), C. Peters & C. Thanos, Eds., vol. 1324 of *Lecture Notes in Computer Science*, Springer.

Ferber, R., Wettler, M., & Rapp, R. (1995). An associative model of word selection in the generation of search queries. *Journal of the American Society for Information Science (JASIS) 46*(9), 685-699.

Fox, E. A., & Lee, W. C. (1991). FASIT-INV: A fast algorithm for building large inverted files. Technical report, VPI&SU Department of Computer Science, Blackburg, VA.

Frakes, W. B., & Baeza-Yates, R., Eds. (1992). *Information Retrieval Data Structures & Algorithms*. Prentice Hall, Englewood Cliffs, New Jersey.

Griffiths, A., Luckhurst, H. C., & Willett, P. (1986). Using interdocument similarity information in document retrieval systems. *Journal of the American Society for Information Science 37*(1), 3–11.

Harman, D. Overview of the Third Text REtreival Conference (TREC-3). WWW-Page: http://trec.nist.gov/pubs/trec3/overview.ps, 1995.

Harman, D. Overview of the Fourth Text REtreival Conference (TREC-4). WWW-Page: http://trec.nist.gov/pubs/trec4/overview.ps, 1996.

Harman, D., Fox, E., Baeza-Yates, R., & Lee, W. (1992). Inverted files. In *Information Retrieval Data Structures & Algorithms*, W. B. Frakes & R. Baeza-Yates, Eds. Englewood Cliffs: Prentice Hall, ch. 3, 28–43.

James, W. (1890). *The Principles of Psychology*. New York: Holt, Reprinted New York: Dover Publications, 1950.

Jones, W. P., & Furnas, G. W. (1987). Pictures of relevance: A geometric analysis of similarity measures. *Journal of the American Society for Information Science 38(6)*, 420-442.

Kuhlen, R. (1977). *Experimentelle Morphologie in der Informationswissenschaft*. Verlag Dokumentation: München.

Lezius, W. (1995). Morphologie und tagging. Technical report, Universität -GH - Paderoborn, FB 2. http://www-psycho.uni-paderborn.de/lezius/morpho.html.

Mannecke, H.-J. (1997). Klassifikation. In *Grundlagen der praktischen Information und Dokumentation*. München: K. G. Saur, ch. B 5, 141-159.

Salton, G., & McGill, M. J. (1983). *Introduction to Modern Information Retrieval*. New York: McGraw-Hill.

Sheridan, P., & Ballerini, J. P. (1996). Experiments in multilingual information retrieval using the SPIDER system. In *Proceedings of the19th Annual International*

ACM SIGIR Conference on Research and Development in Information Retrieval SIGIR '96 (1996), 58-65.

Singhal, A., Buckley, C., & Mitra, M. (1996). Pivoted document length normalization. In *Proceedings of the 19th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval SIGIR 96* (1996), 21-29.

Turtle, H., & Croft, W. B. (1990). Inference networks for document retrieval. In *Proceedings of the 13th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval* (1990), 1-24.

Turtle, H., & Croft, W. B. (1991). Efficient probabilistic inference for text retrieval. In *Proceedings of the RIAO'91* (1991), ACM, 644-661.