BITS Pilani
Pilani Campus

AIMLCZG537/DSECLZG537 Information Retrieval

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Lecture1 :25-10-2025

Course Outline

- **To acquire basic understanding of the components and the different IR methods.**
  - Boolean
  - Vector Space

- **To understand the various application areas of IR:**
  - Text Mining
  - Web Search
  - Cross Lingual IR
  - Multimedia IR
  - Recommender System
  - Neural IR

Books to Refer

1. C. D. Manning, P. Raghavan and H. Schutze. Introduction to Information Retrieval, Cambridge University Press, 2008. http://nlp.stanford.edu/IR-book/
2. Modern Information Retrieval, Ricardo Baeza-Yates and Berthier Ribeiro-Neto, Addison-Wesley, 2000. http://people.ischool.berkeley.edu/~hearst/irbook/
3. Ricci, F.; Rokach, L.; Shapira, B.; Kantor, P.B. (Eds.), Recommender Systems Handbook. 1st Edition., 2011, 845 p. 20 illus., Hardcover, ISBN: 978-0-387-85819-7

Lecture Outline

Introduction

- Information Retrieval
- Information vs. Data Retrieval
- IR task
- Basic Concepts
- Logical view of the documents
- The retrieval process
- Classical IR models

Information Retrieval

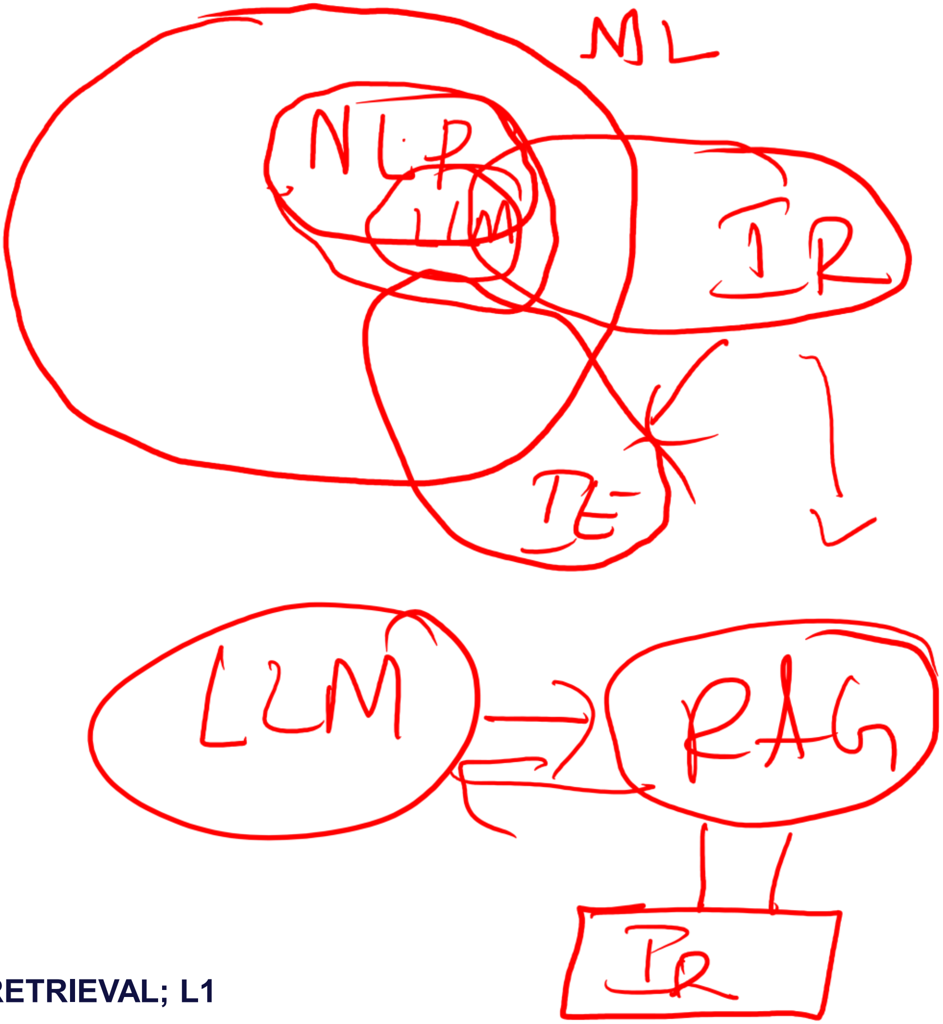
ML

NLP

→ IR - IE

LLM

RAG →



Information Retrieval

- Information Retrieval (IR) is **finding material** (usually documents) of an **unstructured** nature (usually text) that satisfies an **information need** from within **large collections**.

……Not restricted to Web search

- E-mail search
- Searching laptop
- Corporate knowledge bases
- Legal information retrieval

BITS elearn

Query

← Storh ?

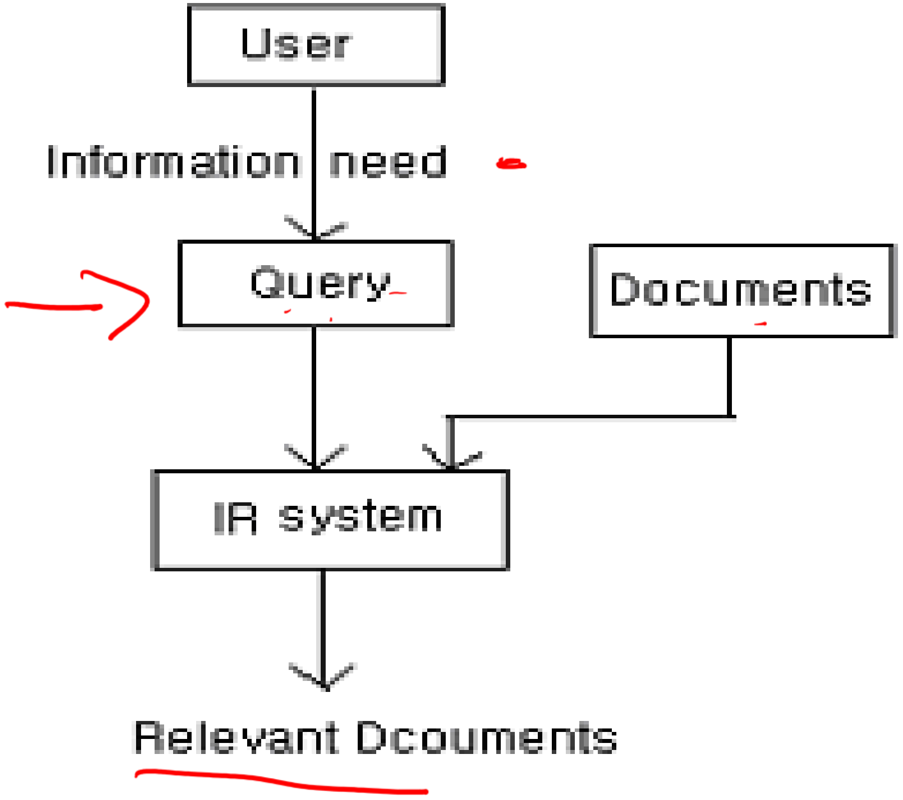
Organizing

"Information retrieval"

Applications of Information Retrieval

- Digital Libraries →
- Search Engines
- Media search
- Information Filtering
- Legal Information Retrieval →
- Document Classification
- Question Answering →

Information Retrieval



Basic Information Retrieval Process

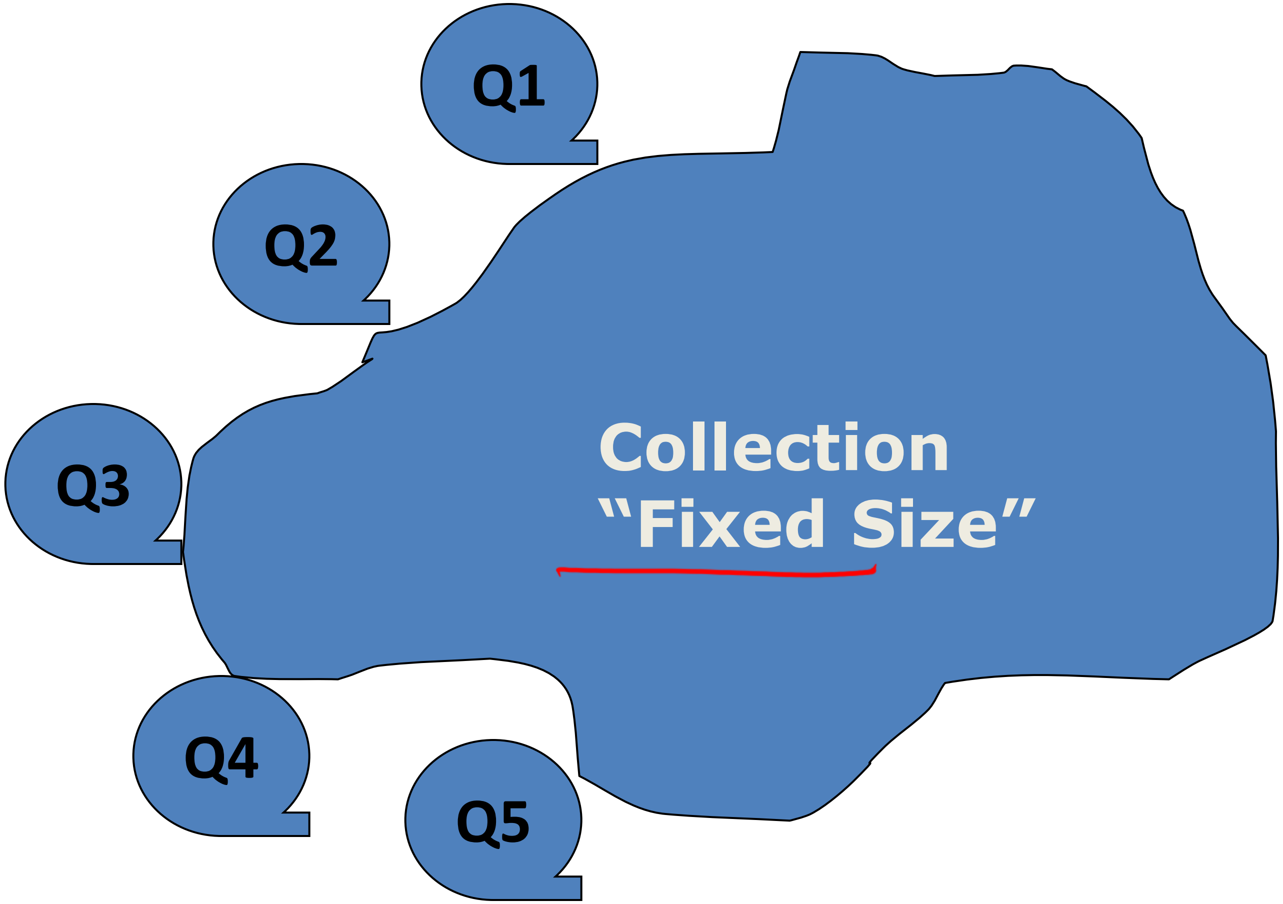
Motivation

- Information Retrieval (IR) is about:
  - Representation →
  - Storage →
  - Organization of →
  - And access to "information items"
- Focus is on user's "information need" rather than a precise query.
- Emphasis is on the retrieval of *information* (not data)

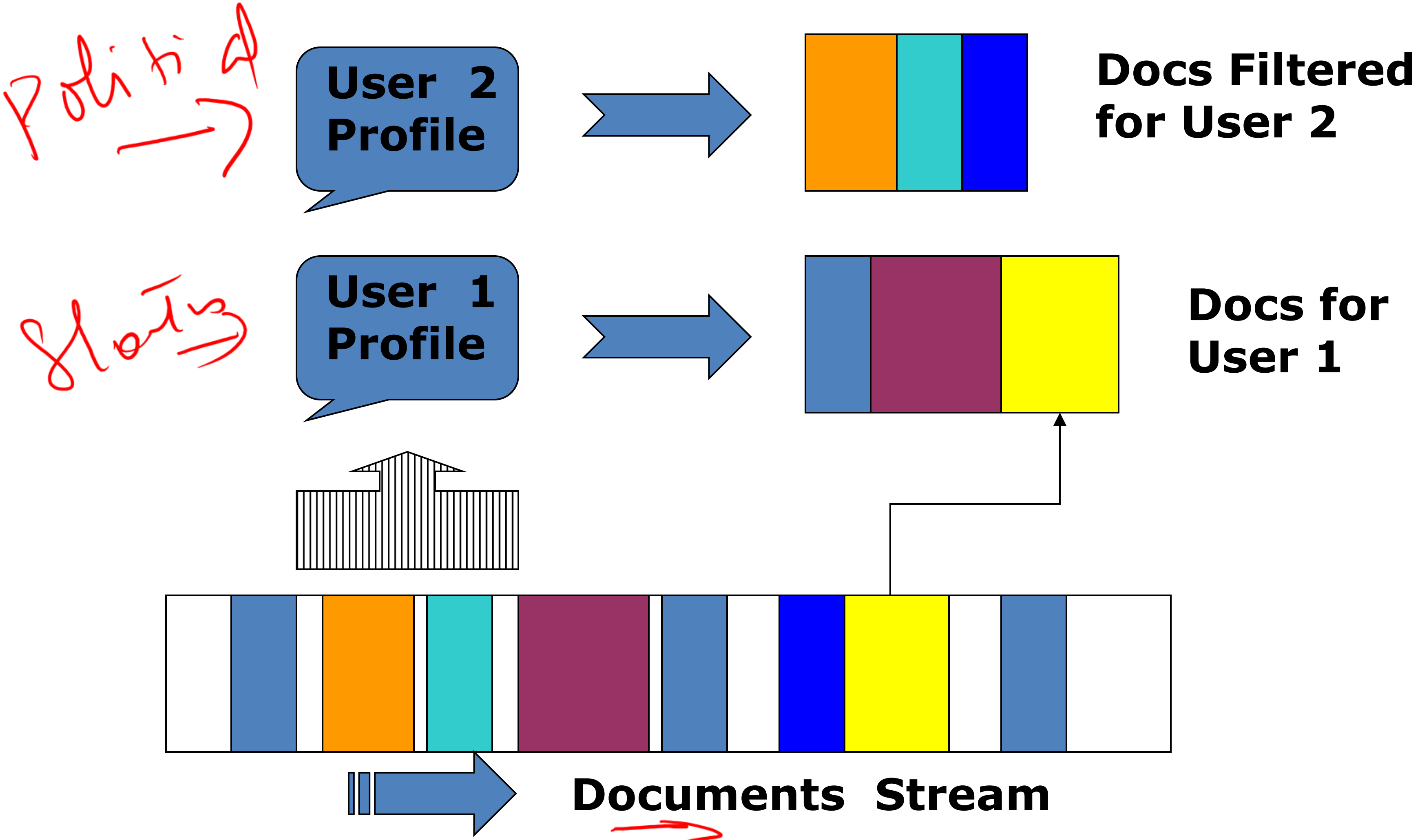
Types of Information Needs

- **Retrospective**
  - “Searching the past”
  - Different queries posed against a static collection
  - Time invariant
- **Prospective**
  - “Searching the future”
  - Static query posed against a dynamic collection
  - Time dependent

Retrieval - Ad hoc



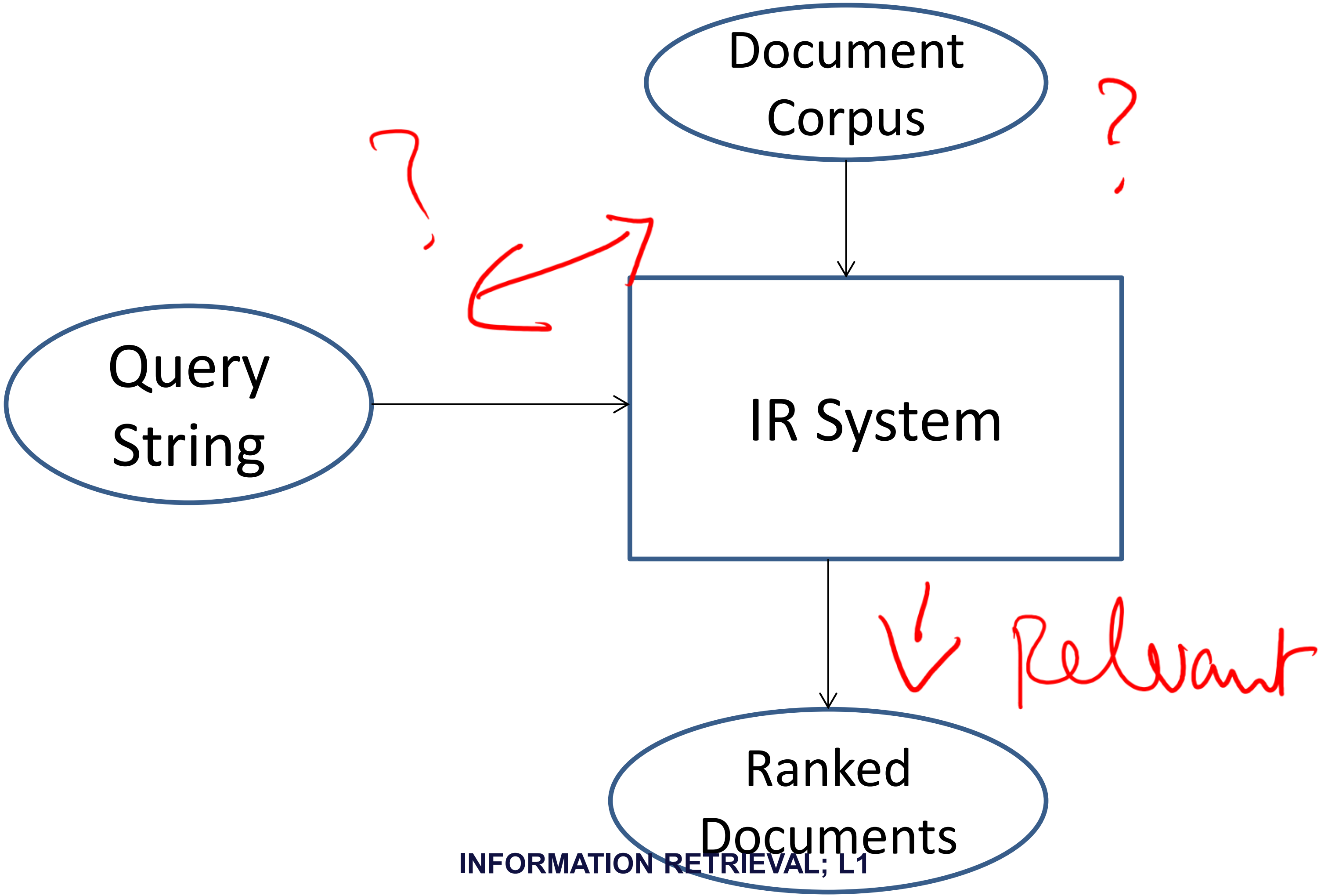
Retrieval - Filtering



IR Task

- **Input:**
  - A corpus of textual natural-language documents
  - A user query in the form of a textual string
- **Output:**
  - A ranked set of documents that are relevant to the query.

IR Task


Document Corpus
?
?
Query String
IR System
✓ Relvant
Ranked Documents

Relevance

- Relevance is a subjective judgment and may include:
  - Being on the proper subject.
  - Being timely (recent information).
  - Being authoritative (from a trusted source).
  - Satisfying the goals of the user and intended use of the information (*information need*).

Intelligent IR

- **Meaning of the words** used
- **Order of words** in the query
- **Direct or indirect feedback**
- **Authority** of the source

IR vs. Data Retrieval

- **Data retrieval**
  - Which documents contain a set of keywords?
  - Well defined structure and semantics
  - A single erroneous object implies failure
  - Provide solution to the user of a database system
- **Information retrieval**
  - Information about a subject or topic
  - Semantics is frequently loose
  - Small errors are tolerated
  - Deals with natural language text

IR vs. Data Retrieval

	Data	IR
Data	**Structured**	**Unstructured**
Fields	**Clear semantics** (SSN, age)	**No fields** (other than text)
Queries	**Defined** (relational algebra, SQL)	**Free text** ("natural language"), Boolean
Matching	**Exact** (results are *always* "correct")	**Imprecise** (need to measure effectiveness)

IR System -Basic Concepts

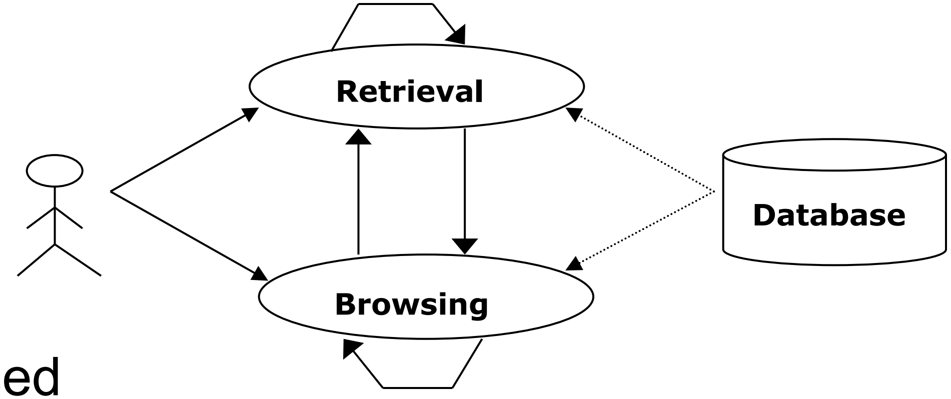
- Efficient retrieval system is directly related to
  - User task
  - Logical view of the documents

Indexing

Store & search } effective

User Task

- The User Task
  - Retrieval
    - Information or data
    - Purposeful
  - Browsing
    - Hypertext systems used
    - Glancing around



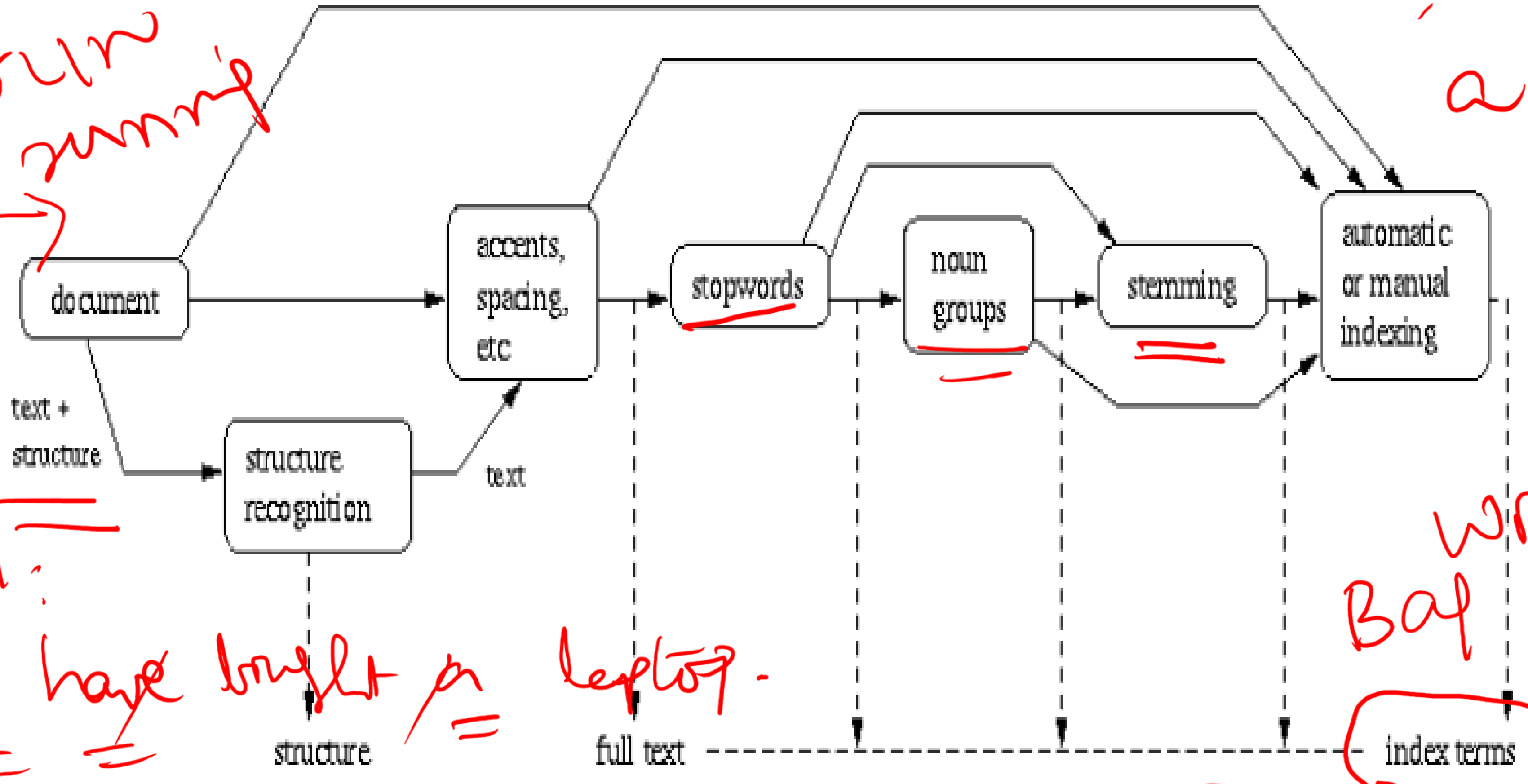
Interaction of the user with the retrieval system through distinct tasks

- Both retrieval(adhoc) and browsing are “pulling” actions
- Alternative is to “push” the information towards the user, to execute the particular retrieval task which consists of “filtering” relevant information.

Logical view of the documents

- Documents in a collection are frequently represented through a set of index terms or keywords
- Keywords are extracted from document
- Keywords are derived automatically or generated by a specialist, they provide a logical view of the document
- Stop-words
  - To reduce the set of representative keywords from large collection
- Function words do not bear useful information for IR,
  - i.e. of, in, about, with, I, although, …
- Stop-list: contain stop-words, not to be used as index
  - Prepositions, Articles, Pronouns
  - Some adverbs and adjectives, Some frequent words (e.g. document)
- The removal of stop-words usually improves IR effectiveness
- A few "standard" stop-lists are commonly used.

Logical View of the Document



run
running

to, the,
a

all:
I have brought a laptop.

Words
Bag of B

1000 →

Logical view of the document: from full text to a set of index terms

Logical view of the documents

- **Noun groups**
  - To identify the noun groups
  - Which eliminates the adjectives, adverbs and verbs
- **Reason for stemming**
  - Different word forms may bear similar meaning (e.g. search, searching): create a “standard” representation for them
- **Stemming**
  - Which reduces distinct words to their common grammatical root
  - Removing some endings of word

computer
compute
computes
computing
computed
computation

comput

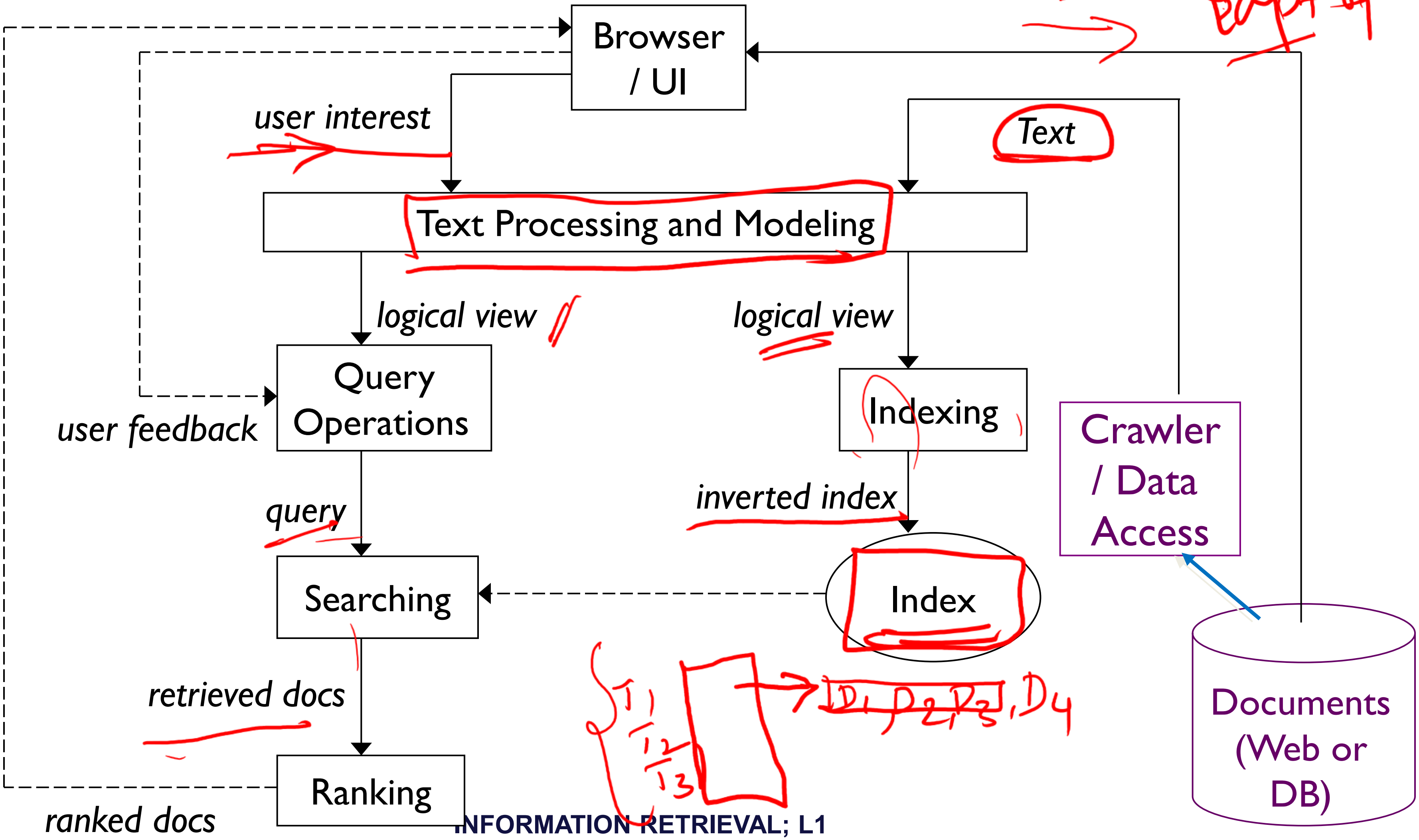
NLTK

Lemmatization

N→180

The Retrieval Process

D1: bought laptop



IR System Components

- Text Operations forms index words (tokens)
  - Stop-word removal
  - Stemming
- Indexing constructs an *inverted index* of word to document pointers
- Searching retrieves documents that contain a given query token from the inverted index
- Ranking scores all retrieved documents according to a relevance metric
- User Interface manages interaction with the user:
  - Query input and document output.
  - Relevance feedback.
  - Visualization of results.
- Query Operations transform the query to improve retrieval:
  - Query expansion
  - Query transformation using relevance feedback

Information Retrieval Models

Information Retrieval Models

- Traditional IR uses *Index Terms* to retrieve documents
- A *ranking* is an ordering of the documents retrieved to the user query
- A ranking is based on fundamental premises regarding the notion of relevance, such as:
  - common sets of index terms
  - sharing of weighted terms
  - likelihood of relevance
- Each set of premises leads to a distinct *IR model*

Boolean → AND, OR, NOT

Information AND

Vector → doc, query → TF-IDF

Relevant

Probabilistic

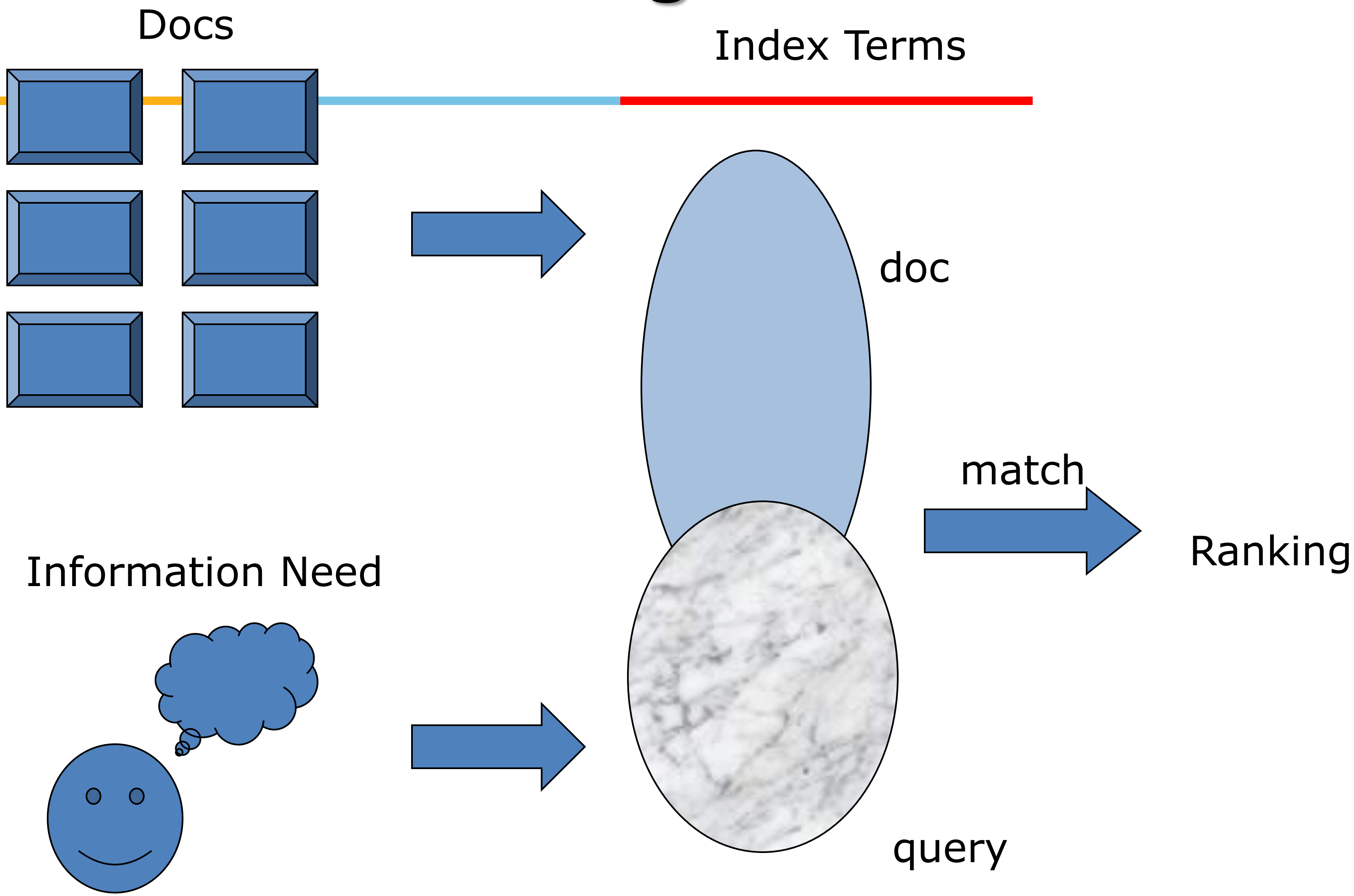
10

q

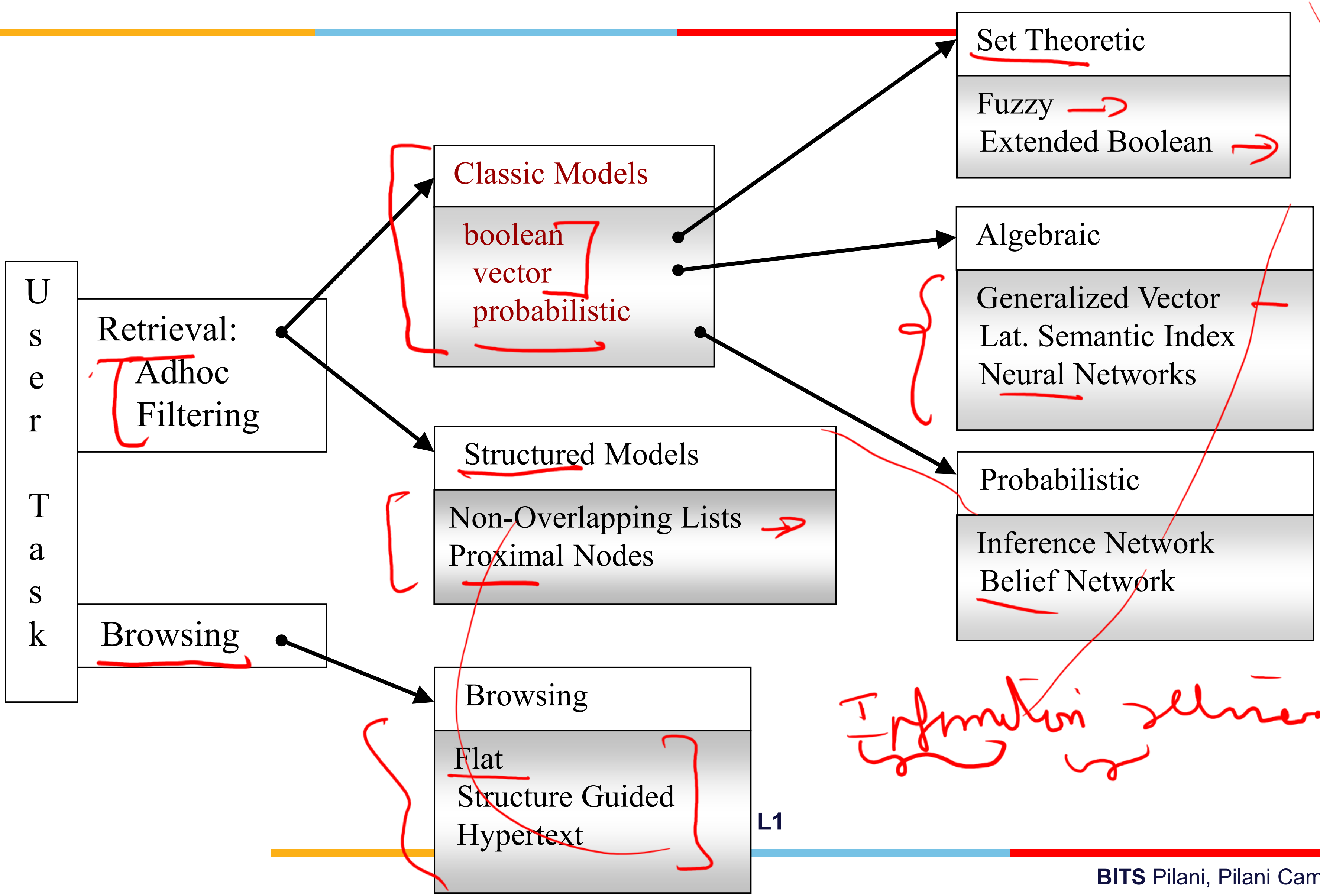
$D_1, D_2 \cdots D_{10}$

"Information retrieval"!!

Modeling



Types of IR Models



User Task

Retrieval:
Adhoc
Filtering

Browsing

Classic Models
boolean
vector
probabilistic

Structured Models
Non-Overlapping Lists
Proximal Nodes

Browsing
Flat
Structure Guided
Hypertext

Set Theoretic
Fuzzy
Extended Boolean

Algebraic
Generalized Vector
Lat. Semantic Index
Neural Networks

Probabilistic
Inference Network
Belief Network

Information selection

Taxonomy of IR Models

- The IR model, the logical view of the docs, and the retrieval task are distinct aspects of the system

LOGICAL VIEW OF DOCUMENTS

USER TASK

	Index Terms	Full Text	Full Text + Structure
Retrieval	Classic Set Theoretic Algebraic Probabilistic	Classic Set Theoretic Algebraic Probabilistic	Structured
Browsing	Flat	Flat Hypertext	Structure Guide Hypertext

Classic IR Models – Basic Concepts

- Each document represented by a set of representative keywords or index terms
- An index term is a document word useful for remembering the document main themes
- Traditionally, index terms were nouns because nouns have meaning by themselves
- However, search engines assume that all words are index terms (full text representation)

Classic IR Models – Ranking

- Not all terms are equally useful for representing the document contents: less frequent terms allow identifying a narrower set of documents
- The *importance* of the index terms is represented by weights associated to them
- Let
  - k_i be an index term
  - d_j be a document
  - w_{ij} is a weight associated with (k_i,d_j)
- The weight w_{ij} quantifies the importance of the index term for describing the document contents

Classic IR Models – Notations

k_i is an index term (keyword)

d_j is a document

t is the total number of docs

$K = (k_1, k_2, \ldots, k_t)$ is the set of all index terms

$w_{ij} >= 0$ is a weight associated with (k_i,d_j)

$w_{ij} = 0$ indicates that term does not belong to doc

$vec(d_j) = (w_{1j}, w_{2j}, \ldots, w_{tj})$ is a weighted vector associated with the document d_j

$g_i(vec(d_j)) = w_{ij}$ is a function which returns the weight associated with pair (k_i,d_j)

Classical IR Models

- Boolean model
- Vector Space model
- Probabilistic model

Boolean Model

Boolean Model

- Simple model based on set theory and Boolean algebra
  - Documents are sets of terms
  - Queries are Boolean expressions on terms
- Historically the most common model
  - Library OPACs
  - Dialog system
  - Many web search engines
- Queries specified as boolean expressions
  - Precise semantics
  - Neat formalism
- Terms are either present or absent. Thus, $w_{ij}\ \varepsilon\ \{1,0\}$
- There are three connectives used: *and, or, not*

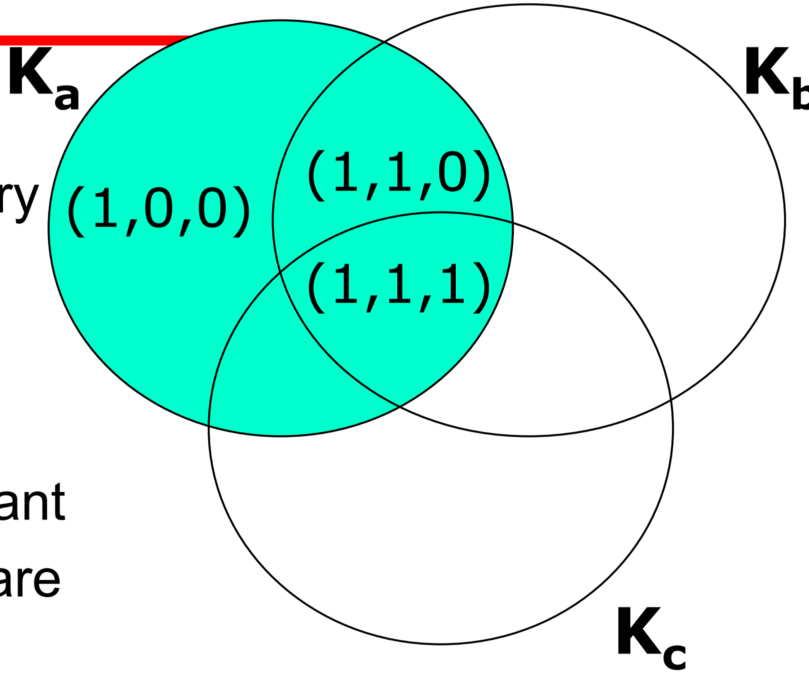
Boolean Model

- **D: set of words (indexing terms) present in a document**
  - each term is either present (1) or absent (0)
- **Q: A Boolean expression**
  - terms are index terms
  - operators are AND, OR, and NOT
- **F: Boolean algebra over sets of terms and sets of documents**
- **R: a document is predicted as relevant to a query expression if it *satisfies the query expression***
- $((\textit{text} \lor \textit{information}) \land \textit{retrieval} \land \neg \textit{theory})$
- Each query term specifies a set of documents containing the term
- AND (∧): the intersection of two sets
- OR (∨): the union of two sets
- NOT (¬): set inverse, or really set difference

Boolean Model

Definition

- Index term weight variables all are binary
- $w_{ij} \varepsilon \{1,0\}$
- Query $q = k_a \wedge (k_b \vee \neg k_c)$
- $sim(q_i,d_j) = \begin{cases} 1, & \text{i.e. doc's are relevant} \\ 0, & \text{otherwise i.e. doc's are not relevant} \end{cases}$



Boolean Model

- **Advantages**
  - Clean Formalism
  - Easy to implement
  - Intuitive concept
  - Still, it is a dominant model for document database systems.

Limitations of Boolean Model

- Retrieval based on binary decision criteria with no notion of partial matching
- No ranking of the documents is provided (absence of a grading scale)
- Information need has to be translated into a Boolean expression which most users find difficult
- The Boolean queries formulated by the users are most often too simplistic
- Frequently returns either too few or too many documents in response to a user query.

Information retrieval → 10

Vector Model

$\{ 10\ d_{10} \rightarrow d_5\ d_1\ d_2$

$\{1, 0\}$

- Use of binary weights is too limiting
- Non-binary weights provide consideration for partial matches
- These term weights are used to compute a *degree of similarity* between a query and each document
- Ranked set of documents provides for better matching

W_{ij}

Define:

- $w_{i,j} >= 0$ associated with the pair *(ki,dj)*
- $vec(d_j) = (w_{1,j}, w_{2,j}, ..., w_{t,j})$
- $w_{i,q} >= 0$ associated with the pair (k_i,q)
- $vec(q) = (w_{1,q}, w_{2,q}, ..., w_{t,q})$
- *t- total no. of index terms in the collection*

$$\vec{d}_j = (w_{1,j}, w_{2,j}, ..., w_{t,j})$$

$$\vec{q} = (w_{1,q}, w_{2,q}, ..., w_{t,q})$$

$p\ 1000^{10}$

$d_1 = < w_{ij}, w_2, ..., w_{tj} >$

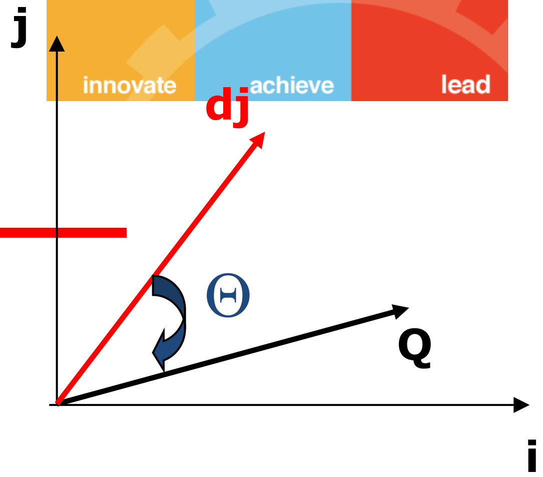
q

Vector Model

$$\vec{d_j} = \left(w_{1,j}, w_{2,j}, \ldots, w_{t,j}\right)$$

$$\vec{q} = \left(w_{1,q}, w_{2,q}, \ldots, w_{t,q}\right)$$

Vector Model



$$Sim(d_j, q) = \frac{\vec{d_j} \cdot \vec{q}}{\left|\vec{d_j}\right| x \left|\vec{q}\right|} = \frac{\sum_{i=1}^{t} (w_{i,j} \, x \, w_{i,q})}{\sqrt{\sum_{i=1}^{t} w_{i,j}^{2} \, x \sum_{j=1}^{t} w_{i,q}^{2}}}$$

- A document is retrieved even if it matches the query terms only partially

A good weight must take into account of two effects:

- quantification of intra-document contents (similarity)
  - *tf* factor, the *term frequency* within a document
- quantification of inter-documents separation (dis-similarity)
  - *idf* factor, the *inverse document frequency*
- w_{ij} = *tf * idf*

Vector Model

- **Advantages**
  - Simple model based on linear algebra
  - Term weights not binary
  - Allows computing a continuous degree of similarity between queries and documents
  - Allows ranking documents according to their possible relevance
  - Allows partial matching
  - Allows efficient implementation for large document collections

Vector Model

- **Disadvantages**
  - Index terms are assumed to be mutually independent
  - Search keywords must precisely match document terms
  - Long documents are poorly represented
  - The order in which the terms appear in the document is lost in the vector space representation
  - Weighting is intuitive, but not very formal.

Probabilistic model

- The model is called as BIR (Binary Independence Retrieval)
- It uses a probabilistic framework
- Given a user query, there is an *ideal* answer set
- Guess at the beginning what they could be (i.e., guess initial description of ideal answer set)
- User look retrieved doc's are either relevant or non-relevant
- Improve by iteration.

Probabilistic model

- An initial set of documents is retrieved, can be done using vector model, Boolean model
- User inspects these docs looking for the relevant ones
- IR system uses this information to refine description of ideal answer set
- By repeating this process, it is expected that the description of the ideal answer set will improve
- Description of ideal answer set is modelled in probabilistic terms.

Probabilistic model- Ranking

- Given a user query *q* and a document *dj*, the probabilistic model tries to estimate the probability that the user will find the document $\boldsymbol{d_j}$ interesting (i.e., relevant)
- The model assumes that this probability of relevance depends on the query and the document representations only
- Ideal answer set is referred to as *R* and should maximize the probability of relevance. Documents in the set *R* are predicted to be relevant.

Probabilistic model

- **Advantages**
  - Documents are ranked in decreasing order of their probability of relevant
- **Disadvantages**
  - Need to guess the initial separation of documents into relevant and non-relevant sets
  - All weights are binary
  - The adoption of the independence assumption for index terms.

Resources

Lucene

Xapian

OpenSearch

Resources

https://ieeexplore.ieee.org/document/10184013

Information Retrieval: Recent Advances and Beyond
KAILASH A. HAMBARDE AND HUGO PROENÇA , (Senior Member, IEEE)