

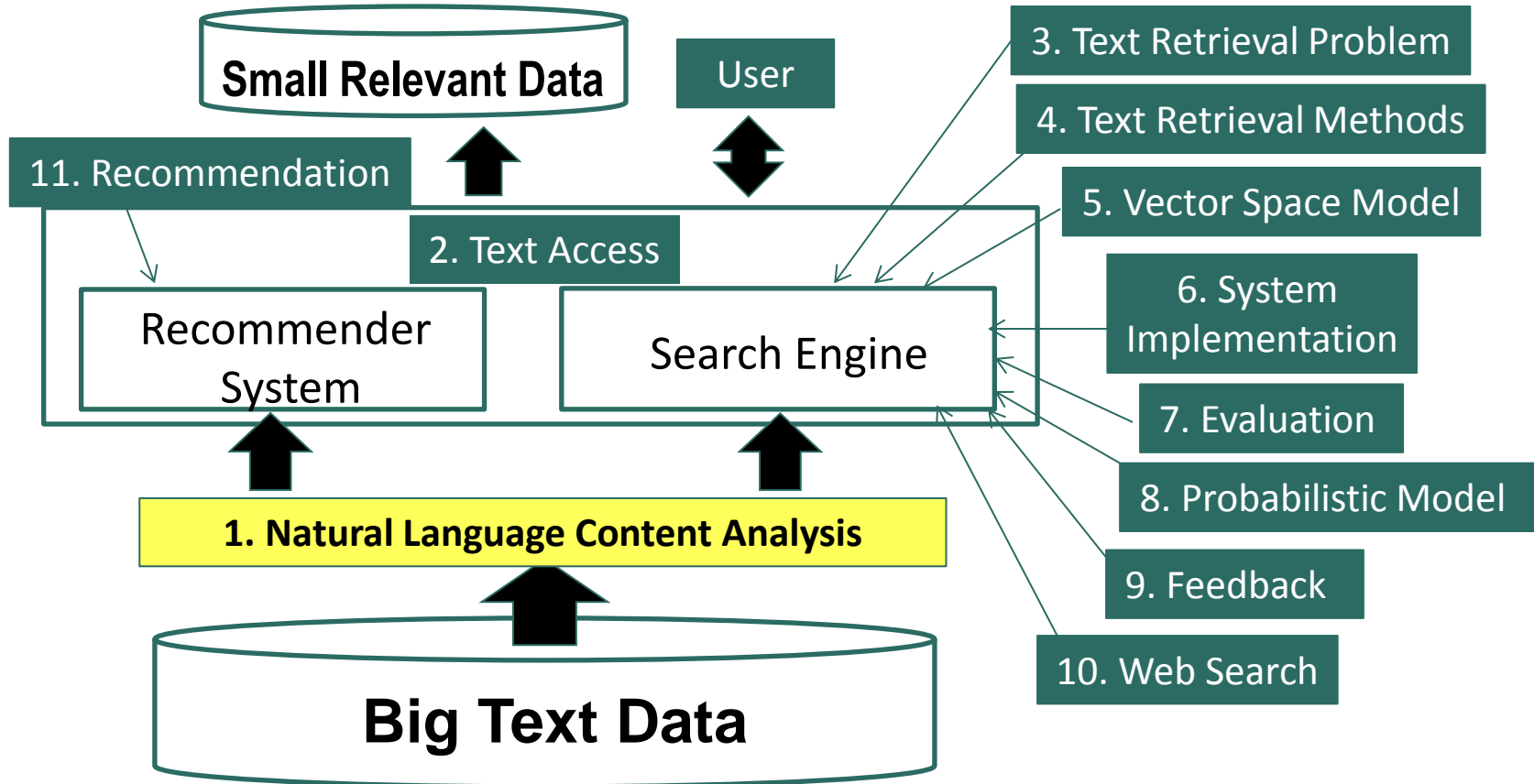


Text Retrieval and Search Engines

Natural Language Content Analysis

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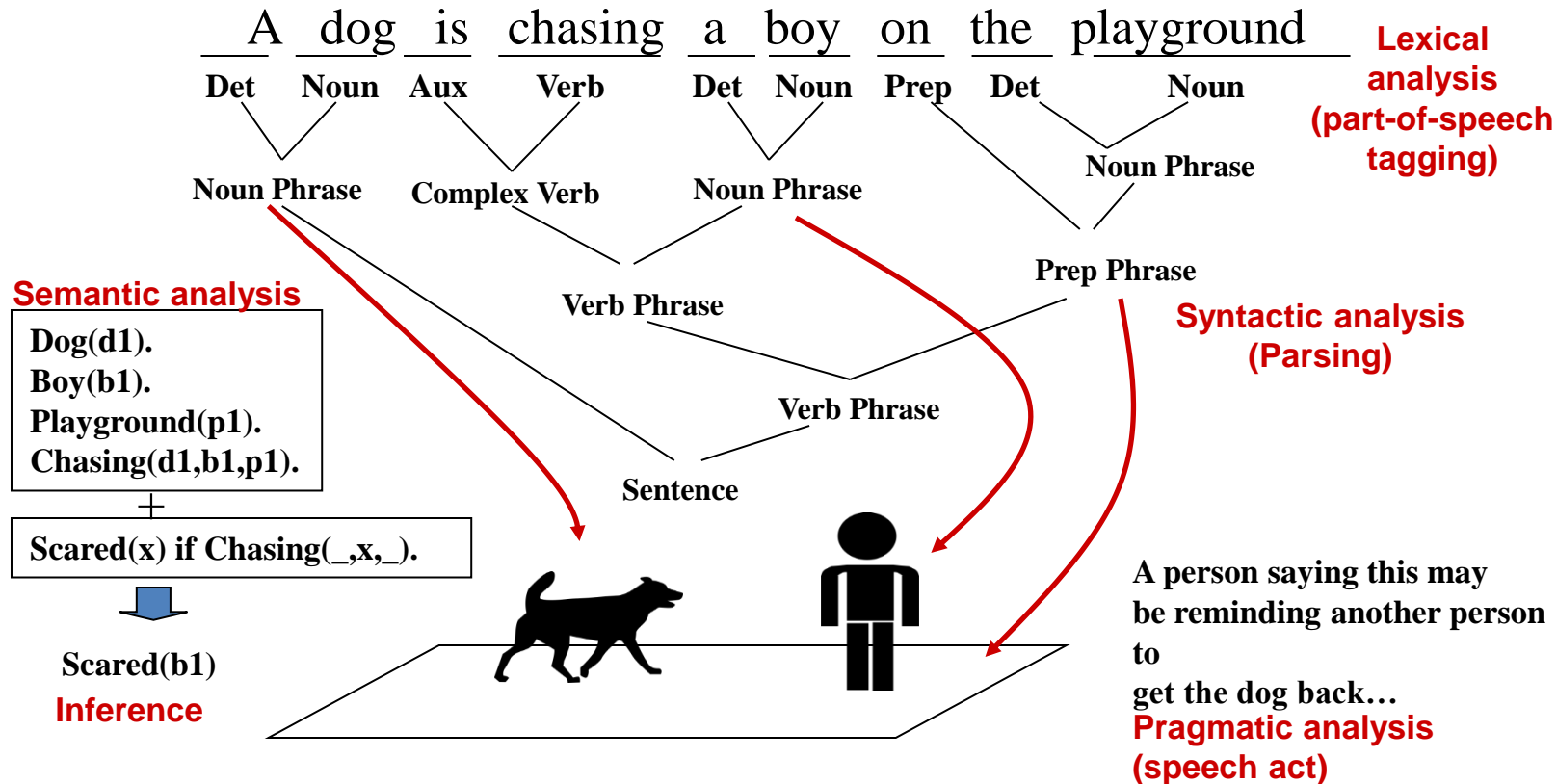
Course Schedule



Overview

- What is Natural Language Processing (NLP)?
- State of the Art in NLP
- NLP for Text Retrieval

An Example of NLP



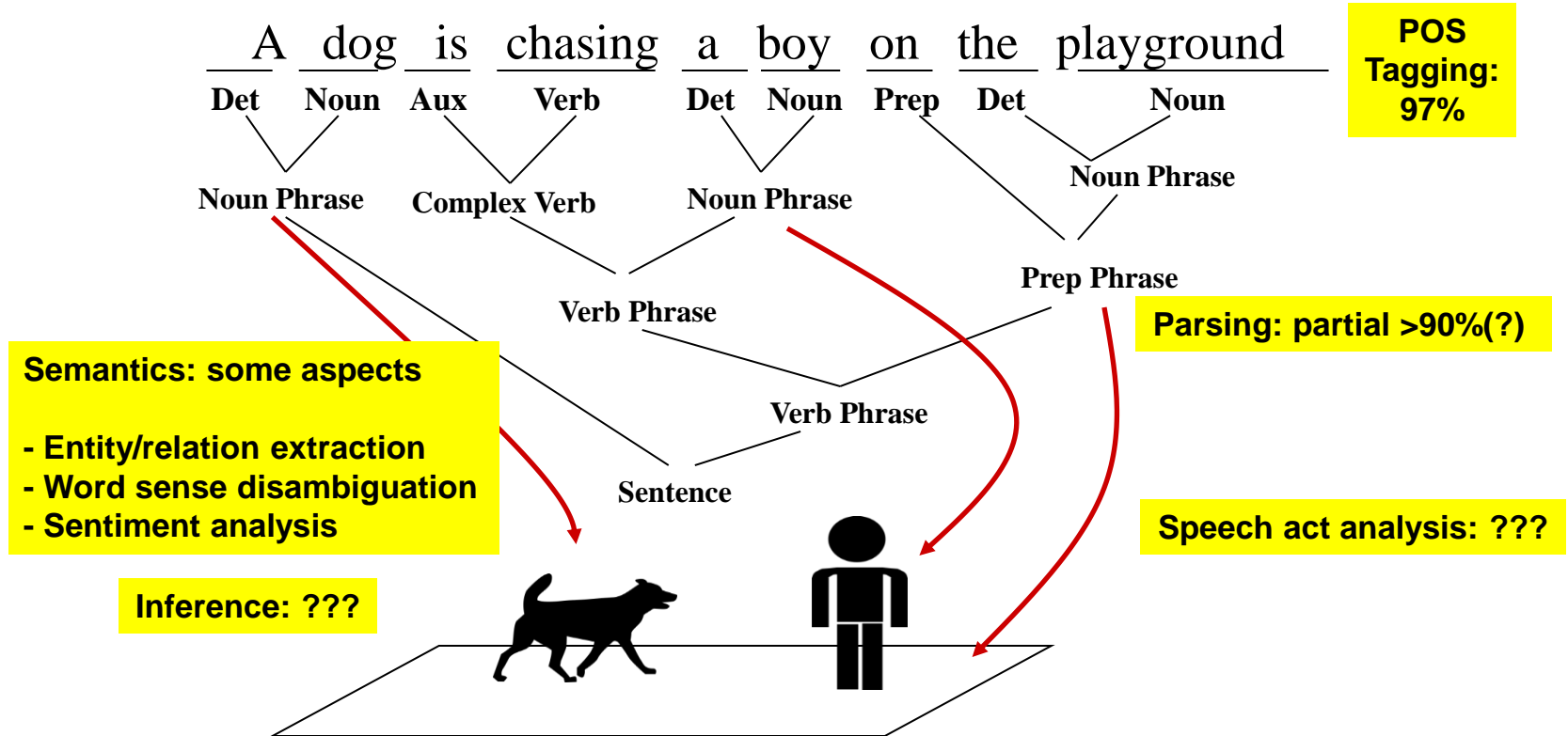
NLP Is Difficult!

- Natural language is designed to make human communication efficient. As a result,
 - we omit a lot of “common sense” knowledge, which we assume the hearer/reader possesses
 - we keep a lot of ambiguities, which we assume the hearer/reader knows how to resolve
- This makes EVERY step in NLP hard
 - Ambiguity is a “killer”!
 - Common sense reasoning is pre-required

Examples of Challenges

- Word-level ambiguity: E.g.,
 - “design” can be a noun or a verb (Ambiguous POS)
 - “root” has multiple meanings (Ambiguous sense)
- Syntactic ambiguity: E.g.,
 - “natural language processing” (Modification)
 - “A man saw a boy with a telescope.” (PP Attachment)
- Anaphora resolution: “John persuaded Bill to buy a TV for himself.” (himself = John or Bill?)
- Presupposition: “He has quit smoking.” implies that he smoked before.

The State of the Art



What We Can't Do

- 100% POS tagging
 - “He turned off the highway.” vs “He turned off the fan.”
- General complete parsing
 - “A man saw a boy with a telescope.”
- Precise deep semantic analysis
 - Will we ever be able to precisely define the meaning of “own” in “John owns a restaurant.”?

**Robust & general NLP tends to be “shallow”
while “deep” understanding doesn’t scale up**

NLP for Text Retrieval

- Must be general robust & efficient → Shallow NLP
- **“Bag of words” representation tends to be sufficient** for most search tasks (but not all!)
- Some text retrieval techniques can naturally address NLP problems
- However, deeper NLP is needed for complex search tasks

Summary

- What is Natural Language Processing (NLP)?
- State of the Art in NLP
- NLP for Text Retrieval

Additional Reading

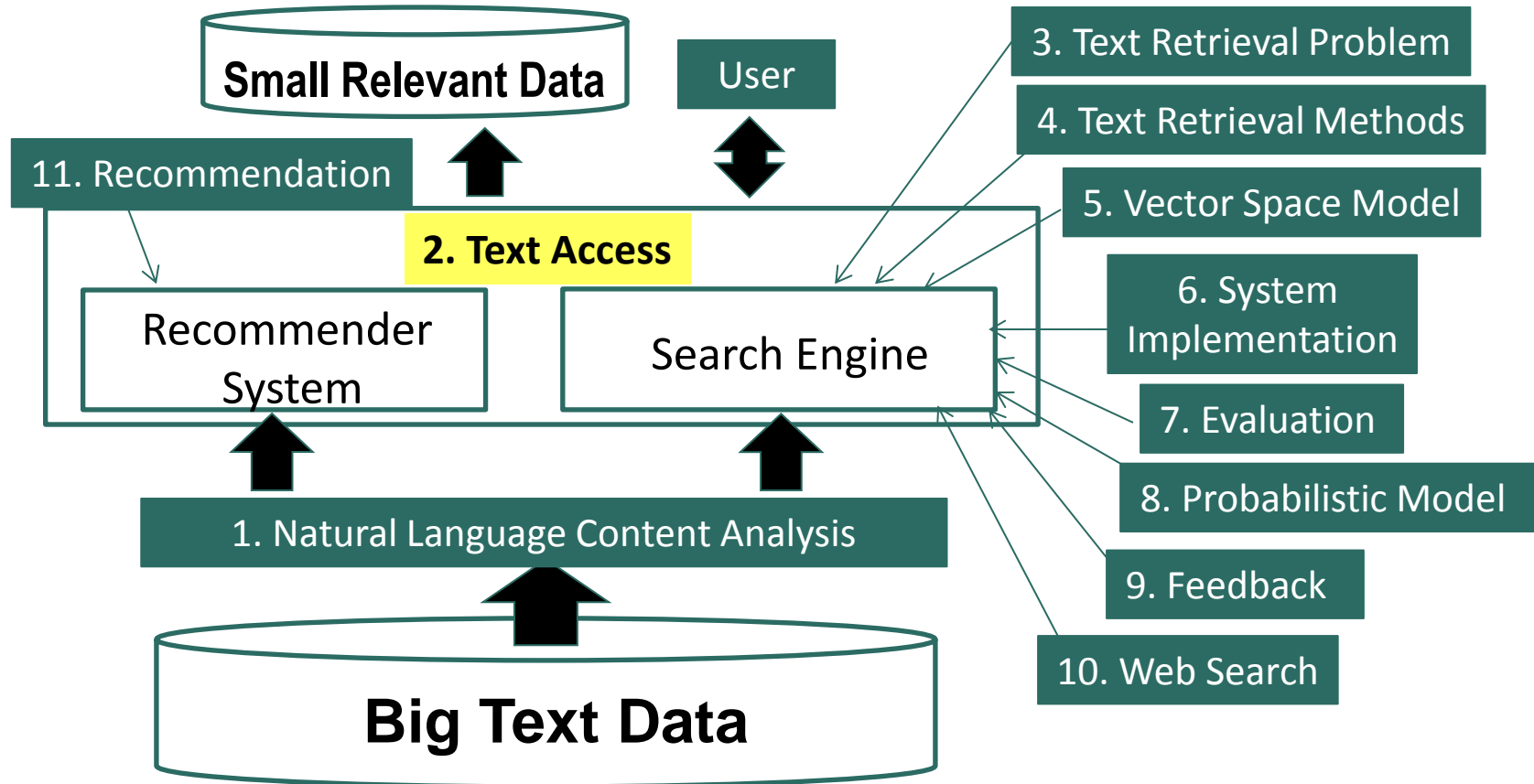
Chris Manning and Hinrich Schütze, Foundations of Statistical Natural Language Processing, MIT Press. Cambridge, MA: May 1999.

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Text Access

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Access to Relevant Text Data

How can a text information system help users get access to the relevant text data?

- Push vs. Pull
- Querying vs. Browsing

Two Modes of Text Access: Pull vs. Push

- **Pull Mode (search engines)**
 - Users take initiative
 - Ad hoc information need
- **Push Mode (recommender systems)**
 - Systems take initiative
 - Stable information need or system has good knowledge about a user's need

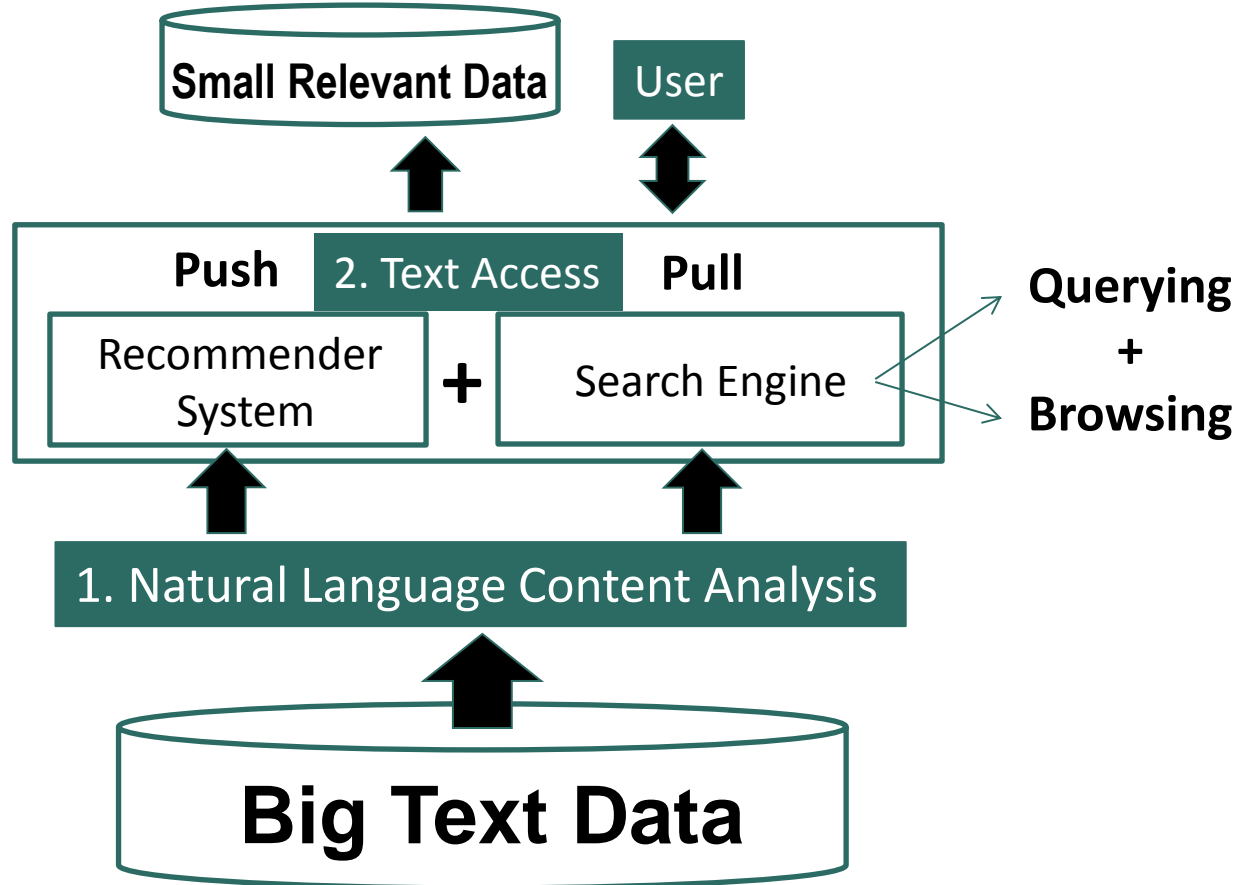
Pull Mode: Querying vs. Browsing

- Querying
 - User enters a (keyword) query
 - System returns relevant documents
 - Works well when the user knows what keywords to use
- Browsing
 - User navigates into relevant information by following a path enabled by the structures on the documents
 - Works well when the user wants to explore information, doesn't know what keywords to use, or can't conveniently enter a query

Information Seeking as Sightseeing

- Sightseeing: Know address of an attraction?
 - Yes: take a taxi and go directly to the site
 - No: walk around or take a taxi to a nearby place then walk
- Information seeking: Know exactly what you want to find?
 - Yes: use the right keywords as a query and find the information directly
 - No: browse the information space or start with a rough query and then browse

Summary



Additional Reading

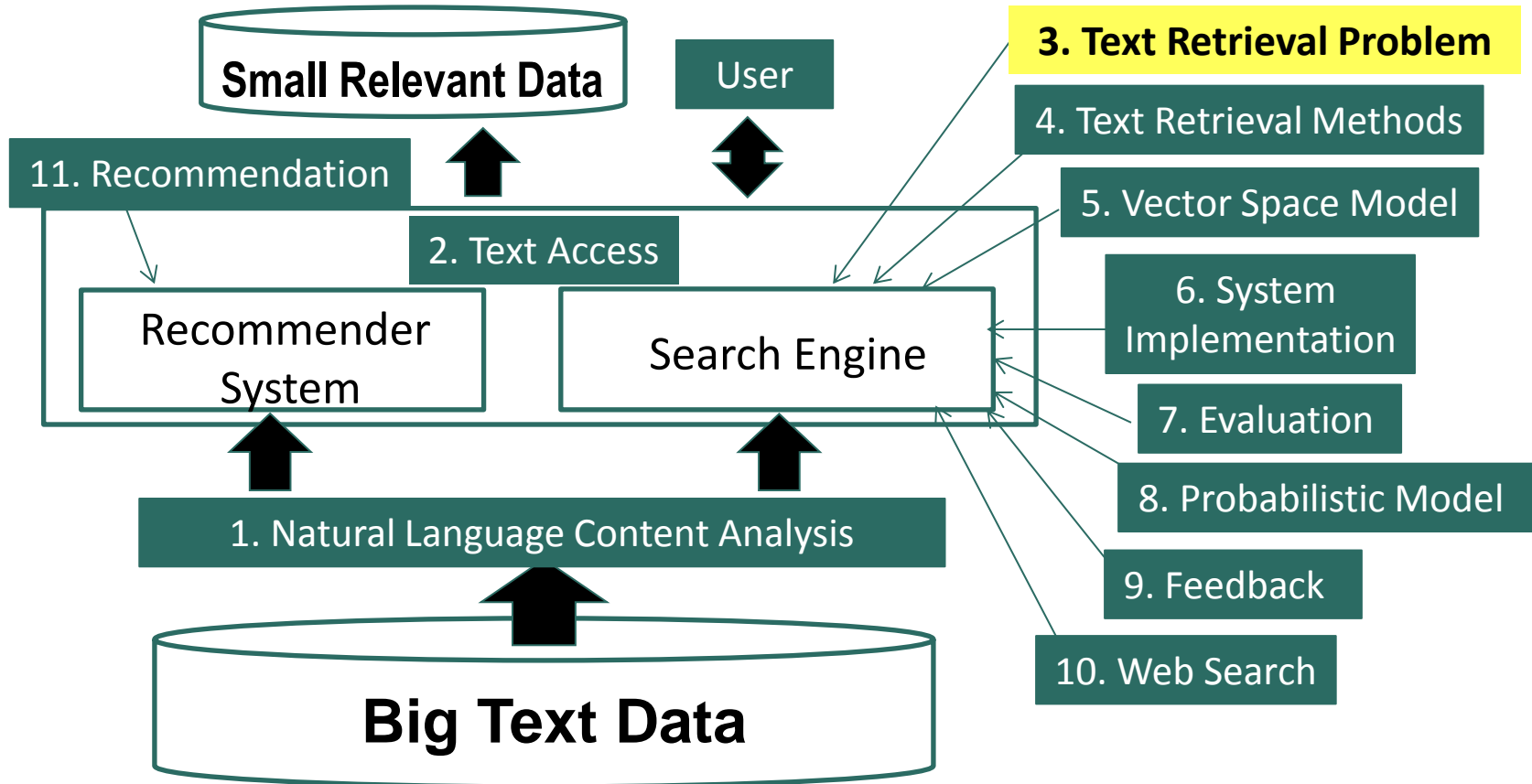
N. J. Belkin and W. B. Croft. 1992. Information filtering and information retrieval: two sides of the same coin?. *Commun. ACM* 35, 12 (Dec. 1992), 29-38.

Text Retrieval and Search Engines

Text Retrieval Problem

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Overview

- What is Text Retrieval?
- Text Retrieval vs. Database Retrieval
- Document Selection vs. Document Ranking

What Is Text Retrieval (TR)?

- Collection of text documents exists
- User gives a query to express the information need
- Search engine system returns relevant documents to users
- Often called “information retrieval” (IR), but IR is actually much broader
- Known as “search technology” in industry

TR vs. Database Retrieval

- Information
 - Unstructured/free text vs. structured data
 - Ambiguous vs. well-defined semantics
- Query
 - Ambiguous vs. well-defined semantics
 - Incomplete vs. complete specification
- Answers
 - Relevant documents vs. matched records
- TR is an empirically defined problem
 - Can't mathematically prove one method is better than another
 - Must rely on **empirical evaluation** involving users!

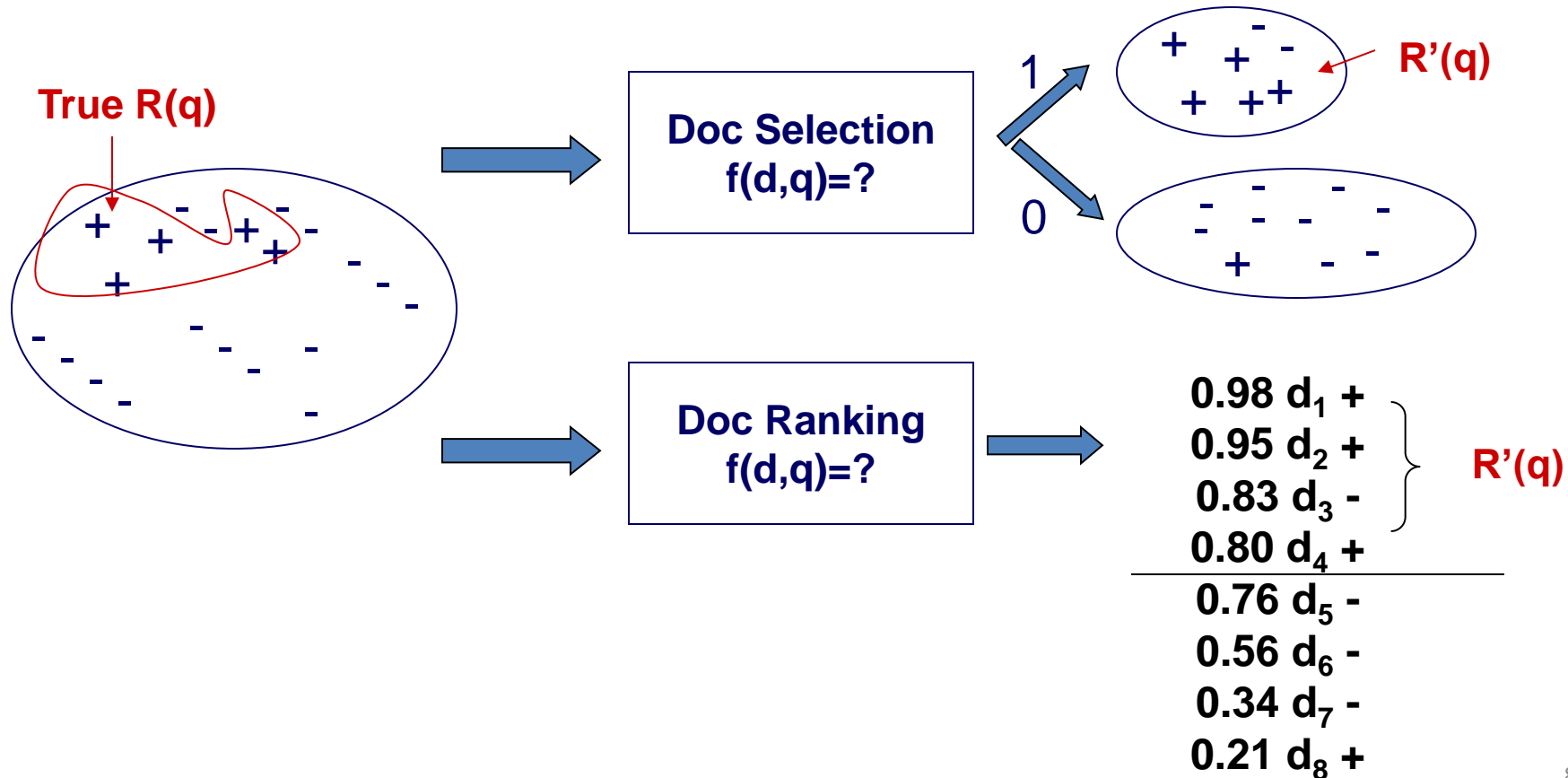
Formal Formulation of TR

- **Vocabulary:** $V = \{w_1, w_2, \dots, w_N\}$ of language
- **Query:** $q = q_1, \dots, q_m$, where $q_i \in V$
- **Document:** $d_i = d_{i1}, \dots, d_{im_i}$, where $d_{ij} \in V$
- **Collection:** $C = \{d_1, \dots, d_M\}$
- **Set of relevant documents:** $R(q) \subseteq C$
 - Generally unknown and user-dependent
 - Query is a “hint” on which doc is in $R(q)$
- **Task** = compute $R'(q)$, an approximation of $R(q)$

How to Compute $R'(q)$

- Strategy 1: Document selection
 - $R'(q) = \{d \in C \mid f(d, q) = 1\}$, where $f(d, q) \in \{0, 1\}$ is an indicator function or binary classifier
 - System must decide if a doc is relevant or not (**absolute relevance**)
- Strategy 2: Document ranking
 - $R'(q) = \{d \in C \mid f(d, q) > \theta\}$, where $f(d, q) \in \mathcal{R}$ is a relevance measure function; θ is a cutoff determined by the user
 - System only needs to decide if one doc is more likely relevant than another (**relative relevance**)

Document Selection vs. Ranking



Problems of Document Selection

- The classifier is unlikely accurate
 - “Over-constrained” query → no relevant documents to return
 - “Under-constrained” query → over delivery
 - Hard to find the right position between these two extremes
- Even if it is accurate, all relevant documents are not equally relevant (relevance is a matter of degree!)
 - Prioritization is needed
- Thus, ranking is generally preferred

Theoretical Justification for Ranking

- **Probability Ranking Principle** [Robertson 77]: Returning a ranked list of documents in descending order of probability that a document is relevant to the query is the optimal strategy under the following two assumptions:
 - The utility of a document (to a user) is **independent** of the utility of any other document
 - A user would browse the results **sequentially**
- Do these two assumptions hold?

Summary

- Text retrieval is an empirically defined problem
 - Which algorithm is better must be judged by users
- Document ranking is generally preferred to
 - Help users prioritize examination of search results
 - Bypass the difficulty in determining absolute relevance (users help decide the cutoff on the ranked list)
- Main challenge: design an effective ranking function
 $f(q,d) = ?$

Additional Readings

- S.E. Robertson, The probability ranking principle in IR. *Journal of Documentation* **33**, 294-304, 1977
- C. J. van Rijsbergen, Information Retrieval, 2nd Edition, Butterworth-Heinemann, Newton, MA, USA, 1979
 - A must-read for anyone doing research in information retrieval. Chapter 6 has an in-depth discussion of PRP.

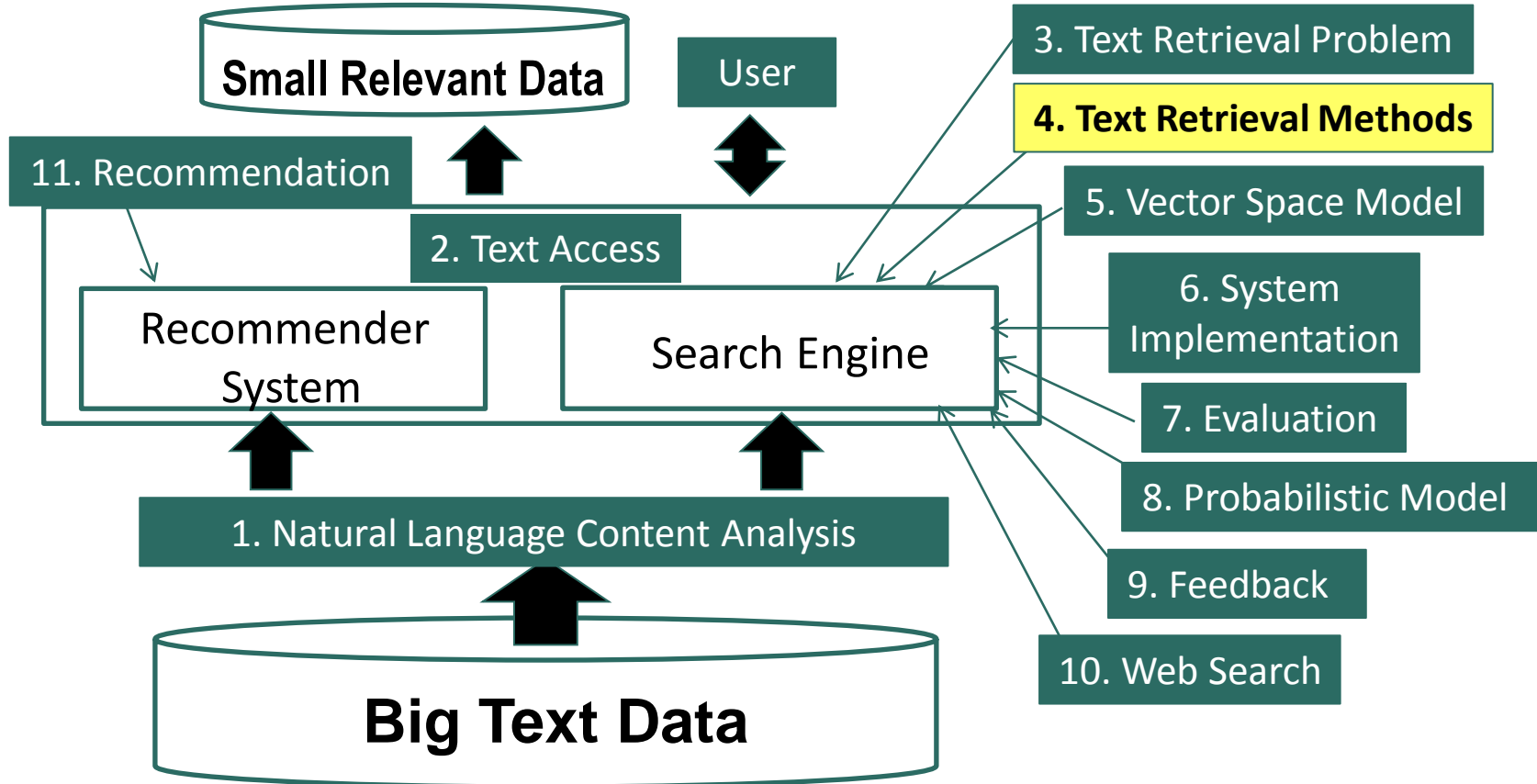


Text Retrieval and Search Engines

Overview of Text Retrieval Methods

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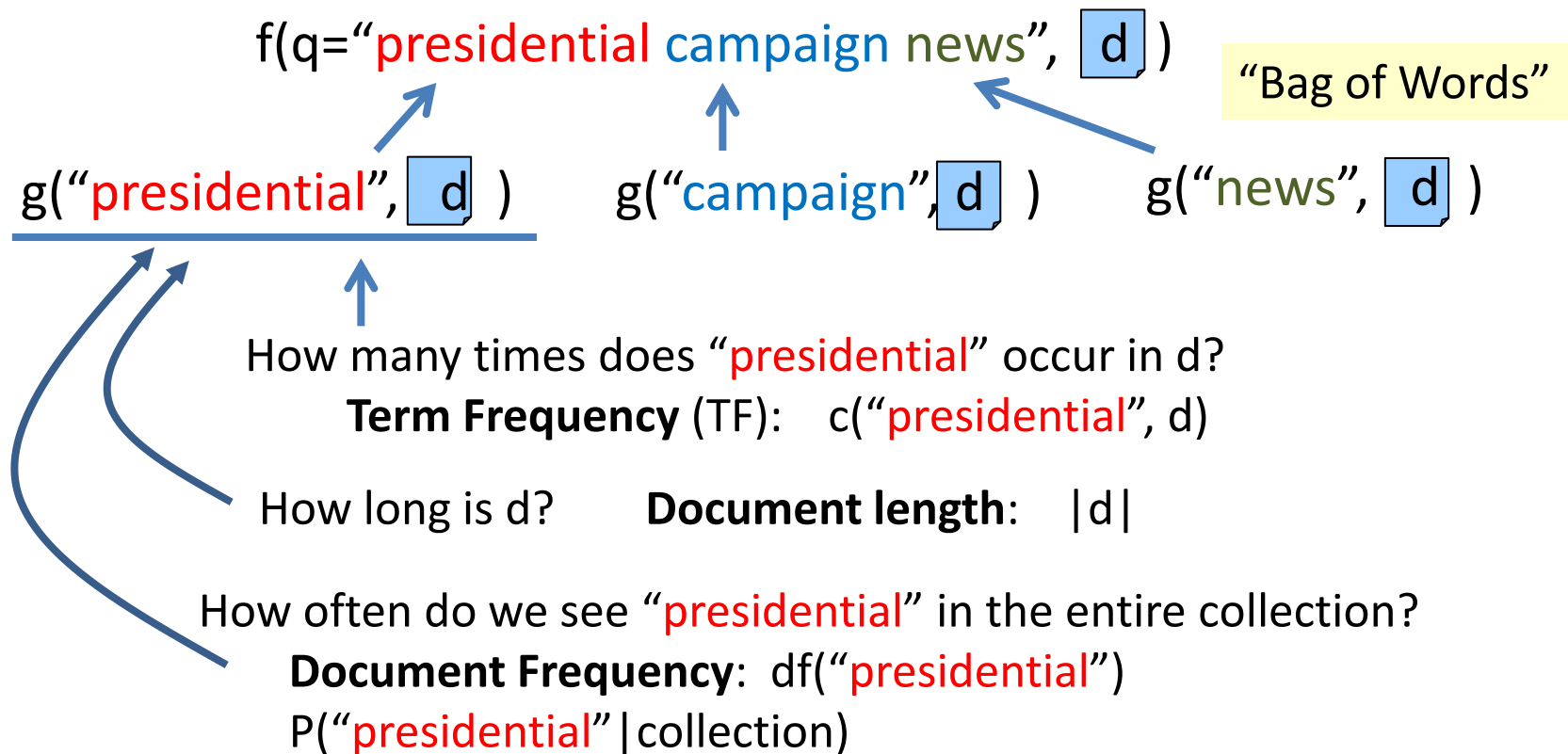
How to Design a Ranking Function

- **Query:** $q = q_1, \dots, q_m$, where $q_i \in V$
- **Document:** $d = d_1, \dots, d_n$, where $d_i \in V$
- **Ranking function:** $f(q, d) \in \mathbb{R}$
- A good ranking function should rank relevant documents on top of non-relevant ones
- Key challenge: how to measure the likelihood that document d is relevant to query q
- **Retrieval model** = formalization of relevance (give a computational definition of relevance)

Many Different Retrieval Models

- **Similarity-based models:** $f(q,d) = \text{similarity}(q,d)$
 - Vector space model
- **Probabilistic models:** $f(d,q) = p(R=1 \mid d,q)$, where $R \in \{0,1\}$
 - Classic probabilistic model
 - Language model
 - Divergence-from-randomness model
- **Probabilistic inference model:** $f(q,d) = p(d \rightarrow q)$
- **Axiomatic model:** $f(q,d)$ must satisfy a set of constraints
- These different models tend to result in similar ranking functions involving similar variables

Common Ideas in State of the Art Retrieval Models



Which Model Works the Best?

- When optimized, the following models tend to perform equally well [Fang et al. 11]:
 - **Pivoted length normalization**
 - **BM25**
 - **Query likelihood**
 - **PL2**
- BM25 is most popular

Summary

- Design of ranking function $f(q,d)$ pre-requires a computational definition of relevance (retrieval model)
- Many models are equally effective with no single winner
- State of the art ranking functions tend to rely on
 - Bag of words representation
 - Term Frequency (TF) and Document Frequency (DF) of words
 - Document length

Additional Readings

- Detailed discussion and comparison of state of the art models
 - Hui Fang, Tao Tao, and Chengxiang Zhai. 2011. Diagnostic Evaluation of Information Retrieval Models. *ACM Trans. Inf. Syst.* 29, 2, Article 7 (April 2011)
- Broad review of different retrieval models
 - ChengXiang Zhai, *Statistical Language Models for Information Retrieval*, Morgan & Claypool Publishers, 2008. (Chapter 2)

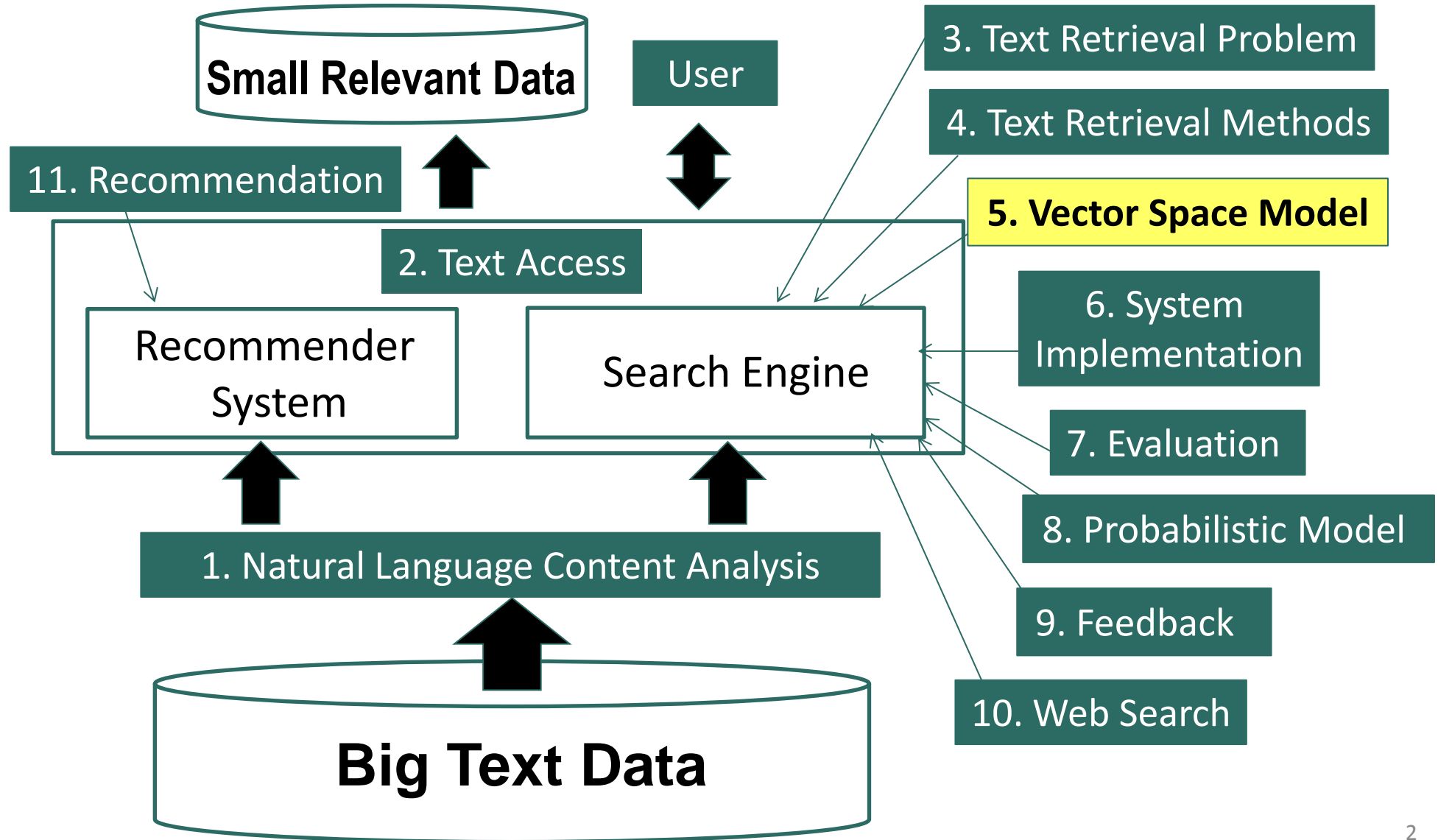


Text Retrieval and Search Engines

Vector Space Retrieval Model: Basic Idea

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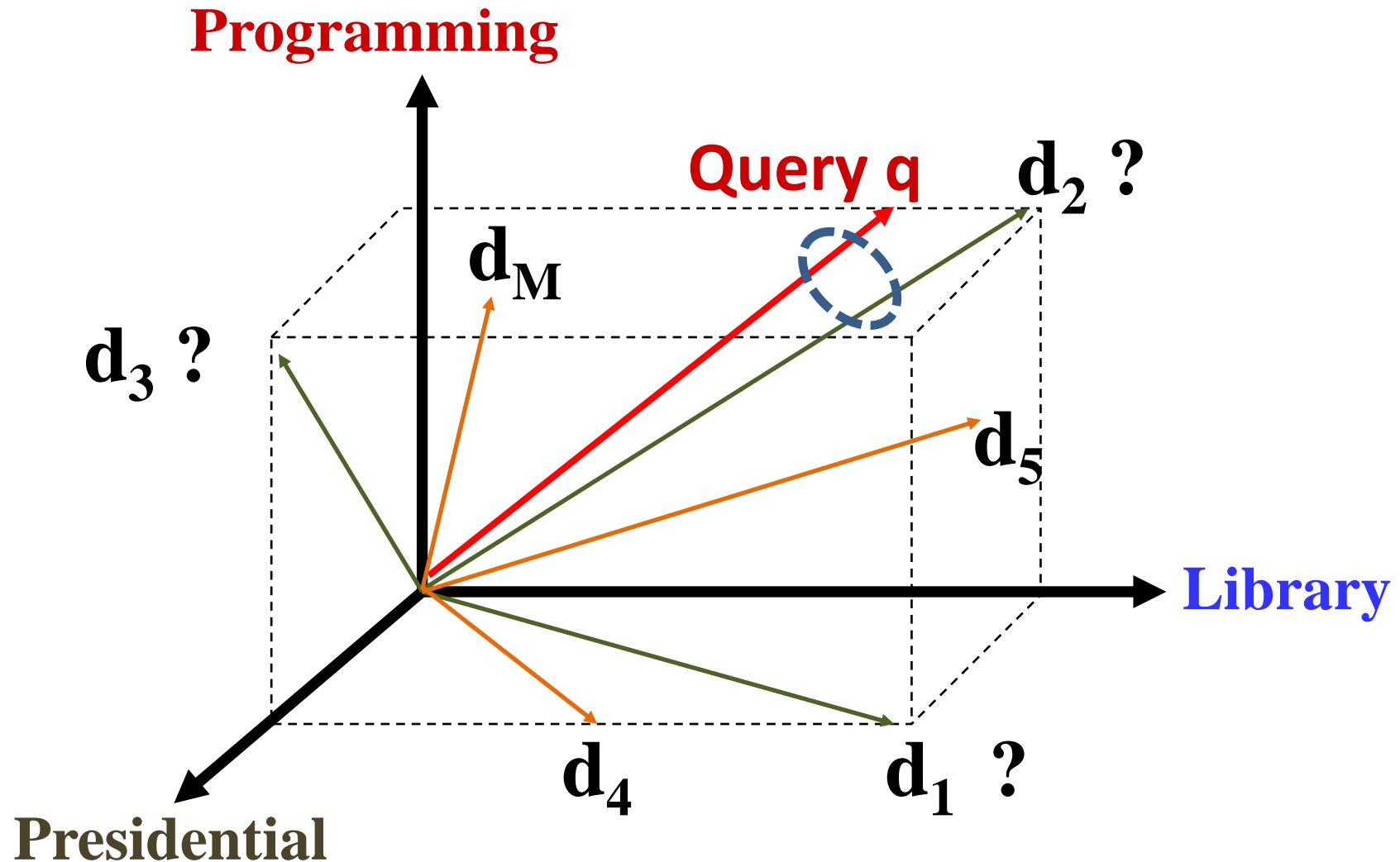
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Many Different Retrieval Models

- Similarity-based models: $f(q,d) = \text{similarity}(q,d)$
 - Vector space model

Vector Space Model (VSM): Illustration



VSM Is a Framework

- Represent a doc/query by a term vector
 - **Term**: basic concept, e.g., word or phrase
 - Each term defines one dimension
 - N terms define an **N-dimensional space**
 - **Query** vector: $\mathbf{q}=(x_1, \dots x_N)$, $x_i \in \mathbb{R}$ is query term weight
 - **Doc** vector: $\mathbf{d}=(y_1, \dots y_N)$, $y_j \in \mathbb{R}$ is doc term weight
- $\text{relevance}(\mathbf{q}, \mathbf{d}) \propto \text{similarity}(\mathbf{q}, \mathbf{d}) = f(\mathbf{q}, \mathbf{d})$

What VSM Doesn't Say

- How to define/select the “basic concept”
 - Concepts are assumed to be orthogonal
- How to place docs and query in the space (= how to assign term weights)
 - Term weight in query indicates importance of term
 - Term weight in doc indicates how well the term characterizes the doc
- How to define the similarity measure

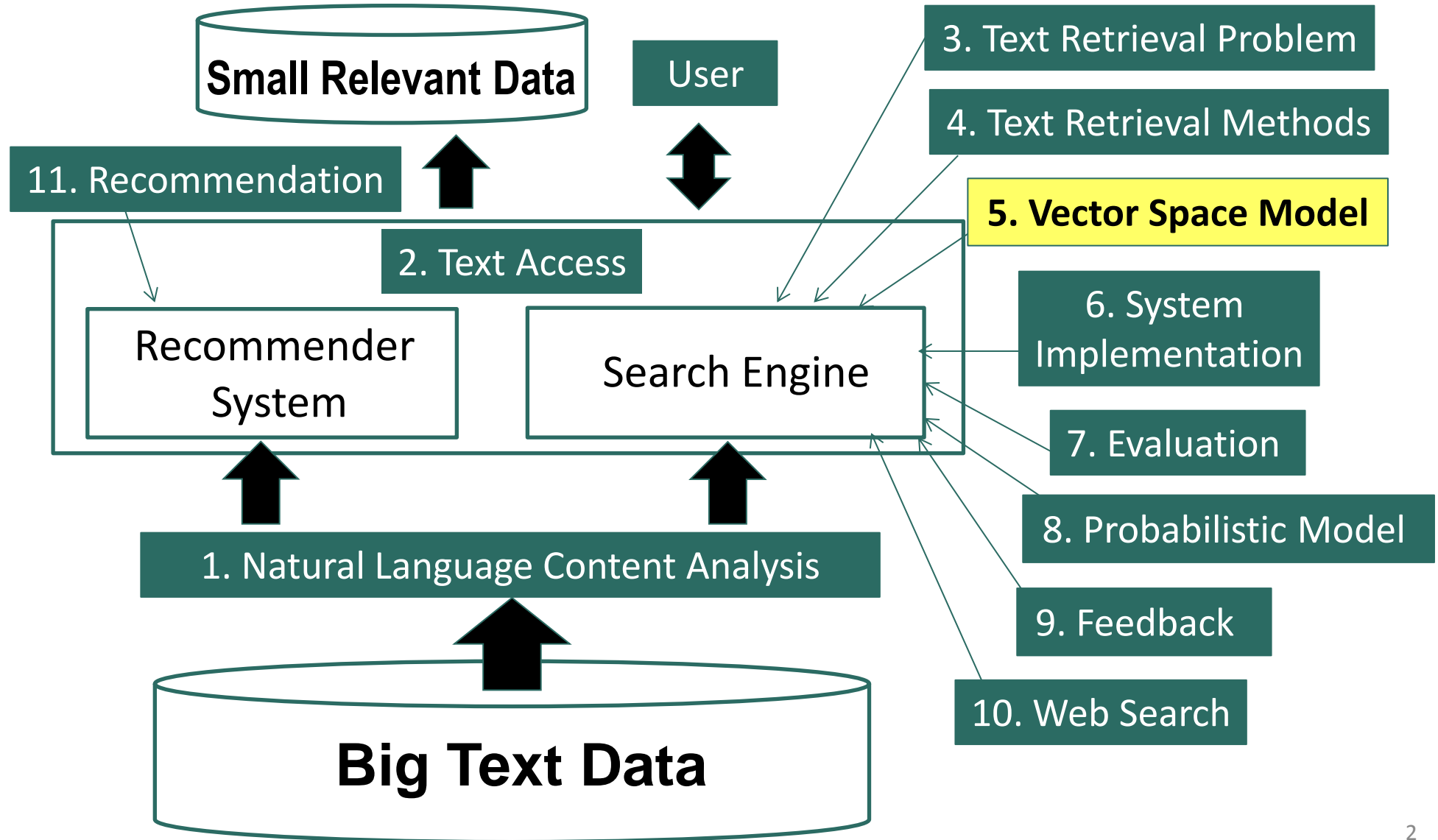


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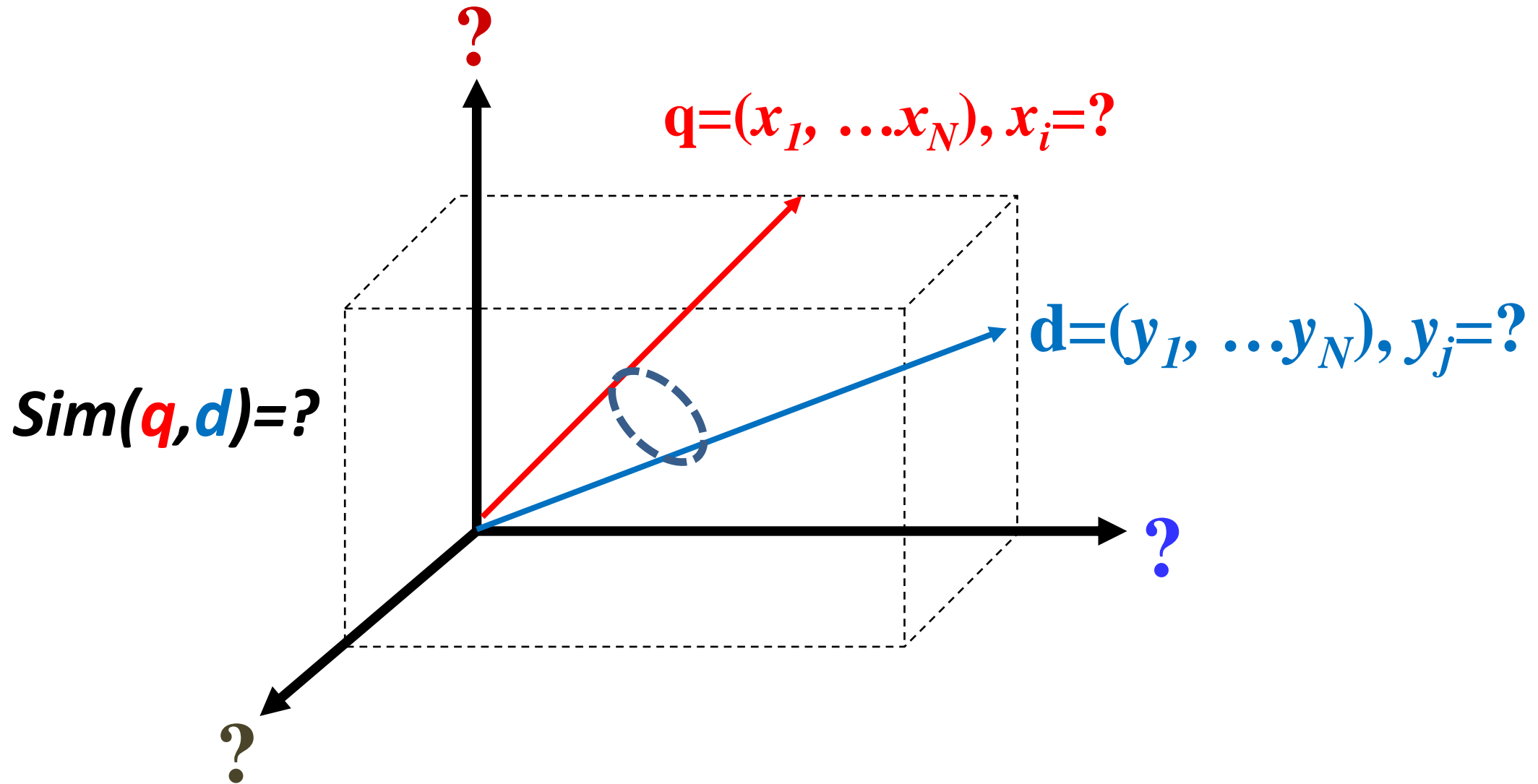
Vector Space Retrieval Model: Simplest Instantiation

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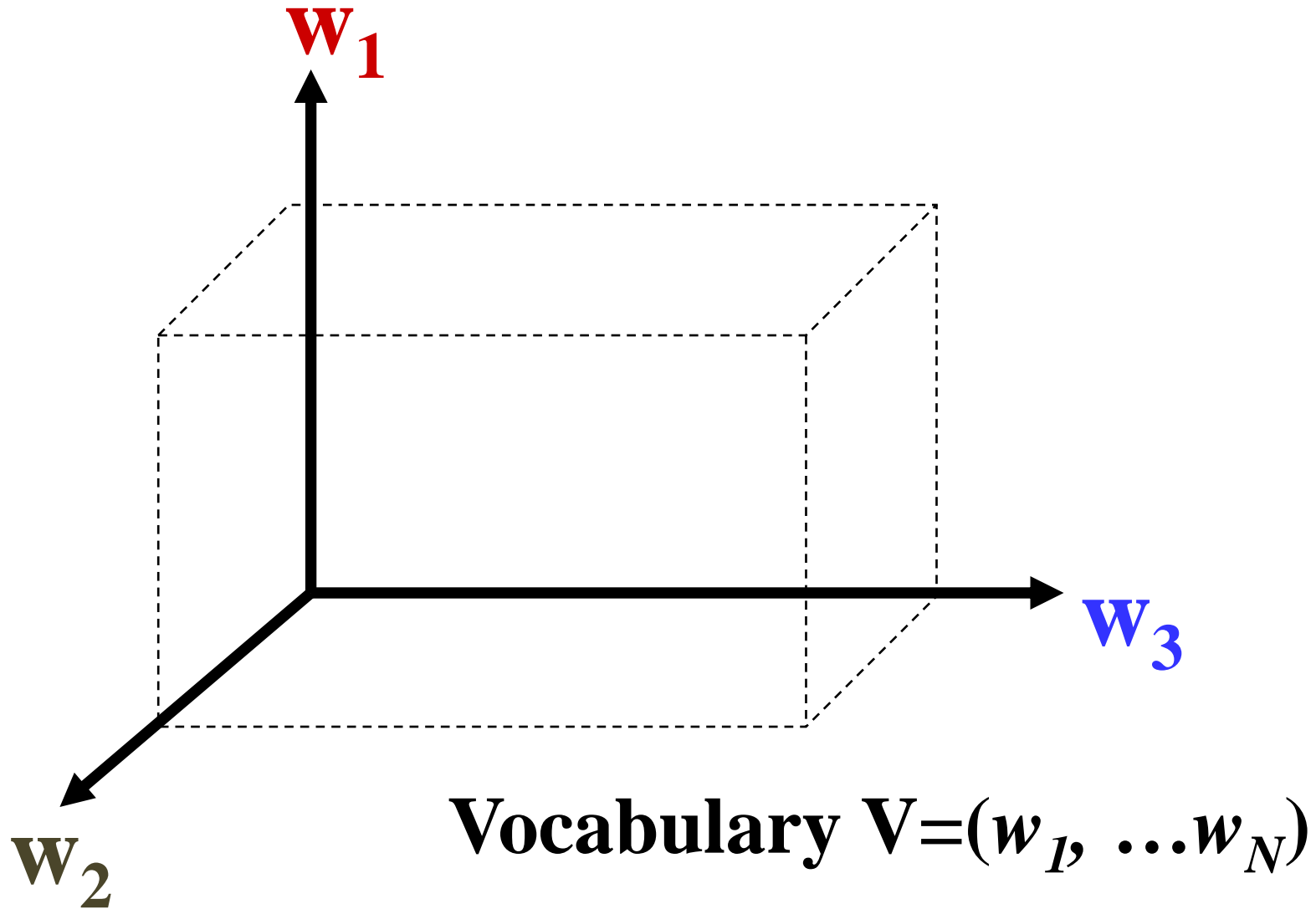
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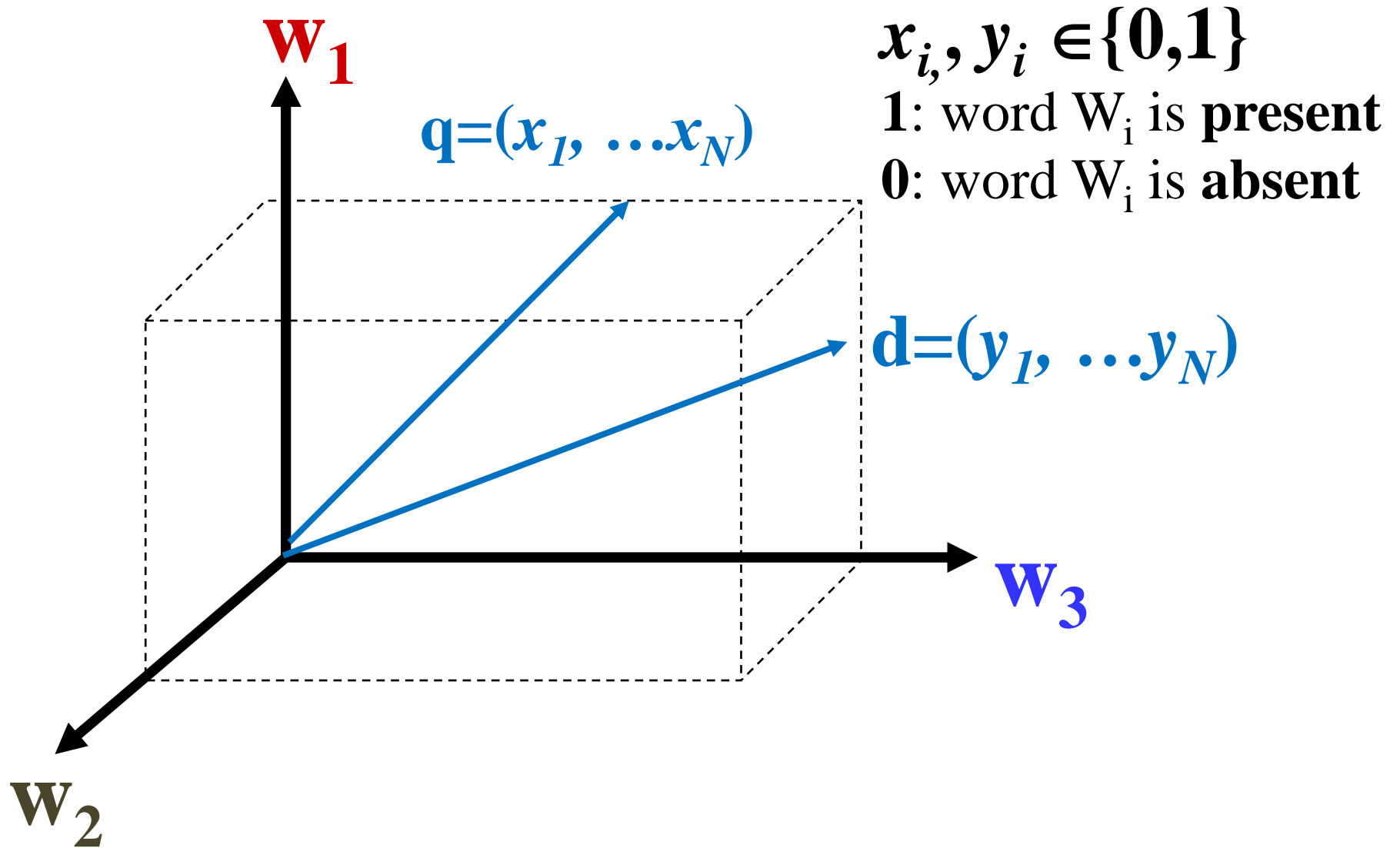
What VSM Doesn't Say



Dimension Instantiation: Bag of Words (BOW)

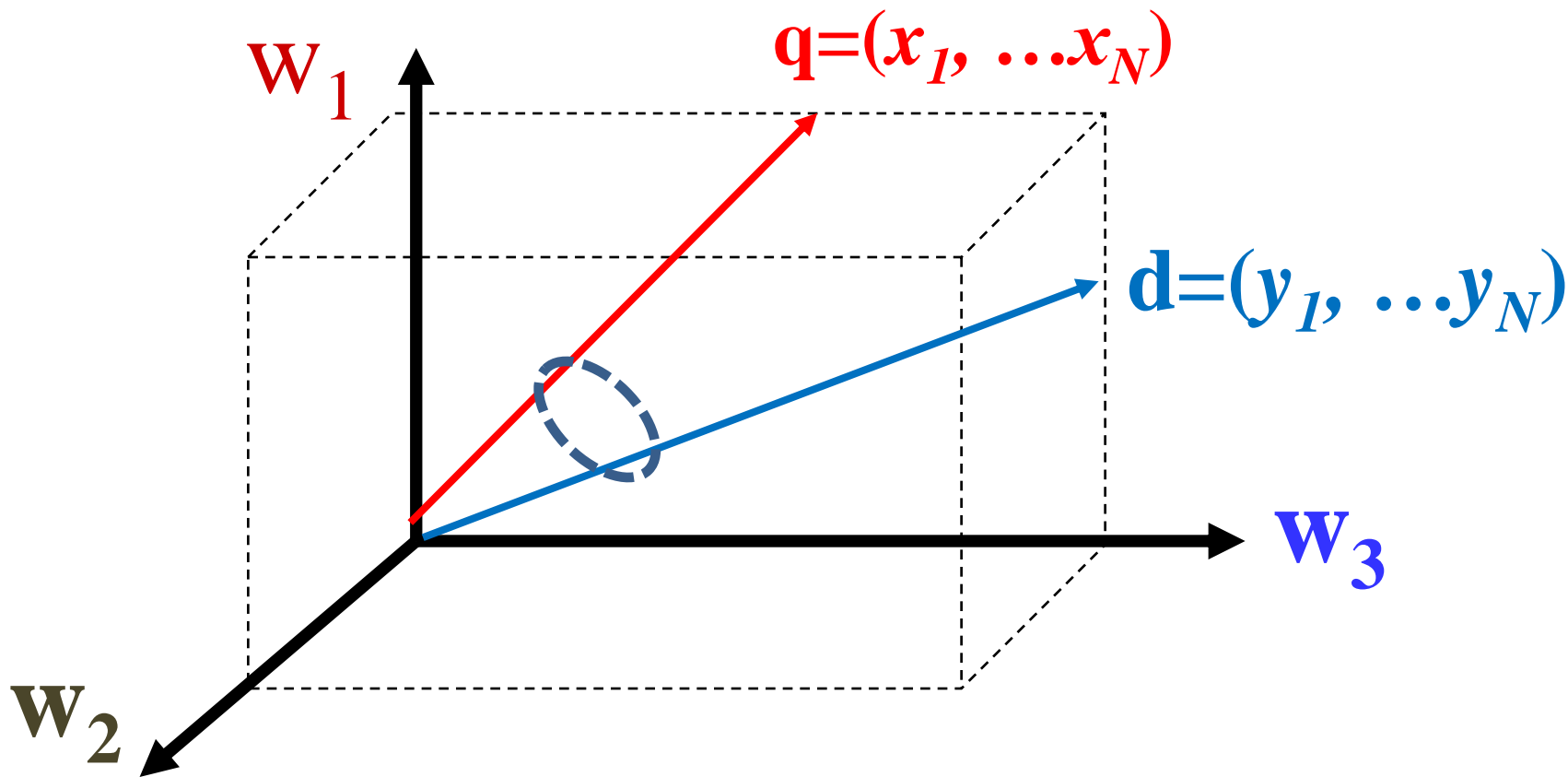


Vector Placement: Bit Vector



Similarity Instantiation: Dot Product

$$\text{Sim}(\mathbf{q}, \mathbf{d}) = \mathbf{q} \cdot \mathbf{d} = x_1 y_1 + \dots + x_N y_N = \sum_{i=1}^N x_i y_i$$



Simplest VSM= Bit-Vector + Dot-Product + BOW

$$\begin{aligned} \mathbf{q} &= (x_1, \dots, x_N) & x_i, y_i &\in \{0, 1\} \\ \mathbf{d} &= (y_1, \dots, y_N) & 1: \text{word } W_i \text{ is present} \\ & & 0: \text{word } W_i \text{ is absent} \end{aligned}$$

$$\text{Sim}(\mathbf{q}, \mathbf{d}) = \mathbf{q} \cdot \mathbf{d} = x_1 y_1 + \dots + x_N y_N = \sum_{i=1}^N x_i y_i$$

What does this ranking function intuitively capture?
Is this a good ranking function?

An Example: How Would You Rank These Documents?

Query = “**news about presidential campaign**”

Ideal Ranking?

d1	... news about ...	d4 +
		d3 +
d2	... news about organic food campaign ...	
d3	... news of presidential campaign ...	
d4	... news of presidential campaign presidential candidate ...	d1 -
		d2 -
d5	... news of organic food campaign ... campaign ... campaign ... campaign ...	d5 -

Ranking Using the Simplest VSM

Query = “**news about presidential campaign**”

d1 ... **news about** ...

d3 ... **news** of **presidential campaign** ...

$V = \{\text{news, about, presidential, campaign, food ...}\}$

$q = (1, 1, 1, 1, 0, \dots)$

$d1 = (1, 1, 0, 0, 0, \dots)$

$f(q, d1) = 1*1 + 1*1 + 1*0 + 1*0 + 0*0 + \dots = 2$

$d3 = (1, 0, 1, 1, 0, \dots)$

$f(q, d3) = 1*1 + 1*0 + 1*1 + 1*1 + 0*0 + \dots = 3$

Is the Simplest VSM Effective?

Query = “news about presidential campaign”

d1	... news about ...	$f(q, d1)=2$
d2	... news about organic food campaign ...	$f(q, d2)=3$
d3	... news of presidential campaign ...	$f(q, d3)=3$
d4	... news of presidential campaign presidential candidate ...	$f(q, d4)=3$
d5	... news of organic food campaign ... campaign ... campaign ... campaign ...	$f(q, d5)=2$

Summary

- VSM instantiation: dimension, vector placement, similarity
- Simplest VSM
 - Dimension = word
 - Vector = 0-1 bit vector (word presence/absence)
 - Similarity = dot product
 - $f(q,d)$ = number of **distinct** query words matched in d