Text-Only Databases

Or at least primarily text

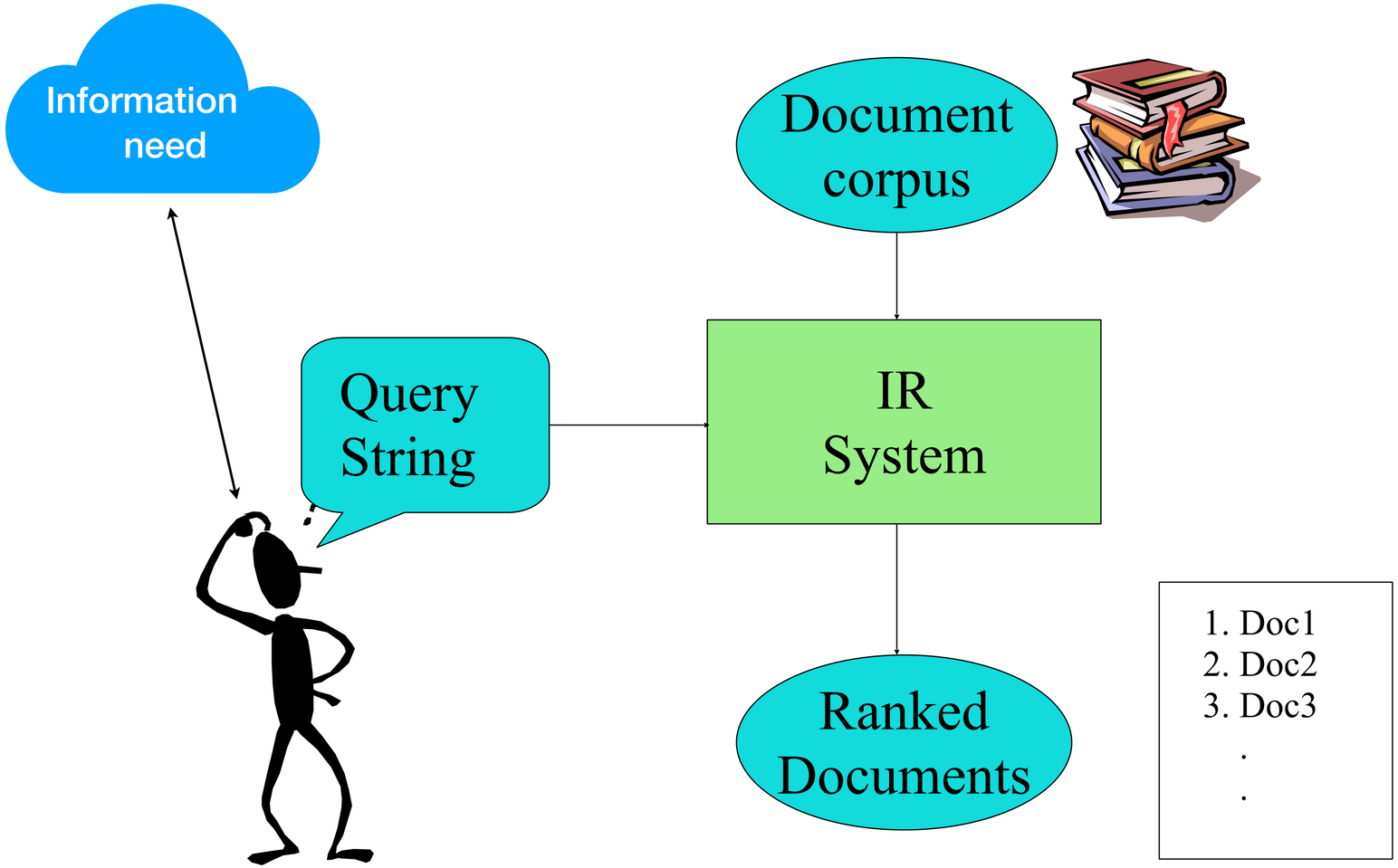
Information Retrieval

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

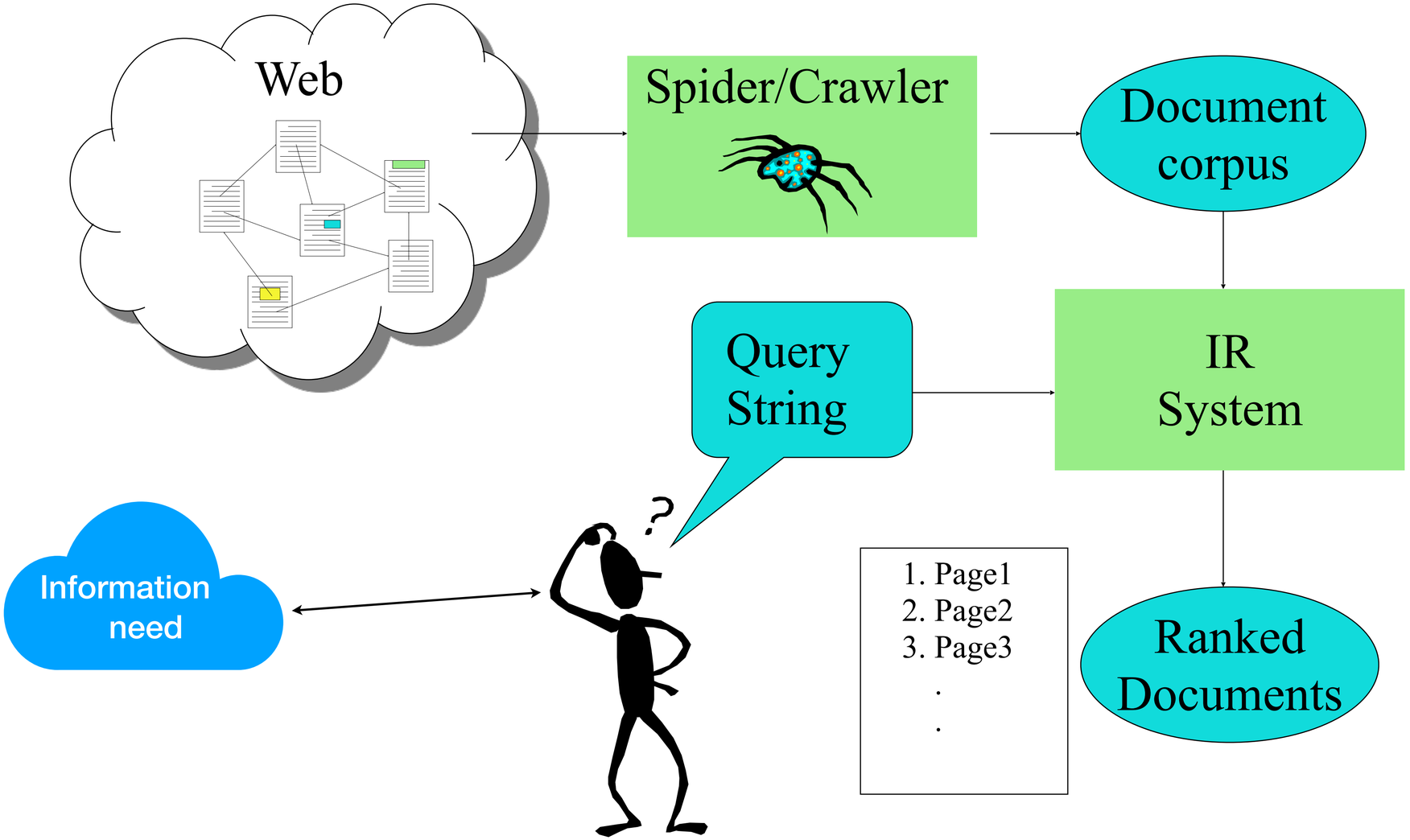
Information Retrieval (IR)

- The indexing and retrieval of textual documents.
- Concerned firstly with retrieving *relevant* documents to a query.
- Concerned secondly with retrieving from *large* sets of documents *efficiently*.

IR System


Information need
Document corpus
Query String
IR System
Ranked Documents
1. Doc1
2. Doc2
3. Doc3
.
.

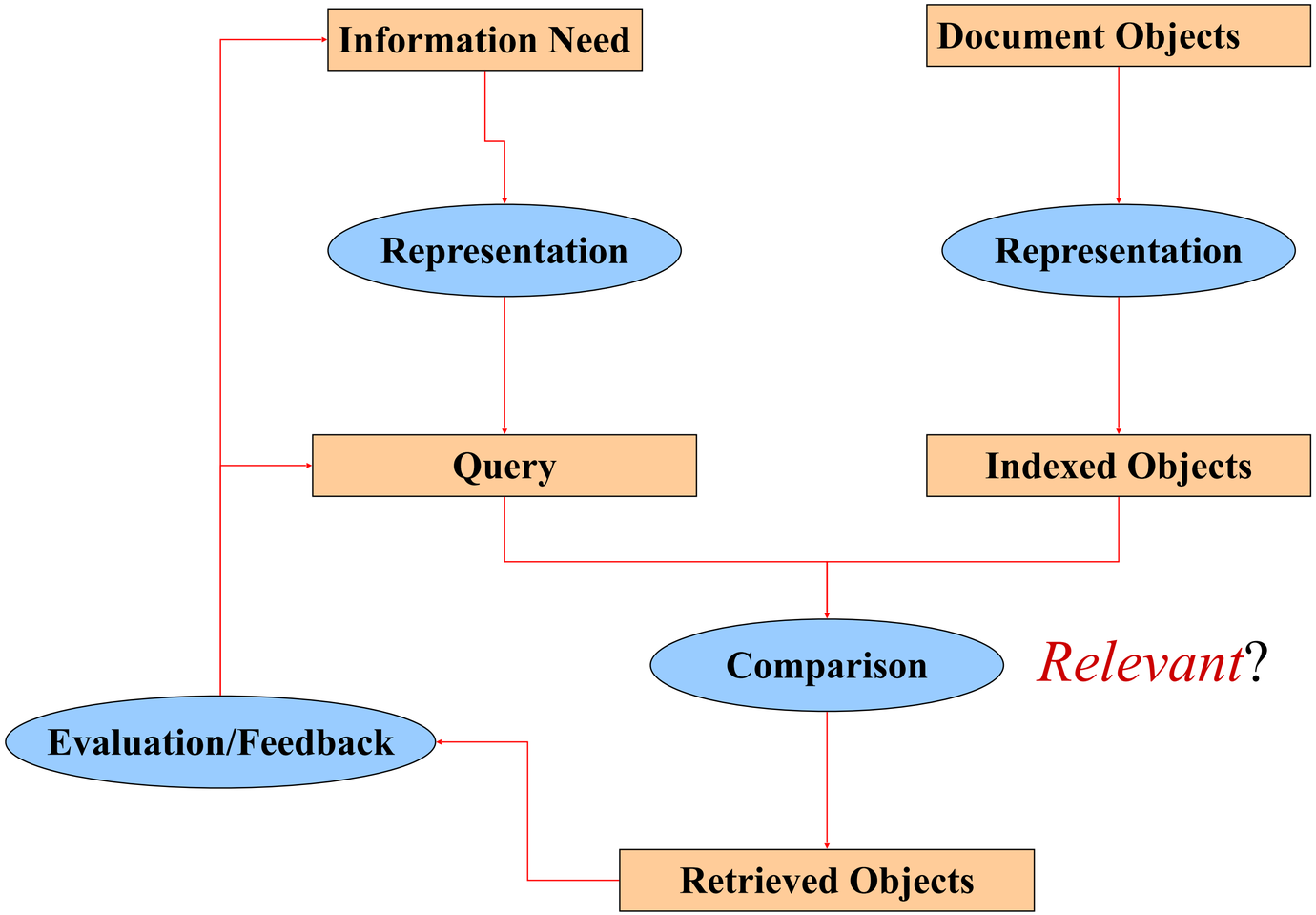
Web Search System



IR v. Database Systems

- Emphasis on effective, efficient retrieval of unstructured (or semi-structured) data
- IR systems typically have very simple schemas
- Query languages emphasize free text and Boolean combinations of keywords
- Matching is more complex than with structured data (semantics is less obvious)
  - easy to retrieve the wrong objects
  - need to measure the accuracy of retrieval
- Less focus on concurrency control and recovery (although update is very important).

Information Retrieval as a Process



Keyword Search

- Simplest notion of relevance is that the query string appears verbatim in the document.
- Slightly less strict notion is that the words in the query appear frequently in the document, in any order (*bag of words*).

Problems with Keywords

- May not retrieve relevant documents that include synonymous terms.
  - “restaurant” vs. “café”
  - “PRC” vs. “China”
- May retrieve irrelevant documents that include ambiguous terms.
  - “bat” (baseball vs. mammal)
  - “Apple” (company vs. fruit)
  - “bit” (unit of data vs. act of eating)

Indexing

- Indexing is the process of transforming items (documents) into a searchable data structure
  - creation of document surrogates to represent each document
  - requires analysis of original documents
    - simple: identify meta-information (e.g., author, title, etc.)
    - complex: linguistic analysis of content

- The search process involves correlating user queries with the documents represented in the index

On what should you index?

- Entire document? Documents have many parts!
- Undifferentiated?
  - handle meta-information separately?
    what is meta-information for books
  - if not separate, how to merge?
- What about the web?
  - link text? Usually not even written by the author!

Index Terms or “Features”

- Most common feature types:
  - Words in text
  - N-grams — (consecutive substrings) of a document
  - Manually assigned terms (controlled vocabulary)
  - Document structure (sentences & paragraphs)
  - Inter- or intra-document links (e.g., citations)
- Composed features
  - Feature sequences (phrases, names, dates, monetary amounts)
  - Feature sets (e.g., synonym classes, concept indexing)
  - Bi-Grams and Tri-Grams
    - there are lots
      - Google TriGram corpus — min freq 40
        - 1-Grams about 13 million — 185 M
        - 2-Grams about 31,000,000 items
        - 3-Grams about 97,000,000 items

Basic Automatic Indexing

1. Parse documents to recognize structure
   - e.g. title, date, other fields
2. Scan for word tokens (Tokenization)
   - lexical analysis using finite state automata(?)
   - numbers, special characters, hyphenation, capitalization, etc.
   - languages like Chinese need *segmentation* since there is not explicit word separation
   - record positional information for *proximity* operators
3. *Stopword* removal
   - based on short list of common words such as “the”, “and”, “or”
   - saves storage overhead of very long postings lists
   - can be dangerous (e.g. “Mr. The”, “and-or gates”)

Basic Automatic Indexing

4. Stem words
   - morphological processing to group word variants such as plurals
   - better than string matching (e.g. comput*)
   - can make mistakes but generally preferred
5. Weight words
   - using frequency in documents and database
   - frequency data is independent of retrieval model
6. Optional
   - phrase indexing / positional indexing
   - thesaurus classes / concept indexing

Tokenization

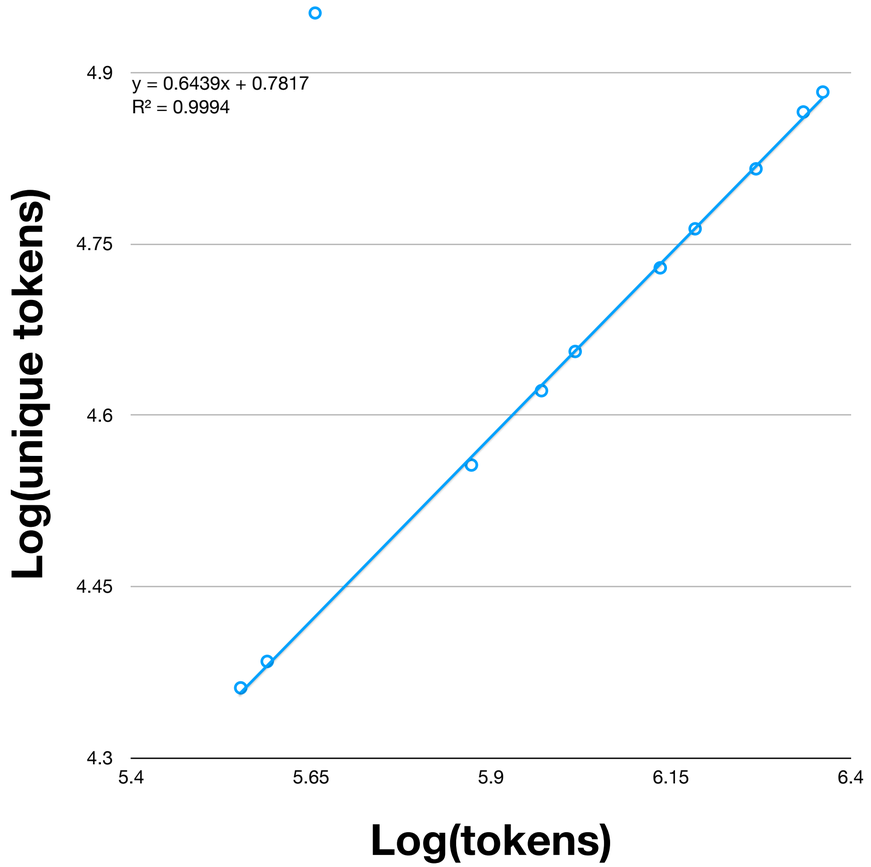
- Turn text strings into searchable items
  - remove suffixes (Stemming)
    - Should you stem??
      - As opposed to stemming, just use N-grams
  - Numbers?
  - Punctuation
    - U.S.A.
    - State-of-the-art
- Fix Misspellings?
  - Tempting to say “yes always”.
    - Sometimes misspelling are highly diagnostic.
      - Misspellings of names — how do you even know?

Stop words

- Idea: exclude from the dictionary the list of words with little semantic content: a, and, or , how, where, to, ….
  - They tend to be the most common words: 30 most common words account for 30% of all words
- But the trend is away from doing this:
  - Good compression techniques means the space for including stop words in a system is very small
  - Good query optimization techniques mean you pay little at query time for including stop words
  - You need them for:
    - Phrase queries: “King of Denmark”
    - Various titles, etc.: “Let it be”, “To be or not to be”
    - “Relational” queries: “flights to London”
  - Google often ignores common words and characters such as where, the, how, and other digits and letters which slow down your search without improving the results.” (Though you can explicitly ask for them to remain)

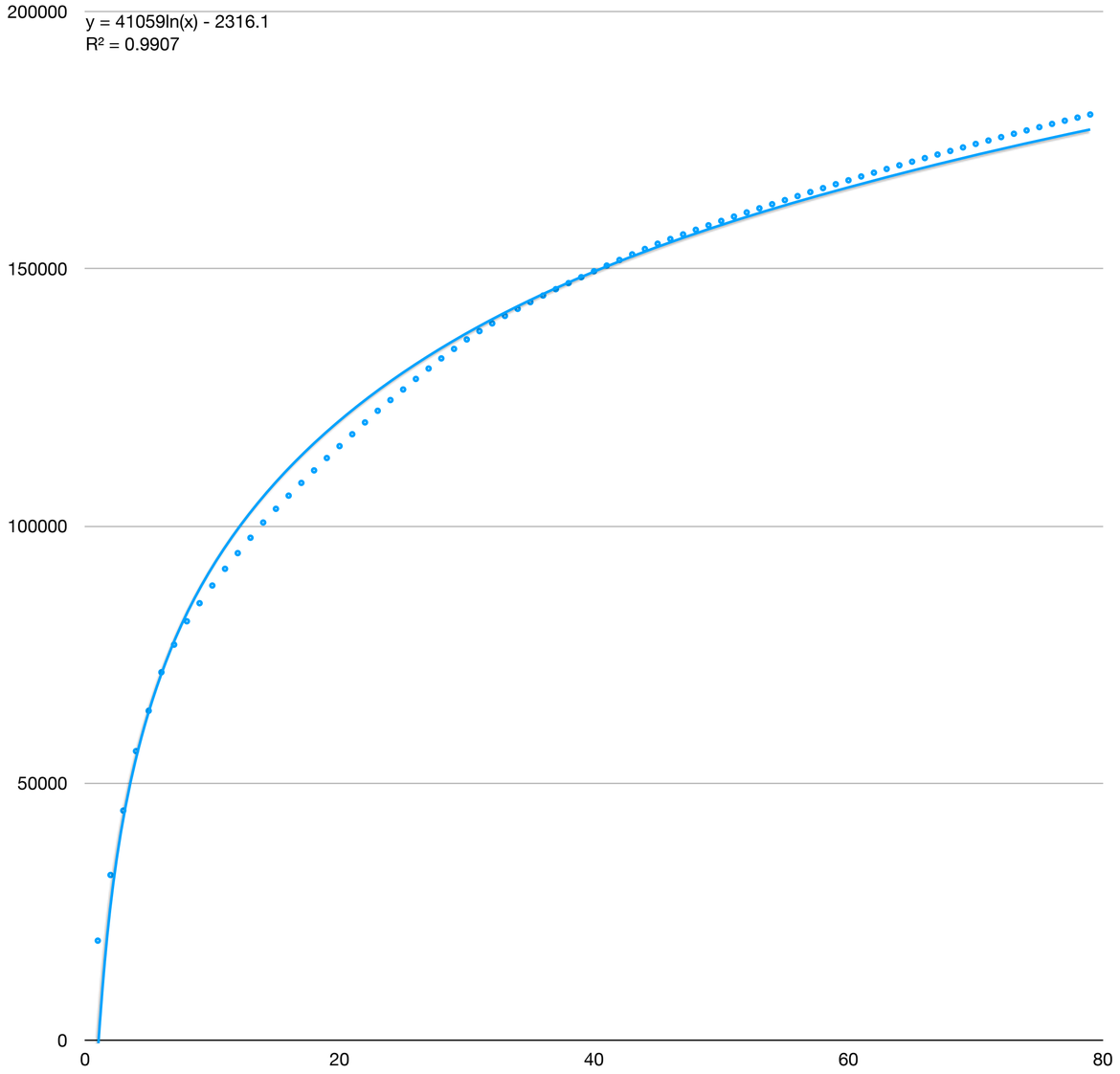
Heaps’ Law & Dickens

- **Heaps' (Herdan's) Law (1960):**
  - **Vocabulary size is a function of collection size.**
- M = kT^b
  - M = vocabulary
  - k = constant
    - typically 30-100
  - T = collection size (just wc)
  - b rate of growth.
    - Typically 0.5
- Dickens
  - k = 6.02 (10^0.78)
  - b = 0.64



Zipf’s law

- the frequency of any word is inversely proportional to its rank in the frequency table
- George Zipf 1935
  - but it predates him
- Zipf's law is asymptotically equivalent to Heaps law



Retrieval Models

- A retrieval model specifies the details of:
  - Document representation
  - Query representation
  - Retrieval function
- Determines a notion of relevance.
- Notion of relevance can be binary or continuous (i.e. *ranked retrieval*).

Statistical Models

- A document is typically represented by a *bag of words* (unordered words with frequencies).

- Bag = set that allows multiple occurrences of the same element.

- User specifies a set of desired terms with optional weights:

  - Weighted query terms:
    Q = < database 0.5; text 0.8; information 0.2 >
  - Unweighted query terms:
    Q = < database; text; information >
  - No Boolean conditions specified in the query.

Statistical Retrieval

- Retrieval based on *similarity* between query and documents.
- Output documents are ranked according to similarity to query.
  - Google?
- Similarity based on occurrence *frequencies* of keywords in query and document.

Google ranking

- Quality Content: The most important SEO factor. Google wants to show users high-quality, informative, and relevant content.
- Backlinks: Links from other websites to your website. They act like votes of confidence. The more high-quality backlinks you have, the higher your website will rank.
- Technical SEO: The technical aspects of your website, such as its website speed, mobile-friendliness, and crawlability. Make sure your website is technically sound so that search engines can easily index and understand your content.
- Keyword Optimization: The process of using relevant keywords throughout your website's content. This helps search engines understand what your website is about.
- User Experience (UX): A measure of how easy and enjoyable it is for users to use your website. Google wants to show users websites that provide a good UX.
- Schema Markup: A type of structured data that you can add to your website to help search engines better understand your content.
- Social Signals: The likes, shares, and other social interactions that your website's content receives. Make sure your website is shareable and encourages social interaction.
- Brand Signals: The overall perception of your brand online. Make sure your brand is well-known and respected.
- Domain Age: Many SEOs believe that Google inherently "trusts" older domains. However, Google's John Mueller has said "domain age helps nothing".
- 2. Keyword Appears in Top Level Domain: Having a keyword in your domain name doesn't give you the SEO boost that it used to. But it still acts as a relevancy signal.
- 3. Domain registration length: A Google patent states: "Valuable (legitimate) domains are often paid for several years in advance, while doorway (illegitimate) domains rarely are used for more than a year. Therefore, the date when a domain expires in the future can be us factor in predicting the legitimacy of a domain."
- Keyword in Subdomain: Moz's expert panel agrees that a keyword appearing in the subdomain can boost rankings.
- Domain History: A site with volatile ownership or several drops may tell Google to "reset" the site's history, negating links pointing to the domain. Or, in certain cases, a penalized domain may carry the penalty over to the new owner.
- Exact Match Domain: Exact Match Domains probably have little to no direct SEO benefit. But if your EMD happens to be a low-quality site, it's vulnerable to the EMD update.
- Public vs. Private WhoIs: Private WhoIs information may be a sign of "something to hide". Googler Matt Cutts is quoted as stating:
- Penalized WhoIs Owner: If Google identifies a particular person as a spammer it makes sense that they would scrutinize other sites owned by that person.
- Country TLD extension: Having a Country Code Top Level Domain (.cn, .pt, .ca) can sometimes help the site rank for that particular country… but it can limit the site's ability to rank globally.
- Keyword in Title Tag: Although not as important as it once was, your title tag remains an important on-page SEO signal.
- Title Tag Starts with Keyword: According to Moz, title tags that start with a keyword tend to perform better than title tags where the keyword appears at the end of the tag.
- Keyword in Description Tag: Google doesn't use the meta description tag as a direct ranking signal. However, your description tag can impact click-through-rate, which is a key ranking factor.
- Keyword Appears in H1 Tag: H1 tags are a "second title tag". Along with your title tag, Google uses your H1 tag as a secondary relevancy signal, according to results from one correlation study:
- **TF-IDF: A fancy way of saying: "How often does a certain word appear in a document?". The more often that word appears on a page, the more likely it is that the page is about that word. Google likely uses a sophisticated versi TF-IDF.**
- Content Length: Content with more words can cover a wider breadth and are likely preferable in the algorithm compared to shorter, superficial articles. Indeed, one recent ranking factors industry study found that the average first page Google result was about 1400 words length.
- Table of Contents: Using a linked table of contents can help Google better understand your page's content. It can also result in sitelinks:
- **Latent Semantic Indexing Keywords in Content (LSI): LSI keywords help search engines extract meaning from words that have more than one meaning (for example: Apple the computer company vs. Apple the fruit) presence/absence of LSI probably also acts as a content quality signal.**
- **LSI Keywords in Title and Description Tags: As with webpage content, LSI keywords in page meta tags probably help Google discern between words with multiple potential meanings. May also act as a relevancy signa**
- Page Covers Topic In-Depth: There's a clear correlation between depth of topic coverage and Google rankings. Therefore, pages that cover every angle likely have an edge vs. pages that only cover a topic partially.
- Page Loading Speed via HTML: Both Google and Bing use page speed as a ranking factor. Google now uses actual Chrome user data to evaluate loading speed.
- Use of AMP: While not a direct Google ranking factor, AMP may be a requirement to rank in the mobile version of the Google News Carousel.
- Entity Match: Does a page's content match the "entity" that a user is searching for? If so, that page may get a rankings boost for that keyword.
- Google Hummingbird: This "algorithm change" helped Google go beyond keywords. Thanks to Hummingbird, Google can now better understand the topic of a webpage.
- Duplicate Content: Identical content on the same site (even slightly modified) can negatively influence a site's search engine visibility.
- Rel=Canonical: When used properly, use of this tag may prevent Google from penalizing your site for duplicate content.
- Image Optimization: Images send search engines important relevancy signals through their file name, alt text, title, description and caption. Optimizing your images for search is critical to ensure they are able to be indexed properly.
- Content Recency: Google Caffeine update favors recently published or updated content, especially for time-sensitive searches. Highlighting this factor's importance, Google shows the date of a page's last update for certain pages:
- Magnitude of Content Updates: The significance of edits and changes also serves as a freshness factor. Adding or removing entire sections is more significant than switching around the order of a few words or fixing a typo.
- Historical Page Updates: How often has the page been updated over time? Daily, weekly, every 5 years? Frequency of page updates also play a role in freshness.
- Keyword Prominence: Having a keyword appear in the first 100 words of a page's content is correlated to first page Google rankings.
- Keyword in H2, H3 Tags: Having your keyword appear as a subheading in H2 or H3 format may be another weak relevancy signal. In fact, Googler John Mueller states:

https://backlinko.com/google-ranking-factors

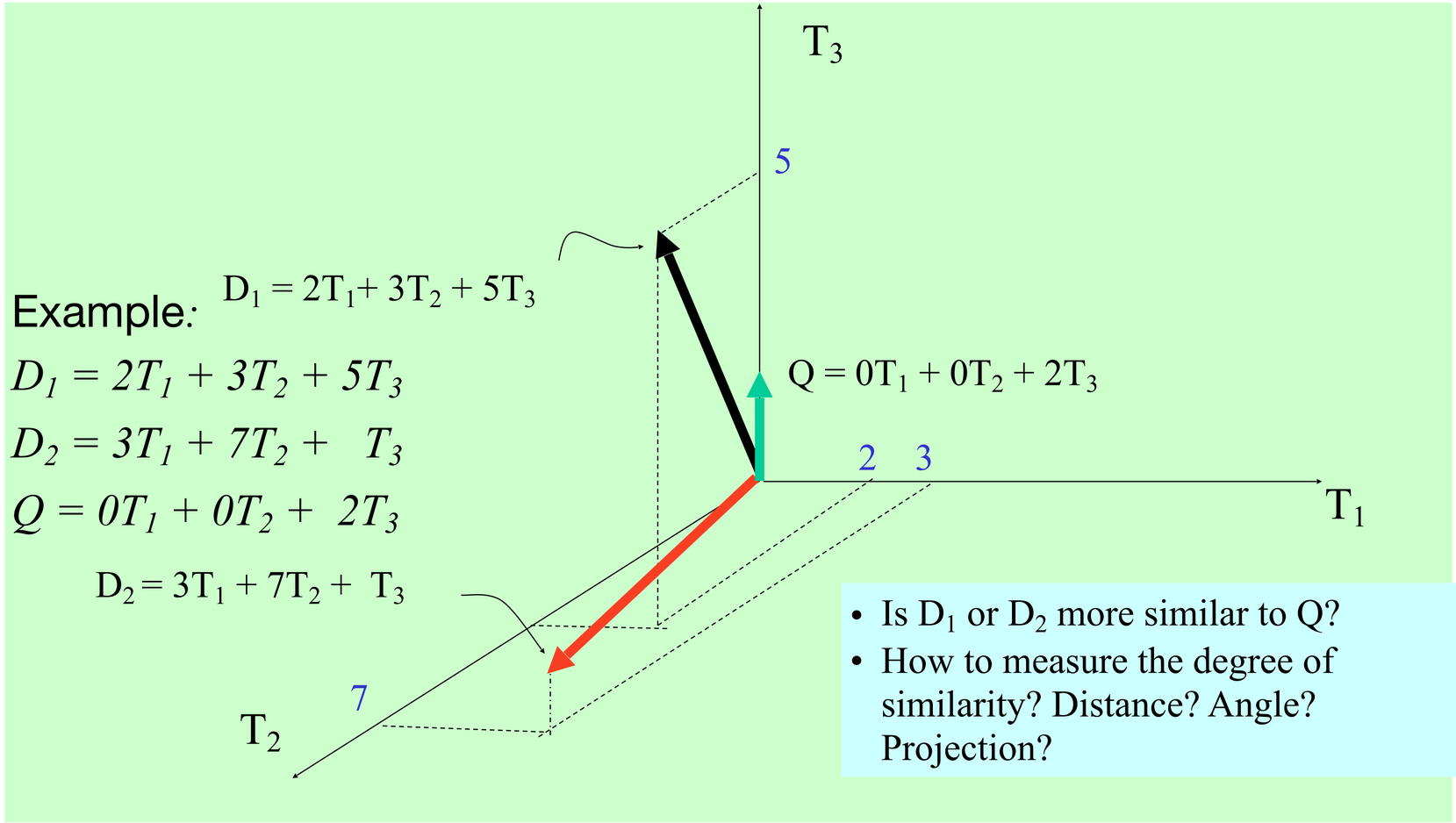
The Vector-Space Model

- Assume t distinct terms remain after preprocessing; call them index terms or the vocabulary.
- These "orthogonal" terms form a vector space.

  Dimensionality = t = |vocabulary|
- Each term, i, in a document or query, j, is given a real-valued weight, $w_{ij.}$
- Both documents and queries are expressed as t-dimensional vectors:

  $d_j = (w_{1j}, w_{2j}, \ldots, w_{tj})$

Graphic Representation



Issues for Vector Space Model

- How to determine important words in a document?
  - Word sense?
  - Word n-grams (and phrases, idioms,…) → terms
- How to determine the degree of importance of a term within a document and within the entire collection?
- How to determine the degree of similarity between a document and the query?
- In the case of the web, what is the collection and what are the effects of links, formatting information, etc.?

Term Weights: Term Frequency

- More frequent terms in a document are more important, i.e. more indicative of the topic.

  f_{ij} = frequency of term i in document j

- May want to normalize *term frequency* (*tf*) by dividing by the frequency of the most common term in the document:

  $tf_{ij} = f_{ij} / max_i\{f_{ij}\}$

Term Weights:

Inverse Document Frequency

- Terms that appear in many *different* documents are *less* indicative of overall topic.

  df_i = document frequency of term i

  = number of documents containing term i

  idf_i = inverse document frequency of term i,

  = $\log_2 (N/ df_i)$

  (N: total number of documents)

- An indication of a term's *discrimination* power.
- Log used to dampen the effect relative to *tf*.

TF-IDF Weighting

- A typical combined term importance indicator is *tf-idf weighting*:

$$w_{ij} = tf_{ij}\, idf_i = tf_{ij} \log_2 (N/ df_i)$$

- A term occurring frequently in the document but rarely in the rest of the collection is given high weight.

- Many other ways of determining term weights have been proposed.

- Experimentally, *tf-idf* has been found to work well.

Computing TF-IDF -- An Example

Given a document containing terms with given frequencies:

A(3), B(2), C(1)

Assume collection contains 10,000 documents and

document frequencies of these terms are:

A(50), B(1300), C(250)

Then:

A: tf = 3/3; idf = $\log_2$(10000/50) = 7.6; tf-idf = 7.6

B: tf = 2/3; idf = $\log_2$ (10000/1300) = 2.9; tf-idf = 2.0

C: tf = 1/3; idf = $\log_2$ (10000/250) = 5.3; tf-idf = 1.8

Similarity Measure
Inner Product

- Similarity between vectors for the document $\boldsymbol{d}_i$ and query $\boldsymbol{q}$ can be computed as the vector inner product (a.k.a. dot product):

$$\text{sim}(\boldsymbol{d}_j, \boldsymbol{q}) = \boldsymbol{d}_j \bullet \boldsymbol{q} = \sum_{i=1}^{t} w_{ij} w_{iq}$$

where w_{ij} is the weight of term i in document j and w_{iq} is the weight of term i in the query

- For binary vectors, the inner product is the number of matched query terms in the document (size of intersection).
- For weighted term vectors, it is the sum of the products of the weights of the matched terms.

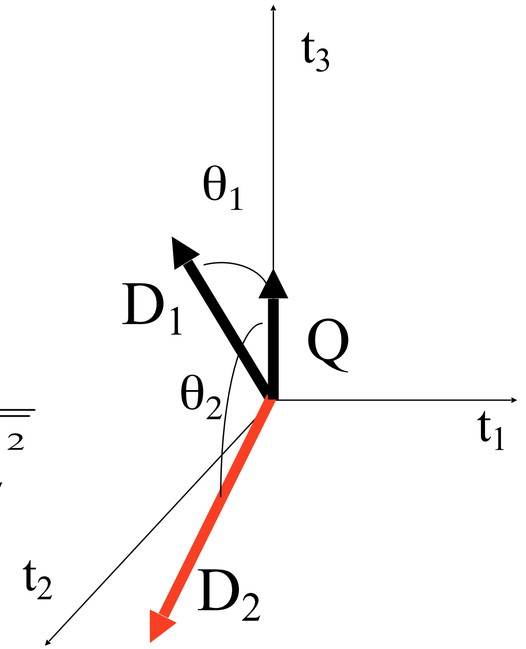
Properties of Inner Product

- The inner product is unbounded.
- Favors long documents with a large number of unique terms.
- Measures how many terms matched but not how many terms are *not* matched.

Cosine Similarity Measure

- Cosine similarity measures the cosine of the angle between two vectors.
- Inner product normalized by the vector lengths.

$$\text{CosSim}(\mathbf{d}_j, \mathbf{q}) = \frac{\sum_{i=1}^{t} (w_{ij} \cdot w_{iq})}{\sqrt{\sum_{i=1}^{t} w_{ij}^2 \cdot \sum_{i=1}^{t} w_{iq}^2}}$$



$D_1 = 2T_1 + 3T_2 + 5T_3$ $\quad \text{CosSim}(D_1, Q) = 10 / \sqrt{(4+9+25)(0+0+4)} = 0.81$

$D_2 = 3T_1 + 7T_2 + 1T_3$ $\quad \text{CosSim}(D_2, Q) = 2 / \sqrt{(9+49+1)(0+0+4)} = 0.13$

$Q = 0T_1 + 0T_2 + 2T_3$

D_1 is 6 times better than D_2 using cosine similarity but only 5 times better using inner product.

Simple Implementation

Convert all documents in collection D to *tf-idf* weighted vectors, $\boldsymbol{d}_j$, for keyword vocabulary V.

Convert query to a *tf-idf*-weighted vector $\boldsymbol{q}$.

For each $\boldsymbol{d}_j$ in D do

Compute score s_j = cosSim($\boldsymbol{d}_j$, $\boldsymbol{q}$)

Sort documents by decreasing score.

Present top ranked documents to the user.

Time complexity: O(|V|·|D|) Bad for large V & D !

|V| = 10,000; |D| = 100,000; |V|·|D| = 1,000,000,000