Web Search

COMP90049
Knowledge Technologies

Lea Frermann and Justin Zobel and Karin Verspoor, CIS

Semester 2, 2019

THE UNIVERSITY OF MELBOURNE

Housekeeping

Mid-semester Test

- **(slight) Time change!**
  Friday Aug 30, 8.20-9.20am (exam start: 8.30 sharp)
- on the desk: pens, studentID
- write your student ID on the exam sheet
- may use blank pages of the exam, but **clearly indicate which Q you're answering!**
- directions (Kwong Lee Dow):
  `https://maps.unimelb.edu.au/parkville/building/263`

Housekeeping

Assignment 1

- Another small glitch, see updated candidates.txt (no more dictionary words)

Housekeeping

Assignment 1

- Another small glitch, see updated candidates.txt (no more dictionary words)

Workshops

- please only attend workshops you're registered for
- if problem persists, we'll go through name lists!

Roadmap

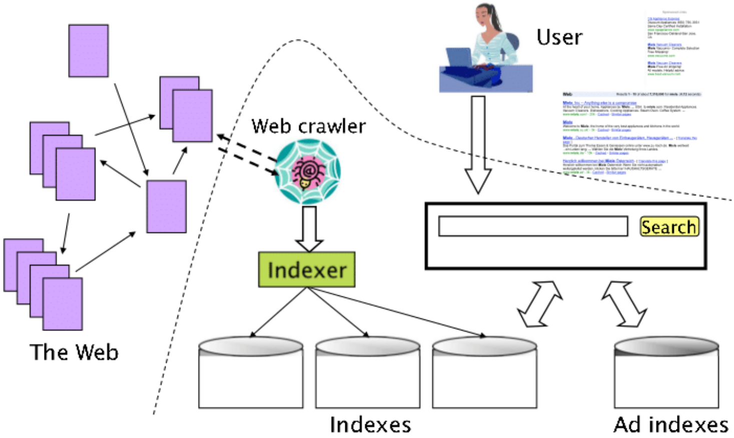
Last week(s): Information retrieval methods and metrics

- ...general view – information (type) and resource can be diverse
- how to measure relevance (similarity)?
- how to evaluate performance?
- **models** of IR

This week: Web Search

- IR specific to the web (huge!)
- IR specific to text-based information (messy!)
- How to store lots of messy information in a useful way?
- How to retrieve efficiently?
- Later on (probably) some (more) recent developments (knowledge graphs, ...)

Elements of a web search engine



Manning et al. (2008) *Introduction to Information Retrieval.* Cambridge University Press (p. 434)

Elements of a web search engine

Web search involves four main technological components.

Crawling: the data to be searched needs to be gathered from the web.

Parsing: the data then needs to be translated into a canonical form.

Indexing: data structures must be built to allow search to take place efficiently.

Querying: the data structures must be processed in response to queries.

Elements of a web search engine

Web search involves four main technological components.

Crawling: the data to be searched needs to be gathered from the web.

Parsing: the data then needs to be translated into a canonical form.

Indexing: data structures must be built to allow search to take place efficiently.

Querying: the data structures must be processed in response to queries.

Next lecture: overview of advanced topics

- link structure (page rank)
- knowledge graphs
- advertising

Crawling fundamentals

Before a document can be queried, the search engine must know that it exists.

- On the web, this is achieved by crawling.
  (Web crawlers are also known as spiders, robots, and bots.)

Crawling fundamentals

Before a document can be queried, the search engine must know that it exists.

- On the web, this is achieved by crawling.
  (Web crawlers are also known as spiders, robots, and bots.)
- Crawlers attempt to visit every page of interest and retrieve them for processing and indexing.

Crawling fundamentals

Before a document can be queried, the search engine must know that it exists.

- On the web, this is achieved by crawling.
  (Web crawlers are also known as spiders, robots, and bots.)
- Crawlers attempt to visit every page of interest and retrieve them for processing and indexing.
- Basic challenge: there is no central index of URLs of interest.

Crawling fundamentals

Before a document can be queried, the search engine must know that it exists.

- On the web, this is achieved by crawling.
  (Web crawlers are also known as spiders, robots, and bots.)
- Crawlers attempt to visit every page of interest and retrieve them for processing and indexing.
- Basic challenge: there is no central index of URLs of interest.
- Secondary challenges:
  - same content as a new URL
  - never return status 'done' on access
  - websites not intended to be crawled
  - content generated on-the-fly from databases → costly for the content provider → excessive visits unwelcome
  - Some content has a short lifespan
  - Some regions and content providers have low bandwidth.

Crawling

The web is a highly linked graph $\rightarrow$ effective harvesting

Assumption: if a web page is of interest, there will be a link to it from another page.

Crawling

The web is a highly linked graph → effective harvesting

Assumption: if a web page is of interest, there will be a link to it from another page.

Corollary: given a sufficiently rich set of starting points, every interesting site on the web will be reached eventually.

Crawling

The web is a highly linked graph $\rightarrow$ effective harvesting

Assumption: if a web page is of interest, there will be a link to it from another page.

In principle:

Create a prioritised list L of URLs to visit
Create a list V of URLs that have been visited and when.

Repeat forever:

1. Choose a URL u from L and fetch the page $p(u)$ at location u.
2. Parse and index $p(u)$
   Extract URLs $\{u'\}$ from $p(u)$.
3. Add u to V and remove it from L
   Add $\{u'\} - V$ to L.
4. Process V to move expired or 'old' URLs to L.

Crawling

The web is a highly linked graph $\rightarrow$ effective harvesting

Assumption: if a web page is of interest, there will be a link to it from another page.

In principle:

> Create a **prioritised** list L of URLs to visit
> Create a list V of URLs that have been visited and when.

Repeat forever:

1. Choose a URL u from L and
2. Parse and index $p(u)$
   Extract URLs $\{u'\}$ from $p(u)$
3. Add u to V and remove it fro
   Add $\{u'\} - V$ to L.
4. Process V to move expired or 'old' URLs to L.

- Every page is visited eventually.
- Synonym URLs are disregarded.
- Significant or dynamic pages are visited sufficiently frequently.
- The crawler isn't cycling indefinitely in a single web site (caught in a crawler trap).

Crawling

The web is a highly linked graph $\rightarrow$ effective harvesting

Assumption: if a web page is of interest, there will be a link to it from another page.

In principle:

> Create a **prioritised** list L of URLs to visit
> Create a list V of URLs that have been visited and when.

Repeat forever:

1. Choose a URL u from L and fetch the page $p(u)$ at location u.
2. Parse and index $p(u)$
   Extract URLs $\{u'\}$ from $p(u)$
3. Add u to V and remove it fro
   Add $\{u'\} - V$ to L.
4. Process V to move expired or 'old' URLs to L.

page processing is much faster than URL resolution, so numerous streams of pages should be processed simultaneously

Challenges

Crawler traps are surprisingly common. For example, a 'next month' link on a calendar can potentially be followed until the end of time.

Challenges

Crawler traps are surprisingly common. For example, a ‘next month’ link on a calendar can potentially be followed until the end of time.

The **Robots Exclusion Standard:** protocol that all crawlers are supposed to observe. It allows website managers to restrict access to crawlers while allowing web browsing.

Challenges

Crawler traps are surprisingly common. For example, a ‘next month’ link on a calendar can potentially be followed until the end of time.

The **Robots Exclusion Standard:** protocol that all crawlers are supposed to observe. It allows website managers to restrict access to crawlers while allowing web browsing.

Simple crawlers are now part of programming languages, for example Perl’s `LibWWW`, and good crawlers are available as part of systems such as `Nutch`.

Page recognition

Once a document has been fetched, it must be **parsed**.

That is, the ~~words~~ tokens in the document are **extracted**, then added to a data structure that records which documents contain which ~~words~~ tokens.

Page recognition

Once a document has been fetched, it must be **parsed**.

That is, the ~~words~~ tokens in the document are **extracted**, then added to a data structure that records which documents contain which ~~words~~ tokens.

At the same time, information such as **links and anchors** can be analysed, **formats** such as PDF or Postscript or Word can be translated, the **language** of the documents can be identified, and so on.

Page recognition

Once a document has been fetched, it must be **parsed**.

First step: determining the format of the page.

The most basic element is the **character encoding**, which has to be captured in the page's metadata.

- For the first decade or so of the web, most pages were in ASCII. (Want to travel in time? Try the **Wayback Machine**. `http://web.archive.org/web/19970501*/https://www.unimelb.edu.au/`)
- HTML markup was used to provide an extended character set.
- ISO-8859 and ISO-8859-* now provide extended Latin character sets (Cyrillic, Thai, Greek, . . .)
- UTF-8 is the dominant character set covering the large-alphabet languages, with codes from 8 to 32 bits. The first 128 of the 8-bit codes are ASCII.

Page analysis

Web pages are supposed to be in HTML or XML (or sometimes in other formats, hence `ftp://` and so on).

The format separates user-visible content from metadata.

Page analysis

Web pages are supposed to be in HTML or XML (or sometimes in other formats, hence `ftp://` and so on).

The format separates user-visible content from metadata.

Many, many websites are not.

- accidental errors
- deliberate attempt to take advantage of known browser behaviour

(improved slightly due to the prevalence of Web publishing software; this also produces non-conformant HTML surprisingly often.)

Parsers therefore need to be robust and flexible.

Page analysis

Scraping

- only some components of the page are considered
- e.g., ignore ads or comments (on a news website)
- only article content is retained

Invisible content

- e.g., white text on white background, non-displayed HTML content
- designers actively seek to avoid indexing invisible content
- misleading for users
- allows spoofing

Tokenisation

Tokenisation

Tokenisation


```
<head>
<META NAME="keywords" CONTENT="science humor, science humour, science,
humor, humour, ig-nobel, ig nobel, ignobel, hotair, hot-air, hot air,
improbable research">
<META HTTP-EQUIV="expires" CONTENT="0">
<title>HotAIR - Rare and well-done tidbits from the Annals of
Improbable Research</title>
</head>

<a href="/navstrip/about.html">About AIR</a>
| <a href="/navstrip/subscribe.html"><font color="red">Subscribe</font></a>
| <a href="http://improbable.typepad.com/">Our blog </a>
| <a href="/navstrip/schedule.shtml">Events calendar</a>
| <a href="/navstrip/contact.html">Contact us</a>
| <a href="/navstrip/google-search.html">Search</a>
<hr>

<img src="/toplevel/banner-2004.gif" width="406" height="200"
alt="The Annals of Improbable Research: HotAIR">

<tr>
<td colspan=2 align="center">
<b><br><b>NOTE THIS:  JoAnn O'Linger-Luscusk and Alasdair
Skelton have <a href="/projects/hair/hair-club-top.html#newest">joined</a>
the Hair Club</b>
</td> </tr>
```

hotair rare and well done tidbits from the annals of improbable research note this joann o linger luscusk and alasdair skelton have joined the hair club

Tokenisation

reduce a web page, or a query, to a sequence of tokens.

- ideally: query tokens will match parsed website tokens $\rightarrow$ query evaluation without approximate matching.

Tokenisation

reduce a web page, or a query, to a sequence of tokens.

- ideally: query tokens will match parsed website tokens → query evaluation without approximate matching.
- Websites typically have reasonably well-formed sentences; should make parsing straightforward. **But** (in English):
  - **Hyphenation**. Is 'Miller-Zadek' one word or two? Is 'under-coating'? 'Re-initialize'? 'Under-standing'?
  - **Compounding.** Is 'football' one word or two? 'Footballgame'?
  - **Possessives.** Is 'Zadek's' meant to be 'Zadek' or 'Zadeks'? 'Smiths'?
  - Other languages have different issues.

Tokenisation

reduce a web page, or a query, to a sequence of tokens.

- ideally: query tokens will match parsed website tokens $\rightarrow$ query evaluation without approximate matching.
- Websites typically have reasonably well-formed sentences; should make parsing straightforward. **But** (in English):
  - **Hyphenation**. Is 'Miller-Zadek' one word or two? Is 'under-coating'? 'Re-initialize'? 'Under-standing'?
  - **Compounding.** Is 'football' one word or two? 'Footballgame'?
  - **Possessives.** Is 'Zadek's' meant to be 'Zadek' or 'Zadeks'? 'Smiths'?
  - Other languages have different issues.
- **ambiguities**: 'listen to the wind' vs. 'wind up the clock'; 'apple (fruit)' vs. 'apple (computer)'.
- particularly difficult in queries (context!)

Canonicalisation

Indexing process that relies on fact extraction needs information in a **canonical form**

Tokenisation (usually) entails canonicalising the underlying **wordform**.

Canonicalisation

Indexing process that relies on fact extraction needs information in a **canonical form**

But **other information** may also need to be canonicalised, including:

- Dates. Consider 5/4/2011, 4/5/2011, April 5 2011, first Tuesday in April 2001.
- Numbers. 18.230,47 versus 18,230.47. Or 18 million versus 18,000,000.
- Variant spelling. Color versus colour.
- Variant usage. Dr versus Doctor. (What is the top match for `Dr Who` under Google?)
- Variant punctuation. 'e.g.' versus 'eg'.

- removing stop words ('content-free' terms such as `the`, `or`, and so on) (controversial!)
- delete 'weird tokens' from queries (e.g., $>$ 64 characters)

Stemming

Arguably the most significant form of canonicalisation (for English words)

$$\text{inexpensive} \rightarrow \text{in+expense+ive}$$

- attempt to undo the processes that lead to word formation
- no guarantee that the resulting stem looks like a “word”
- words in English are derived from a root or **stem**
- challenge: every word has a different set of legal suffixes
- result does not necessarily look like a proper ‘word’ (cf., **lemmatization**)

Stemming

Arguably the most significant form of canonicalisation (for English words)

inexpensive → in+expense+ive

- attempt to undo the processes that lead to word formation
- no guarantee that the resulting stem looks like a “word”
- words in English are derived from a root or **stem**
- challenge: every word has a different set of legal suffixes
- result does not necessarily look like a proper ‘word’ (cf., **lemmatization**)

suffix stripping (Porter Stemmer)

- `sses` → `ss`
- `ies` → `i`
- `tional` → `tion`
- `tion` → `t`

Stemming

NLTK Stemming Demo!

https://text-processing.com/demo/stem/

Zoning

Web documents can usually be segmented into discrete zones such as **title, anchor text, headings**, and so on.

Parsers also consider issues such as **font size**, to determine which text is most prominent on the page and thus generate further zones.

Web search engines typically calculate **weights** for each of these zones, and compute similarities for documents by combining these results on the fly.

Web search engines tend to favour pages with the **query terms in titles**.

Indexing

Index

- for fast query evaluation
- data structure that maps terms to the documents that contain them
- e.g., index of a book maps term $\rightarrow$ page numbers
- allows to restrict processing to documents which contain query term(s)
- many different types of index have been suggested

Indexing

The only practical index structure for text query evaluation is the **inverted index**

- collection of lists (one per term)
- each containing IDs of documents containing that term
- aka “term-document matrix” (but more efficient representation)

(There’s nothing fundamentally different between a ‘forward’ and an ‘inverted’ index.)

Inverted index components

Conceptually,

- we want a structure which can process query terms
- find document(s) that contain term
- access the resulting documents

We require three elements

- the search structure (vocabulary)
- an inverted list for each term in the vocabulary
- a mapping table of document identifiers to documents

(By convention, the "inverted index" refers to just the inverted lists.)

Inverted index components

Search structure

For each distinct word t, the search structure contains:

- A pointer to the start of the corresponding inverted list.
- A count f_t of the documents containing t.

That is, the search structure contains the vocabulary.

Inverted index components

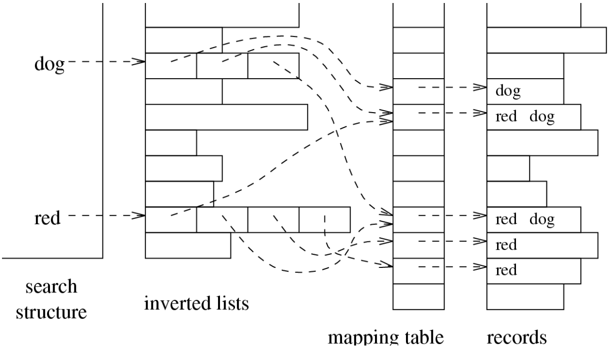
Inverted lists

For each distinct word t, the inverted list contains:

- The identifiers d of documents containing t, as ordinal numbers.
- The associated frequency $f_{d,t}$ of t in d.
  (We could instead store $w_{d,t}$ or $w_{d,t}/W_d$.)

Example inverted index

Together with an array of W_d values (stored separately), the search structure and inverted index provide all the information required for Boolean and ranked query evaluation.



Example inverted index

For example:

We few, we happy few, we band of brothers

$$\langle \text{a}, \text{aardvark}, \ldots, \text{band}, \ldots, \text{brothers}, \ldots, \text{few}, \ldots, \text{happy}, \ldots \rangle$$

$$\langle 0, 0, \ldots, 1, \ldots, 1, \ldots, 2, \ldots, 1, \ldots \rangle$$

Example inverted index

Inverted index (one document):

band	$\rightarrow$	(1,1)
brothers	$\rightarrow$	(1,1)
few	$\rightarrow$	(1,2)
happy	$\rightarrow$	(1,1)
of	$\rightarrow$	(1,1)
we	$\rightarrow$	(1,3)

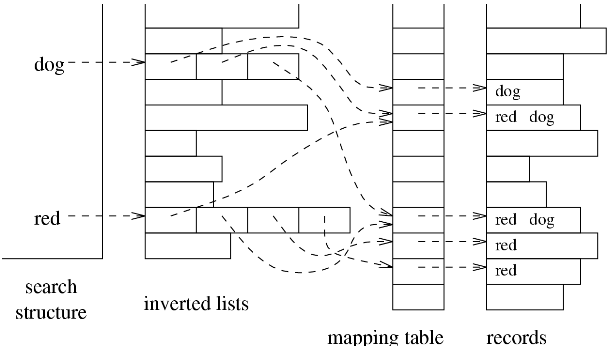
Example inverted index

Inverted index (multiple documents):

$$
\begin{array}{llllll}
\ldots & & & & & \\
\text{band} & \to \ldots & \to & (d, f_{d,\text{band}}) & \to & \ldots \\
\ldots & & & & & \\
\text{brothers} & \to \ldots & \to & (d, f_{d,\text{brothers}}) & \to & \ldots \\
\ldots & & & & & \\
\text{few} & \to \ldots & \to & (d, f_{d,\text{few}}) & \to & \ldots \\
\ldots & & & & & \\
\text{happy} & \to \ldots & \to & (d, f_{d,\text{happy}}) & \to & \ldots \\
\ldots & & & & & \\
\text{of} & \to \ldots & \to & (d, f_{d,\text{of}}) & \to & \ldots \\
\ldots & & & & & \\
\text{we} & \to \ldots & \to & (d, f_{d,\text{we}}) & \to & \ldots \\
\ldots & & & & &
\end{array}
$$

Example inverted index

An inverted index allows for fast querying because:
(1) the terms in the query correspond to the search structure
(2) the index only indicates documents where the term is present



Inverted index size

In a simple representation, for (say) a gigabyte of newswire data,

- 12 MB (say) for 400,000 words, pointers, counts.
- 280 MB for 70,000,000 document identifiers (4 bytes each).
- 140 MB for 70,000,000 document frequencies (2 bytes each).

The total size is 432 MB, or just over 40% of the original data.

For 100 GB of web data, the total size is about 21 GB, or just over 20% of the original text. (Many web pages contain large volumes of unindexed data such as markup.)

Using a term-document matrix (TDM)

- TDM is compact to store (1b per term per document)
- bitwise comparisons are fast
- desirable for modest document collections
- memory issue: consider hundreds of millions of documents
- space waste: most values in the matrix are 0 $\rightarrow$ never used in any comparison

Boolean Querying

Using an inverted index

- Fetch the inverted list for each query term.
- Use intersection of lists to resolve AND.
- Use union of lists to resolve OR.
- Take the complement of a list to resolve NOT (how?).
- Ignore within-document frequencies.

Boolean Querying

Using an inverted index

- Fetch the inverted list for each query term.
- Use intersection of lists to resolve AND.
- Use union of lists to resolve OR.
- Take the complement of a list to resolve NOT (how?).
- Ignore within-document frequencies.

For strictly conjunctive queries

- start with the query term with lowest f_t
- shortest list as a set of candidates
- then eliminate documents that do not appear in the other lists (working from shortest to longest)

Ranked Querying principles

Goal: Document ranking for a typical TF-IDF model

- Cosine as a similarity measure
- $w_{d,t}$: The frequency of each query term in each document (TF)
- f_t: The number of documents where each query term occurs (DF)
- W_d: The length of each document

Ranked Querying principles

Goal: Document ranking for a typical TF-IDF model

- Cosine as a similarity measure
- $w_{d,t}$: The frequency of each query term in each document (TF)
- f_t: The number of documents where each query term occurs (DF)
- W_d: The length of each document

Typical cosine:

$$S(q,d) = \frac{q \cdot d}{|q||d|} = \frac{\sum_i q_i \cdot d_i}{|q||d|}$$

- calculate the dot product
- divide by the vector lengths
- length of the query q is often ignored (constant)

Ranked Querying principles

Goal: Document ranking for a typical TF-IDF model

- Cosine as a similarity measure
- $w_{d,t}$: The frequency of each query term in each document (TF)
- f_t: The number of documents where each query term occurs (DF)
- W_d: The length of each document

Typical cosine:

$$S(q,d) = \frac{q \cdot d}{|q||d|} = \frac{\sum_i q_i \cdot d_i}{|q||d|}$$

Non-boolean TDM (32 bits per term per document): is too large to contemplate for a typical document collection on the WWW

Inverted index is not designed to allow us to compare documents one at a time.

Ranked Querying using an inverted index

Inverted index to evaluate a query under the **cosine measure**,

1. Allocate an accumulator A_d for each document d initialize $A_d \leftarrow 0$.
2. For each query term t,
    1. Calculate $w_{q,t}$, and fetch the inverted list for t.
    2. For each pair $\langle d_t, f_{d,t} \rangle$ in the inverted list
       Calculate $w_{d,t}$, and
       Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$
3. Read the array of W_d values
   for each $A_d > 0$, set $A_d \leftarrow A_d / W_d$.
4. Identify the r greatest A_d values and return the corresponding documents.

Ranked Querying using an inverted index

Inverted index to evaluate a query under the **cosine measure**,

1. Allocate an **accumulator** A_d for each document d initialize $A_d \leftarrow 0$.
2. For each query term t,
   1. Calculate $w_{q,t}$, and fetch the inverted list for t.
   2. For each pair $\langle d_t, f_{d,t} \rangle$ in the inverted list

      Calculate $w_{d,t}$, and

      Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$
3. Read the array of W_d values

   for each $A_d > 0$, set $A_d \leftarrow A_d / W_d$.
4. Identify the r greatest A_d values and return the corresponding documents.

Ranked Querying using an inverted index

Inverted index to evaluate a query under the **cosine measure**,

1. Allocate an accumulator A_d for each document d initialize $A_d \leftarrow 0$.
2. For each **query term** t,
   1. Calculate $w_{q,t}$, and **fetch the inverted list** for t.
   2. For each pair $\langle d_t, f_{d,t} \rangle$ in the inverted list

      Calculate $w_{d,t}$, and

      Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$
3. Read the array of W_d values

   for each $A_d > 0$, set $A_d \leftarrow A_d / W_d$.
4. Identify the r greatest A_d values and return the corresponding documents.

Ranked Querying using an inverted index

Inverted index to evaluate a query under the **cosine measure**,

1. Allocate an accumulator A_d for each document d initialize $A_d \leftarrow 0$.
2. For each query term t,
    1. Calculate $w_{q,t}$, and fetch the inverted list for t.
    2. For each **pair** $\langle d_t, f_{d,t} \rangle$ **in the inverted list**
       Calculate $w_{d,t}$, and
       Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$ (**increment the accumulator**)
3. Read the array of W_d values
   for each $A_d > 0$, set $A_d \leftarrow A_d / W_d$
4. Identify the r greatest A_d values and return the corresponding documents.

Ranked Querying using an inverted index

Inverted index to evaluate a query under the **cosine measure**,

1. Allocate an accumulator A_d for each document d initialize $A_d \leftarrow 0$.
2. For each query term t,
   1. Calculate $w_{q,t}$, and fetch the inverted list for t.
   2. For each pair $\langle d_t, f_{d,t} \rangle$ in the inverted list

      Calculate $w_{d,t}$, and

      Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$
3. Read the array of W_d values

   for each $A_d > 0$, set $A_d \leftarrow A_d / W_d$ (**normalize by doc length**)
4. Identify the r greatest A_d values and return the corresponding documents.

Ranked Querying using an inverted index

Inverted index to evaluate a query under the **cosine measure**,

1. Allocate an accumulator A_d for each document d initialize $A_d \leftarrow 0$.
2. For each query term t,
   1. Calculate $w_{q,t}$, and fetch the inverted list for t.
   2. For each pair $\langle d_t, f_{d,t} \rangle$ in the inverted list

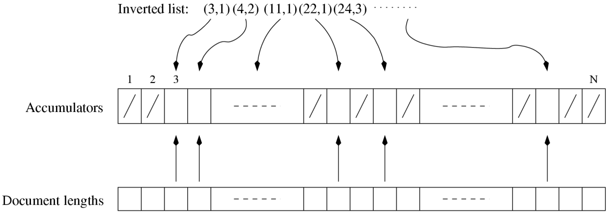
      Calculate $w_{d,t}$, and

      Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$
3. Read the array of W_d values

   for each $A_d > 0$, set $A_d \leftarrow A_d / W_d$
4. Identify the r **greatest** A_d **values** and return the corresponding documents (**ranking!**)

Ranked Querying using an inverted index ...

In a nutshell,



- start with a set of N zero'ed accumulators
- use the inverted lists to update the accumulators term by term
- use the document lengths to normalize each non-zero accumulator

Accumulator costs

With the standard query evaluation algorithm and long queries, **most accumulators are non-zero** and an **array** is the **most space- and time-efficient** structure.

But the majority of those accumulator values are **trivially small**, with the only matching terms being **one or more common words**. And note that the accumulators are required on a per-query basis.

Accumulator costs

With the standard query evaluation algorithm and long queries, **most accumulators are non-zero** and an **array** is the **most space- and time-efficient** structure.

But the majority of those accumulator values are **trivially small**, with the only matching terms being **one or more common words**. And note that the accumulators are required on a per-query basis.

If only low f_t (that is, **rare) terms are allowed to create accumulators**, the number of accumulators is greatly reduced.

A simple mechanism is to impose a **limit** L **on the number of accumulators**. This is another example of an efficiency-driven **compromise** that **alters the set of documents** returned, and may therefore impact on effectiveness.

The “limiting” approach

1. Create an empty set A of accumulators and **set a length limit L**
2. For each query term t, **ordered by decreasing** $w_{q,t}$
    1. Calculate $w_{q,t}$, and fetch the inverted list for t.
    2. For each pair $\langle d_t, f_{d,t} \rangle$ in the inverted list

        If there is no Accumulator for d **and** $|\mathrm{A}|<\mathrm{L}$

            Create an accumulator A_d for d

        If d has an accumulator

            Calculate $w_{d,t}$

            Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$
3. For each accumulator set $A_d \leftarrow A_d / W_d$.
4. Identify the r greatest A_d values and return these documents.

There are many variations on these algorithms.

The "thresholding" approach

1. Create an empty set A of accumulators, and **set a threshold** S
2. For each query term t, **ordered by decreasing** $w_{q,t}$
   1. Calculate $w_{q,t}$, and fetch the inverted list for t.
   2. For each pair $\langle d_t, f_{d,t} \rangle$ in the inverted list

      Calculate $w_{d,t}$

      If there is no Accumulator for d **and** $w_{q,t} \times w_{d,t} > S$

          Create an accumulator A_d for d

      If d has an accumulator

          Set $A_d \leftarrow A_d + w_{q,t} \times w_{d,t}$
3. For each accumulator set $A_d \leftarrow A_d / W_d$.
4. Identify the r greatest A_d values and return these documents.

There are many variations on these algorithms.

Querying costs

Several resources must be considered.

Disk space: for the index, at 40% of the size of the data. (With unstemmed terms, the index can be around 80% of the size of the data.)

Memory space: for accumulators, for the vocabulary, and for caching of previous results.

CPU time: for processing inverted lists and updating accumulators.

Disk traffic: to fetch inverted lists.

By judicious use of **compression** and careful **pruning**, all of these costs can be dramatically reduced compared to this first implementation. (Any practical implementation must make some use of compression.)

Readings

Brin, Sergey and Lawrence Page (1998). “The Anatomy of a Large-Scale Hypertextual Web Search Engine”. Computer Networks 30: 107–117.

Barroso, Luiz André, Jeffrey Dean, and Urs Hötzle (2003) “Web Search for a Planet: The Google Cluster Architecture”. IEEE Micro 23 (2): 22–28. doi:10.1109/MM.2003.1196112

Zobel, Justin and Alistair Moffatt (2006). “Inverted Files for Text Search Engines”. ACM Computing Surveys 38 (2): 1–56. doi:10.1145/1132956.1132959

Manning, Christopher D., Prabhakar Raghavan, Heinrich Schütze (2008). “Introduction to Information Retrieval”. Chapters 1–2, 20–21. Cambridge University Press.