CS276A

Information Retrieval

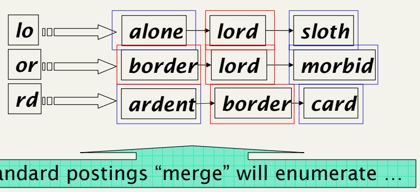
Lecture 5

Plan

- Last lecture: Tolerant retrieval
  - Wildcards
  - Spell correction
  - Soundex
- This time:
  - Index construction

Matching trigrams

- Consider the query ***lord*** – we wish to identify words matching 2 of its 3 bigrams (***lo, or, rd***)



Adapt this to using Jaccard (or another) measure.

Index construction

- How do we construct an index?
- What strategies can we use with limited main memory?

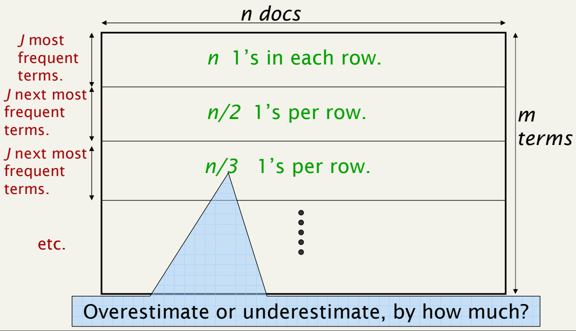
Recall our corpus

- Number of docs = n = 1M
  - Each doc has 1K terms
- Number of distinct terms = m = 500K
- Use Zipf to estimate number of postings entries

Zipf estimation of postings

- Recall the blocks in the matrix of Lecture 3
- Each row corresponds to term
  - Rows ordered by diminishing term frequency
- Each column corresponds to a document
- We broke up the matrix into blocks.
- We are asking: how many 1’s in this matrix?

Rows by decreasing frequency



How many postings?

- Number of 1's in the i th block = nJ/i
- Summing this over m/J blocks, we have

$$\sum_{i=1}^{m/J} nJ/i = nJ\ H_{m/J} \sim nJ \ln m/J.$$

- For our numbers, this should be about 667 million postings.

Recall index construction

- Documents are parsed to extract words and these are saved with the Document ID.

Doc 1

I did enact Julius Caesar I was killed i' the Capitol; Brutus killed me.

Doc 2

So let it be with Caesar. The noble Brutus hath told you Caesar was ambitious

Term	Doc #
I	1
did	1
enact	1
julius	1
caesar	1
I	1
was	1
killed	1
i'	1
the	1
capitol	1
brutus	1
killed	1
me	1
so	2
let	2
it	2
be	2
with	2
caesar	2
the	2
noble	2
brutus	2
hath	2
told	2
you	2
caesar	2
was	2
ambitious	2

Key step

- After all documents have been parsed the inverted file is sorted by terms.

We focus on this sort step.
We have 667M items to sort.

Term	Doc #
I	1
did	1
enact	1
julius	1
caesar	1
I	1
was	1
killed	1
i'	1
the	1
capitol	1
brutus	1
killed	1
me	1
so	2
let	2
it	2
be	2
with	2
caesar	2
the	2
noble	2
brutus	2
hath	2
told	2
you	2
caesar	2
was	2
ambitious	2

Term	Doc #
ambitious	2
be	2
brutus	1
brutus	2
capitol	1
caesar	1
caesar	2
caesar	2
did	1
enact	1
hath	1
I	1
I	1
i'	1
it	2
julius	1
killed	1
killed	1
let	2
me	1
noble	2
so	2
the	1
the	2
told	2
you	2
was	1
was	2
with	2

Index construction

- As we build up the index, cannot exploit compression tricks
  - Parse docs one at a time.
  - <u>Final postings for any term – incomplete until the end</u>.
  - (actually you can exploit compression, but this becomes a lot more complex)
- At 10-12 bytes per postings entry, demands several temporary gigabytes

System parameters for design

- Disk seek ~ 10 milliseconds
- Block transfer from disk ~ 1 microsecond per byte (*following a seek*)
- All other ops ~ 10 microseconds
  - E.g., compare two postings entries and decide their merge order

Bottleneck

- Parse and build postings entries one doc at a time
- Now sort postings entries by term (then by doc within each term)
- Doing this with random disk seeks would be too slow – must sort *n*=667M records

If every comparison took 2 disk seeks, and *n* items could be sorted with $n\log_2 n$ comparisons, how long would this take?

Sorting with fewer disk seeks

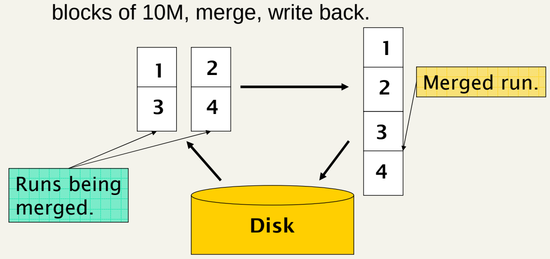
- 12-byte (4+4+4) records *(term, doc, freq)*.
- These are generated as we parse docs.
- Must now sort 667M such 12-byte records by *term*.
- Define a Block ~ 10M such records
  - can "easily" fit a couple into memory.
  - Will have 64 such blocks to start with.
- Will sort within blocks first, then merge the blocks into one long sorted order.

Sorting 64 blocks of 10M records

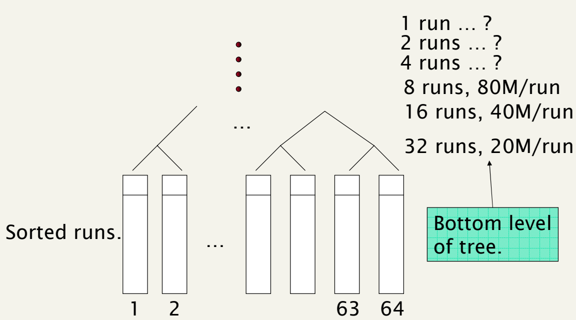
- First, read each block and sort within:
  - Quicksort takes 2*n* ln *n* expected steps
  - In our case 2 x (10M ln 10M) steps
- *Exercise: estimate total time to read each block from disk and and quicksort it.*
- 64 times this estimate - gives us 64 sorted *runs* of 10M records each.
- Need 2 copies of data on disk, throughout.

Merging 64 sorted runs

- Merge tree of $\log_2 64$= 6 layers.
- During each layer, read into memory runs in blocks of 10M, merge, write back.



Merge tree



Merging 64 runs

- Time estimate for disk transfer:
- 6 x (64runs x 120MB x 10^{-6}sec) x 2 ~ 25hrs.

Disk block transfer time. Why is this an Overestimate?

Work out how these transfers are staged, and the total time for *merging*.

Layers in merge tree

Read + Write

Exercise - fill in this table

	Step	Time
1	64 initial quicksorts of 10M records each	
2	Read 2 sorted blocks for merging, write back	
3	Merge 2 sorted blocks	
? 4	Add (2) + (3) = time to read/merge/write	
5	64 times (4) = total merge time	

Large memory indexing

- Suppose instead that we had 16GB of memory for the above indexing task.
- *Exercise: What initial block sizes would we choose? What index time does this yield?*
- *Repeat with a couple of values of n, m.*
- In practice, spidering often interlaced with indexing.
  - Spidering bottlenecked by WAN speed and many other factors - more on this later.

Improvements on basic merge

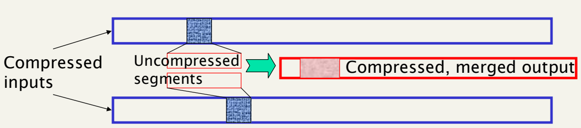
- Compressed temporary files
  - compress terms in temporary dictionary runs
- How do we merge compressed runs to generate a compressed run?
  - Given two γ-encoded runs, merge them into a new γ-encoded run
  - To do this, first γ-decode a run into a sequence of gaps, then actual records:
  - 33,14,107,5… $\rightarrow$ 33, 47, 154, 159
  - 13,12,109,5… $\rightarrow$ 13, 25, 134, 139

Merging compressed runs

- Now merge:
  - 13, 25, 33, 47, 134, 139, 154, 159
- Now generate new gap sequence
  - 13,12,8,14,87,5,15,5
- Finish by γ-encoding the gap sequence
- But what was the point of all this?
  - If we were to uncompress the entire run in memory, we save no memory
  - How do we gain anything?

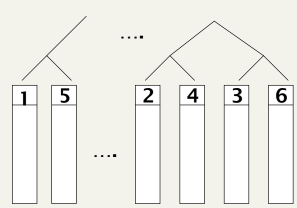
"Zipper" uncompress/decompress

- When merging two runs, bring their γ-encoded versions into memory
- Do NOT uncompress the entire gap sequence at once – only a small segment at a time
  - Merge the uncompressed segments
  - Compress merged segments again



Improving on binary merge tree

- Merge more than 2 runs at a time
  - Merge *k>2* runs at a time for a shallower tree
  - maintain heap of candidates from each run



Dynamic indexing

- Docs come in over time
  - postings updates for terms already in dictionary
  - new terms added to dictionary
- Docs get deleted

Simplest approach

- Maintain "big" main index
- New docs go into "small" auxiliary index
- Search across both, merge results
- Deletions
  - Invalidation bit-vector for deleted docs
  - Filter docs output on a search result by this invalidation bit-vector
- Periodically, re-index into one main index

Issue with big and small indexes

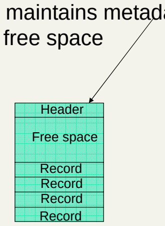
- Corpus-wide statistics are hard to maintain
- E.g., when we spoke of spell-correction: which of several corrected alternatives do we present to the user?
  - We said, pick the one with the most hits
- How do we maintain the top ones with multiple indexes?
  - One possibility: ignore the small index for such ordering
- Will see more such statistics used in results ranking

More complex approach

- Fully dynamic updates
- Only one index at all times
  - No big and small indices
- Active management of a pool of space

Fully dynamic updates

- Inserting a (variable-length) record
  - e.g., a typical postings entry
- Maintain a pool of (say) 64KB *chunks*
- Chunk header maintains metadata on records in chunk, and its free space



Global tracking

- In memory, maintain a global record address table that says, for each record, the chunk it's in.
- Define one chunk to be current.
- Insertion
  - if current chunk has enough free space
    - extend record and update metadata.
  - else look in other chunks for enough space.
  - else open new chunk.

Building positional indexes

- Still a sorting problem (but larger) ← Why?
- Recall the harder exercise of Lecture 3 for estimating the number of positional index entries
- Exercise: given 1GB of memory, how would you adapt the block merge described above?

Building *n*-gram indexes

- As text is parsed, enumerate *n*-grams.
- For each *n*-gram, need pointers to all dictionary terms containing it – the "postings".
- Note that the same "postings entry" can arise repeatedly in parsing the docs – need efficient "hash" to keep track of this.
  - E.g., that the trigram *uou* occurs in the term ***deciduous*** will be discovered on each text occurrence of ***deciduous***

Building *n*-gram indexes

- Once all (*n*-gram∈***term***) pairs have been enumerated, must sort for inversion
- Recall average English dictionary term is ~8 characters
  - So about 6 trigrams per term on average
  - For a vocabulary of 500K terms, this is about 3 million pointers – can compress

Changes to dictionary

- New terms appear over time
  - cannot use a static perfect hash for dictionary
- OK to use term character string w/pointers from postings as in Lecture 3.

Index on disk vs. memory

- Most retrieval systems keep the dictionary in memory and the postings on disk
- Web search engines frequently keep both in memory
  - massive memory requirement
  - feasible for large web service installations
  - less so for commercial usage where query loads are lighter

Indexing in the real world

- Typically, don't have all documents sitting on a local filesystem
  - Documents need to be *spidered*
  - Could be dispersed over a WAN with varying connectivity
  - Must schedule distributed spiders/indexers
  - Could be (secure content) in
    - Databases
    - Content management applications
    - Email applications

Content residing in applications

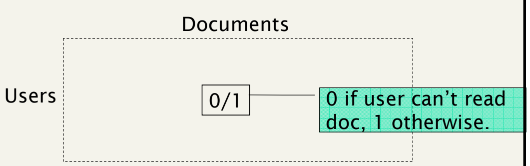
- Mail systems/groupware, content management contain the most “valuable” documents
- http often not the most efficient way of fetching these documents - native API fetching
  - Specialized, repository-specific connectors
  - These connectors also facilitate *document viewing* when a search result is selected for viewing

Secure documents

- Each document is accessible to a subset of users
  - Usually implemented through some form of Access Control Lists (ACLs)
- Search users are authenticated
- Query should retrieve a document only if user can access it
  - So if there are docs matching your search but you’re not privy to them, “Sorry no results found”
  - E.g., as a lowly employee in the company, I get “No results” for the query “salary roster”

Users in groups, docs from groups

- Index the ACLs and filter results by them



- Often, user membership in an ACL group verified at query time – slowdown

Exercise

- Can spelling suggestion compromise such document-level security?
- Consider the case when there are documents matching my query, but I lack access to them.

Compound documents

- What if a doc consisted of *components*
  - Each component has its own ACL.
- Your search should get a doc only if your query meets one of its components that you have access to.
- More generally: doc assembled from *computations* on components
  - e.g., in Lotus databases or in content management systems
- How do you index such docs?

No good answers …

“Rich” documents

- (How) Do we index images?
- Researchers have devised Query Based on Image Content (QBIC) systems
  - “show me a picture similar to this orange circle”
  - watch for lecture on vector space retrieval
- In practice, image search based on meta-data such as file name e.g., monalisa.jpg

Passage/sentence retrieval

- Suppose we want to retrieve not an entire document matching a query, but only a passage/sentence - say, in a very long document
- Can index passages/sentences as mini-documents – what should the index units be?
- More on this when discussing XML search

Next up – scoring/ranking

- Thus far, documents either match a query or do not.
- It's time to become more discriminating - how well does a document match a query?
- Gives rise to ranking and scoring

Resources

- MG Chapter 5