file organization

many slides courtesy James Allan@umass

file organization

- indexes
- bitmaps
- signature files
- inverted files
- wildcards

file organization

Choices for accessing data during query evaluation

- Scan the entire collection
  - Typical in early (batch) retrieval systems
  - Computational and I/O costs are O(characters in collection)
  - Practical for only small text collections
  - Large memory systems make scanning feasible
- Use indexes for direct access
  - Evaluation time O(query term occurrences in collection)
  - Practical for large collections
  - Many opportunities for optimization
  - ML(Nearest Neighbor) research with image databases shows that indexes can be difficult
- Hybrids: Use small index, then scan a subset of the collection

indexes

What should the index contain?

- Database systems index primary and secondary keys
  - This is the hybrid approach
  - Index provides fast access to a subset of database records
  - Scan subset to find solution set

- IR Problem: Cannot predict keys that people will use in queries
  - Every word in a document is a potential search term

- IR Solution: Index by *all* keys (words)

indexes

Index is accessed by the atoms of a query language

- The atoms are called “features” or “keys” or “terms”
- Most common feature types:
  - Words in text, punctuation
  - Manually assigned terms (controlled and uncontrolled vocabulary)
  - Document structure (sentence and paragraph boundaries)
  - Inter- or intra-document links (e.g., citations)
- Composed features
  - Feature sequences (phrases, names, dates, monetary amounts)
  - Feature sets (e.g., synonym classes)
- Indexing and retrieval models drive choices
  - Must be able to construct all components of those models

indexes

Indexing choices (there is no “right” answer)

- What is a word (tokenization)?
  - Embedded punctuation (e.g., *DC-10*, *long-term*, *AT&T*)
  - Case folding (e.g., *New* vs *new*, *Apple* vs *apple*)
  - Stopwords (e.g., *the*, *a*, *its*)
  - Morphology (e.g., *computer*, *computers*, *computing*, *computed*)

- Index granularity has a large impact on speed and effectiveness
  - Index stems only?
  - Index surface forms only?
  - Index both?

indexes

The contents depend upon the retrieval model

- Feature presence/absence
  - Boolean
  - Statistical (*tf, df, ctf, doclen, maxtf)*
  - Often about 10% the size of the raw data, compressed

- Positional
  - Feature location *within* document
  - Granularities include word, sentence, paragraph, etc
  - Coarse granularities are less precise, but take less space
  - Word-level granularity about 20-30% the size of the raw data, compressed

indexes: implementation

Common implementations of indexes

- Bitmaps
- Signature files
- Inverted files

Common index components

- Dictionary (lexicon)
- Postings
  - document ids
  - word positions

indexes: bitmaps

- Bag-of-words index only
- For each term, allocate vector with one bit per document
- If feature present in document *n*, set *n*th bit to 1, otherwise 0
- Boolean operations very fast
- Space efficient for common terms (why?)
- Space inefficient for rare terms (why?)
- Good compression with run-length encoding (why?)
- Difficult to add/delete documents (why?)
- Not widely used

indexes: signature files

- Bag-of-words only
- Also called *superimposed coding*
- For each term, allocate fixed size s-bit vector(*signature*)

- Define hash function:
  - Single function: word $\rightarrow$ $1..2^s$ [sets all s-bits]
  - Multiple functions: word $\rightarrow$ $1..s$ [selects which bits to set]
- Each term has an s-bit signature
  - may not be unique!

- *OR* the term signatures to form document signature
- Long documents are a problem (why?)
  - Usually segment them into smaller pieces

indexes: signature files

Term	Hash string
cold	1000 0000 0010 0100
days	0010 0100 0000 1000
hot	0000 1010 0000 0000
in	0000 1001 0010 0000
it	0000 1000 1000 0010
like	0100 0010 0000 0001
nine	0010 1000 0000 0100
old	1000 1000 0100 0000
pease	0000 0101 0000 0001
porridge	0100 0100 0010 0000
pot	0000 0010 0110 0000
some	0100 0100 0000 0001
the	1010 1000 0000 0000

$\underbrace{\hspace{10em}}_{\text{16 bit signatures}}$

indexes: signature files

Document	Text	Descriptor
1	Pease porridge hot, pease porridge cold,	1100 1111 0010 0101
2	Pease porridge in the pot,	1110 1111 0110 0001
3	Nine days old.	1010 1100 0100 1100
4	Some like it hot, some like it cold,	1100 1110 1010 0111
5	Some like it in the pot,	1110 1111 1110 0011
6	Nine days old.	1010 1100 0100 1100

indexes: signature files

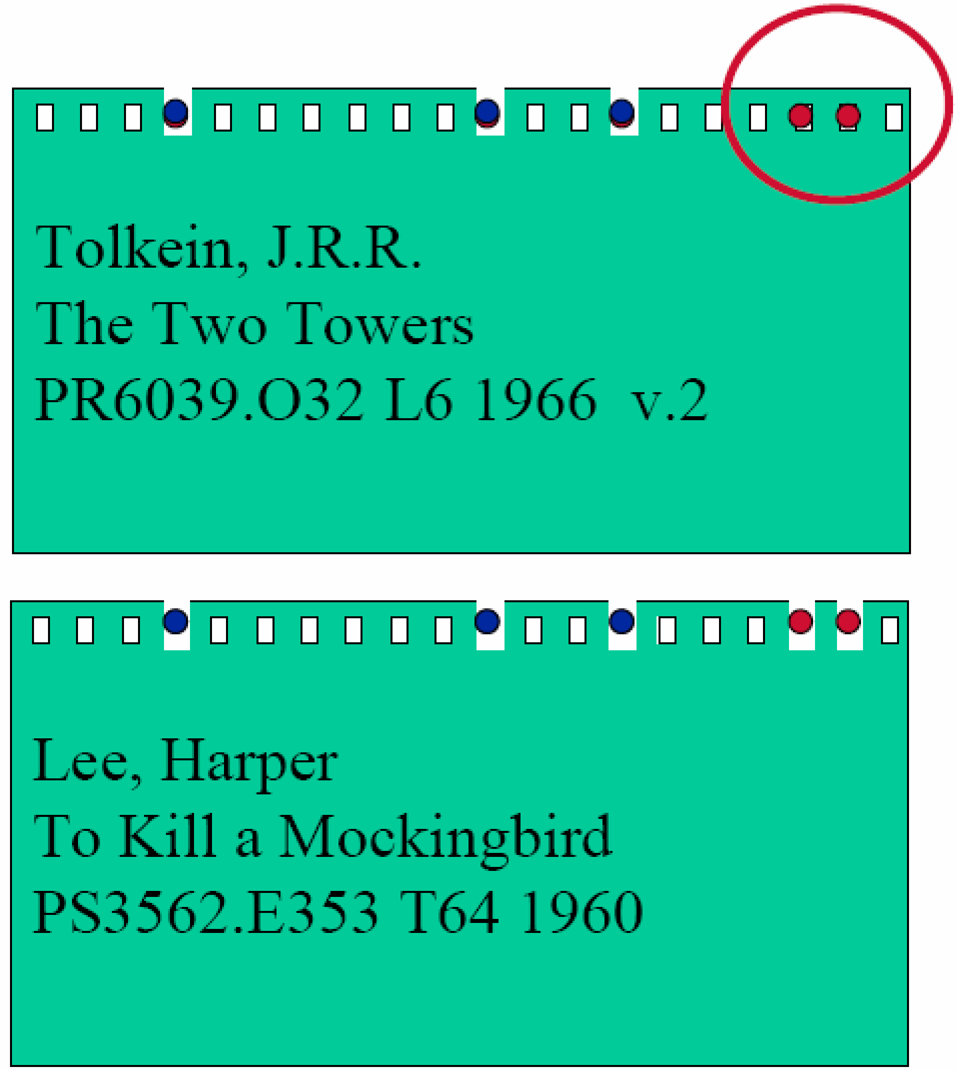
- At query time:
  - Lookup signature for query (how?)
  - If all corresponding 1-bits are “on” in document signature, document *probably* contains that term

- Vary *s* to control Pr[false alarm]
  - Note space tradeoff
- Optimal *s* changes as collection grows (why?)

- Many variations
- Widely studied
- Not widely used

signature files trivia

- Punch card as "card catalogue"
- Punch out bits of signature
  - Tolkein = 4, 11, & 14
  - Harper = 4, 14, 19
  - Lee = 11, 18
  - …
- To find an item
  - Calculate its signature
  - Run rods through "bits"
  - "Harper Lee" is 5 bits
- "Tolkein" is 3 bits



indexes: inverted lists

Inverted lists are currently the most common indexing technique

- Source file: collection, organized by document
- Inverted file: collection organized by term
  - one record per term, listing locations where term occurs

- During evaluation, traverse lists for each query term
  - OR: the *union* of component lists
  - AND: an *intersection* of component lists
  - Proximity: an *intersection* of component lists
  - SUM: the *union* of component lists; each entry has a score

inverted files

Document	Text
1	Pease porridge hot, pease porridge cold,
2	Pease porridge in the pot,
3	Nine days old.
4	Some like it hot, some like it cold,
5	Some like it in the pot,
6	Nine days old.

Example text; each line is one document.

inverted files

Document	Text
1	Pease porridge hot, pease porridge cold,
2	Pease porridge in the pot,
3	Nine days old.
4	Some like it hot, some like it cold,
5	Some like it in the pot,
6	Nine days old.

Number	Term	Documents
1	cold	1, 4
2	days	3, 6
3	hot	1, 4
4	in	2, 5
5	it	4, 5
6	like	4, 5
7	nine	3, 6
8	old	3, 6
9	pease	1, 2
10	porridge	1, 2
11	pot	2, 5
12	some	4, 5
13	the	2, 5

inverted files: word level

Document	Text
1	Pease porridge hot, pease porridge cold,
2	Pease porridge in the pot,
3	Nine days old.
4	Some like it hot, some like it cold,
5	Some like it in the pot,
6	Nine days old.

Number	Term	(Document; Words)
1	cold	(1; 6), (4; 8)
2	days	(3; 2), (6; 2)
3	hot	(1; 3), (4; 4)
4	in	(2; 3), (5; 4)
5	it	(4; 3, 7), (5; 3)
6	like	(4; 2, 6), (5; 2)
7	nine	(3; 1), (6; 1)
8	old	(3; 3), (6; 3)
9	pease	(1; 1, 4), (2; 1)
10	porridge	(1; 2, 5), (2; 2)
11	pot	(2; 5), (5; 6)
12	some	(4; 1, 5), (5; 1)
13	the	(2; 4), (5; 5)

indexes and language models

- Assume query likelihood approach

$$P(q_1, \ldots, q_k | M_D) = \prod_{i=1}^{k} P(q_i | M_D)$$

- Jelinek-Mercer smoothing for each query term

$$P(q_t | M_D) = \lambda ML_{estim}(q_t | M_D) + (1 - \lambda) BKGRND_{prob}$$

- Probably use logs to avoid tiny numbers

$$\log P(q_1, \ldots, q_k | M_D) = \sum_{i=1}^{k} \log P(q_i | M_D)$$

document-based approach

- For each document D in collection
  - Calculate $\log P(Q|MD)$
- Sort scores
- Drawbacks
  - Most documents have no query terms
  - Very slow

using inverted files

- Simple approach to using inverted list

- Use list to find documents containing any query term
  - All others assumed to have low and constant probability

- For each document in that pool
  - Calculate log P(Q|MD)

- Sort scores
- Better
  - Only plausible documents considered
  - Still requires accessing entire document

better use of inverted files

- Recall score being calculated

$$\log P(q_1, \ldots, q_k | M_D) = \sum_{i=1}^{k} \log P(q_i | M_D)$$

- Can be done in parts
  - Do q_1 for every document that contains q_1
  -
  - Then q_2 then q_3 then …

- Keep array Score[] with cumulative scores

better use of inverted files

- For each query word qi
  - Fetch its inverted list
  - For each document Dk in list

- Calculate log P(q_i | Dk)
- Add to accumulator Score[k]

- Sort array
  - Or keep running list of top *n* documents
- Why do the calculation?
  - Store pre-computed log P(qi | Dk) in list
  - Or store partial results if necessary

- May have to smooth at query time

inverted lists: access methods

How is a file of inverted lists accessed?

- B-Tree (B+ Tree, B* Tree, etc)
  - Supports exact-match and range-based lookup
  - $O(\log n)$ lookups to find a list
  - Usually easy to expand
- Hash table
  - Supports exact-match lookup
  - O(1) lookups to find a list
  - May be complex to expand

inverted lists: access optimizations

- Skip lists:
  - A table of contents to the inverted list
  - Embedded pointers that jump ahead *n* documents

- Separating presence information from location information
  - Many operators only need presence information
  - Location information takes substantial space (I/O)
  - If split,
    - reduced I/O for presence operators
    - increased I/O for location operators (or larger index)
  - Common in CD-ROM implementations

wildcard matching

- X* is probably easy (why? when not?)
- What about *X, *X*, X*Y?

- Permuterm index
  - Prefix each term X with a ╠
  - Rotate each augmented term cyclically (with wraparound) by
    one character, to produce n new terms
  - Append an ╣ to the end of each word form
  - Insert all forms in the dictionary

- Lookup
  - X: search for ╠X╣
  - X*: search for all terms beginning with ╠X
  - *X: search for all terms beginning with X╠
  - *X*: search for all terms beginning with X
  - X*Y: search for all terms beginning with Y╠X

building indexes

Indexes expensive to update; usually done in batches

- Typical build/update procedure:
  - One or more documents arrive to be added / updated
  - Documents parsed to generate index modifications
  - Each inverted list updated for *all* documents in the batch

- Concurrency control required
  - To synchronize changes to documents and index
  - To prevent readers and writers from colliding

- Common to split index into static / dynamic components
  - All updates to dynamic components
  - Search both static and dynamic component
  - Periodically merge dynamic into static

indexes : summary

Characteristics	Inverted Files	Bitmaps	Signature Files
Ease of update (edit a doc)	-	+	+-
Query evaluation speed	+	+-	+-
Uncompressed space efficiency	-	-	+
Compressed space efficiency	+	+	-
Index fidelity	+	+	-
Can store word positions	+	-	-