Using and storing the index

Review: Inverted Index

- For each term, keep list of document entries, one for each document in which it appears: a postings list
  - Document entry is list of positions at which term occurs and attributes for each occurrence: a posting
- Keep summary term information
- Keep summary document information

meta-data

Consider “advanced search” queries

Content Coordination
- Phrases
- Numeric range
- NOT
- OR

Document Meta-data
- •Language
- •Geographic region
- •File format
- •Date published
- •From specific domain
- •Specific licensing rights
- •Filtered by “safe search”

Issue of efficient retrieval

Basic retrieval algorithms

- One term
- AND of several terms
- OR of several terms
- NOT term
- proximity

Basic postings list processing: Merging posting lists

- Have two lists must coordinate
  - Find shared entries and do “something”
  - “something” changes for different operations
    - Set operations UNION? INTERSECTION? DIFFERENCE? …
  - Filter with document meta-data as process

Basic retrieval algorithms: using merging of postings lists

HOW?
- AND of several terms
- OR of several terms
- NOT term
- proximity

Basic retrieval algorithms

- One term:
  - look up posting list in (inverted) index
- AND of several terms:
  - Intersect posting lists of the terms: a list merge
- OR of several terms:
  - Union posting lists of the terms
  - eliminate duplicates: a list merge
- NOT term
  - If *terms* AND NOT(other *terms*), take a difference
  - a list merge (similar to AND)
- Proximity
  - a list merge (similar to AND)

Algorithms for Merging Postings Lists: two unsorted lists

How?

Role call

Merging two unsorted lists

- X Read 2nd list over and over - once for each entry on 1st list
  - computationally expensive
    time $O(|L_1|*|L_2|)$ where |L| length list L
- Build hash table on entry values;
  insert entries of one list, then other;
  look for collisions
  - must have good hash table
  - unwanted collisions expensive
  - often can't fit in memory: disk version
- Sort lists; use algorithm for sorted lists
  - often lists on disk: external sort
  - can sort in O(|L| log |L|) operations

Sorted lists

- Lists sorted by some identifier
  - same identifier both lists; not nec. unique
- Read both lists in "parallel"
  - Classic list merge:
    (sorted list_1 , sorted list_2) ⇒ sorted set union
  - General merge: if no duplicates, get time $|L_1|+|L_2|$
- Build lists so sorted
  - pay cost at most once
  - maybe get sorted order "naturally"
- If only one list sorted, can do binary search of sorted list for entries of other list
  - Must be able to binary search! - rare!
    - can't binary search disk

Keys for documents

For posting lists, entries are documents
What value is used to sort?

- Unique document IDs
  - can still be duplicate documents
  - consider for Web when consider crawling
- document scoring function that is independent of query
  - PageRank, HITS authority
  - sort on document IDs as secondary key
  - allows for approximate "highest k" retrieval
    - approx. k highest ranking doc.s for a query

Keys within document list

Processing within document posting

- Proximity of terms
  - merge lists of terms occurrences within same doc.
- Sort on term position

Computing document score

- "On fly"- as find each satisfying document
- Separate phase after build list of satisfying documents
- For either, must sort doc.s by score

Web query processing: limiting size

- For Web-scale collections, may not process complete posting list for each term in query
  - at least not initially
- Need docs sorted first on global (static) quantity
  - why not by term frequency for doc?
- Only take first k doc.s on each term list
  - k depends on query - how?
  - k depends on how many want to be able to return
    - Google: 1000 max returns
  - Flaws w/ partial retrieval from each list?
- Other limits? query size
    - Google: 32 words max query size

Limiting size with term-based sorting

- Can sort doc.s on postings list by score of term
  - term frequency + …
- Lose linear merge - salvage any?
- Tiered index:
  - tier 1: docs with highest term-based scores, sorted by ID or global quantity
  - tier 2: docs in next bracket of score quality, sorted
  - etc.
  - need to decide size or range of brackets
- If give up AND of query terms, can use idf too
  - only consider terms with high idf = rarer terms

Data structure for inverted index?

How access individual terms and each associated postings list?

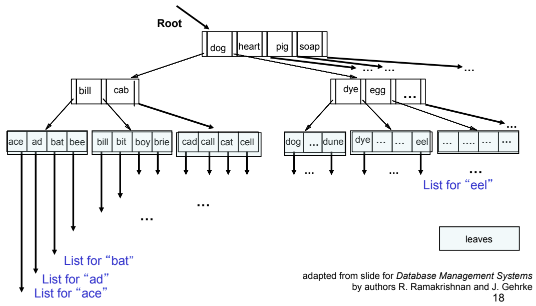
Assume an entry for each term points to its posting list

Data structure for inverted index?

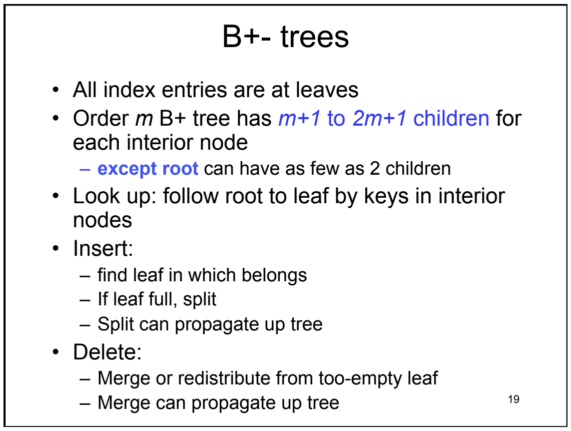
- Sorted array:
  - binary search IF can keep in memory
  - High overhead for additions
- Hashing
  - Fast look-up
  - Collisions
- Search trees: B+-trees
  - Maintain balance - always log look-up time
  - Can insert and delete

Example B+ Tree

order = 2: 2 to 4 search keys per interior node

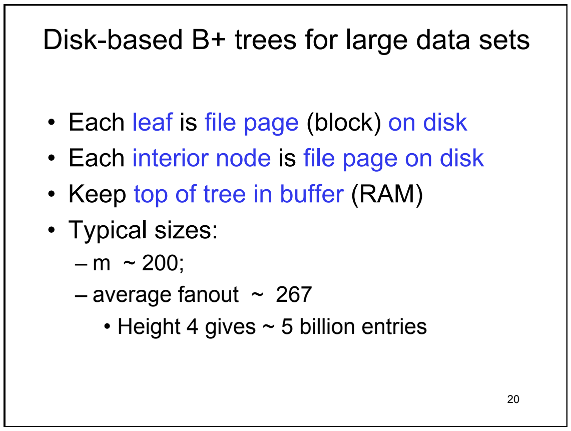


adapted from slide for *Database Management Systems* by authors R. Ramakrishnan and J. Gehrke



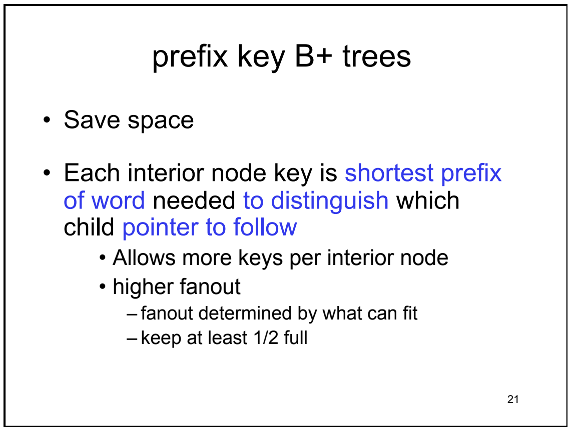
B+- trees

- All index entries are at leaves
- Order *m* B+ tree has *m+1* to *2m+1* children for each interior node
  - **except root** can have as few as 2 children
- Look up: follow root to leaf by keys in interior nodes
- Insert:
  - find leaf in which belongs
  - If leaf full, split
  - Split can propagate up tree
- Delete:
  - Merge or redistribute from too-empty leaf
  - Merge can propagate up tree



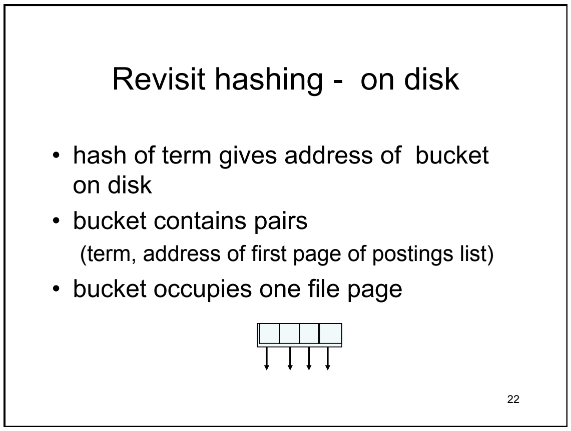
Disk-based B+ trees for large data sets

- Each leaf is file page (block) on disk
- Each interior node is file page on disk
- Keep top of tree in buffer (RAM)
- Typical sizes:
  - m ~ 200;
  - average fanout ~ 267
    - Height 4 gives ~ 5 billion entries



prefix key B+ trees

- Save space
- Each interior node key is shortest prefix of word needed to distinguish which child pointer to follow
  - Allows more keys per interior node
  - higher fanout
    - fanout determined by what can fit
    - keep at least 1/2 full



Revisit hashing - on disk

- hash of term gives address of bucket on disk
- bucket contains pairs

  (term, address of first page of postings list)
- bucket occupies one file page