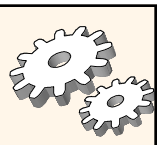
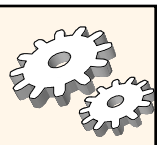


Hash-Based Indexes

Chapter 11

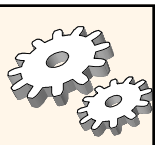


Overview

Topics covered in this chapter:

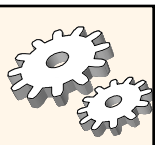
- Static hashing
- Extendable hashing
- Linear hashing
- Extendable vs. linear hashing

Introduction

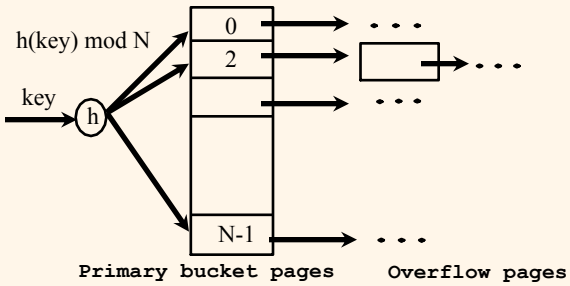


- *As for any index, 3 alternatives for data entries* **k***:
  - Data record with key value **k**
  - **<k**, rid of data record with search key value **k>**
  - **<k**, list of rids of data records with search key **k>**
  - Choice orthogonal to the *indexing technique*
- *Hash-based* indexes are best for *equality selections*. ***Cannot*** support range searches.
- Static and dynamic hashing techniques exist; trade-offs similar to ISAM vs. B+ trees.

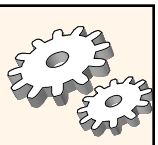
Static Hashing



- # primary pages fixed, allocated sequentially, never de-allocated; overflow pages if needed.
- **h**(*k*) mod N = bucket to which data entry with key *k* belongs. (N = # of buckets)

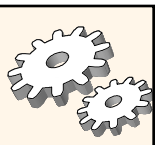


Static Hashing (Contd.)



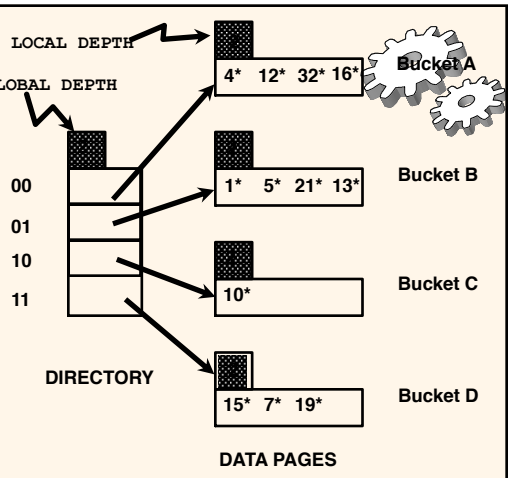
- Buckets contain *data entries*.
- Hash fn works on *search key* field of record *r*. Must distribute values uniformly over range 0 ... N-1.
  - **h**(*key*) = (a * *key* + b) usually works well.
  - a and b are constants; lots known about how to tune **h**.
- Long overflow chains can develop and degrade performance.
  - *Extendible* and *Linear Hashing*: Dynamic techniques to fix this problem.

Extendible Hashing



- Situation: Bucket (primary page) becomes full. Why not re-organize file by *doubling* # of buckets?
  - Reading and writing all pages is expensive!
  - *Idea*: Use *directory of pointers to buckets*, double # of buckets by *doubling the directory*, splitting just the bucket that overflowed!
  - Directory much smaller than file, so doubling it is much cheaper. Only one page of data entries is split. *No overflow page*!
  - Trick lies in how hash function is adjusted!

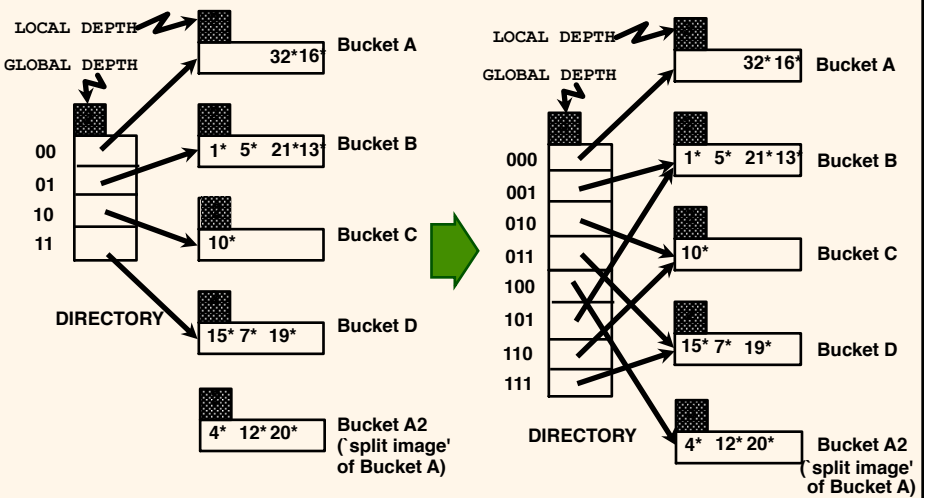
Example



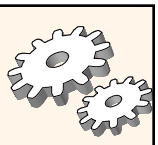
- Directory is array of size 4.
- To find bucket for *r*, take last `*global depth*' # bits of **h**(*r*); we denote *r* by **h**(*r*).
  - If **h**(*r*) = 5 = binary 101, it is in bucket pointed to by 01.

- **Insert**: If bucket is full, *split* it (*allocate new page, re-distribute*).
- *If necessary*, double the directory. (As we will see, splitting a bucket does not always require doubling; we can tell by comparing *global depth* with *local depth* for the split bucket.)

Insert ***h****(r)=20 (Causes Doubling)*

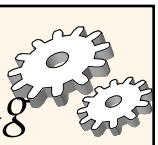


Points to Note



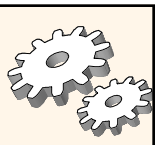
- 20 = binary 10100. Last **2** bits (00) tell us *r* belongs in A or A2. Last **3** bits needed to tell which.
  - *Global depth of directory*: Max # of bits needed to tell which bucket an entry belongs to.
  - *Local depth of a bucket*: # of bits used to determine if an entry belongs to this bucket.
- When does bucket split cause directory doubling?
  - Before insert, *local depth* of bucket = *global depth*. Insert causes *local depth* to become > *global depth*; directory is doubled by *copying it over* and `fixing' pointer to split image page. (Use of least significant bits enables efficient doubling via copying of directory!)

Comments on Extendible Hashing



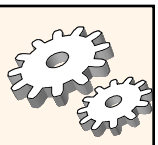
- If directory fits in memory, equality search answered with one disk access; else two.
  - 100MB file, 100 bytes/rec, 4KB pages contains 1,000,000 records (as data entries) and *25,000 directory elements*; chances are high that directory will fit in memory.
  - Directory grows in spurts, and, if the distribution *of hash values* is skewed, directory can grow large.
  - Multiple entries with same hash value cause problems!
- **Delete**: If removal of data entry makes bucket empty, can be merged with `split image'. If each directory element points to same bucket as its split image, can halve directory.

Linear Hashing



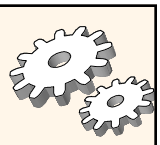
- This is another dynamic hashing scheme, an alternative to Extendible Hashing.
- LH handles the problem of long overflow chains without using a directory.
- *Idea*: Use a family of hash functions $\mathbf{h}_0$, $\mathbf{h}_1$, $\mathbf{h}_2$, ...
  - $\mathbf{h}_i(key) = \mathbf{h}(key) \bmod (2^i N)$; N = initial # buckets
  - **h** is some hash function
  - If $N = 2^{d_0}$, for some d_0, $\mathbf{h}_i$ consists of applying **h** and looking at the last d_i bits, where $d_i = d_0 + i$.
  - $\mathbf{h}_{i+1}$ doubles the range of $\mathbf{h}_i$ (similar to directory doubling)

Linear Hashing (Contd.)

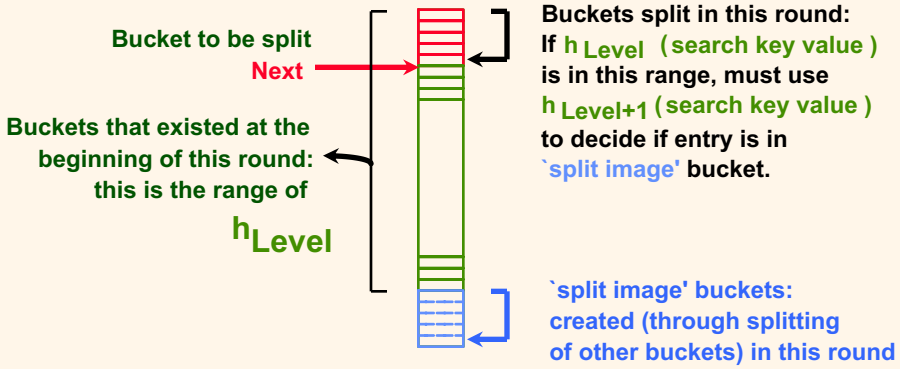


- Directory avoided in LH by using overflow pages, and choosing bucket to split round-robin.
  - Splitting proceeds in `rounds'. Round ends when all N_R initial (for round R) buckets are split. Buckets 0 to *Next-1* have been split; *Next* to N_R yet to be split.
  - Current round number is *Level*.
  - **Search:** To find bucket for data entry r, find $\mathbf{h}_{Level}(r)$:
    - If $\mathbf{h}_{Level}(r)$ in range `*Next* to N_R', r belongs here.
    - Else, r could belong to bucket $\mathbf{h}_{Level}(r)$ or bucket $\mathbf{h}_{Level}(r) + N_R$; must apply $\mathbf{h}_{Level+1}(r)$ to find out.

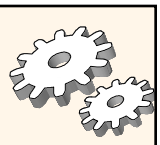
Overview of LH File



- In the middle of a round.



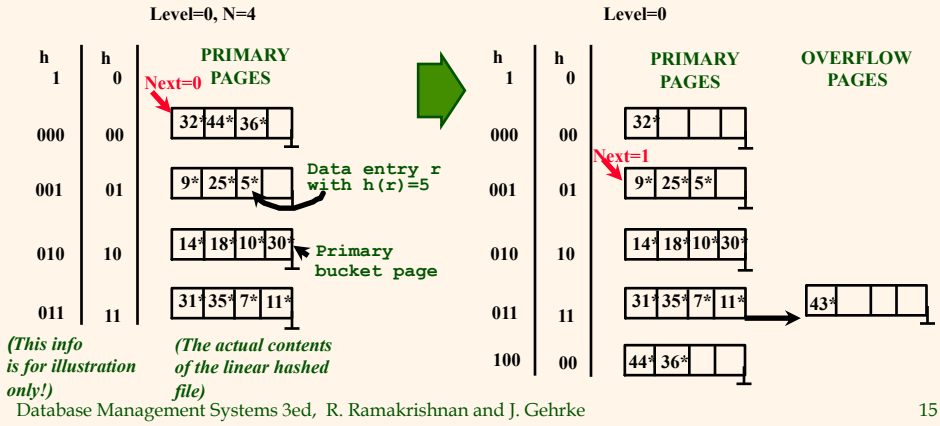
Linear Hashing (Contd.)



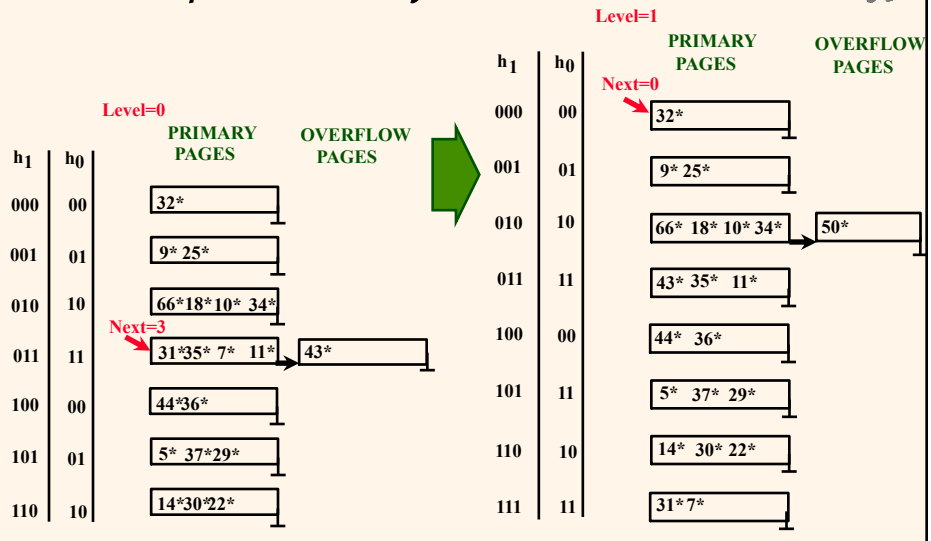
- **Insert**: Find bucket by applying $\mathbf{h}_{Level}$ / $\mathbf{h}_{Level+1}$:
  - If bucket to insert into is full:
    - Add overflow page and insert data entry.
    - Split *Next* bucket and increment *Next*.
- Can choose any *criterion* to `trigger' split.
- Since buckets are split round-robin, long overflow chains don't develop!
- Doubling of directory in Extendible Hashing is similar; switching of hash functions is *implicit* in how the # of bits examined is increased.

Example of Linear Hashing

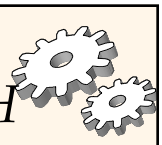
- On split, $\mathbf{h}_{Level+1}$ is used to re-distribute entries.



Example: End of a Round

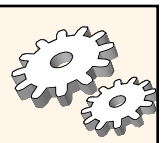


LH Described as a Variant of EH



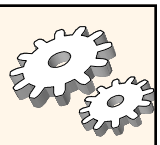
- The two schemes are actually quite similar:
  - Begin with an index where directory has *N* elements.
  - Use overflow pages, split buckets round-robin.
  - First split is at bucket 0. (Imagine directory being doubled at this point.) We only need to add directory element *N* now. Elements <1,*N*+1>, <2,*N*+2>, ... are the same.
    - When bucket 1 splits, create directory element *N*+1, etc.
- So, directory can double gradually. Also, primary bucket pages are created in order. If they are *allocated* in sequence too (so that finding i'th is easy), we actually don't need a directory!

Summary



- Hash-based indexes: best for equality searches, cannot support range searches.
- Static Hashing can lead to long overflow chains.
- Extendible Hashing avoids overflow pages by splitting a full bucket when a new data entry is to be added to it. (*Duplicates may require overflow pages.*)
  - Directory to keep track of buckets, doubles periodically.
  - Can get large with skewed data; additional I/O if this does not fit in main memory.

Summary (Contd.)



- Linear Hashing avoids directory by splitting buckets round-robin, and using overflow pages.
  - Overflow pages not likely to be long.
  - Duplicates handled easily.
  - Space utilization could be lower than Extendible Hashing, since splits not concentrated on `dense' data areas.
    - Can tune criterion for triggering splits to trade-off slightly longer chains for better space utilization.
- For hash-based indexes, a *skewed* data distribution is one in which the *hash values* of data entries are not uniformly distributed!