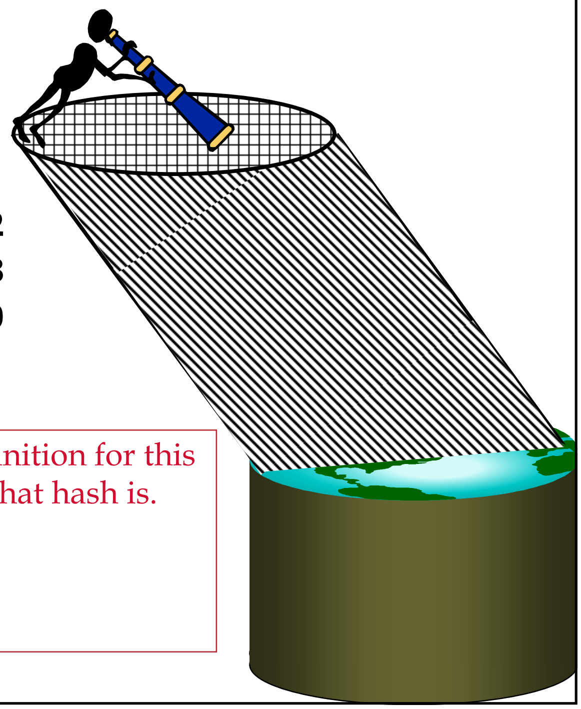
Hash-based Indexes

CS 186, Fall 2002
Lecture 18
R &G Chapter 10



HASH, x. There is no definition for this word -- nobody knows what hash is.

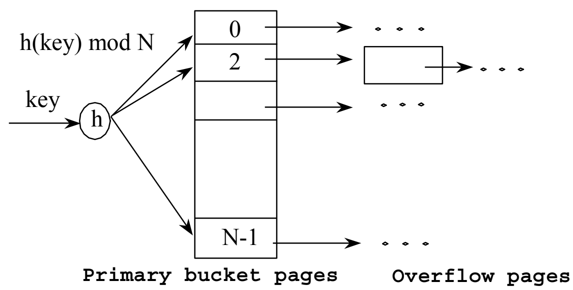
Ambrose Bierce,
"The Devil's Dictionary", 1911

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 M= bucket to which data entry with key *k* belongs. (M = # of buckets)**



Static Hashing (Contd.)

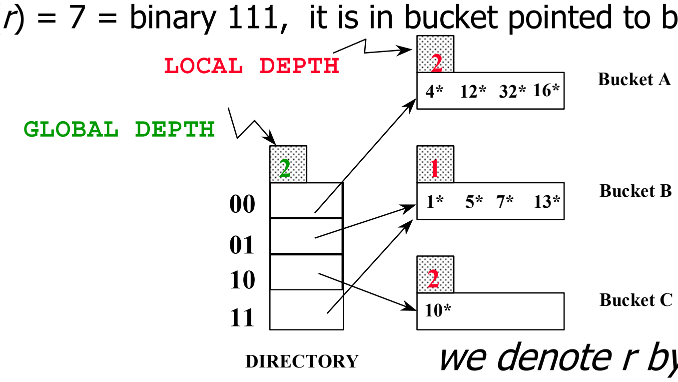
- **Buckets contain *data entries*.**
- **Hash fn works on *search key* field of record *r*. Use its value MOD M to distribute values over range 0 ... M-1.**
  - **h**(*key*) = (a * *key* + b) usually works well.
  - a and b are constants; lots known about how to tune **h**.
- **Long overflow chains 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.**
- **Bucket for record *r* has entry with index = `*global depth*' least significant bits of h(*r*);**
  - If **h**(*r*) = 5 = binary 101, it is in bucket pointed to by 01.
  - If **h**(*r*) = 7 = binary 111, it is in bucket pointed to by 01.



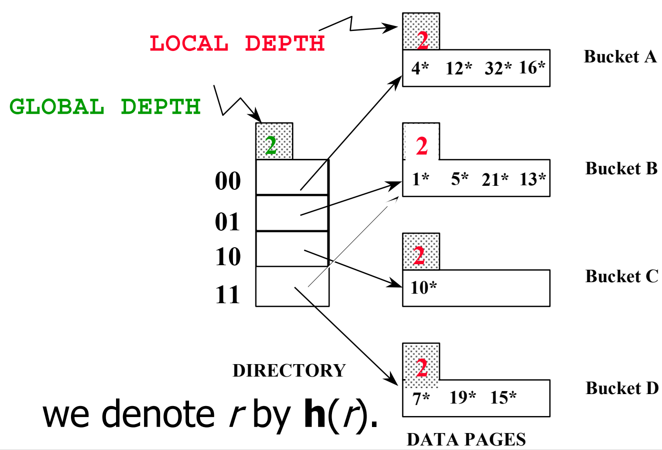
*we denote r by **h**(r).*

Handling Inserts

- Find bucket where record belongs.
- If there's room, put it there.
- Else, if bucket is full, *split* it:
  - increment local depth of original page
  - allocate new page with new local depth
  - re-distribute records from original page.
  - add entry for the new page to the directory

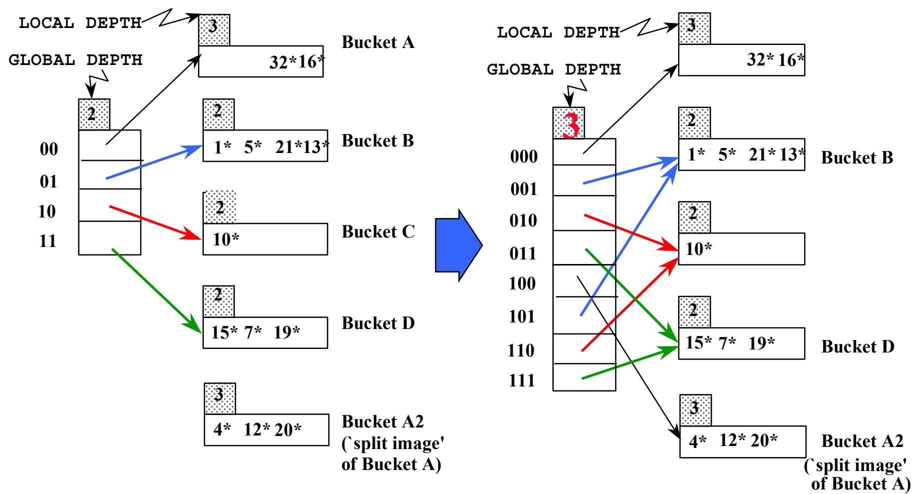
Example: Insert 21, then 19, 15

- **21 = 10101**
- **19 = 10011**
- **15 = 01111**



we denote *r* by **h**(*r*).

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

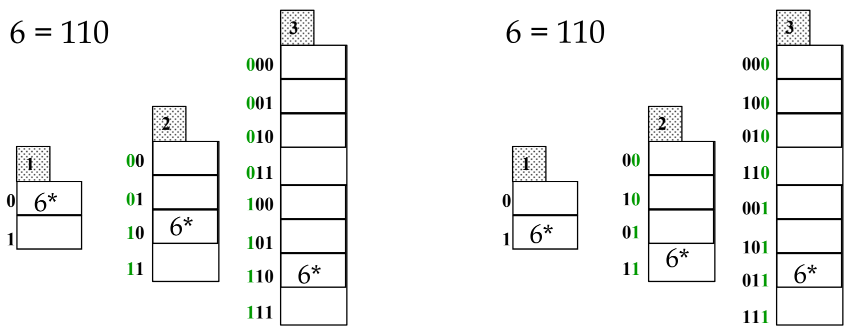


Points to Note

- **20 = binary 10100. Last** 2 **bits (00) tell us *r* belongs in either 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.

Directory Doubling

Why use least significant bits in directory?
 Allows for doubling via copying!



Least Significant vs. Most Significant

Comments on Extendible Hashing

- **If directory fits in memory, equality search answered with one disk access; else two.**
  - 100MB file, 100 bytes/rec, 4K 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

- A dynamic hashing scheme that handles the problem of long overflow chains without using a directory.
- Directory avoided in LH by using *temporary* overflow pages, and choosing the bucket to split in a *round-robin* fashion.
- When *any* bucket overflows split the bucket that is currently pointed to by the "*Next*" pointer and then increment that pointer to the next bucket.

Linear Hashing – The Main Idea

- **Use a family of hash functions h_0, h_1, h_2, ...**
- $h_i(key) = h(key) \bmod (2^i N)$
  - N = initial # buckets
  - **h** is some hash function
- h_{i+1} doubles the range of h_i (similar to directory doubling)

Linear Hashing (Contd.)

- Algorithm proceeds in `rounds'. Current round number is "*Level*".
- There are N_{Level} (= N * 2^{Level}) buckets at the beginning of a round
- Buckets 0 to *Next-1* have been split; *Next* to N_{Level} have not been split yet this round.
- Round ends when all initial buckets have been split (i.e. *Next* = N_{Level}).
- To start next round:

  Level++;

  Next = 0;

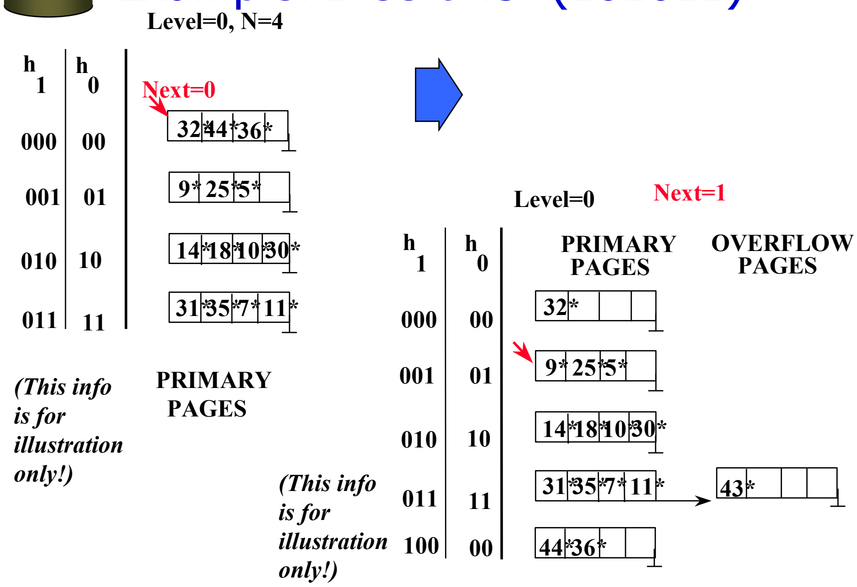
LH Search Algorithm

- **To find bucket for data entry *r*, find $h_{Level}(r)$:**
  - If $\mathbf{h}_{Level}(r)$ >= Next (i.e., $\mathbf{h}_{Level}(r)$ is a bucket that hasn't been involved in a split this round) then *r* belongs in that bucket for sure.
  - Else, r could belong to bucket $\mathbf{h}_{Level}(r)$ ***or*** bucket $\mathbf{h}_{Level}(r) + N_{Level}$; must apply $\mathbf{h}_{Level+1}(r)$ to find out.

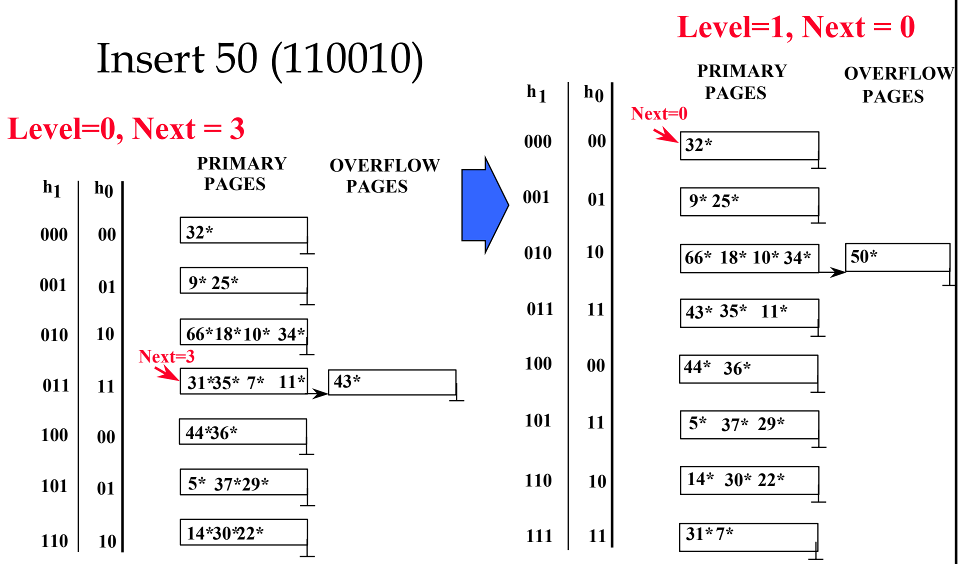
Linear Hashing - Insert

- **Find appropriate bucket**
- **If bucket to insert into is full:**
  - Add overflow page and insert data entry.
  - Split *Next* bucket and increment *Next*.
    - Note: This is likely NOT the bucket being inserted to!!!
    - to split a bucket, create a new bucket anduse $\mathbf{h}_{Level+1}$ to re-distribute entries.
- Since buckets are split round-robin, long overflow chains don't develop!

Example: Insert 43 (101011)



Example: End of a Round



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.
  - 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!**