Hash Indexes: Chap. 11

CS634
Lecture 6

Slides based on "Database Management Systems" 3rd ed, Ramakrishnan and Gehrke

HW 2 Bench Table

- Table of 1M rows, Columns of different "cardinalities"

```
CREATE TABLE BENCH (
        KSEQ integer primary key,
        K500K integer not null, K250K integer not null,
       K100K integer not null, K40K integer not null,
       K10K integer not null,  K1K integer not null,
       K100 integer not null,  K25 integer not null,
        K10 integer not null,  K5 integer not null,
        K4 integer not null,   K2 integer not null,
        S1 char(8) not null,   S2 char(20) not null,
        S3 char(20) not null,  S4 char(20) not null,
        S5 char(20) not null,  S6 char(20) not null,
        S7 char(20) not null,  S8 char(20) not null)
tablespace setq storage(initial 1 M next 1 M );
```

- **Column K500K has 500K different values 1, 2, …, 500,000**
- **Column K2 has 2 different values 1,2 (cardinality 2)**

Table Bench is in tablespace setq

```
create tablespace setq
  datafile
 '/home/oracle/app/oracle/oradata/dbs3/eoneil_setq.dbf'
  size 1 G
  default storage ( initial 1 M next 1 M);
```

- Shows how a disk file becomes part of the database. Oracle makes the file based on this spec.
- MySQL v. 5.7 is the first version to allow this simple way of adding a file to an Innodb database,
- CREATE TABLESPACE *tablespace_name* ADD DATAFILE '*file_name*'
- No size spec, so presumably auto-extend.

Loading table bench

- First a C program creates a datafile bench.dat:

```
% head -3 bench.dat
1 16808 225250 50074 23659 8931 273 45 4 4 5 1 2 12345678
12345678900987654321 12345678900987654321
12345678900987654321 12345678900987654321
12345678900987654321 12345678900987654321
12345678900987654321
2 484493 243043 7988 2504 2328 730 41 13 4 5 2 2 12345678
12345678900987654321 12345678900987654321
12345678900987654321 12345678900987654321
12345678900987654321 12345678900987654321
12345678900987654321
3 129561 70934 93100 279 1817 336 98 2 3 3 3 2 12345678
12345678900987654321 12345678900987654321
12345678900987654321 12345678900987654321
12345678900987654321 12345678900987654321
12345678900987654321
```

Then a bulk load

```
topcat$ more bench.ctl
load data
replace
into table bench
fields terminated by " "
(KSEQ, K500K, K250K, K100K, K40K, K10K, K1K, K100, K25,
K10, K5, K4, K2, S1, S2, S3, S4, S5, S6, S7, S8)
```

- Note this builds the PK index, not clustered.
- Would be slower if the data file was on networked disk.
- The load of bench took about one minute.
  - That's 210 MB data read in about 60 s, or about 3 MB/s read rate.
- Load of bench250: 53 GB in 160 min, about 5 MB/s
  - Vs. only 6 min to create input file with C program.

Then add secondary indexes on some columns

```
CREATE INDEX k500kin ON bench (k500k)
   storage (initial 1 M next 1 M) pctfree 5 tablespace setq;
COMMIT WORK;
CREATE  INDEX k100kin on bench (k100k)
   storage (initial 1 M next 1 M) pctfree 5 tablespace setq
COMMIT WORK;
CREATE INDEX k10kin on bench (k10k)
   storage (initial 1 M next 1 M) pctfree 5 tablespace setq;
COMMIT WORK;
CREATE INDEX k100in on bench (k100)
   storage (initial 1 M next 1 M) pctfree 5 tablespace setq;
COMMIT WORK;
CREATE INDEX k10in on bench (k10)
   storage (initial 1 M next 1 M) pctfree 5 tablespace setq;
COMMIT WORK;
CREATE INDEX k4in on bench (k4)
   storage (initial 1 M next 1 M) pctfree 5 tablespace setq;
COMMIT WORK;
```

We could make a tablespace for these indexes and get better performance for some queries, if we were using two disks, say. But we are using RAID over many disks.

Final Steps for Bench Table

- Analyze the table to get stats for the query processor

```
SQL>exec dbms_stats.gather_table_stats(
'SETQ_DB', 'BENCH',cascade=>true);
```

  - Here cascade means analyze its indexes too.

- Make it publicly readable:

```
grant select on bench to public;
```

Try it out from another (non-priv) account

```
dbs2(20)% sqlplus cs634test/…
SQL> select count(*) from setq_db.bench;
  COUNT(*)
----------
   1000000
SQL> select tablespace_name from all_tables
  where table_name = 'BENCH';

TABLESPACE_NAME
------------------------------
SETQ

SQL> select index_name,index_type, uniqueness from all_indexes where
table_name='BENCH';
INDEX_NAME                     INDEX_TYPE                  UNIQUENES
------------------------------ --------------------------- ---------

SYS_C00149010                  NORMAL                      UNIQUE
K500KIN                        NORMAL                      NONUNIQUE
K100KIN                        NORMAL                      NONUNIQUE
…
```

Overview

- Hash-based indexes are best for equality selections
  - *Cannot* support range searches, except by generating all values
  - Static and dynamic hashing techniques exist
- Hash indexes not as widespread as B+-Trees
  - Some DBMS do not provide hash indexes
  - But hashing still useful in query optimizers (DB Internals)
  - E.g., in case of equality joins
- As for tree indexes, 3 alternatives for data entries *k**
  - Choice orthogonal to the indexing technique

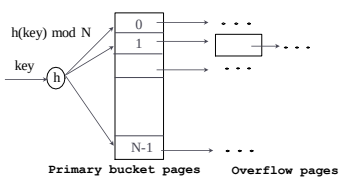
Hashing in Memory and on Disk

- The hash table may be located in memory, supporting fast lookup to records on disk, or even on disk, supporting fast access to further disk.
- In fact, a disk-resident hash table that is in frequent use ends up being in memory because of the memory "caching" of disk pages in the file system.

keys →	hash table →	Data records	Example
memory	memory	memory	typical HashMap apps
memory	memory	disk	use HashMap to hold disk record locations as values
memory	disk	disk	hashed files, some database tables

Static Hashing

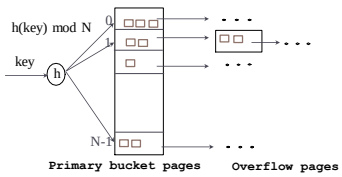
- Number of buckets *N* fixed, each with primary, overflow pages
  - primary pages are allocated sequentially
  - overflow pages may be needed when file grows
  - Buckets contain data entries
- **Hash value:** h(*k*) mod N = bucket for data entry with key *k*



Static Hashing

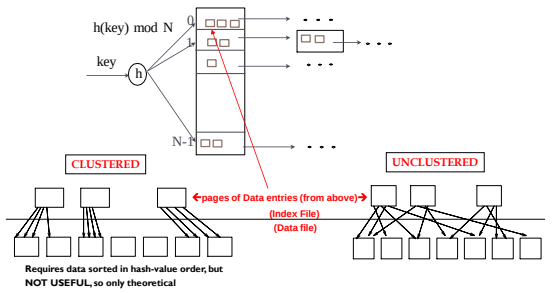
- Hash function is applied on *search key* field
  - Must distribute values over range 0 … N-1.
  - **h(*key*) = (a * *key* + b)** is a typical choice (for numerical keys)
  - a and b are constants, chosen to "tune" the hashing, and prime
  - Example: h(key) = 37*key + 101
- Hash function for string keys? A tricky subject, easy to go wrong
  - See Wikipedia article https://en.wikipedia.org/wiki/Hash_function
  - Algorithm used by Perl: https://en.wikipedia.org/wiki/Jenkins_hash_function

Data entries can be full rows (Alt (1))



- Primary pages are sequential on disk, so full table scan is fast if not too many overflow pages, or overflow pages are also sequential
- Is a clustered index (data records in hash key order), but the clustering is not useful.

Data entries can be (key, rid(s)) (Alt (2,3))



Static Hashing

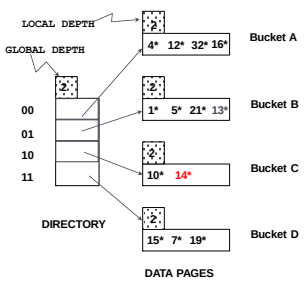
- Works well if we know how many keys there can be
  - Then we can size the primary page sequence properly: keep it under about half full
  - Can have "collisions": two keys with same hash value
- But when file grows considerably there are problems
- Long overflow chains develop and degrade performance
  - Example: loader took over an hour to load a big program
  - Found it was hashing using 1000-spot hash table for global symbols! One line edit→ solved the problem.
- General Solution: Dynamic Hashing, 2 contenders described:
  - Extendible Hashing
  - Linear Hashing

Extendible Hashing

- Main Idea: when primary page becomes full, double the number of buckets
  - But reading and writing all pages is expensive
  - Use directory of pointers to buckets
  - Double the directory size, and only split the bucket that just overflowed!
  - Directory much smaller than file, so doubling it is cheap
  - There are no overflow pages (unless the same key appears a lot of times, i.e., very skewed distribution – many duplicates)

Extendible Hashing Example

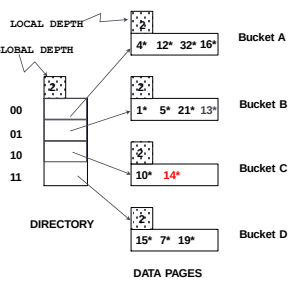
- Directory is array of size 4
- Directory entry corresponds to last two bits of hash value
- If **h**(*k*) = 5 = binary 101, it is in bucket pointed to by 01
- Insertion into non-full buckets is trivial
- Insertion into full buckets requires split and **directory doubling**
- E.g., insert h(k)=20



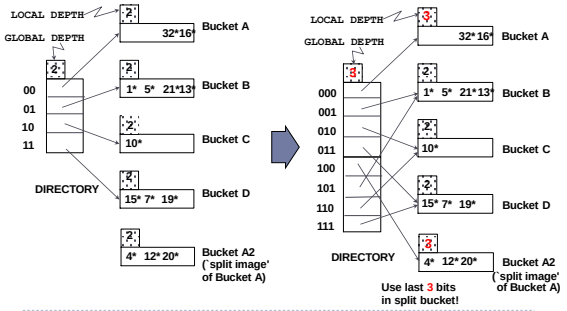
Insert h(k)=20 (Causes Doubling)

- Insert h(k)=20 = 10100
- But bucket for 00 (Bucket A) is full.
- Need to split Bucket A
  - Look at its hash values: all are …00, i.e. have last two binary digits = 00.
  - But now we'll use last 3 binary digits:

4 = 100 → new bucket
12 = 1100 → new bucket
32 = 10000 gets left in old bucket
16 = 1000 gets left in old bucket
New value:
20 = 10100 → new bucket



Insert h(k)=20 (Causes Doubling)

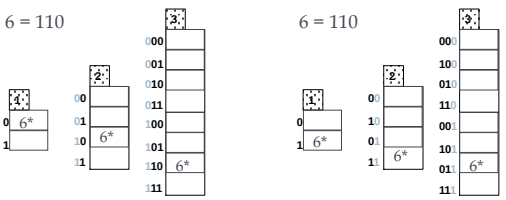


Global vs Local Depth

- *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*
    - Use of least significant bits enables efficient doubling via copying of directory
- Delete: if bucket becomes empty, merge with `split image'
  - If each directory element points to same bucket as its split image, can halve directory

Directory Doubling

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



Least Significant vs. Most Significant

Extendible Hashing Properties

- If directory fits in memory, equality search answered with one I/O; otherwise with two I/Os
  - 100MB file, 100 bytes/rec, 4K pages contains 1,000,000 records
    - (That's 100MB/(100 bytes/rec) = 1M recs)
  - 25,000 directory elements will fit in memory
    - (That's assuming a bucket is one page, 4KB = 4096 bytes, so can hold 4000 bytes/(100 bytes/rec)= 40 recs, plus 96 bytes of header, so 1Mrecs/(40 recs/bucket) = 25,000 buckets, so 25,000 directory elements)
  - Multiple entries with same hash value cause problems!
    - These are called collisions
    - Cause possibly long overflow chains

Linear Hashing

- Dynamic hashing scheme
- Handles the problem of long overflow chains
  - But does not require a directory!
  - Deals well with collisions!

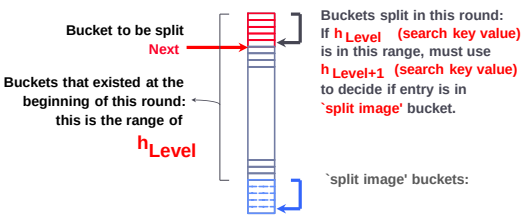
Linear Hashing

- Main Idea: use a family of hash functions $\mathbf{h}_0, \mathbf{h}_1, \mathbf{h}_2, \ldots$
  - $\mathbf{h}_i(key) = \mathbf{h}(key) \bmod (2^i N)$
    - N = initial number of buckets
  - If $N = 2^{d0}$, for some d_0, $\mathbf{h}_i$ consists of applying $\mathbf{h}$ 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)
  - Example:
  - N=4, conveniently a power of 2
  - $\mathbf{h}_i(key)$ = h(key)mod(2^iN)=h(key), last 2+i bits of key
  - $\mathbf{h}_0(key)$ = last 2 bits of key
  - $\mathbf{h}_1(key)$ = last 3 bits of key
  - …

Linear Hashing: Rounds

- During round 0, use $\mathbf{h}_0$ and $\mathbf{h}_1$
- During round 1, use $\mathbf{h}_1$ and $\mathbf{h}_2$
- ...
- Start a round when some bucket overflows
  - (or possibly other criteria, but we consider only this)
- Let the overflow entry itself be held in an overflow chain
- During a round, split buckets, in order from the first
- Do one bucket-split per overflow, to spread out overhead
- So some buckets are split, others not yet, during round.
- Need to track division point: Next = bucket to split next

Overview of Linear Hashing



Note this is a "file", i.e., contiguous in memory or in a real file.

Linear Hashing Properties

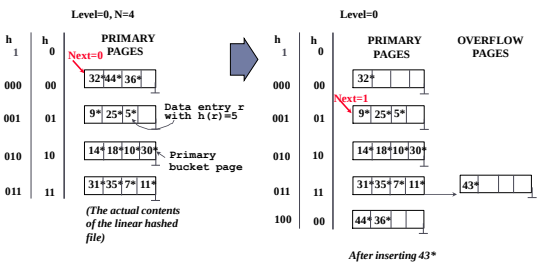
- Buckets are split round-robin
  - Splitting proceeds in `rounds'
    - Round ends when all N_R initial buckets are split (for round *R*)
    - Buckets 0 to *Next-1* have been split; *Next* to N_R yet to be split.
  - Current round number referred to as *Level*
- Search for data entry *r* :
  - If $\mathbf{h}_{Level}(r)$ in range `*Next* to N_R', search bucket $\mathbf{h}_{Level}(r)$
  - Otherwise, apply $\mathbf{h}_{Level+1}(r)$ to find bucket

Linear Hashing Properties

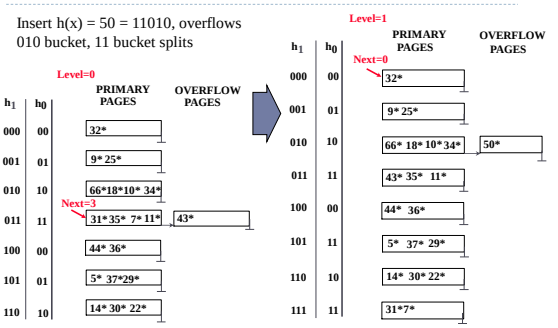
- Insert:
  - Find bucket by applying $\mathbf{h}_{Level}$ or $\mathbf{h}_{Level+1}$ (based on *Next* value)
  - If bucket to insert into is full:
    - Add overflow page and insert data entry.
    - Split *Next* bucket and increment *Next*
- Can choose other criterion to trigger split
  - E.g., occupancy threshold
- Split round-robin prevents long overflow chains

Example of Linear Hashing

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



End of a Round



Advantages of Linear Hashing

- Linear Hashing avoids directory by:
  - splitting buckets round-robin
  - using overflow pages
  - in a way, it is the same as having directory doubling gradually
- Primary bucket pages are created in order
- Easy in a disk file, though may not be really contiguous
- But hard to allocate huge areas of memory

Summary

- Hash-based indexes: best for equality searches, (almost) 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 in the early part of a round.
- For hash-based indexes, a *skewed* data distribution is one in which the *hash values* of data entries are not uniformly distributed
- Need a good hash function!

Indexes in Standards

- SQL92/99/03 does not standardize use of indexes
- (BNF for SQL2003)
  - But all DBMS providers support it
  - X/OPEN actually standardized CREATE INDEX clause

```
CREATE [UNIQUE] INDEX indexname ON tablename
      (colname [ASC | DESC] [,colname [ASC | DESC] ,. . .]);
```

- ASC|DESC are just there for compatibility, have no effect in any DB I know of.
- Index has as key the concatenation of column names
  - In the order specified

Indexes in Oracle

- Oracle supports mainly B+-Tree Indexes
  - These are the default, so just use create index…
  - No way to ask for clustered directly
  - Clustering on PK is available via index-organized tables (IOTs)
    - In this case, the RID is different, affecting secondary index performance
  - Also "table cluster" for co-locating data of tables often joined
- Hashing: via "hash cluster"
  - Also a form of hash partitioning supported
  - Also supports bitmap indexes
  - Hash cluster example→

Example Oracle Hash Cluster

```
CREATE CLUSTER trial_cluster (trialno DECIMAL(5,0))
  SIZE 1000 HASH IS trialno HASHKEYS 100000;
CREATE TABLE trial ( trialno DECIMAL(5,0) PRIMARY KEY, ...)
  CLUSTER trial_cluster (trialno);
```

- SIZE should estimate the max storage in bytes of the rows needed for one hash key
- Here HASHKEYS <value> specifies a limit on the number of unique keys in use, for hash table sizing. Oracle rounds up to a prime, here 100003. This is static hashing.

Oracle Hash Index, continued

- For static hashing in general: rule of thumb—
  - Estimate the max possible number of keys and double it. This way, about half the hash cells are in use at most.
- The hash cluster is a good choice if queries usually specify an exact trialno value.
- Oracle will also create a B-tree index on trialno because it is the PK. But it will use the hash index for equality searches.

MySQL Indexes, for InnoDB Engine

- CREATE [UNIQUE] INDEX ***index_name*** [***index_type***] ON ***tbl_name*** (***index_col_name***,...)
- ***index_col_name***: ***col_name*** [(***length***)] [ASC | DESC]
- ***index_type***: USING {BTREE | HASH}

- Syntax allows for hash index, but not supported by InnoDB.
- For InnoDB, index on primary key is clustered.

Clustered index on PK: choose your PK wisely

- Available in Oracle and MySQL, as only kind of clustered B-tree index.
- Common PKs are ids, arbitrary, not commonly used in range queries, so not getting the good from the clustered B-tree.
- However, a PK is what we say it is for a table, and doesn't need to be minimalistic, just a unique identifier.
- So (zipcode, custid) works as a PK and clusters the data by zipcode. Custid is a "uniquifier" here.
- Then useful range queries on zipcode run fast.

Indexes in Practice

- Typically, data is inserted first, then index is created
- Exception: alternative (1) indexes (of course!)
  - Then best to sort first, then load
  - How to sort? Use database: load, sort, dump, load for real
- Index bulk-loading is a good idea – recall it is much faster
- Delete an index
  DROP INDEX indexname;

- Guidelines:
  - Create index if you frequently retrieve less than 15% of the table
  - To improve join performance, index columns used for joins
  - Small tables do not require indexes, except ones for PKs.

Compare B-Tree and Hash Indexes

- Dynamic Hash tables have variable insert times
- Worst-case access time & best average access time
- But only useful for equality key lookups
- Note there are bitmap indexes too