CS 235: Introduction to Databases

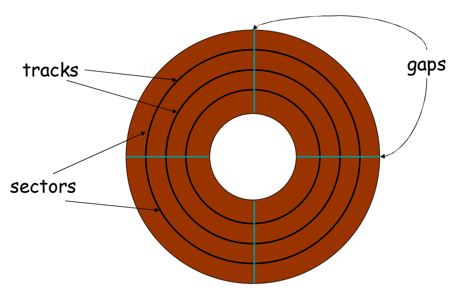
Svetlozar Nestorov

Lecture Notes #22

Outline

- Physical organization of data on disk
- Indexing (and SQL)
- Indexing sequential files
  - Primary, secondary
  - Clustering, non-clustering
  - Dense, sparse.
  - Multi-level
- Other indexing structures
  - Linear, B-tree, hashing

Disk Surface



Sectors and Blocks

- Sector: smallest physical unit of data transferred between disk and main memory.
- Block: logical unit of data, consists of several *consecutive* sectors.
- Databases deal with blocks.

Data Layout

- Each block contains:
  - Block header (meta data)
  - Records (corresponding to tuples)
- Each record contains:
  - Record header
  - Fields (attributes)

Indexing

- Get a particular record (or several records) given a value for some field.
  - Read all blocks with records.
  - Use an index to locate block(s) with record(s).

Indexes in SQL

CREATE INDEX index_name
ON table(attr1, attr2,…);

CREATE INDEX bar_idx
ON Sells(bar);

- Indexes can be included in the table declaration.

MySQL Indexes

```
CREATE TABLE Sells(
        bar varchar(20),
        beer varchar(20),
        price real,
        INDEX (bar),
        INDEX beerIdx (beer)
);

DROP INDEX beerIdx ON Sells;
SHOW INDEX FROM Sells;
```


Using Indexes: Selection

SELECT beer FROM Sells WHERE bar = 'Level';

SELECT price FROM Sells WHERE beer = 'Bud';

SELECT price FROM Sells WHERE beer = 'Bud'
AND bar = 'Rainbo';

SELECT MAX(price) FROM Sells WHERE bar <>
'Cans';

Using Indexes: Joins

SELECT beer
FROM Sells AS S, Frequents AS F
WHERE S.bar = F.bar AND drinker = 'Sally';

SELECT beer
FROM Sells AS S, Frequents AS F
WHERE S.bar = F.bar AND price < 10;

Indexing Sequential Files

- Records stored in a sorted order
  - often by primary key
- Primary index
  - on a sorting field
  - determines record location

Clustering

- Clustering index packs records with the same values of indexed attributes in as few blocks as possible
  - Not necessarily sorted

Dense Indexes

- Record pointer for each key value
- Number of index entries = number of records
  - Is it worth it?
- Example
- Block vs. Record pointers

Sparse Indexes

- Index only the first record in a block.
- Example.
- Always better than dense indexes?
- Records must be sorted.

Multiple Level Indexes

- What if indexes occupy many blocks?
- First-level index can be sparse or dense
- Higher level indexes must be sparse.
- Example.

Record Modifications

- Deletion
- Insertion
- Updates
- Reorganization policy
  - immediate
  - postpone (overflow blocks)
- Examples

Secondary Indexes

- Records not sorted (in order of indexing field).
- First level index must be dense.
- Higher levels indexes can be (must be?) sparse.

Applications

- Multiple keys, only one can be primary
  - Only one primary index!
- Non-key fields
- Clustering
  - Store records of two different types on the same block

Buckets

- Buckets of record pointers
- Index points to buckets
- Another level of indirection
- Example
- Is it worth it?
  - Efficient joins.

B-trees

- Balanced trees
- Each node is at least half full.
- Find any record with fixed number of I/O
  - In most cases 1 or 2
- Many variants: B+ trees

B-tree Structure

- Every node is stored in a block
- Each node has space for
  - n values
  - n+1 pointer
- Three types of nodes:
  - Root
  - Interior
  - Leaf nodes

Leaf Nodes

- All leaf nodes are chain-linked together
  - One pointer per node.
- Number of pairs of value and record pointer:
  - Max: n
  - Min: $\lfloor (n+1)/2 \rfloor$
- Example

Interior Node

- Values and pointers to nodes of the next (lower) level:
  - Max: n values, n+1 pointers
  - Min: $\lceil (n-1)/2 \rceil$ values, $\lceil (n+1)/2 \rceil$ pointers

Root Node

- Pointer(s) to next level
- Min: 2
- Max: n+1
- Example
- Extreme case: the root is also a leaf

Lookup

- Given a key x,
- Start at the root node.
- Follow the pointer before the smallest value that is strictly greater than x, or last pointer if there's no such value.
- Repeat until you reach a leaf node.
- If x exists in the leaf node follow pointer to record, otherwise there's no such record.

Range Queries

SELECT beer
FROM Sells
WHERE beer < 'Corona';

SELECT drinker
FROM Drinkers
WHERE drinker > 'Amy'
AND drinker < 'Rick';

Insertion

- Possible cases:
  1. No structural change
  2. Leaf node overflow
  3. Interior node overflow
  4. Root overflow
- A single insertion can trigger cases 2,3, and 4!

Deletion

- Possible cases:
  1. No structural changes
     – But we may update a value in a higher level
  2. Leaf node underflow
  3. Interior node underflow
  4. Root underflow
- Often deletion reorganization is ignored.

Performance

- Reorganization is rare
- Lookup, insert, delete take k I/Os, where k is the depth of the tree.
- k is at most 4
  - For less than 4 billion records
- The root is often kept in memory
  - And possibly (part) of second level
- So, operations take 1-3 I/Os.

Hashing

- Main memory hashing
- Secondary storage hashing
- Static hashing
- Extensible hashing
  - Double the the number of buckets
- Linear hashing
  - Increase the number of buckets by 1