INDEX TUNING
Index

An index is a data structure that supports efficient access to data.

- Different indexes are good for different query types.
- We identify categories of queries with different index requirements.
Index Performance Issues

- Type of Query
- Index Data Structure
- Organization of data on disk
- Index Overhead
- Data Distribution
- Covering
Types of Queries

1. **Point Query**
   
   ```sql
   SELECT balance
   FROM accounts
   WHERE number = 1023;
   ```

2. **Multipoint Query**
   
   ```sql
   SELECT balance
   FROM accounts
   WHERE branchnum = 100;
   ```

3. **Range Query**
   
   ```sql
   SELECT number
   FROM accounts
   WHERE balance > 10000;
   ```

4. **Prefix Match Query**
   
   ```sql
   SELECT *
   FROM employees
   WHERE name = 'Jensen'
   and firstname = 'Carl'
   and age < 30;
   ```
Types of Queries

5 Extremal Query

SELECT *
FROM accounts
WHERE balance =
  max(select balance from accounts)

6 Ordering Query

SELECT *
FROM accounts
ORDER BY balance;

7 Grouping Query

SELECT branchnum, avg(balance)
FROM accounts
GROUP BY branchnum;

8 Join Query

SELECT distinct branch.adresse
FROM accounts, branch
WHERE
  accounts.branchnum =
  branch.number
  and accounts.balance > 10000;
Search Keys

- A (search) key is a sequence of attributes.

- Types of keys
  - Sequential: the value of the key is monotonic with the insertion order (e.g., counter or timestamp)
  - Non sequential: the value of the key is unrelated to the insertion order (e.g., social security number)
Indexes

- **B+-trees**
  - B+-Tree is a balanced tree whose leaves contain a sequence of key-pointer pairs.

- **Hash table (hash map)**
  - Hash is a method of storing key-value pairs based on a pseudo-randomizing function called a hash function.

- **R-trees**
  - R-tree is an index used for spatial access methods, i.e., for indexing multi-dimensional information (geography or geometry).

- **Bitmaps**
  - Bitmap is simply an array of bits.

- **T-trees**
  - A T-tree is a balanced index tree data structure optimized for cases where both the index and the actual data are fully kept in memory.
Clustered – Non clustered index

- Clustered index (primary index)
  - A clustered index on attribute X co-locates records whose X values are near to one another.
  - There might be only one clustered indexes per table.

- Non-clustered index (secondary index)
  - A non clustered index does not constrain table organization.
  - There might be several non-clustered indexes per table.
Sparse/Dense Index

- **Sparse index**
  - Pointers are associated to pages

- **Dense index**
  - Pointers are associated to records
  - Non clustered indexes are dense
Index Implementations in some major DBMS

- **SQL Server**
  - B+-Tree data structure
  - Clustered indexes are sparse
  - Indexes maintained as updates/insertions/deletes are performed

- **DB2**
  - B+-Tree data structure, spatial extender for R-tree
  - Clustered indexes are dense
  - Explicit command for index reorganization

- **Oracle**
  - B+-tree, hash, bitmap, spatial extender for R-Tree
  - Clustered index
    - Index organized table (unique/clustered)
    - Clusters used when creating tables.

- **TimesTen** (Main-memory DBMS)
  - T-tree
Index Tuning -- data

- Settings:
  - employees(ssnum, name, lat, long, hundreds1, hundreds2);
  - clustered index c on employees(hundreds1) with fillfactor = 100;
  - nonclustered index nc on employees (hundreds2);
  - index nc3 on employees (ssnum, name, hundreds2);
  - index nc4 on employees (lat, ssnum, name);

- 1000000 rows ;
- Dual Xeon (550MHz,512Kb), 1Gb RAM, Internal RAID controller from Adaptec (80Mb), 4x18Gb drives (10000RPM), Windows 2000
Index Tuning -- operations

- **Operations:**

  - **Update:**
    update employees set name = ‘XXX’ where ssnum = ?;

  - **Insert:**
    insert into employees values (1003505,'polo94064',97.48,84.03,4700.55,3987.2);

  - **Multipoint query:**
    select * from employees where hundreds1= ?;
    select * from employees where hundreds2= ?;

  - **Covered query:**
    select ssnum, name, lat from employees;

  - **Range Query:**
    select * from employees where long between ? and ?;

  - **Point Query:**
    select * from employees where ssnum = ?
Clustered Index

• Benefits of a clustered index:
  ‣ A sparse clustered index stores fewer pointers than a dense index
    - This might save up to one level in the B-tree index
  ‣ A clustered index is good for multipoint queries
    - White pages in a paper telephone book
  ‣ A clustered index based on a B-Tree supports range, prefix, extremal and ordering queries well
  ‣ A clustered index (on attribute X) can reduce lock contention:
    - Retrieval of records or update operations using an equality, a prefix match or a range condition based on X will access and lock only a few consecutive pages of data

• Cost of a clustered index
  - Cost of overflow pages
  - Due to insertions
  - Due to updates (e.g., a NULL value by a long string)
Clustered Index

- Multipoint query that returns 100 records out of 1000000
- Clustered index is twice as fast as non-clustered index and orders of magnitude faster than a scan
Positive Points of Clustering indexes

• If the index is sparse, it has less points --less I/Os
  - Good for multipoint queries (e.g. Looking up names in telephone dir)
  - Good for equijoin.
  - Good for range, prefix match, and ordering queries

• Because there is only one clustered index per table, it might be a good idea to replicate a table in order to use a clustered index on two different attributes
  - Yellow and white pages in a paper telephone book
  - Low insertion/update rate
Non-Clustered Index

- Benefits of non-clustered indexes
  - A dense index can eliminate the need to access the underlying table through covering
    - It might be worth creating several indexes to increase the likelihood that the optimizer can find a covering index

- A non-clustered index is good if each query retrieves significantly fewer records than there are pages in the table
  - Point queries
  - Multipoint queries:
    - number of distinct key values > c * number of records per page
    - Where c is the number of pages retrieved in each prefetch
Positive/negative points of non-clustering indexes

- Eliminate the need to access the underlying table
  - eg. Index on (A, B, C)
  - select B,C from R where A=5

- Good if each query retrieves significantly fewer records than there are pages in DB

- May not be good for multipoint queries
Scan Can Sometimes Win

- IBM DB2 v7.1 on Windows 2000
- Range Query
- If a query retrieves 10% of the records or more, scanning is often better than using a non-clustering non-covering index. Crossover > 10% when records are large or table is fragmented on disk – scan cost increases.
Covering Index

- Select name from employee where department="marketing"
  - Good covering index would be on (department, name)
  - Index on (name, department) less useful
  - Index on department alone moderately useful

- Covering index performs better than clustering index when first attributes of index are in the where clause and last attributes in the select
- When attributes are not in order then performance is much worse
Evaluation of clustered indexes with insertions

- Index is created with fillfactor= 100
- Insertions cause page splits and extra I/O for each query
- Maintenance consists in dropping and recreating the index
- With maintenance performance is constant while performance degrades significantly if no maintenance is performed
Evaluation of clustered indexes with insertions

- Index is created with pctfree = 0
- Insertions cause records to be appended at the end of the table
- Each query thus traverses the index structure and scans the tail of the table
- Performances degrade slowly when no maintenance is performed
Evaluation of clustered indexes with insertions

- In Oracle, clustered index are approximated by an index defined on a clustered table
- No automatic physical reorganization
- Index defined with pctfree = 0
- Overflow pages cause performance degradation
Index on Small Tables

- Tuning manuals suggest to avoid indexes on small tables
  - If all data from a relation fits in one page then an index page adds an I/O
  - If each record fits in a page then an index helps performance
Index on Small Tables

If transactions update a single record, without an index, each transaction scans through many records before it locks the relevant record, thus reducing update concurrency.

- Small table: 100 records, i.e., a few pages
- Two concurrent processes perform updates (each process works for 10ms before it commits)
- No index: the table is scanned for each update. No concurrent updates
- A clustered index allows to take advantage of row locking
Bitmap vs. Hash vs. B+-Tree

- Settings:

```sql
employees(ssnum, name, lat, long, hundreds1, hundreds2);
create cluster c_hundreds (hundreds2 number(8)) PCTFREE 0;
create cluster c_ssnum(ssnum integer) PCTFREE 0 size 60;
create cluster c_hundreds(hundreds2 number(8)) PCTFREE 0 HASHKEYS 1000 size 600;
create cluster c_ssnum(ssnum integer) PCTFREE 0 HASHKEYS 1000000 SIZE 60;
create bitmap index b on employees (hundreds2);
create bitmap index b2 on employees (ssnum);

- 1000000 rows ;
- Dual Xeon (550MHz,512Kb), 1Gb RAM, Internal RAID controller from Adaptec (80Mb), 4x18Gb drives (10000RPM), Windows 2000
Multipoint Query: B-Tree, Hash Tree, Bitmap

- There is an overflow chain in a hash index
- In a clustered B-Tree index records are on contiguous pages
- Bitmap is proportional to size of table and non-clustered for record access
B-Tree, Hash Tree, Bitmap

- Hash indexes don’t help when evaluating range queries
- Hash index outperforms B-tree on point queries
Index Tuning Summary

- Use a hash index for point queries only!
- Use a B-tree if multipoint queries or range queries are used!
- Use clustering
  - if your queries need all or most of the fields of each records returned
  - if multipoint or range queries are asked
- Use a dense index to cover critical queries
- Don’t use an index if the time lost when inserting and updating overwhelms the time saved when querying