Optimizing Database Performance

Database Design

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Introduction

Motivation

- DBMS stores vast quantities of data
- Data is stored on external storage devices and fetched into main memory as needed for processing
- Page is unit of information read from or written to disk. (in DBMS, page may have size 8KB or more).
- Data on external storage devices:
  - Disks: Can retrieve random page at fixed cost
    But reading several consecutive pages is much cheaper than reading them in random order
  - Tapes: Can read pages only in sequence
    Cheaper than disks; used for archival storage
- Cost of page I/O dominates cost of typical database operations

Files and indices

- **File organization:**
  - Method of arranging a file of records on external storage.
  - Record id (rid) is sufficient to physically locate a record
- **Indexes:**
  - Indexes are data structures that allow us to find the record ids of records with given values in index search key fields

Alternative File Organizations

Many alternatives exist, each ideal for some situations, and not so good in others:

- Heap (random order) files: Suitable when typical access is a file scan retrieving all records.
- Sorted Files: Best if records must be retrieved in some order, or only a `range' of records is needed.
- Indexes: Data structures to organize records via trees or hashing.
  - Like sorted files, they speed up searches for a subset of records, based on values in certain ("search key") fields
  - Updates are much faster than in sorted files.

Indexing

Introduction

❑ Scan Search

```
CREATE TABLE dbo.PhoneBook
(
   LastName varchar(50) NOT NULL,
   FirstName varchar(50) NOT NULL,
   PhoneNumber varchar(50) NOT NULL
);
```

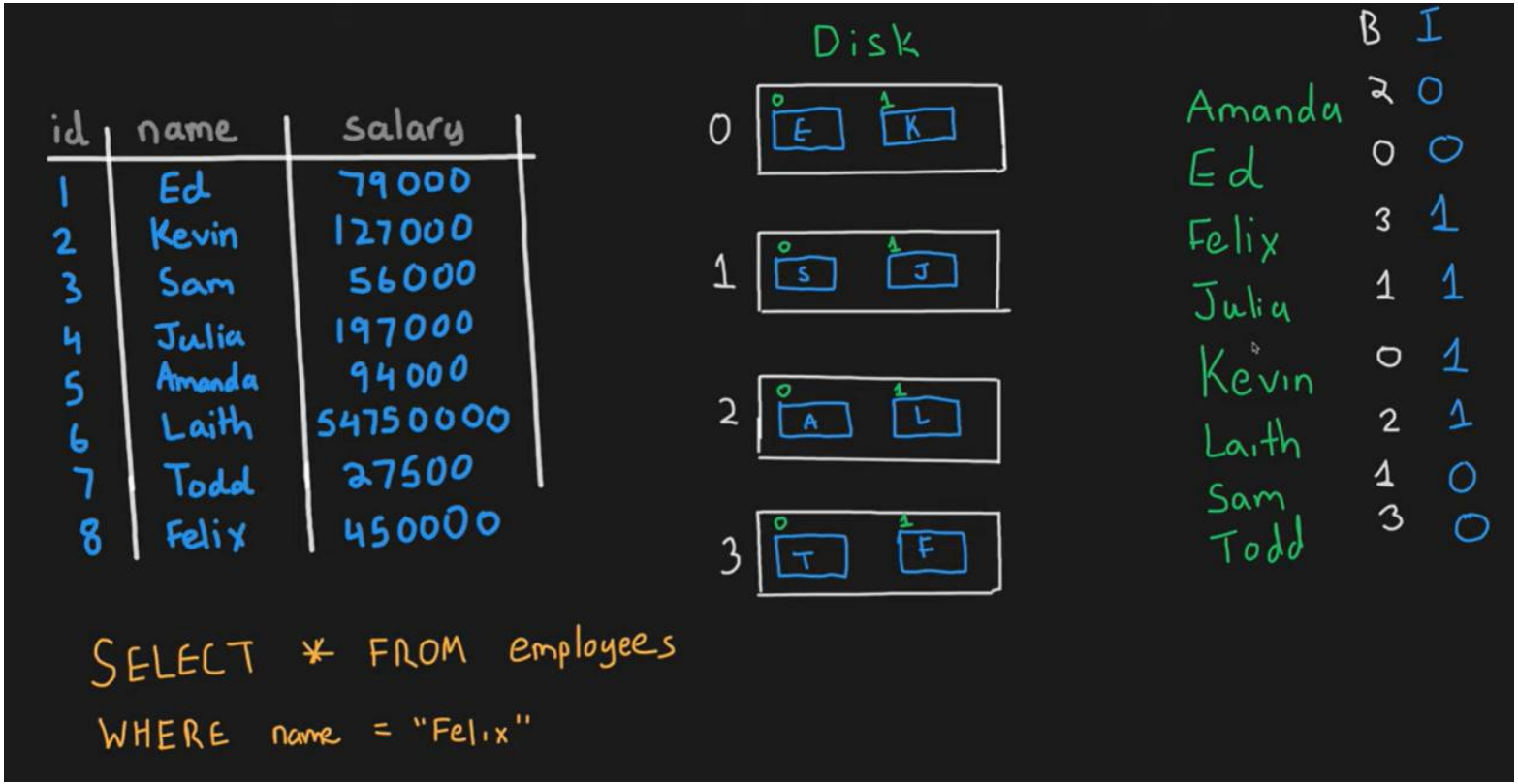
```
SELECT PhoneNumber
  FROM dbo.PhoneBook
  WHERE LastName = 'Logan' AND FirstName = 'Todd';
```

It is insufficient!!!

Results:

783-555-0110

Introduction



Indexes

- An *index* on a file speeds up selections on the *search key fields* for the index.
  - Any subset of the fields of a relation can be the search key for an index on the relation (e.g., age or colour).
  - *Search key* is not the same as *key* (minimal set of fields that uniquely identify a record in a relation).
- An index contains a collection of *data entries*, and supports efficient retrieval of all data entries **k*** with a given key value **k**.

Indexes

- In Internal schema of Three-Schema Architecture!

- An index for an attribute (or attributes) of a relation is a data structure used to speed access to tuples of a relation, given values of the attribute(s).
- In a DBMS it is a balanced search tree with giant nodes (a full disk page) called a B-tree.
- Can make query answering and joins involving the attribute much faster.
- On the other hand, modifications are more complex and take longer.

Declaring Indexes

- No standard!
- Typical syntax:

```
CREATE INDEX foodInd ON foods(nationality);
CREATE INDEX SellInd ON Sells(resturant, food);
```

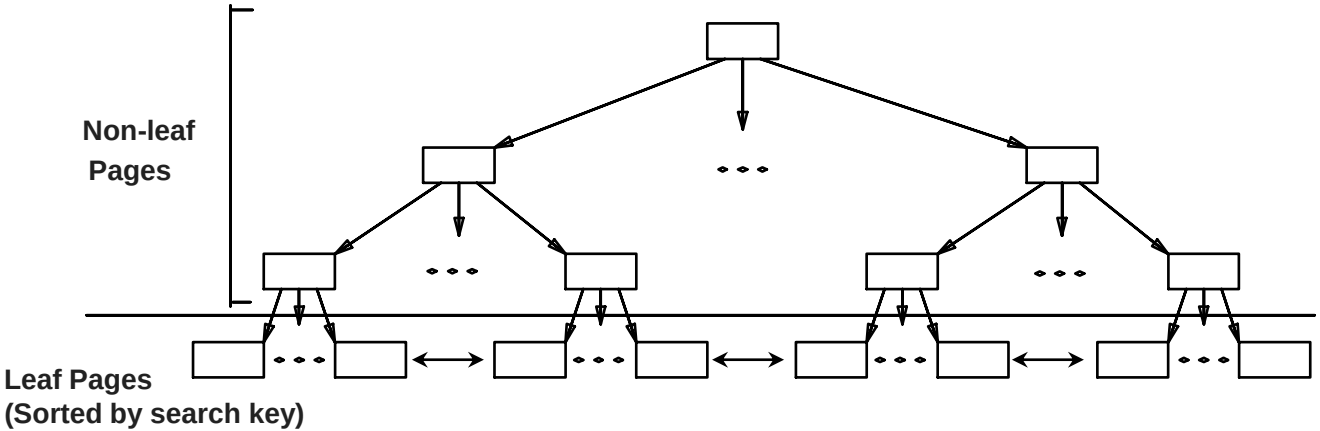
Using Indexes

- Given a value *v*, the index takes us to only those tuples that have *v* in the attribute(s) of the index.
- Example: use foodInd and SellInd to find the prices of foods which nationality is Iranian and sold by Joe. (next slide)
- With the indices, just retrieve tuples satisfying these conditions
  - Clearly, can result in huge savings (vs. retrieving all tuples from the mentioned relations)

```
SELECT price
FROM foods, Sells
WHERE nationality = 'Iranian' AND
    foods.name = Sells.food AND
    resturant = 'Joe''s resturant';
```

1. Use foodInd to get all the foods which Iranian nationality.
2. Then use SellInd to get prices of those foods, with resturant = ' Joe' ' s resturant'

E.g., Tree index



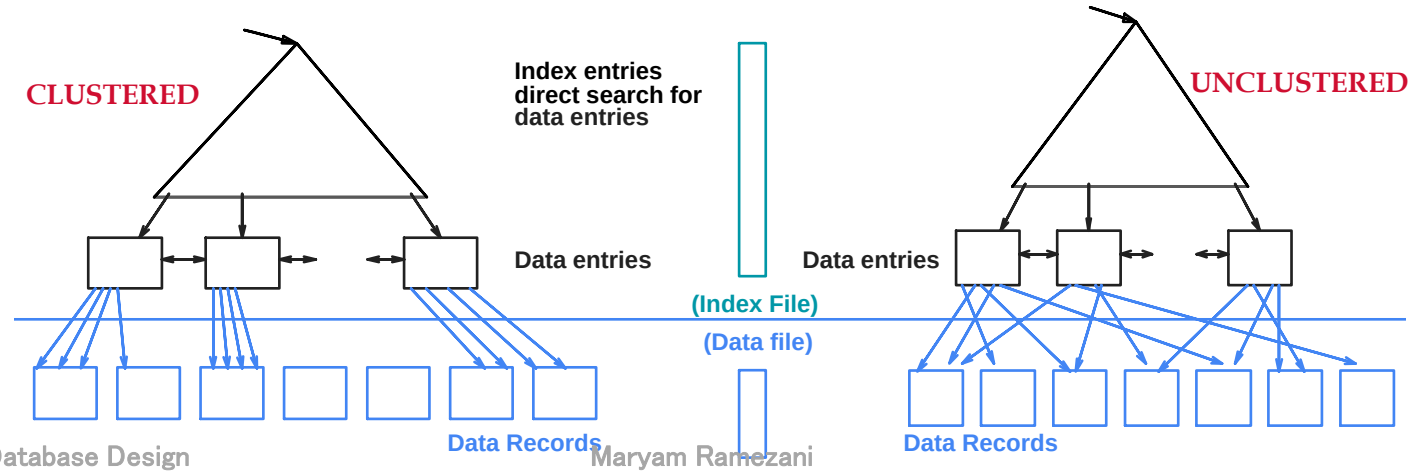
- Leaf pages contain *data entries*
- Non-leaf pages have *index entries;* used only to direct searches:

Alternatives for Data Entry k* in Index

- Three alternatives:
  - 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**⟩
- Alternative 3 more compact than Alternative 2, but leads to variable sized data entries even if search keys are of fixed length.
- Choice of alternative for data entries is orthogonal to the indexing technique used to locate data entries with a given key value k
  - Examples of indexing techniques: B+ tree, hash based structures
  - Typically, index contains auxiliary information that directs searches to the desired data entries
- Clustered vs. unclustered: If order of data records is the same as, or `close to', order of data entries, then called clustered index.

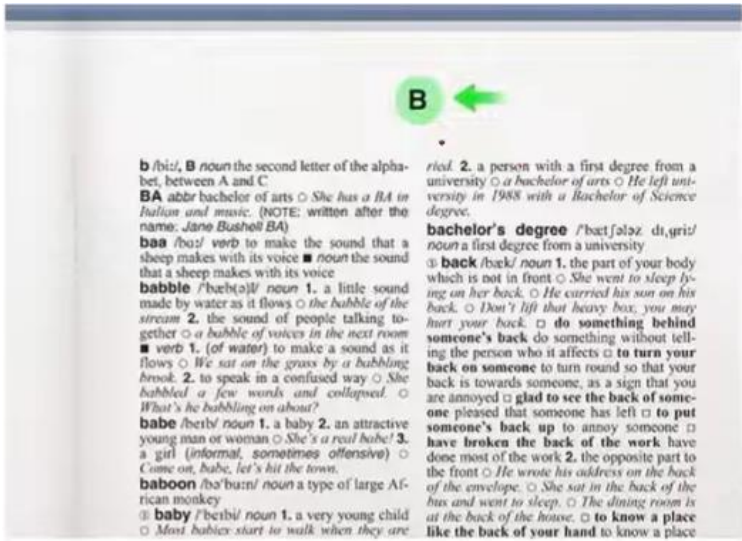
Clustered vs. Unclustered Index

- Suppose that Alternative (2) is used for data entries, and that the data records are stored in a Heap file.
  - To build clustered index, first sort the Heap file (with some free space on each page for future inserts).
  - Overflow pages may be needed for inserts. (Thus, order of data recs is `close to', but not identical to, the sort order.)

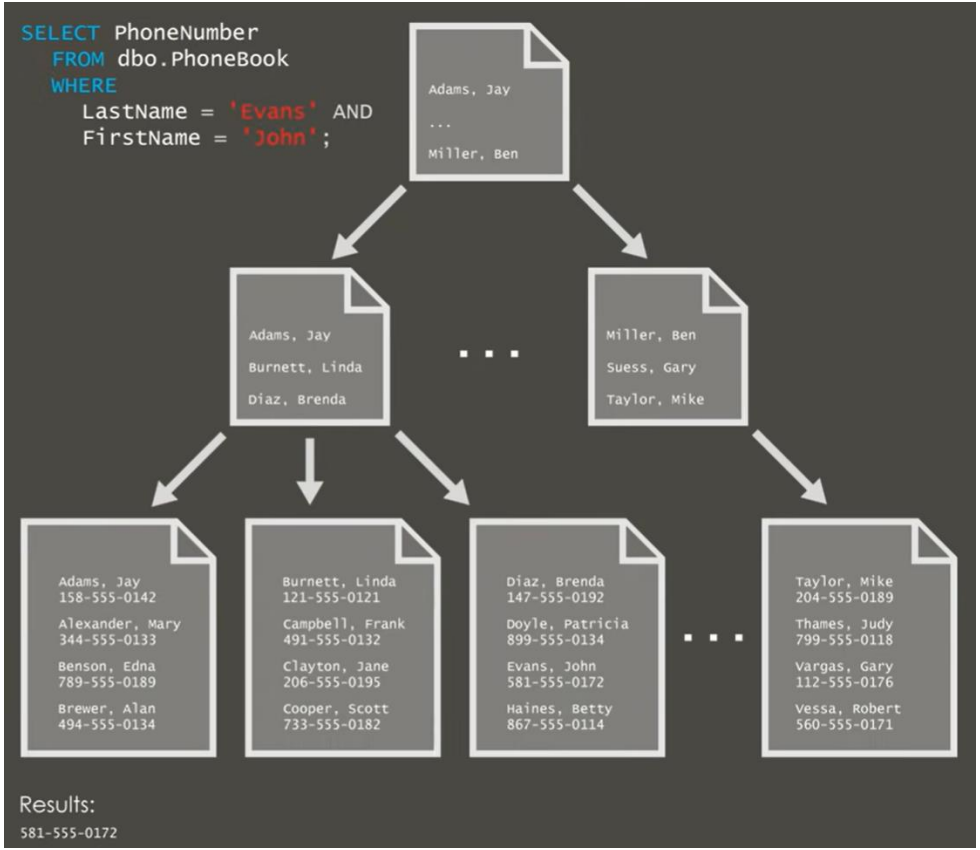


Clustered Index

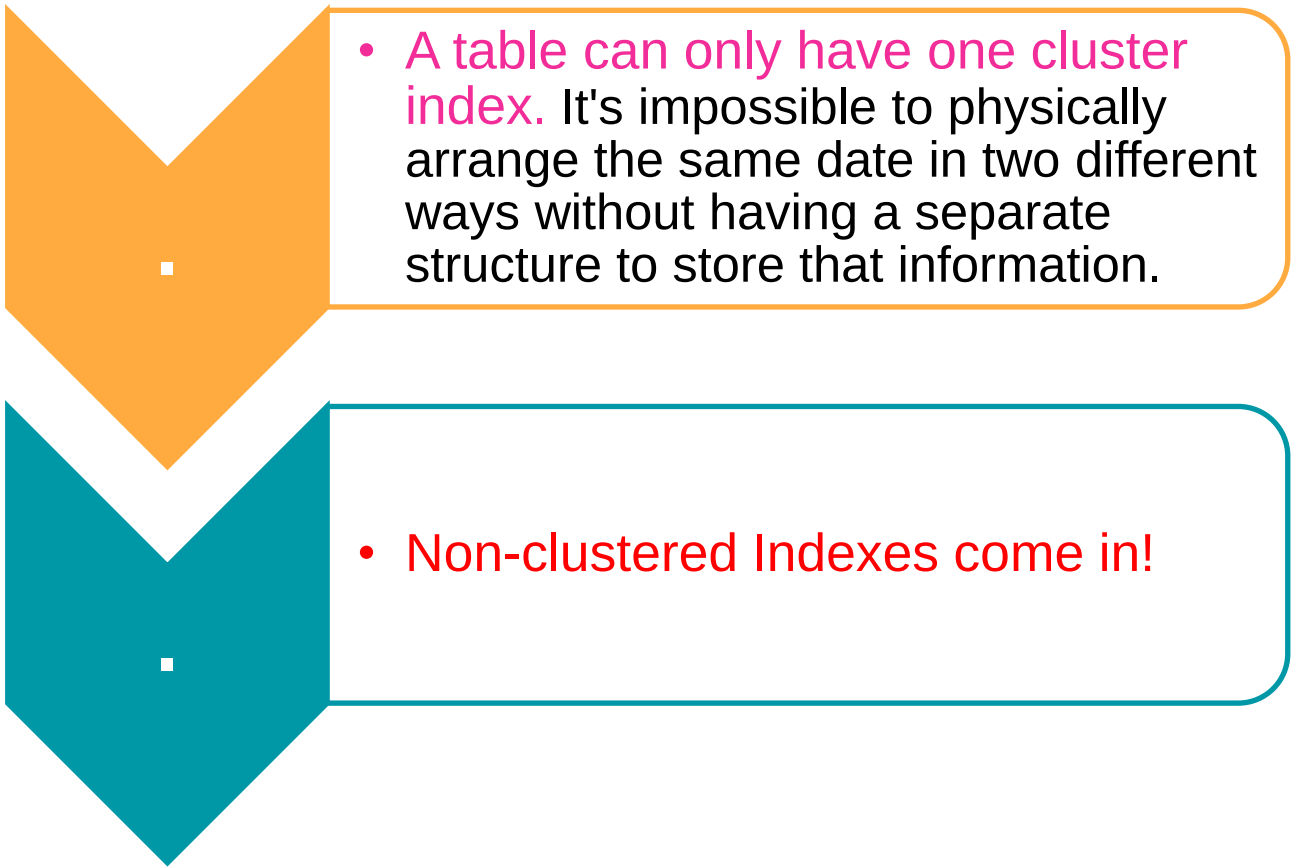
- A cluster index defined the order in which data is physically stored in a table.
  - For example Dictionary.
- A table can only have one cluster index.
- If you configure a PRIMARY KEY, Database Engine automatically creates a clustered index, unless a clustered index already exists.



Clustered Index



Clustered Index



Non-Clustered Index

- A non-clustered index is stored at one place and table data is stored in another place. For example Book Index.
- Instead of having base table at the leaf of tree, we have a set of pointers or references back to the base data.
- A table can have multiple non-clustered index.
- Non-clustered index is slower than clustered index.
- If the index is non-unique, a uniquified value is adds internally to make it unique, and it carries through into reference values. RIDs are always unique.

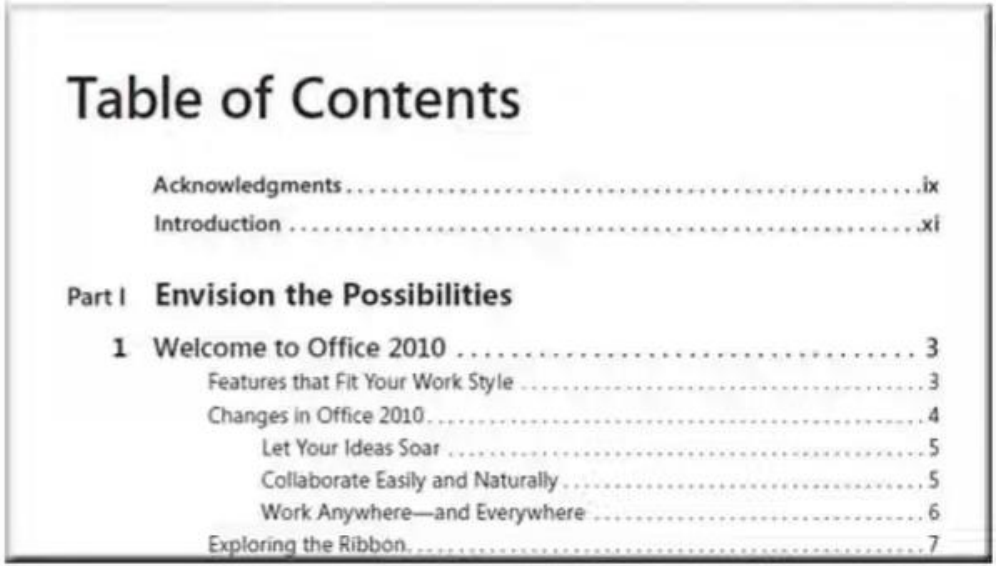
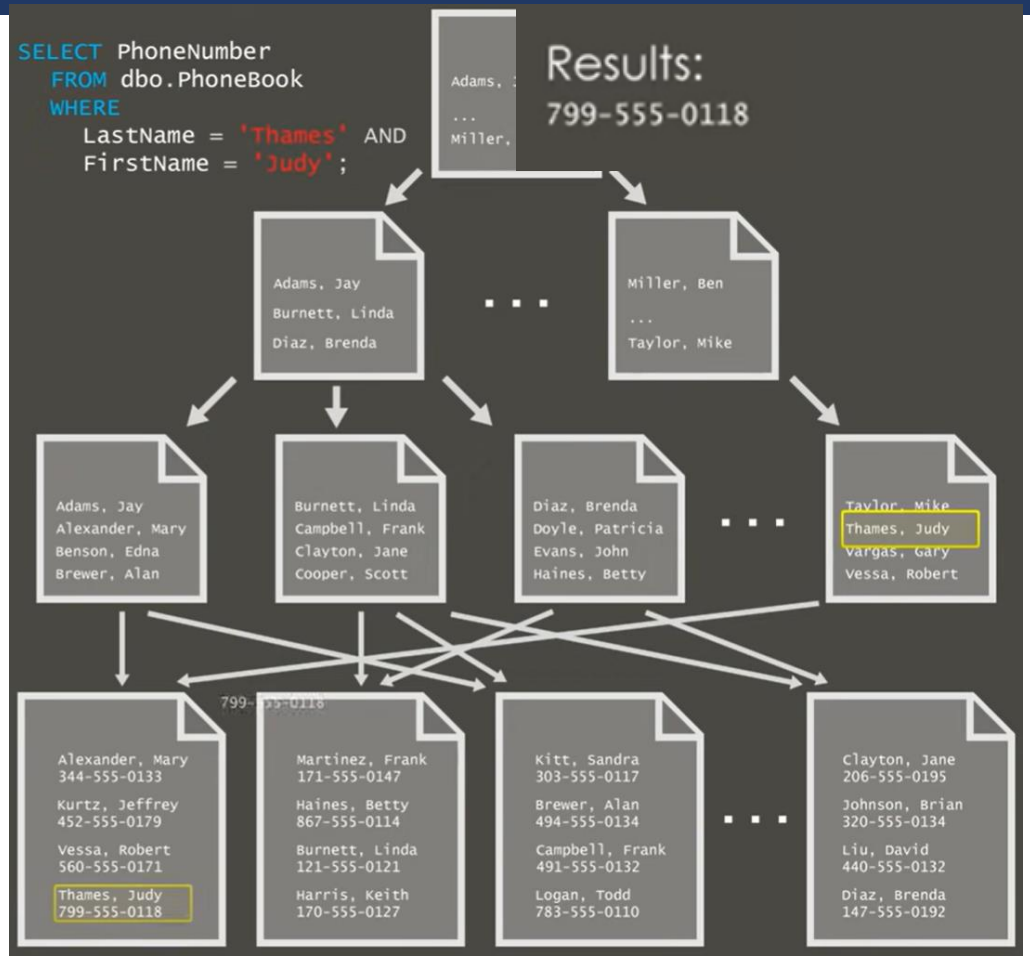


Table of Contents

Non-Clustered Index

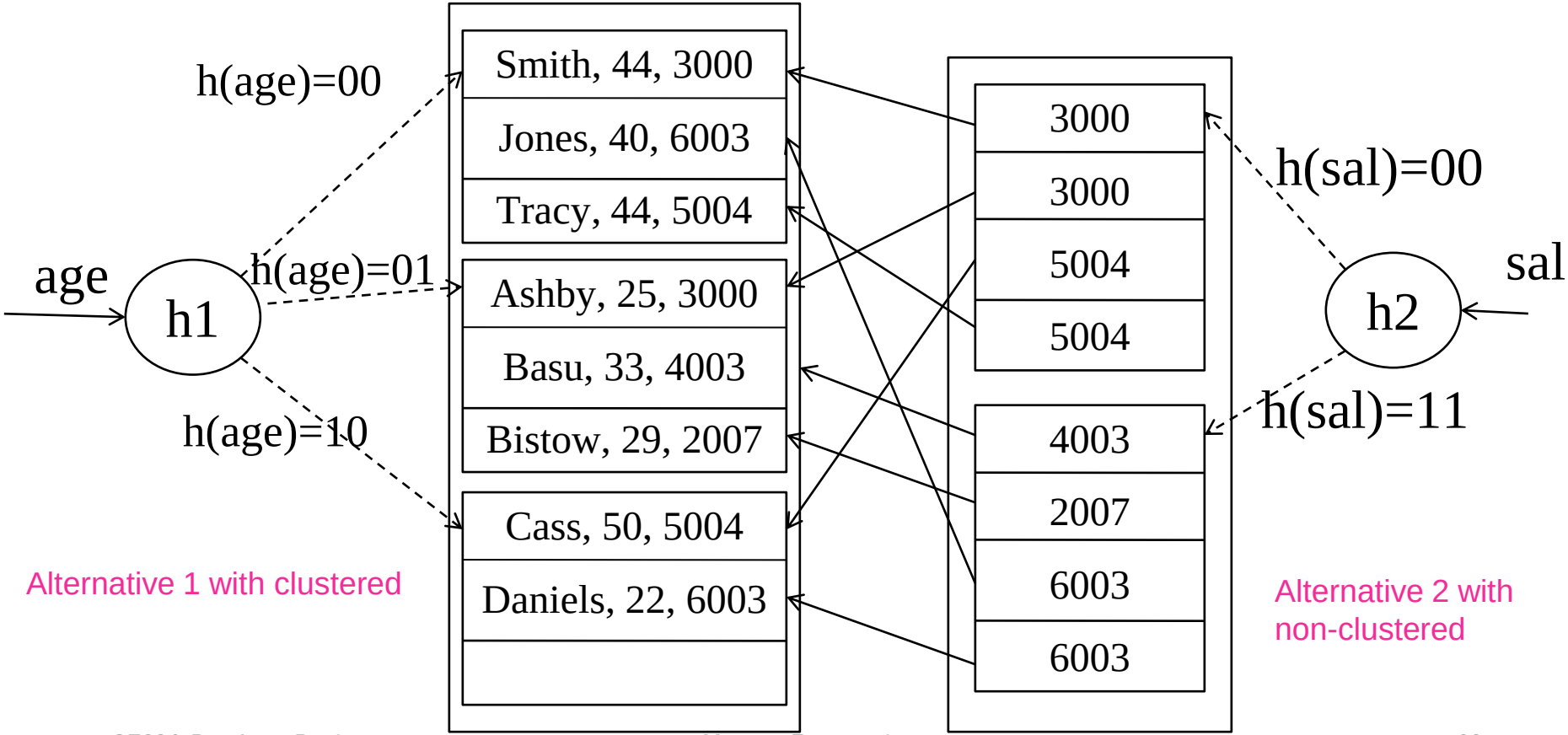


RID=Row Identifier= physical location of the rows in the table.

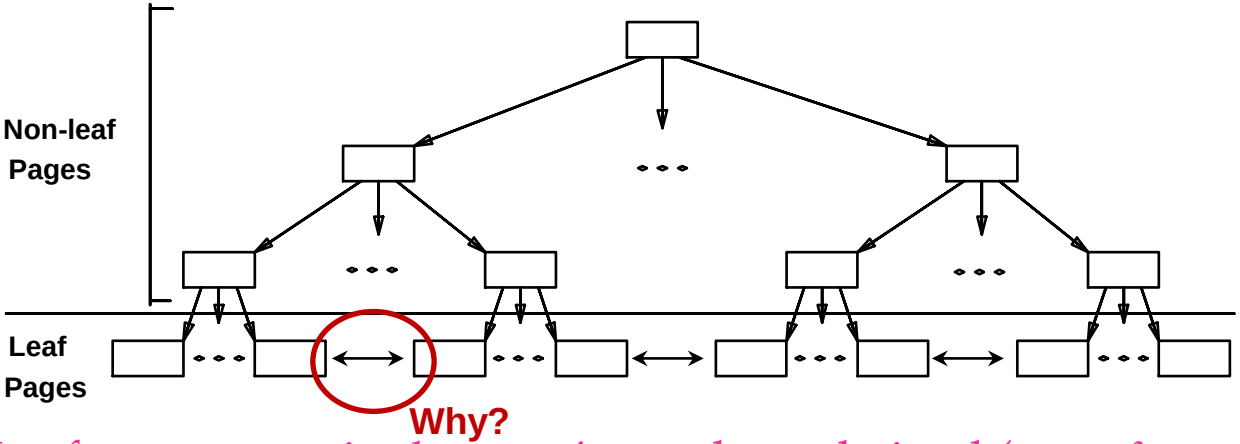
Hash-Based Indexes

- Good for equality selections.
  - Index is a collection of *buckets*. Bucket = *primary* page plus zero or more *overflow* pages.
  - *Hashing function* **h**: **h**(*r*) = bucket in which record *r* belongs. **h** looks at the *search key* fields of *r*.
- If Alternative (1) is used, the buckets contain the data records; otherwise, they contain <key, rid> or <key, rid-list> pairs.

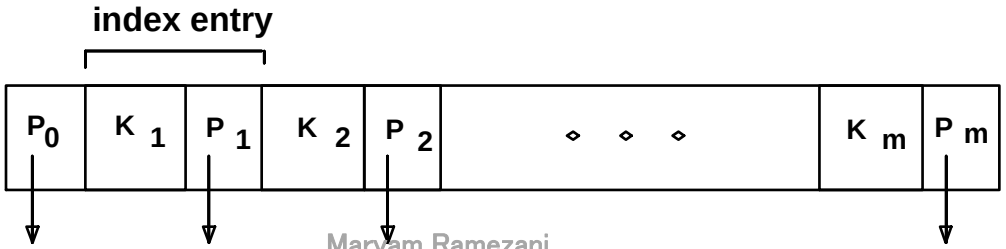
Index-organized file hashed on age, with auxiliary index on sal



B+ Tree Indexes



- Leaf pages contain *data entries*, and are chained (prev & next)
- Non-leaf pages contain *index entries*; they direct searches:

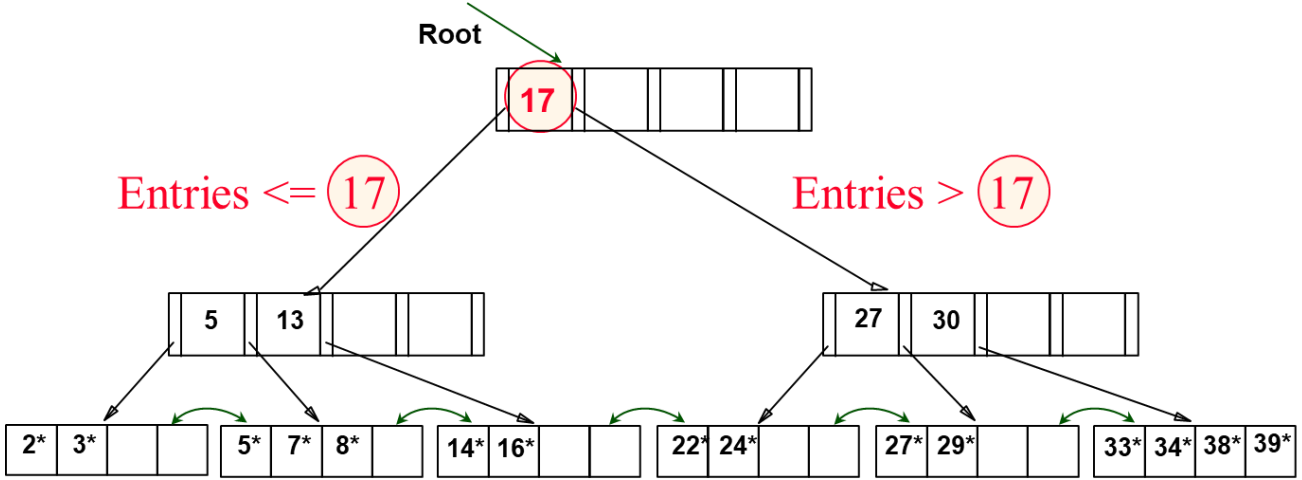


B+ Tree Indexes

- Faster than binary search.
- Lots of pointer while the height o tree is at most 3 or 4!
- Pages at leaves are linked for interval search!
- Example
  - Number of pointers: 100 with height:4 will be 100^4 leaves.
  - Order of tree is 4 but binary search is log(10^4)

Example B+ Tree

- Find 28*?
- Find 29*?
- Find All > 17* and < 30*
- Insert/delete: Find data entry in leaf, then change it. Need to adjust parent sometimes.
  - And change sometimes bubbles up the tree



Lets test on Postgres

- `explain analyze select * from athlete a where sport_id=1`
- `explain analyze select athlete_id from athlete a where athlete_id =15`
- `explain analyze select * from athlete a where athlete_id =15`
- `explain analyze select * from athlete a where a.athlete_name ='browntoni'`
- `explain analyze select * from athlete a where a.athlete_name like '%b%'`

Using Both Clustered & Non-Clustered

- Since a non-clustered index is separate from the base data, the base data could exist instead as clustered index. So the references in leaf of non-clustered index are not RID, but instead are the clustered index key values.

Filtered Indexes

- Filtered indexes only contain rows that meet a user-defined predicate, by adding WHERE clause to the index definition. (In Postgres its name **Partial Index**)

```
CREATE INDEX IX_PhoneBook_NCI
   ON dbo.PhoneBook(LastName, FirstName)
   WHERE (LastName >= 'Burnett');
```

- A clustered index can't be filtered because it has to contain all the data in the table.

Database Tuning

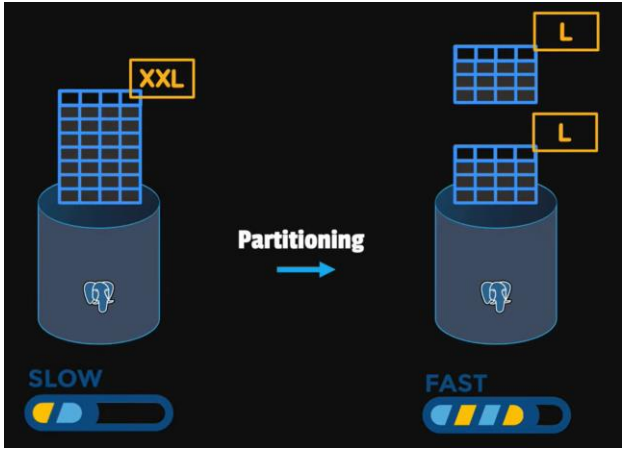
- A major problem in making a database run fast is deciding which indexes to create.
- Recall:
  - Pro: An index speeds up queries that can use it.
  - Con: An index slows down modifications on its relation because the index must be modified too.
- The key for a relation is usually the most useful attribute to have an index on:
  - Queries in which a value for a key is specified are common.
  - For a given key value there is only one tuple. Thus the index returns at most one tuple, requiring just 1 page from the relation instance to be retrieved.

Partitioning

Partitioning

- When the table size grows over time, each operation cost on the table will increase as well.
- We can't increase the size of the table over 32GB in normal conditions. Before reaching this size performance issues may arise.

Good Solution: Partitioning



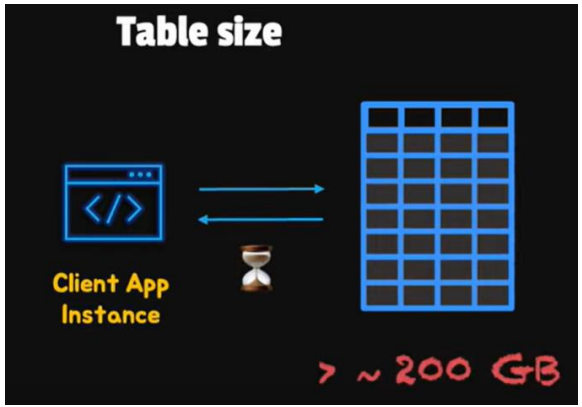
Add partitioning for a table?

- It shouldn't be the first option to improve performance!!!

  Why?
  - It adds another level of complexity!!
  - Unlike other performance enhancing such as indexing, partitions are part of table definition so its difficult to change!!

Add partitioning for a table?

- Signs to check a table needs partitioning:
  1) Table Size: there is no rule! But encounter long responses time and table is larger than 200GB

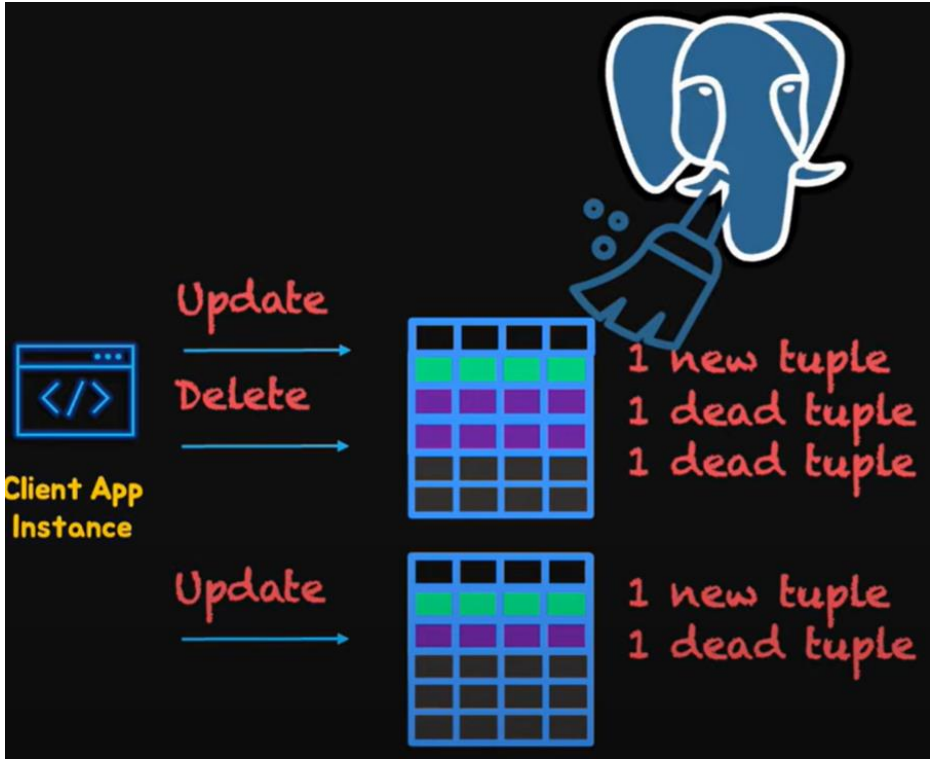


Add partitioning for a table?

2) Table Bloat: For a DELETE, it simply marks the row as unavailable for future transactions, and for UPDATE, under the hood it's a combined INSERT then DELETE, where the previous version of the row is marked unavailable.

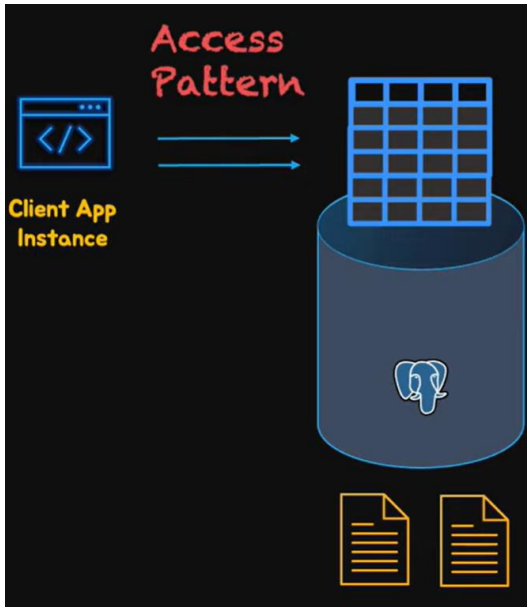
The space cannot be used. To then mark the space as available for use by the database, a vacuum process (manually or automatically) needs to come along behind the operations, and mark that space available for the database to use.

Vacuum process should scan all rows. If table is large vacuum process will take longer. Partitioning can help to make it faster with less CPU.

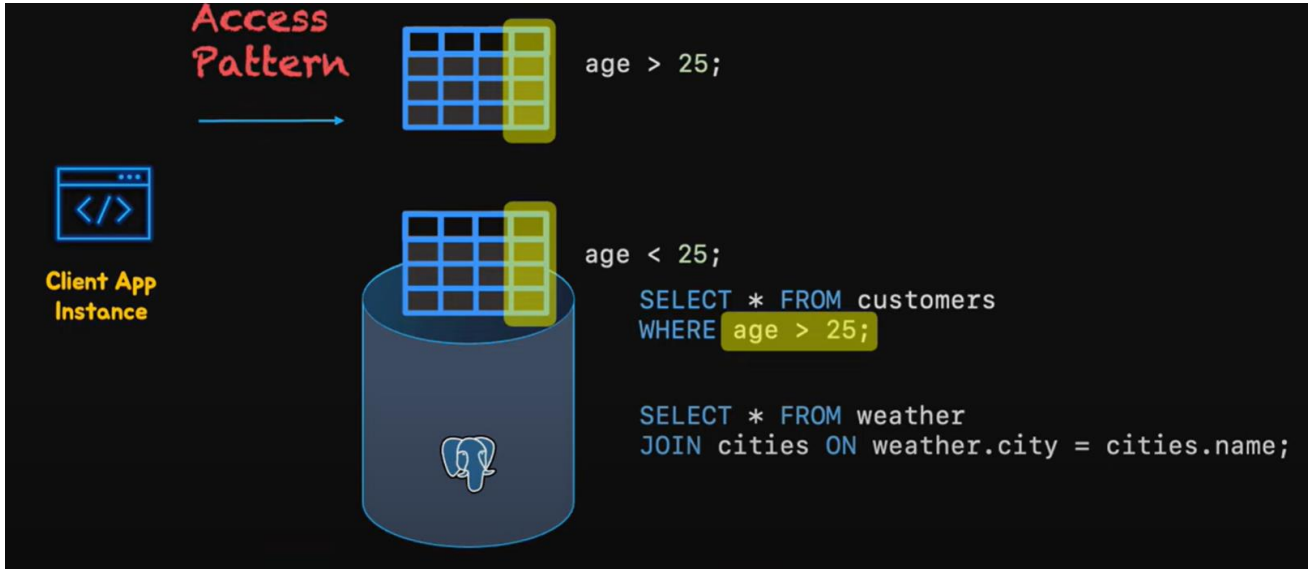


How should the Tables be partitioned?

- Partitioning can drastically improve performance on a table when done right, but when not needed o done wrong can make the performance worse or it can make the database unstable.
- First look for access patterns for splitting the tables:
  - By knowing the applications that access the database.
  - Monitoring the logs and generating reports.

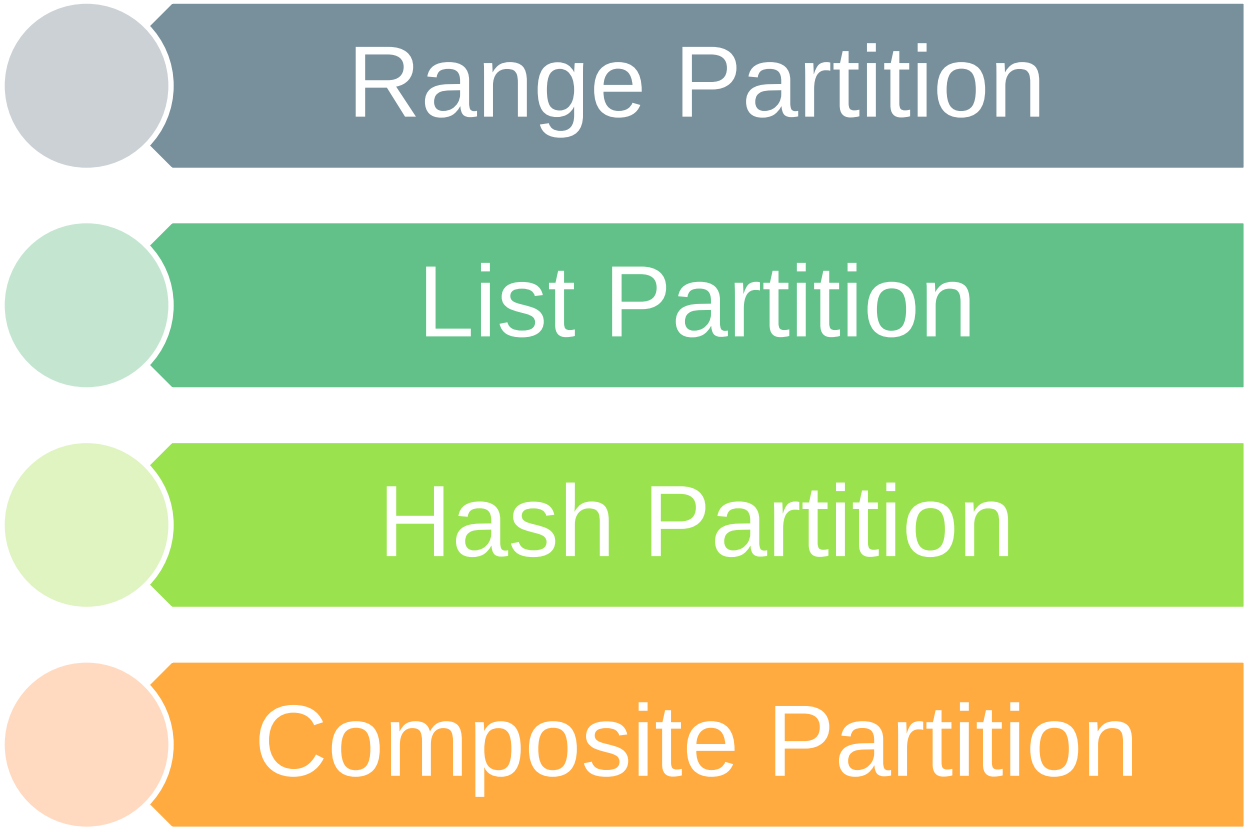


How should the Tables be partitioned?



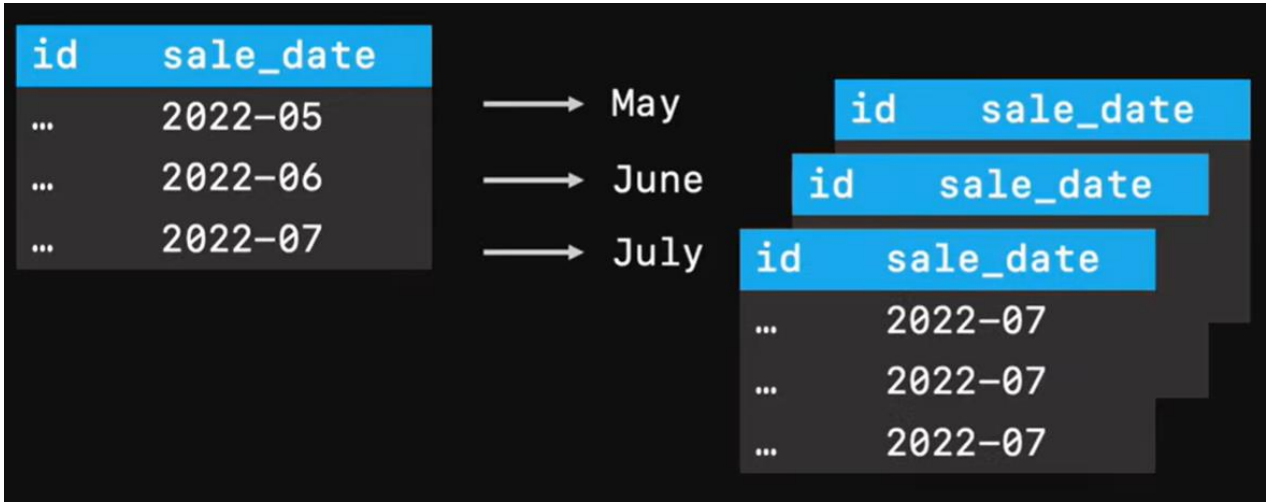
We look for columns that are either in **where** or in **join** conditions.
These will be the partition keys.
In a good design, we have a small subset of data rather than the whole

Partitioning Methods



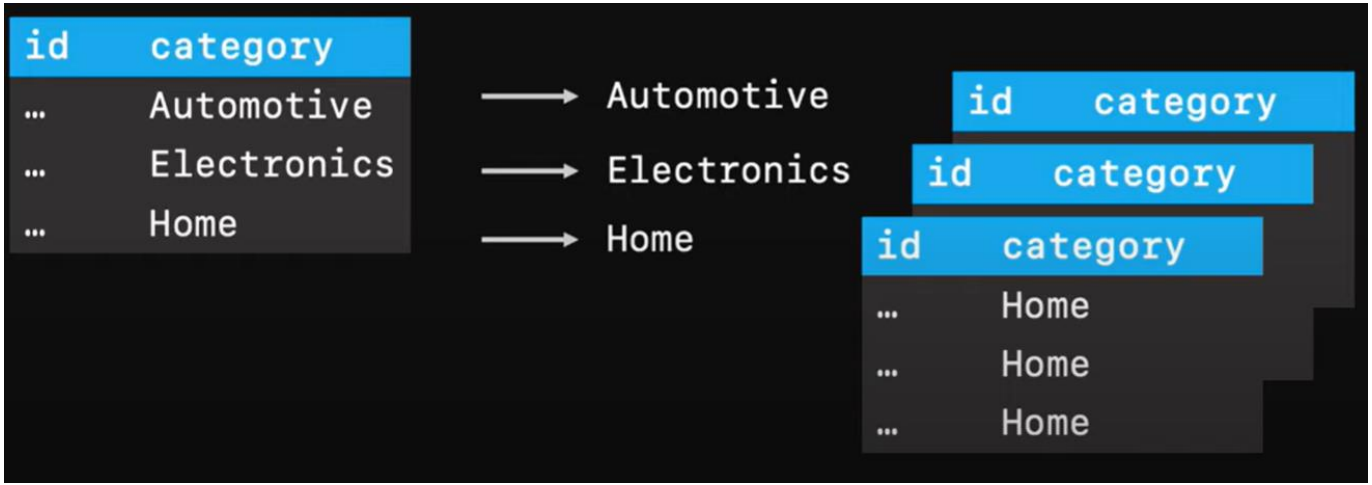
Partitioning Methods

- Range partitioning maps data to partitions on the basis of ranges of partition key values for each partition.



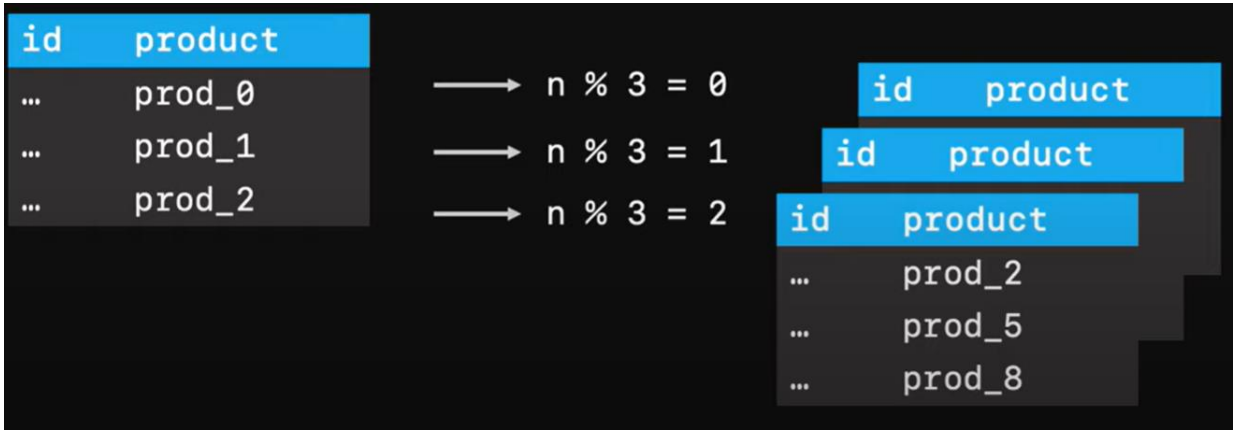
Partitioning Methods

- List partitioning maps rows to partitions by using a list of discrete values for the partitioning column.
  - Good when partition key is category value.



Partitioning Methods

- Hash partitioning maps data to partitions by using a hashing algorithm applied to a partitioning key.
  - Especially useful when there is no obvious way of diving data into logical groups.

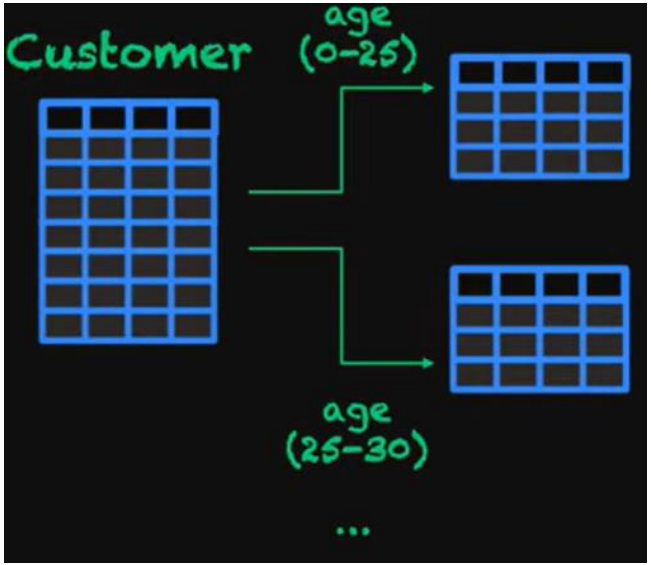


Partitioning Methods

- Composite partitioning:
  - Range–Hash sub partitions the range partitions using a hashing algorithm.
  - Range–List sub partitions the range partitions using an explicit list.

Range Partition – Example

- Consider following table with not null age attribute:



Range Partition– Example

- `create table customers (id integer, name text, age numeric) partition by range(age)`
- `create table cust_young partition of customers for values from (MINVALUE) to (25)`
- `create table cust_medium partition of customers for values from (25) to (75)`
- `create table cust_old partition of customers for values from (75) to (MAXVALUE)`
- `insert into customers values (1,'Bob',20), (2,'Alice',20),(3,'Doe',38),(4,'Richard',80)`
- `select * from customers c`
- `select tableoid::regclass,* from customers c`