CHANDIGARH ENGINEERING COLLEGE

B.TECH.(CSE 5th Sem.)

Notes Subject: Database Management System

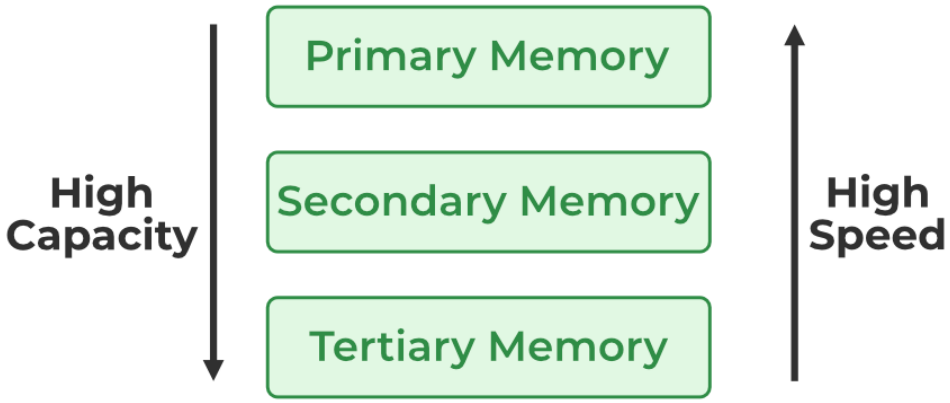
Subject Code: ((BTCS 501-18))

Unit 3

Storage strategies in DBMS

The records in databases are stored in file formats. Physically, the data is stored in electromagnetic format on a device. The electromagnetic devices used in database systems for data storage are classified as follows:

1. Primary Memory
2. Secondary Memory
3. Tertiary Memory



Types of Memory

1. Primary Memory

The primary memory of a server is the type of data storage that is directly accessible by the central processing unit, meaning that it doesn't require any other devices to read from it. The primary memory must, in general, function flawlessly with equal contributions from the electric power supply, the hardware backup system, the supporting devices, the coolant that moderates the system temperature, etc.

- The size of these devices is considerably smaller and they are volatile.
- According to performance and speed, the primary memory devices are the fastest devices, and this feature is in direct correlation with their capacity.
- These primary memory devices are usually more expensive due to their increased speed and performance.

The cache is one of the types of Primary Memory.

- **Cache Memory:** Cache Memory is a special very high-speed memory. It is used to speed up and synchronize with a high-speed CPU. Cache memory is costlier than main memory or disk memory but more economical than CPU registers. Cache memory is an extremely fast memory type that acts as a buffer between RAM and the CPU.

2. Secondary Memory

Data storage devices known as secondary storage, as the name suggests, are devices that can be accessed for storing data that will be needed at a later point in time for various purposes or database actions. Therefore, these types of storage systems are sometimes called backup units as well. Devices that are plugged or connected externally fall under this memory category, unlike primary memory, which is part of the CPU. The size of this group of devices is noticeably larger than the primary devices and smaller than the tertiary devices.

- It is also regarded as a temporary storage system since it can hold data when needed and delete it when the user is done with it. Compared to primary storage devices as well as tertiary devices, these secondary storage devices are slower with respect to actions and pace.
- It usually has a higher capacity than primary storage systems, but it changes with the technological world, which is expanding every day.

Some commonly used Secondary Memory types that are present in almost every system are:

- **Flash Memory:** Flash memory, also known as flash storage, is a type of nonvolatile memory that erases data in units called blocks and rewrites data at the byte level. Flash memory is widely used for storage and data transfer in consumer devices, enterprise systems, and industrial applications. Unlike traditional hard drives, flash memories are able to retain data even after the power has been turned off
- **Magnetic Disk Storage:** A Magnetic Disk is a type of secondary memory that is a flat disc covered with a magnetic coating to hold information. It is used to store various programs and files. The polarized information in one direction is represented by 1, and vice versa. The direction is indicated by 0.

3. Tertiary Memory

For data storage, Tertiary Memory refers to devices that can hold a large amount of data without being constantly connected to the server or the peripherals. A device of this type is connected either to a server or to a device where the database is stored from the outside.

- Due to the fact that tertiary storage provides more space than other types of device memory but is most slowly performing, the cost of tertiary storage is lower than primary and secondary. As a means to make a backup of data, this type of storage is commonly used for making copies from servers and databases.
- The ability to use secondary devices and to delete the contents of the tertiary devices is similar.

Some commonly used Tertiary Memory types that are almost present in every system are:

- **Optical Storage:** It is a type of storage where reading and writing are to be performed with the help of a laser. Typically data written on CDs and DVDs are examples of Optical Storage.
- **Tape Storage:** Tape Storage is a type of storage data where we use magnetic tape to store data. It is used to store data for a long time and also helps in the backup of data in case of data loss.

Memory Hierarchy

A computer system has a hierarchy of memory. Direct access to a CPU's main memory and inbuilt registers is available. Accessing the main memory takes less time than running a CPU. Cache memory is introduced to minimize this difference in speed. Data that is most frequently accessed by the CPU resides in cache memory, which provides the fastest access time to data. Fastest-accessing memory is the most expensive. Although large storage devices are slower and less expensive than CPU registers and cache memory, they can store a greater amount of data.

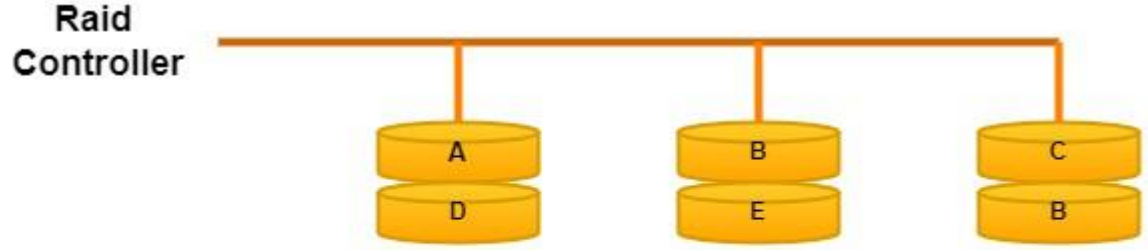
1. Magnetic Disks

Present-day computer systems use hard disk drives as secondary storage devices. Magnetic disks store information using the concept of magnetism. Metal disks are coated with magnetizable material to create hard disks. Spindles hold these disks vertically. As the read/write head moves between the disks, it de-magnetizes or magnetizes the spots under it. There are two magnetized spots: 0 (zero) and 1 (one). Formatted hard disks store data efficiently by storing them in a defined order. The hard disk plate is divided into many concentric circles, called tracks. Each track contains a number of sectors. Data on a hard disk is typically stored in sectors of 512 bytes.

2. Redundant Array of Independent Disks(RAID)

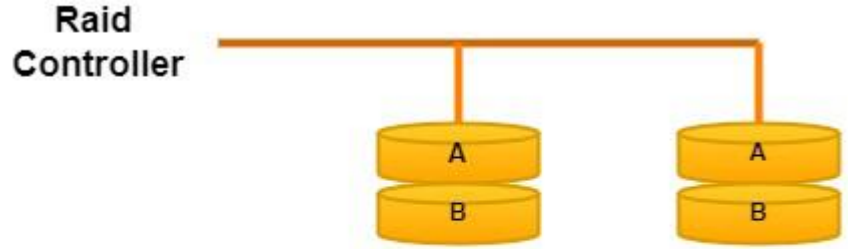
In the Redundant Array of Independent Disks technology, two or more secondary storage devices are connected so that the devices operate as one storage medium. A RAID array consists of several disks linked together for a variety of purposes. Disk arrays are categorized by their RAID levels.

- **RAID 0:** At this level, disks are organized in a striped array. Blocks of data are divided into disks and distributed over disks. Parallel writing and reading of data occur on each disk. This improves performance and speed. Level 0 does not support parity and backup.



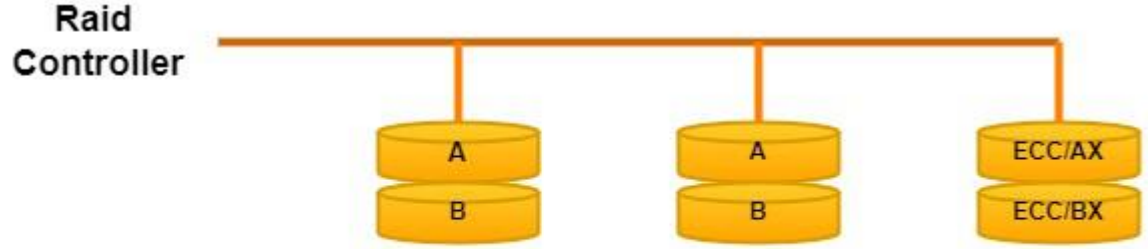
Raid-0

- **RAID 1:** Mirroring is used in RAID 1. A RAID controller copies data across all disks in an array when data is sent to it. In case of failure, RAID level 1 provides 100% redundancy.



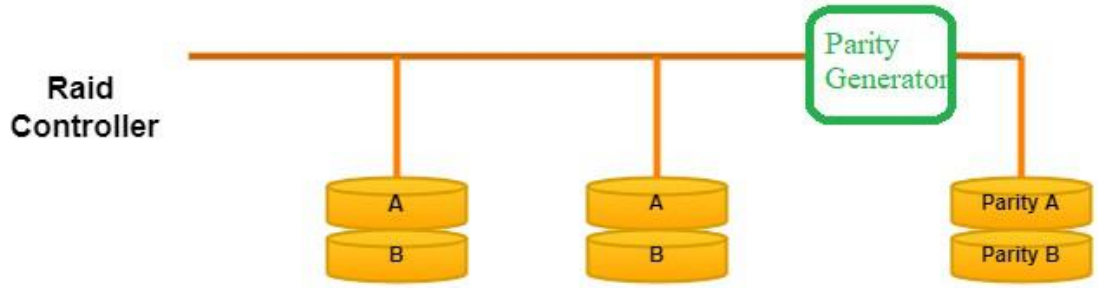
Raid-1

- **RAID 2:** The data in RAID 2 is striped on different disks, and the Error Correction Code is recorded using Hamming distance. Similarly to level 0, each bit within a word is stored on a separate disk, and ECC codes for the data words are saved on a separate set of disks. As a result of its complex structure and high cost, RAID 2 cannot be commercially deployed.



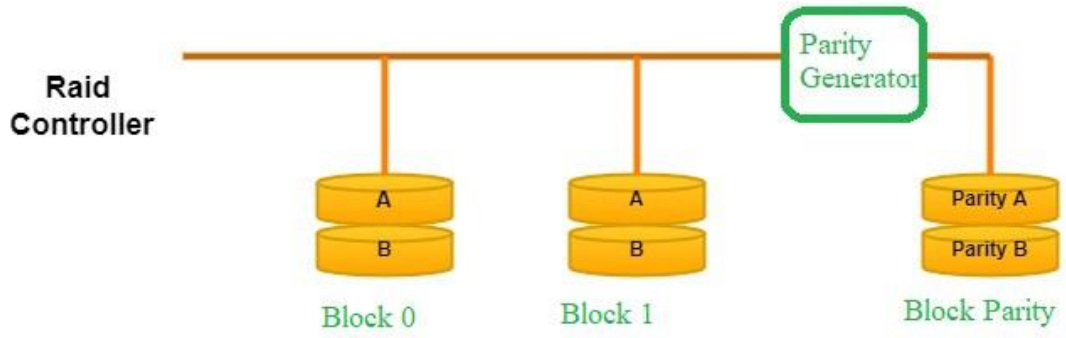
Raid-2

- **RAID 3:** Data is striped across multiple disks in RAID 3. Data words are parsed to generate a parity bit. It is stored on a different disk. Thus, single-disk failures can be avoided.



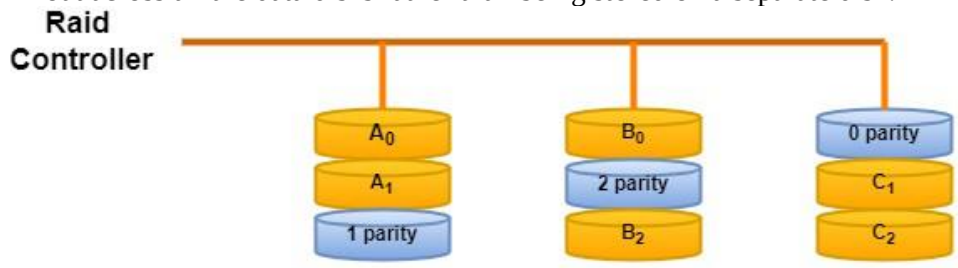
Raid-3

- **RAID 4:** This level involves writing an entire block of data onto data disks, and then generating the parity and storing it somewhere else. At level 3, bytes are striped, while at level 4, blocks are striped. Both levels 3 and 4 require a minimum of three disks.



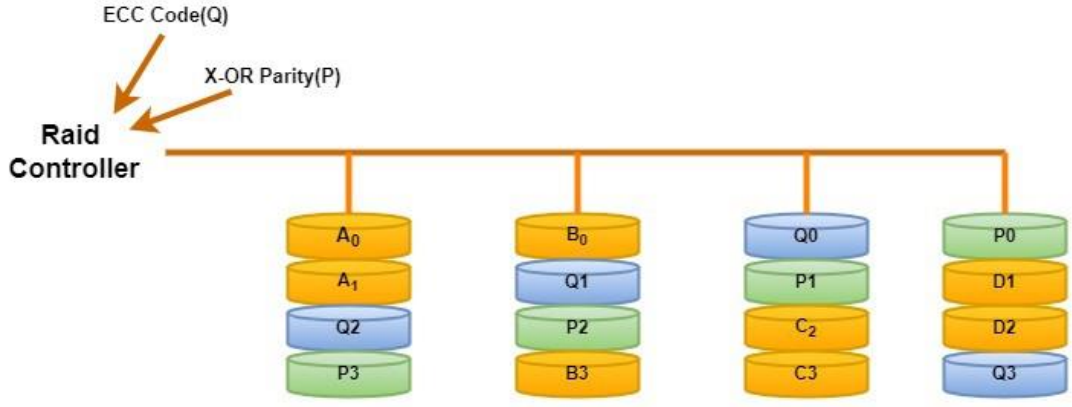
Raid-4

- **RAID 5:** The data blocks in RAID 5 are written to different disks, but the parity bits are spread out across all the data disks rather than being stored on a separate disk.



Raid-5

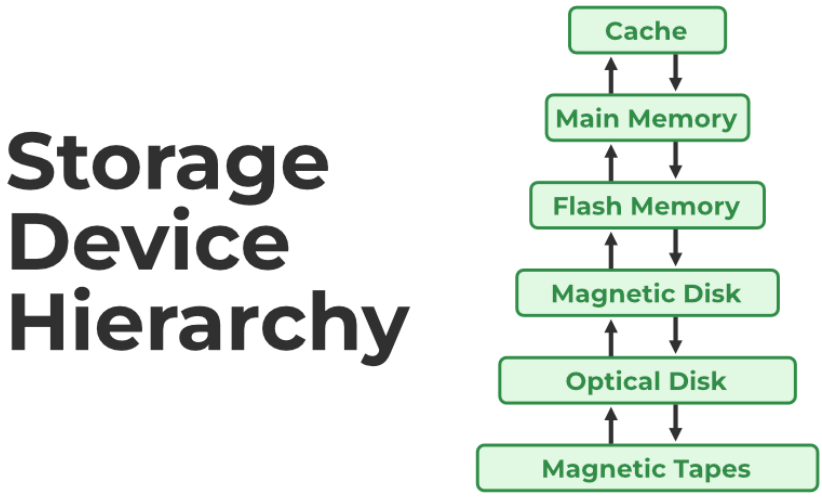
- **RAID 6:** The RAID 6 level extends the level 5 concept. A pair of independent parities are generated and stored on multiple disks at this level. A pair of independent parities are generated and stored on multiple disks at this level. Ideally, you need four disk drives for this level.



Raid-6

Storage Hierarchy

Rather than the storage devices mentioned above, there are also other devices that are also used in day-to-day life. These are mentioned below in the form of faster speed to lower speed from top to down.



What is Indexing in DBMS?

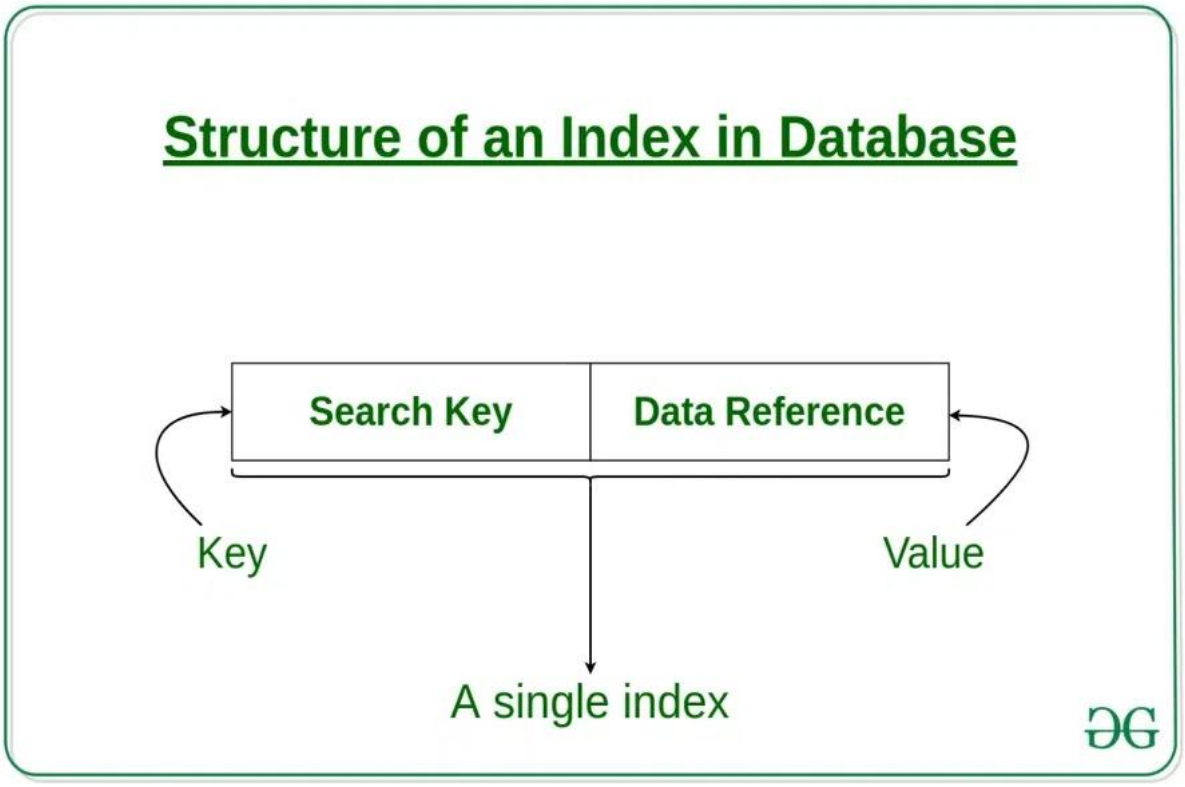
Indexing is a technique for improving database performance by reducing the number of disk accesses necessary when a query is run. An index is a form of data structure. It's used to swiftly identify and access data and information present in a database table.

Structure of Index

We can create indices using some columns of the database.

Indexing improves database performance by minimizing the number of disc visits required to fulfill a query. It is a data structure technique used to locate and quickly access data in databases. Several database fields are used to generate indexes. The main key or candidate key of the table is duplicated

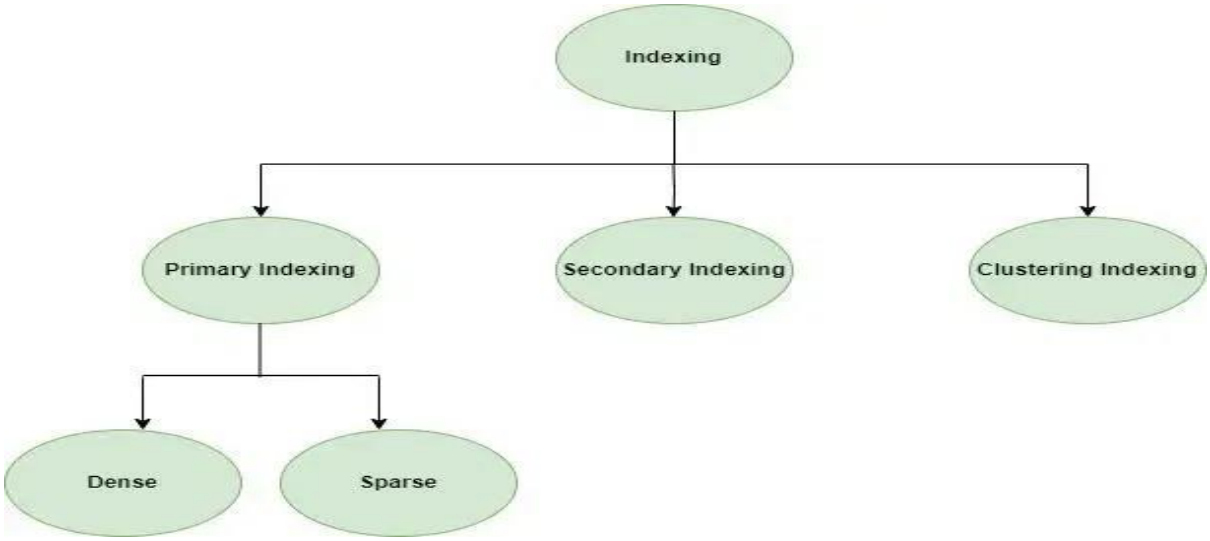
in the first column, which is the Search key. To speed up data retrieval, the values are also kept in sorted order. It should be highlighted that sorting the data is not required. The second column is the Data Reference or Pointer which contains a set of pointers holding the address of the disk block where that particular key value can be found.



Structure of Index in Database

Attributes of Indexing

- **Access Types:** This refers to the type of access such as value-based search, range access, etc.
- **Access Time:** It refers to the time needed to find a particular data element or set of elements.
- **Insertion Time:** It refers to the time taken to find the appropriate space and insert new data.
- **Deletion Time:** Time taken to find an item and delete it as well as update the index structure.
- **Space Overhead:** It refers to the additional space required by the index.



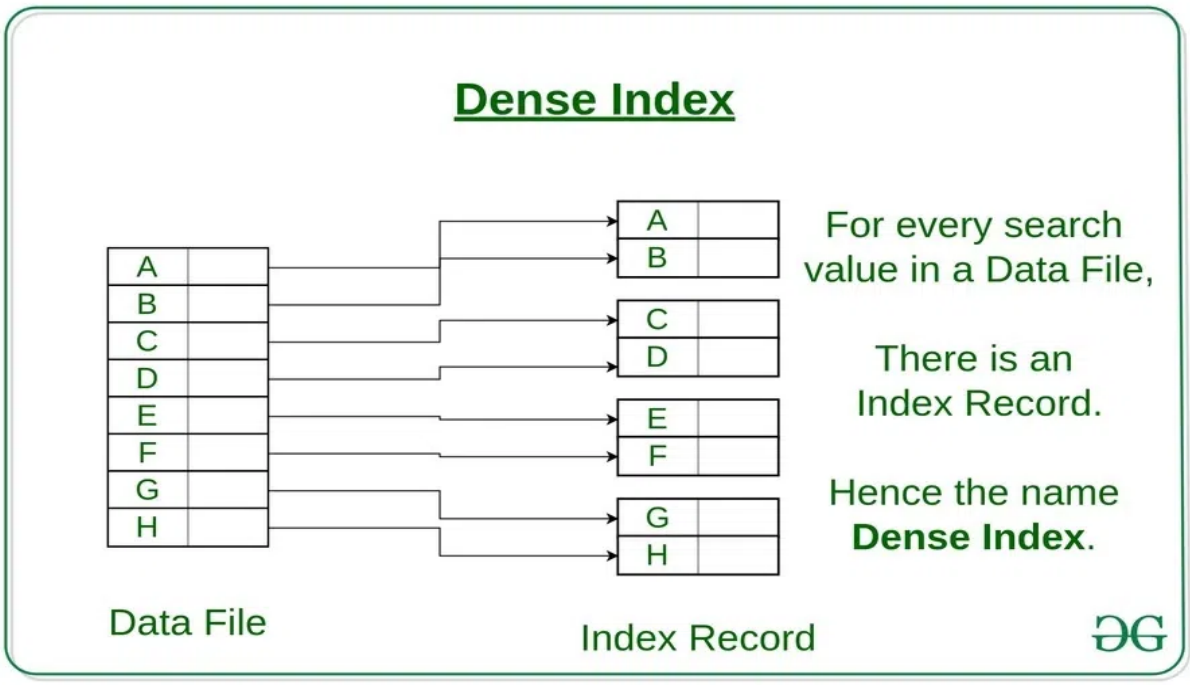
Structure of Index in Database

In general, there are two types of file organization mechanisms that are followed by the indexing methods to store the data:

Sequential File Organization or Ordered Index File

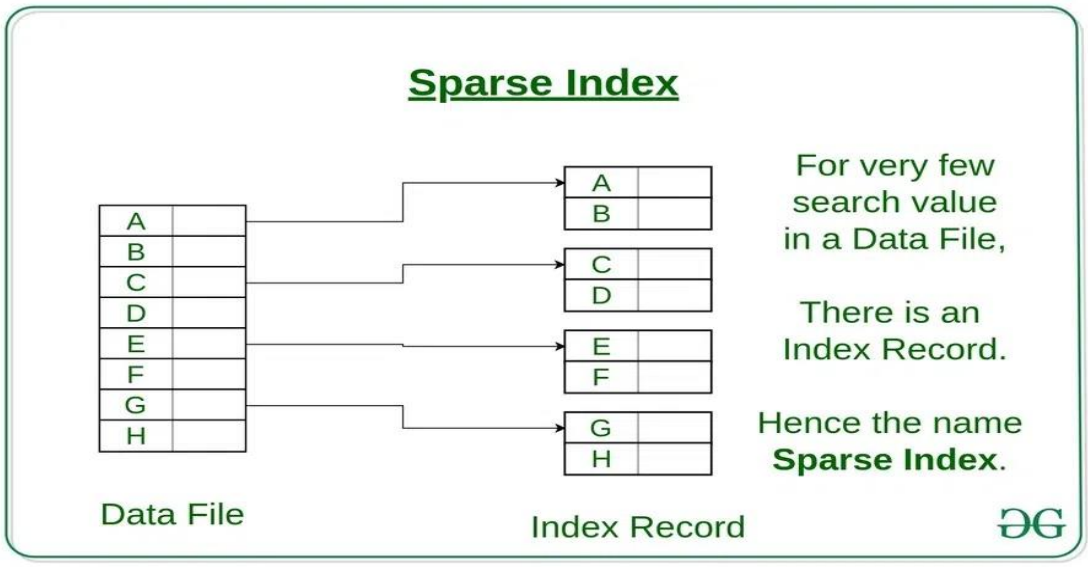
In this, the indices are based on a sorted ordering of the values. These are generally fast and a more traditional type of storing mechanism. These Ordered or Sequential file organizations might store the data in a dense or sparse format.

- **Dense Index**
    - For every search key value in the data file, there is an index record.
    - This record contains the search key and also a reference to the first data record with that search key value.



Dense Index

- **Sparse Index**
    - The index record appears only for a few items in the data file. Each item points to a block as shown.
    - To locate a record, we find the index record with the largest search key value less than or equal to the search key value we are looking for.
    - We start at that record pointed to by the index record, and proceed along with the pointers in the file (that is, sequentially) until we find the desired record.
    - Number of Accesses required=$\log_2(n)+1$, (here n=number of blocks acquired by index file)

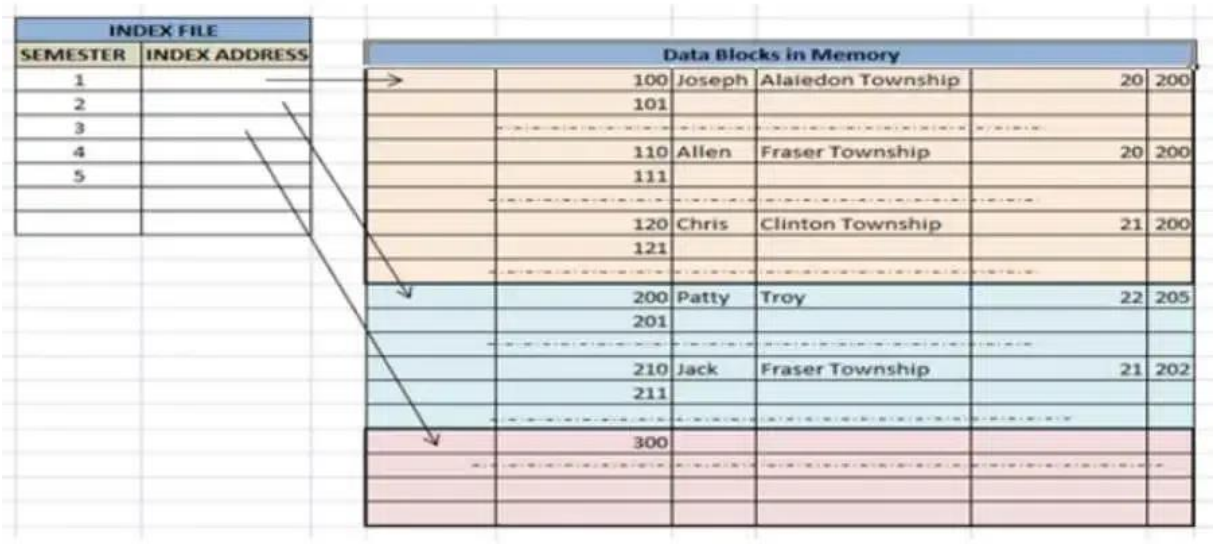


Sparse Index

Hash File Organization

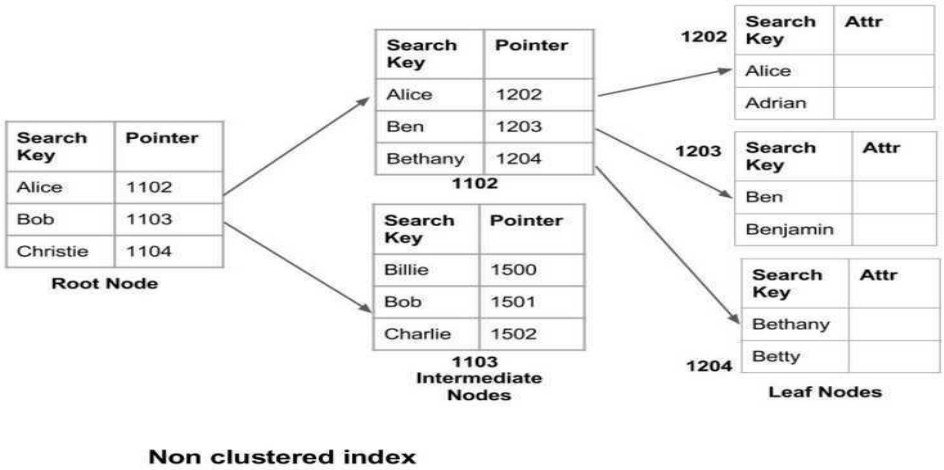
Indices are based on the values being distributed uniformly across a range of buckets. The buckets to which a value is assigned are determined by a function called a hash function. There are primarily three methods of indexing:

- **Clustered Indexing**: When more than two records are stored in the same file this type of storing is known as cluster indexing. By using cluster indexing we can reduce the cost of searching reason being multiple records related to the same thing are stored in one place and it also gives the frequent joining of more than two tables (records).
  The clustering index is defined on an ordered data file. The data file is ordered on a non-key field. In some cases, the index is created on non-primary key columns which may not be unique for each record. In such cases, in order to identify the records faster, we will group two or more columns together to get the unique values and create an index out of them. This method is known as the clustering index. Essentially, records with similar properties are grouped together, and indexes for these groupings are formed.
  Students studying each semester, for example, are grouped together. First-semester students, second-semester students, third-semester students, and so on are categorized.



Clustered Indexing

- **Primary Indexing:** This is a type of Clustered Indexing wherein the data is sorted according to the search key and the primary key of the database table is used to create the index. It is a default format of indexing where it induces sequential file organization. As primary keys are unique and are stored in a sorted manner, the performance of the searching operation is quite efficient.
- **Non-clustered or Secondary Indexing**: A non-clustered index just tells us where the data lies, i.e. it gives us a list of virtual pointers or references to the location where the data is actually stored. Data is not physically stored in the order of the index. Instead, data is present in leaf nodes. For eg. the contents page of a book. Each entry gives us the page number or location of the information stored. The actual data here(information on each page of the book) is not organized but we have an ordered reference(contents page) to where the data points actually lie. We can have only dense ordering in the non-clustered index as sparse ordering is not possible because data is not physically organized accordingly.
  It requires more time as compared to the clustered index because some amount of extra work is done in order to extract the data by further following the pointer. In the case of a clustered index, data is directly present in front of the index.



Non clustered index

Non Clustered Indexing

- **Multilevel Indexing:** With the growth of the size of the database, indices also grow. As the index is stored in the main memory, a single-level index might become too large a size to store with multiple disk accesses. The multilevel indexing segregates the main block into various smaller blocks so that the same can be stored in a single block. The outer blocks are divided into inner blocks which in turn are pointed to the data blocks. This can be easily stored in the main memory with fewer overheads.

Advantages of Indexing

- **Improved Query Performance:** Indexing enables faster data retrieval from the database. The database may rapidly discover rows that match a specific value or collection of values by generating an index on a column, minimizing the amount of time it takes to perform a query.
- **Efficient Data Access:** Indexing can enhance data access efficiency by lowering the amount of disk I/O required to retrieve data. The database can maintain the data pages for frequently visited columns in memory by generating an index on those columns, decreasing the requirement to read from disk.
- **Optimized Data Sorting:** Indexing can also improve the performance of sorting operations. By creating an index on the columns used for sorting, the database can avoid sorting the entire table and instead sort only the relevant rows.
- **Consistent Data Performance:** Indexing can assist ensure that the database performs consistently even as the amount of data in the database rises. Without indexing, queries may take longer to run as the number of rows in the table grows, while indexing maintains a roughly consistent speed.
- By ensuring that only unique values are inserted into columns that have been indexed as unique, indexing can also be utilized to ensure the integrity of data. This avoids storing duplicate data in the database, which might lead to issues when performing queries or reports.

Overall, indexing in databases provides significant benefits for improving query performance, efficient data access, optimized data sorting, consistent data performance, and enforced data integrity

Disadvantages of Indexing

- Indexing necessitates more storage space to hold the index data structure, which might increase the total size of the database.
- **Increased database maintenance overhead:** Indexes must be maintained as data is added, destroyed, or modified in the table, which might raise database maintenance overhead.
- Indexing can reduce insert and update performance since the index data structure must be updated each time data is modified.

Introduction of B-Tree

The limitations of traditional binary search trees can be frustrating. Meet the B-Tree, the multi-talented data structure that can handle massive amounts of data with ease. When it comes to storing and searching large amounts of data, traditional binary search trees can become impractical due to their poor performance and high memory usage. B-Trees, also known as B-Tree or Balanced Tree, are a type of self-balancing tree that was specifically designed to overcome these limitations.

Unlike traditional binary search trees, B-Trees are characterized by the large number of keys that they can store in a single node, which is why they are also known as “large key” trees. Each node in a B-Tree can contain multiple keys, which allows the tree to have a larger branching factor and thus a shallower height. This shallow height leads to less disk I/O, which results in faster search and insertion

operations. B-Trees are particularly well suited for storage systems that have slow, bulky data access such as hard drives, flash memory, and CD-ROMs.

B-Trees maintains balance by ensuring that each node has a minimum number of keys, so the tree is always balanced. This balance guarantees that the time complexity for operations such as insertion, deletion, and searching is always O(log n), regardless of the initial shape of the tree.

Time Complexity of B-Tree:

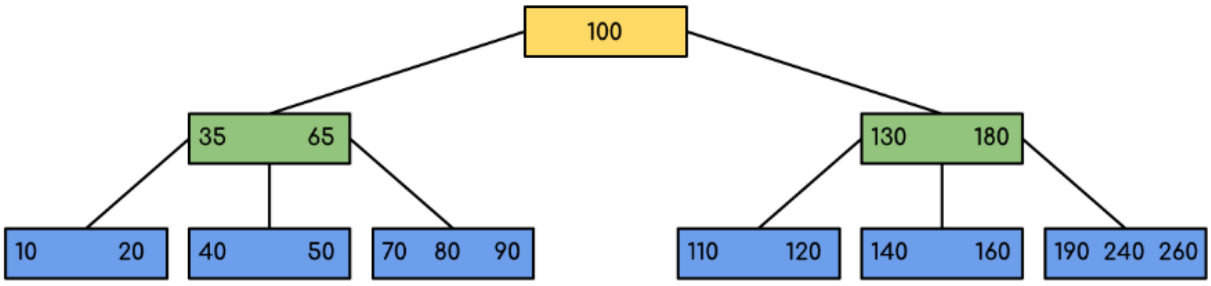
Sr. No.	Algorithm	Time Complexity
1.	Search	O(log n)
2.	Insert	O(log n)
3.	Delete	O(log n)

Note: "n" is the total number of elements in the B-tree

Properties of B-Tree:

- All leaves are at the same level.
- B-Tree is defined by the term minimum degree '**t**'. The value of '**t**' depends upon disk block size.
- Every node except the root must contain at least t-1 keys. The root may contain a minimum of **1** key.
- All nodes (including root) may contain at most (**2*t – 1**) keys.
- Number of children of a node is equal to the number of keys in it plus **1**.
- All keys of a node are sorted in increasing order. The child between two keys **k1** and **k2** contains all keys in the range from **k1** and **k2**.
- B-Tree grows and shrinks from the root which is unlike Binary Search Tree. Binary Search Trees grow downward and also shrink from downward.
- Like other balanced Binary Search Trees, the time complexity to search, insert, and delete is O(log n).
- Insertion of a Node in B-Tree happens only at Leaf Node.

Following is an example of a B-Tree of minimum order 5
Note: that in practical B-Trees, the value of the minimum order is much more than 5.



We can see in the above diagram that all the leaf nodes are at the same level and all non-leafs have no empty sub-tree and have keys one less than the number of their children.

Interesting Facts about B-Trees:

- *The minimum height of the B-Tree that can exist with n number of nodes and m is the maximum number of children of a node can have is:*
- *The maximum height of the B-Tree that can exist with n number of nodes and t is the minimum number of children that a non-root node can have is:* *and*

Traversal in B-Tree:

Traversal is also similar to Inorder traversal of Binary Tree. We start from the leftmost child, recursively print the leftmost child, then repeat the same process for the remaining children and keys. In the end, recursively print the rightmost child.

Search Operation in B-Tree:

Search is similar to the search in Binary Search Tree. Let the key to be searched is k.

- Start from the root and recursively traverse down.
- For every visited non-leaf node,
    - If the node has the key, we simply return the node.
    - Otherwise, we recur down to the appropriate child (The child which is just before the first greater key) of the node.
- If we reach a leaf node and don't find k in the leaf node, then return NULL.

Searching a B-Tree is similar to searching a binary tree. The algorithm is similar and goes with recursion. At each level, the search is optimized as if the key value is not present in the range of the parent then the key is present in another branch. As these values limit the search they are also known as limiting values or separation values. If we reach a leaf node and don't find the desired key then it will display NULL.

Hashing in DBMS

Hashing in DBMS is a technique to quickly locate a data record in a database irrespective of the size of the database. For larger databases containing thousands and millions of records, the indexing data structure technique becomes very inefficient because searching a specific record through indexing will consume more time. This doesn't align with the goals of DBMS, especially when performance and data

retrieval time are minimized. So, to counter this problem hashing technique is used. In this article, we will learn about various hashing techniques.

The hashing technique utilizes an auxiliary hash table to store the data records using a hash function. There are 2 key components in hashing:

- **Hash Table:** A hash table is an array or data structure and its size is determined by the total volume of data records present in the database. Each memory location in a hash table is called a '***bucket***' or hash indice and stores a data record's exact location and can be accessed through a hash function.
- **Bucket:** A bucket is a memory location (index) in the hash table that stores the data record. These buckets generally store a disk block which further stores multiple records. It is also known as the hash index.
- **Hash Function:** A hash function is a mathematical equation or algorithm that takes one data record's primary key as input and computes the hash index as output.

Hash Function

A hash function is a mathematical algorithm that computes the index or the location where the current data record is to be stored in the hash table so that it can be accessed efficiently later. This hash function is the most crucial component that determines the speed of fetching data.

Working of Hash Function

The hash function generates a hash index through the primary key of the data record.

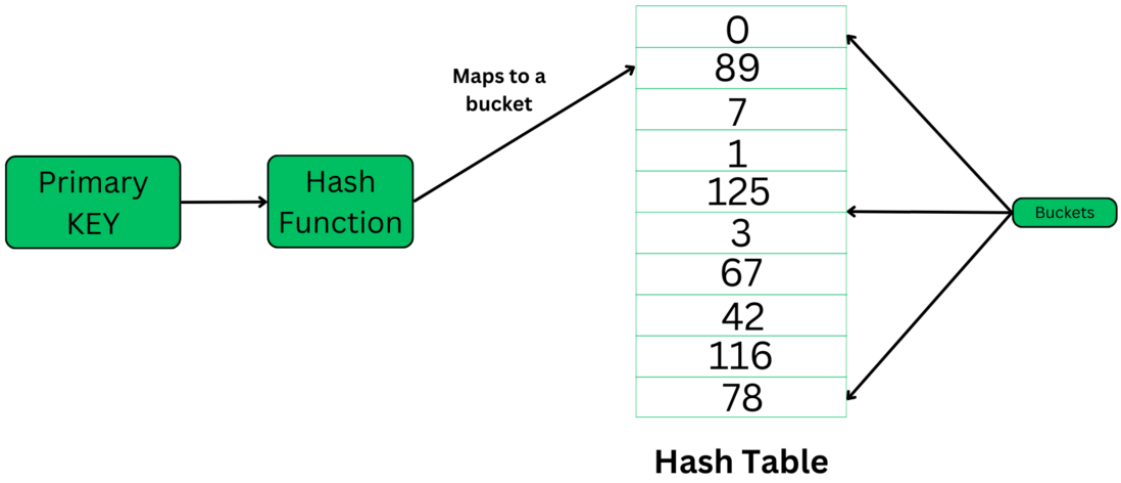
Now, there are 2 possibilities:

1. The hash index generated isn't already occupied by any other value. So, the address of the data record will be stored here.

2. The hash index generated is already occupied by some other value. This is called collision so to counter this, a collision resolution technique will be applied.

3. Now whenever we query a specific record, the hash function will be applied and returns the data record comparatively faster than indexing because we can directly reach the exact location of the data record through the hash function rather than searching through indices one by one.

Example:



Hashing

Types of Hashing in DBMS

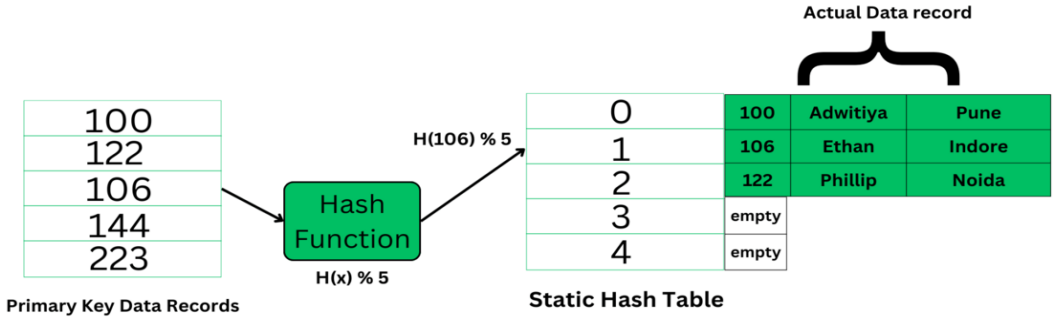
There are two primary hashing techniques in DBMS.

1. Static Hashing

In static hashing, the hash function always generates the same bucket's address. For example, if we have a data record for employee_id = 107, the hash function is mod-5 which is - H(x) % 5, where x = id. Then the operation will take place like this:

H(106) % 5 = 1.
This indicates that the data record should be placed or searched in the 1st bucket (or 1st hash index) in the hash table.

Example:



Static Hashing Technique

The primary key is used as the input to the hash function and the hash function generates the output as the hash index (bucket's address) which contains the address of the actual data record on the disk block.

Static Hashing has the following Properties

- **Data Buckets:** The number of buckets in memory remains constant. The size of the hash table is decided initially and it may also implement chaining that will allow handling some collision issues though, it's only a slight optimization and may not prove worthy if the database size keeps fluctuating.
- **Hash function:** It uses the simplest hash function to map the data records to its appropriate bucket. It is generally modulo-hash function
- **Efficient for known data size:** It's very efficient in terms when we know the data size and its distribution in the database.
- It is inefficient and inaccurate when the data size dynamically varies because we have limited space and the hash function always generates the same value for every specific input. When the data size fluctuates very often it's not at all useful because collision will keep happening and it will result in problems like - bucket skew, insufficient buckets etc.

To resolve this problem of bucket overflow, techniques such as - chaining and open addressing are used. Here's a brief info on both:

1. Chaining

Chaining is a mechanism in which the hash table is implemented using an array of type nodes, where each bucket is of node type and can contain a long chain of linked lists to store the data records. So, even if a hash function generates the same value for any data record it can still be stored in a bucket by adding a new node.

However, this will give rise to the problem bucket skew that is, if the hash function keeps generating the same value again and again then the hashing will become inefficient as the remaining data buckets will stay unoccupied or store minimal data.

2. Open Addressing/Closed Hashing

This is also called closed hashing this aims to solve the problem of collision by looking out for the next empty slot available which can store data. It uses techniques like **linear probing**, **quadratic probing**, **double hashing,** etc.

2. Dynamic Hashing

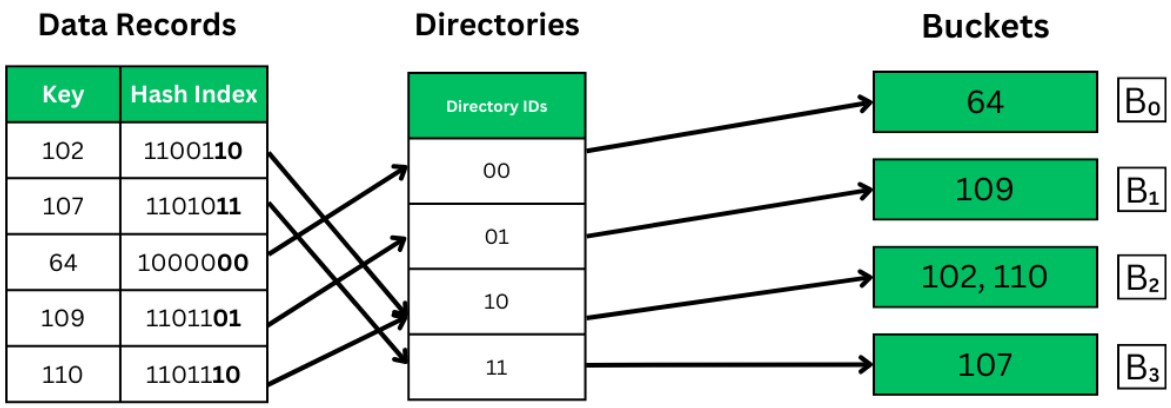
Dynamic hashing is also known as extendible hashing, used to handle database that frequently changes data sets. This method offers us a way to add and remove data buckets on demand dynamically. This way as the number of data records varies, the buckets will also grow and shrink in size periodically whenever a change is made.

Properties of Dynamic Hashing

- The buckets will vary in size dynamically periodically as changes are made offering more flexibility in making any change.
- Dynamic Hashing aids in improving overall performance by minimizing or completely preventing collisions.
- **It has the following major components:** Data bucket, Flexible hash function, and directories
- A flexible hash function means that it will generate more dynamic values and will keep changing periodically asserting to the requirements of the database.
- Directories are containers that store the pointer to buckets. If bucket overflow or bucket skew-like problems happen to occur, then bucket splitting is done to maintain efficient retrieval time of data records. Each directory will have a directory id.
- **Global Depth:** It is defined as the number of bits in each directory id. The more the number of records, the more bits are there.

Working of Dynamic Hashing

Example: If global depth: k = 2, the keys will be mapped accordingly to the hash index. K bits starting from LSB will be taken to map a key to the buckets. That leaves us with the following 4 possibilities: 00, 11, 10, 01.



Dynamic Hashing - mapping