Database Management System 24

Index

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Single-Level Indexes
Primary Indexes
Clustering Indexes
Secondary Indexes
Dense/Sparse Indexes
Multilevel Indexing
Search Trees
B-Trees
B^+-Trees
B-Trees vs. B^+-Trees

Index

Index

An index is a data structure that organizes data records on disk to optimize the retrieval operations. An index is used to efficiently retrieve all records that satisfy search conditions on the **search key** fields of the index

The index structure typically provides secondary access path, which provides alternative way of retrieving the records without affecting the physical storage of records on the disk

On a same file, multiple indexes on different fields can be constructed

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Single-Level Indexes

Single-Level Indexes

Index is usually defined on a single attribute or field of a file, called *indexing field* or *indexing attribute*

Generally, the index stores each value of the index field along with a list of pointers to all disk blocks that contain records with that field value

The values in the index are ordered so that binary search can be performed on the index. The index file is much smaller than the data file, so searching the index using a binary search is highly efficient

Student

roll	name	age	gender	contact
101	Ashok	19	Male	123
102	Mahesh	19	Male	345
103	Jency	21	Female	678
104	Vikash	20	Male	245
105	Manish	20	Male	789
106	Rahul	22	Male	567

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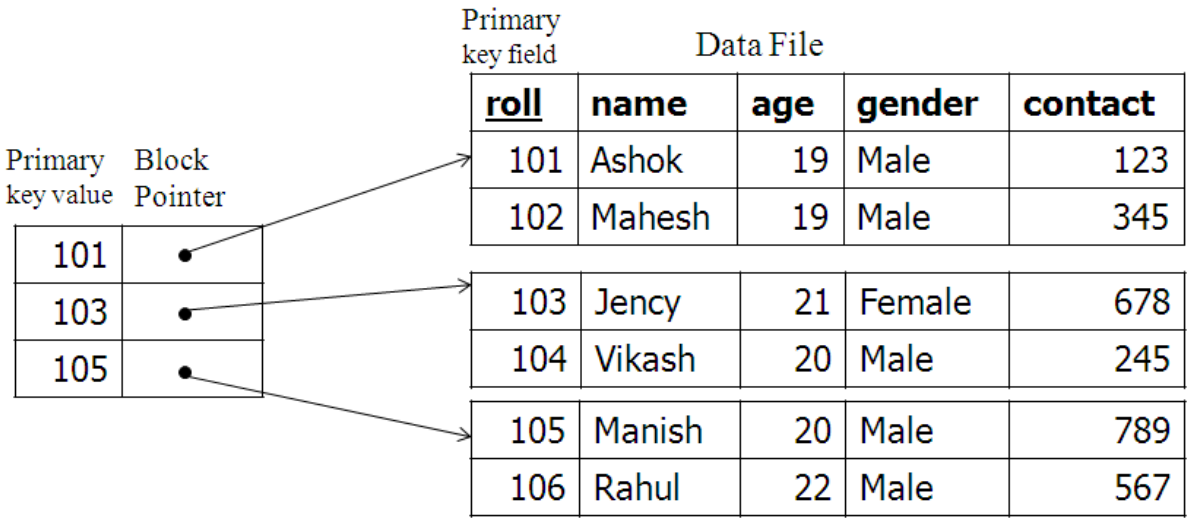
Primary Indexes

Primary Indexes

A primary index is an ordered file whose records are of fixed length with two fields. The first field is of the same data type as the ordering key field of the data file, called the primary key and the second field is a pointer to a disk block

There is one index entry in the index file for each block in the data file. Each index entry has the value of the primary key field for the first record in a block and a pointer to that block as its two field values



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Primary Indexes...

The index file for a primary index needs substantially fewer blocks than does the data file, for two reasons. First, there are fewer index entries than there are records in the data file. Second,each index entry is typically smaller in size than a data record because it has only two fields. A binary search on the index file hence requires fewer block accesses than a binary search on the data file

When a user wants to insert a record to its correct position in the data file, the existing records should be moved to make space for the new record as well as index entries will be changed

Similarly, deletion process is also difficult due to the index entries updation. But, record deletion is commonly handled by using deletion markers

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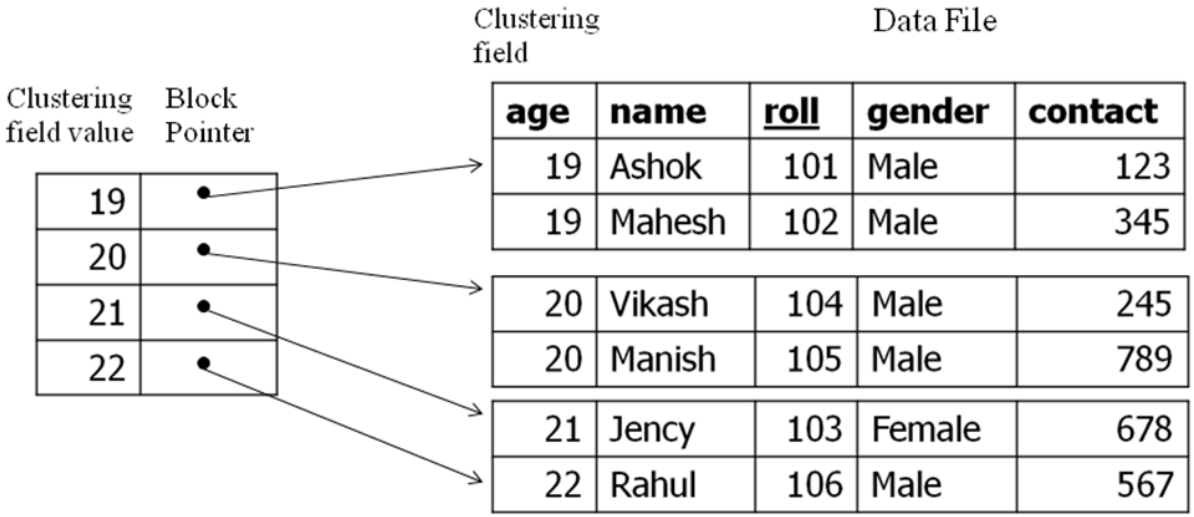
Clustering Indexes

Clustering Indexes

If records of a file are physically ordered on a non-key field, that field is called the clustering field. Thus, clustering index is the index created on the clustering field to speed up retrieval of records that have the same value for the clustering field

This differs from a primary index, which requires that the ordering field of the data file have a distinct value for each record



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Clustering Indexes...

Clustering Indexes...

There is one entry in the clustering index for each distinct value of the clustering field, containing the value and a pointer to the first block in the data file that has a record with that value for its clustering field

To solve the problem of insertion, it is common to reserve a whole block (or a cluster of contiguous blocks) for each value of the clustering field; all records with that value are placed in the block (or block cluster). This makes insertion and deletion relatively straightforward

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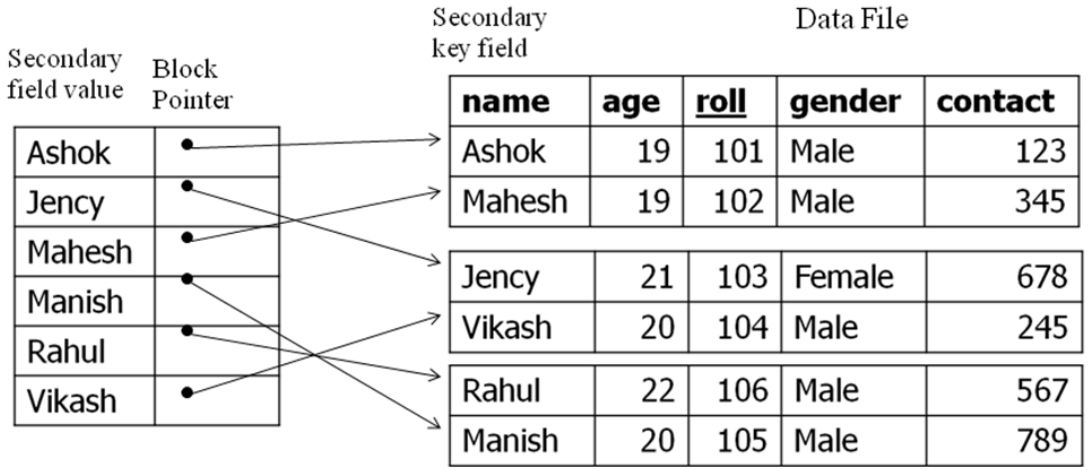
Secondary Indexes

Secondary Indexes

A secondary index is also an ordered file with two fields. The first field is of the same data type as some nonordering field of the data file that is an indexing field. The second field is either a block pointer or a record pointer. There can be many secondary indexes for the same file

In this case there is one index entry for each record in the data file, which contains the value of the secondary key for the record and a pointer either to the block in which the record is stored or to the record itself



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Secondary Indexes...

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Secondary Indexes...

A secondary index usually needs more storage space and longer search time than does a primary index, because of its larger number of entries

Secondary index provides a logical ordering on the records by the indexing field

A data file can have either a primary index or a cluster index depending on its ordering field. It can have several secondary indexes, however

Dense/Sparse Indexes

Dense/Sparse Indexes

Indexes can also be characterized as dense or sparse:

- A dense index has an index entry for every search key value (and hence every record) in the data file
- A sparse or nondense index has index entries for only some of the search values

Primary index $\rightarrow$ Nondense

Clustering index $\rightarrow$ Nondense

Secondary index $\rightarrow$ Dense

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Multilevel Indexing

Multilevel Indexing

A multilevel indexing can contain any number of levels, each of which acts as a non-dense index to the level below. The top level contains a single entry

A multilevel index can be created for any type of first-level index (whether it is primary, clustering or secondary) as long as the first-level index consists of more than one disk block

The advantage of multilevel index is that it reduces the number of blocks accessed when searching a record, given its indexing field value

The problems associated with index insertions and deletions still exist because all index levels are physically ordered files

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Multilevel Indexing...

Because of the insertion and deletion problem, most multilevel indexes use B-tree or B^+-tree data structures, which leave space in each tree node (disk block) to allow for new index entries

In B-Tree and B^+-Tree data structures, each node corresponds to a disk block. Here, each node is kept between half-full and completely full

An insertion into a node that is not full is quite efficient. On the other hand, if a node is full the insertion causes a split into two nodes

Similarly, a deletion is quite efficient if a node does not become less than half full. If a deletion causes a node to become less than half-full, it must be merged with the neighboring nodes

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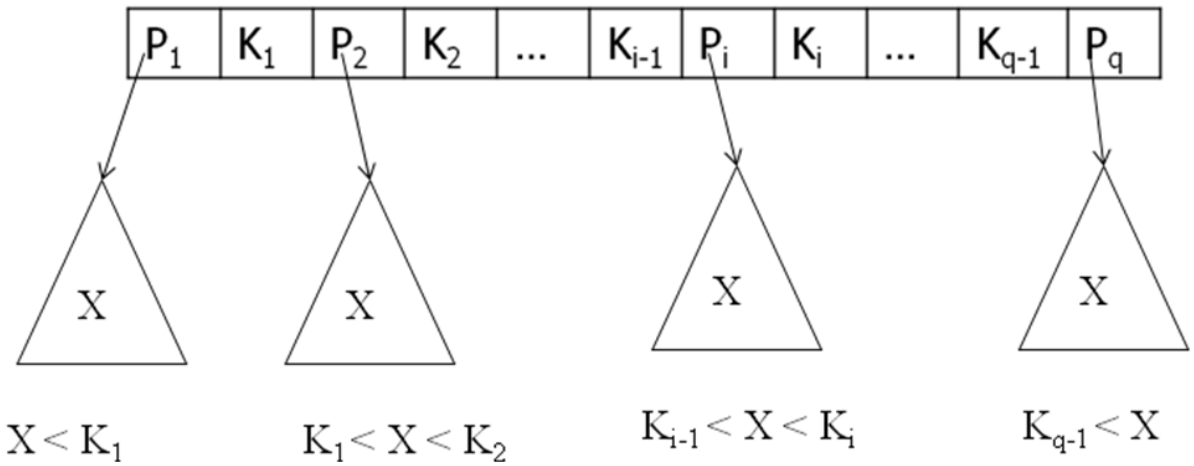
Search Trees

A search tree is a special type of tree that is used to search a record, given the value of one of the record's fields

A search tree of order 'p' is a tree such that each node contains at most 'p-1' search values and 'p' pointers in the order $< P_1, K_1, P_2, K_2, \ldots P_{q-1}, K_{q-1}, P_q >$, where $q \leq p$; each P_i is a pointer to a child node and each K_i is a search value from some ordered set of values

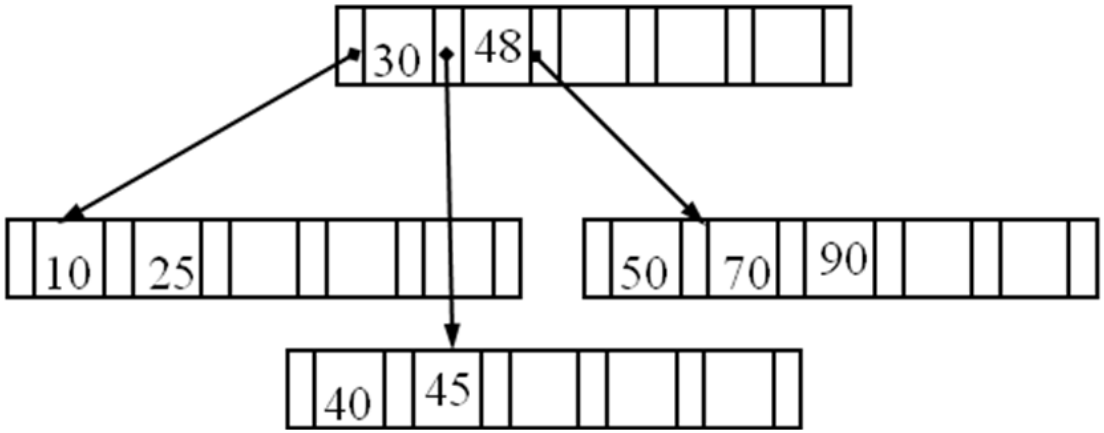
All of these search values are unique



Search Trees...

Two constraints must hold at all times on the search tree:

- Within each node, $K_1 < K_2 < ... < K_{q-1}$
- For all values X in the subtree pointed at by P_i, X < K_1; K_{i-1} < X < K_i for 1 < i < q; and K_{i-1} < X for i = q



When a user wants search a value X, he has to follow the appropriate pointer P_i according to the formula in condition 2

A search tree is balanced when all of its leaf nodes are at the same level

B-Trees

B-tree is a specialized multi-way tree designed especially for use on disk. A B-tree of order 'p' can be defined as follows:

- Each internal node is of the form <P_1, <K_1>, P_2, <K_2> ... <K_{q-1}>, P_q> , where q $\leq$ p. Each P_i is a tree pointer, which is a pointer to another node in the B-tree
- Within each node, $K_1 < K_2 < ... < K_{q-1}$
- Each node has at most 'p' tree pointers
- For all search key field values X in the subtree pointed by P_i, the rule is X < K_1; K_{i-1} < X < K_i for 1 < i < q; and K_{i-1} < X for i = q
- All non-leaf nodes except the root have at least $\lceil$ p / 2 $\rceil$ children. The root is either a leaf node, or it has from two to p children
- A node with q tree pointers, q $\leq$ p, has q-1 search key field values
- All leaf nodes are at the same level. Leaf nodes have the same structure as internal nodes except that all of their tree pointers P_i are null

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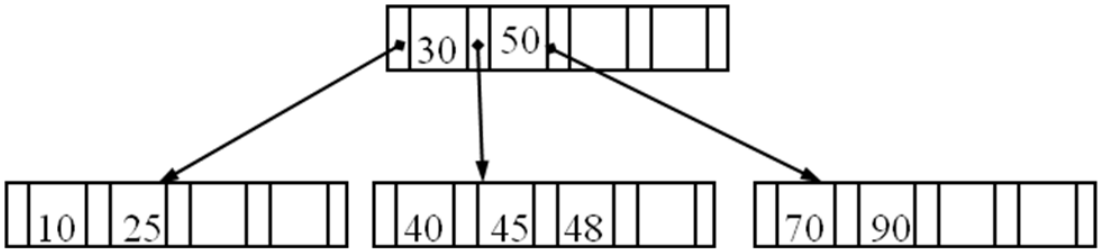
B-Trees...

Insertion

The insertion to a B-tree is an easier process. A B-tree starts with a single root node at level 0. The rules for the insertion to B-tree are:

- It attempts to insert the new key into a leaf. If this would result in that leaf becoming too big, split the leaf into two, promoting the middle key to the leaf's parent
- If the insertion would result in the parent becoming too big, split the parent into two, promoting the middle key. This strategy might have to be repeated all the way to the top
- If necessary, the root is split in two and the middle key is promoted to a new root, making the tree one level higher

Ex: Draw the B-tree of the order 5 for the data items 10, 50, 30, 70, 90, 25, 40, 45, 48



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B-Trees...

Deletion

At deletion, removal should be done from a leaf:

- If the key is already in a leaf node, and removing it doesn't cause that leaf node to have too few keys, then simply remove the key to be deleted
- If the key is not in a leaf, then it is guaranteed that its predecessor or successor will be in a leaf. In this case, delete the key and promote the predecessor or successor key to the non-leaf deleted key's position
- If first or second condition lead to a leaf node containing less than the minimum number of keys, then look at the siblings immediately adjacent to the leaf:
  - If one of them has more than the minimum number of keys, then promote one of its keys to the parent and take the parent key into the lacking leaf
  - If neither of them has more than the minimum number of keys, then the lacking leaf and one of its neighbours can be combined with their shared parent; & the new leaf will have the correct number of keys. If this step leaves the parent with too few keys, repeat the process up to the root itself

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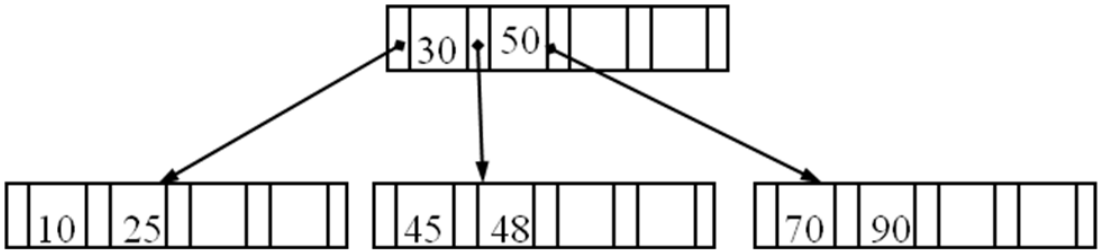
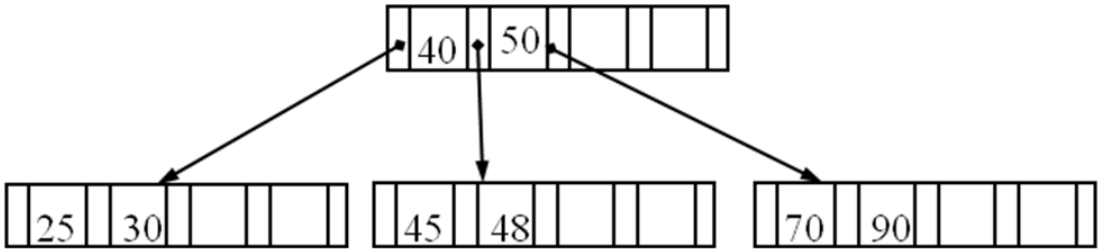
B-Trees...

Deletion of 40



Deletion of 10



The maximum number of items in a B-tree of order p and height h = p^{h+1} - 1. For example, when the order p=5 and height h=1, the maximum number of nodes= 5^2-1=24

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B^+-Trees

The leaf nodes of the B^+-tree are usually linked together to provide ordered access on the search field to the records. These leaf nodes are similar to the first level of an index

Internal nodes of the B^+-tree correspond to the other levels of a multilevel index. The structure of the **internal nodes** of a B^+-tree of order p is as follows:

- Each internal node is of the form <P_1, <K_1>, P_2, <K_2> ... <K_{q-1}>, P_q> , where q $\leq$ p and each P_i is a tree pointer
- Within each internal node, $K_1 < K_2 < ... < K_{q-1}$
- Each internal node has at most 'p' tree pointers
- For all search field values X in the subtree pointed by P_i, the rule is X $\leq K_1$; $K_{i-1} <$ X $\leq K_i$ for 1 < i < q; and $K_{i-1} <$ X for i = q
- Each internal node has at least $\lceil$ p / 2 $\rceil$ children. The root has at least two children if it is an internal node
- An internal node with q tree pointers, q $\leq$ p, has q-1 search key field values

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B^+-Trees...

The structure of the **leaf nodes** of a B^+-tree of order p is as follows:

- Each leaf node is of the form «K_1, Pr_1>, <K_2, Pr_2> ... <K_{q-1}, Pr_{q-1}>, P_{next}>, where q $\leq$ p, each Pr_i is a data pointer and P_{next} is the pointer to the next leaf node
- Each leaf node has at least $\lceil$ p / 2 $\rceil$ values
- All leaf nodes are at the same level
- Within each leaf node, $K_1 \leq K_2 \leq ... \leq K_{q-1}$

The pointers in internal nodes are the tree pointers, which point to blocks that are tree nodes, whereas the pointers in leaf nodes are the data pointers to the data file records

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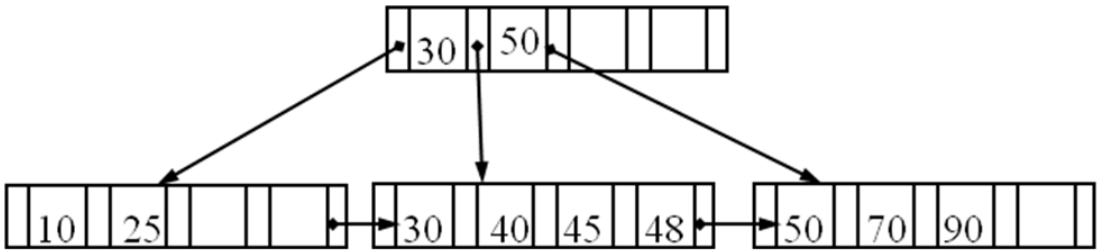
B^+-Trees...

Insertion

The rules for the insertion of a data item to the B^+-tree are:

- Find correct leaf L
- Put data entry onto L. There are two options for this entry:
  - If L has enough space, done!
  - Else, split L into L and a new node L2. Redistribute entries evenly and copy up the middle key. Also, insert index entry pointing to L2 into parent of L
- For each insertion, this process will be repeated



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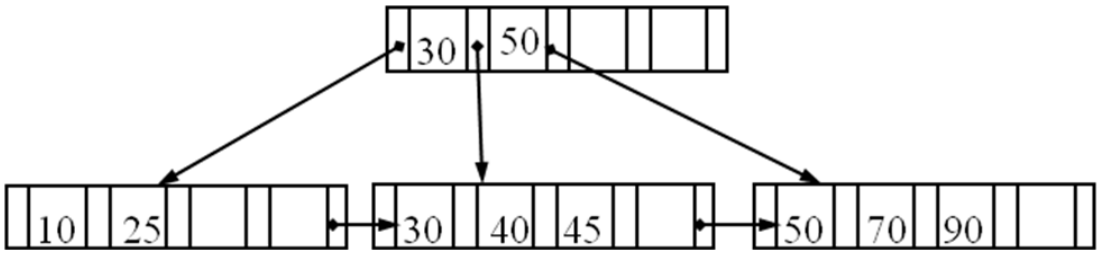
B^+-Trees...

Deletion

The rules for deleting a data item from the B^+-tree are:

- Find the correct leaf L
- Remove the entry. There may be two possible cases for this deletion:
  - If L is at least half-full, done!
  - Else, try to re-distribute the entries by borrowing from the adjacent node or sibling. If re-distribution fails, merge L and the sibling. If merge occurred, then delete the entry (pointing to L or sibling) from parent of L
- The merging process could propagate to root; thus, decreasing the height

Deletion of 48



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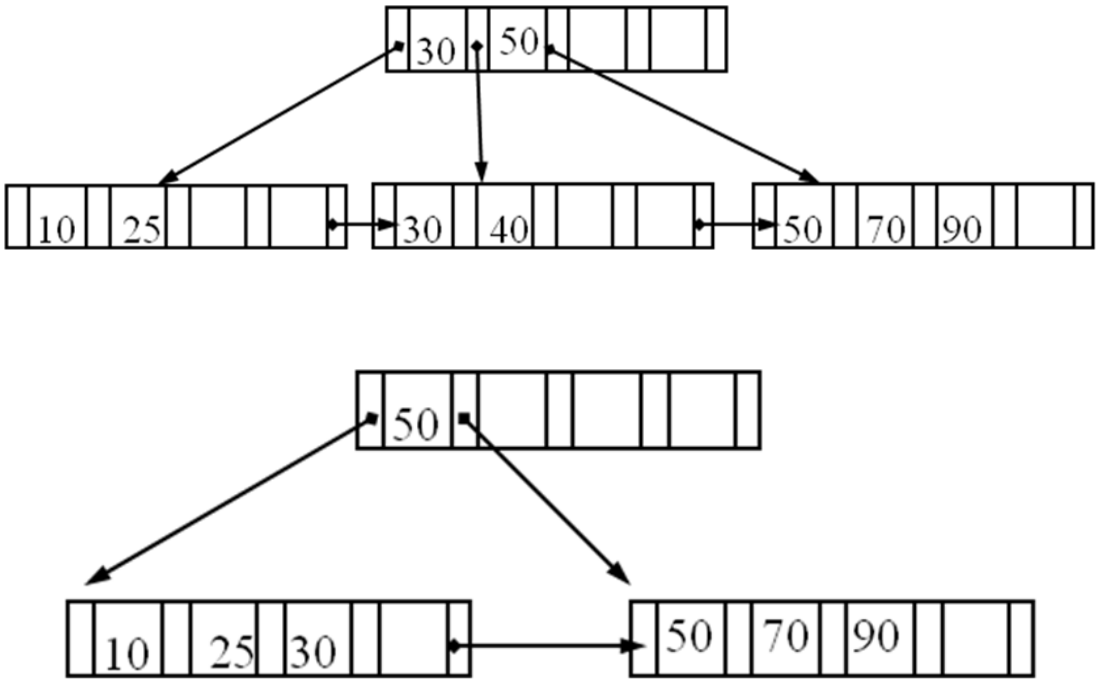
Deletion of 45 followed by 40



The maximum number of records stored in a B^+-tree of order p and height h = p^h- p^{h-1}. Similarly, the minimum number of records stored = $2(p/2)^{h-1}$; and the minimum number of keys in a B^+-tree of order p and height h = $2(p/2)^h$ - 1

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- B^+-tree searching is faster than the B-tree searching; because in B^+-tree, all records are stored at the leaf level of the tree; and only keys are stored in interior nodes
- B^+-tree takes more storage space than B-tree, because it uses extra pointers than B-tree
- Insertion and deletion operations in B-tree are more complex than those in B^+-tree

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