Lecture 3

Indexing Structures for Files

Lecture Outline

- Types of Single-level Ordered Indexes
  - Primary Indexes
  - Clustering Indexes
  - Secondary Indexes
- Multilevel Indexes
- Dynamic Multilevel Indexes Using B Trees and B+ Trees.

Indexes as Access Paths

- Indexes are auxiliary files that make it more efficient to search for a record in the data file.
- The index is usually specified on one field of the file (although it could be specified on several fields)
- One form of an index is a file of entries
  <field value, pointer to record/ block>
  which is ordered by field value
- A binary search on the index yields a pointer to the file record

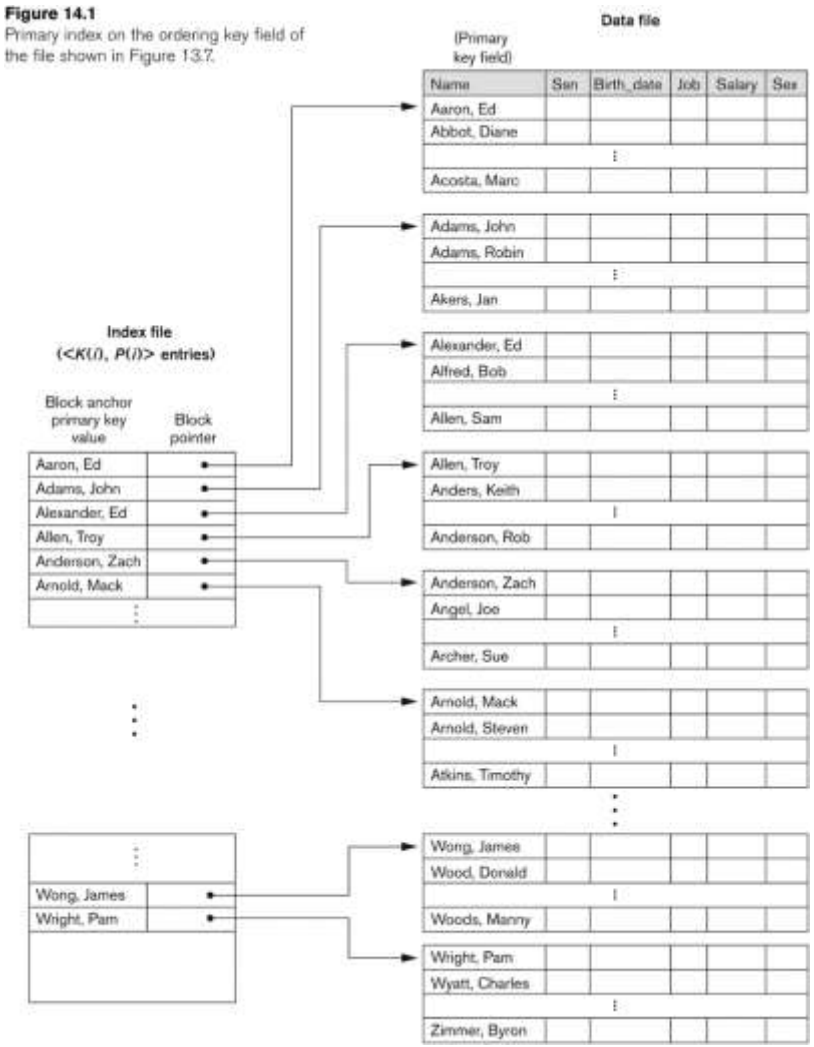
Indexes as Access Paths

- The index file usually occupies considerably less disk blocks than the data file because its entries are much smaller.
- Indexes can 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 non-dense) index** has index entries for only some of the search values.

Types of Single-Level Indexes

- Primary Index
  - Defined on an ordered data file.
  - The data file is ordered on a ***key field.***
  - Includes *one index entry for each block in the data file*; the index entry has the key field value for the *first record* in the block, which is called the *block anchor.*
  - A similar scheme can use the *last record* in a block.
  - A primary index is a *non-dense (sparse) index*, since it includes an entry for each disk block of the data file and the keys of its anchor record rather than for every search value.

Primary index on the ordering key field

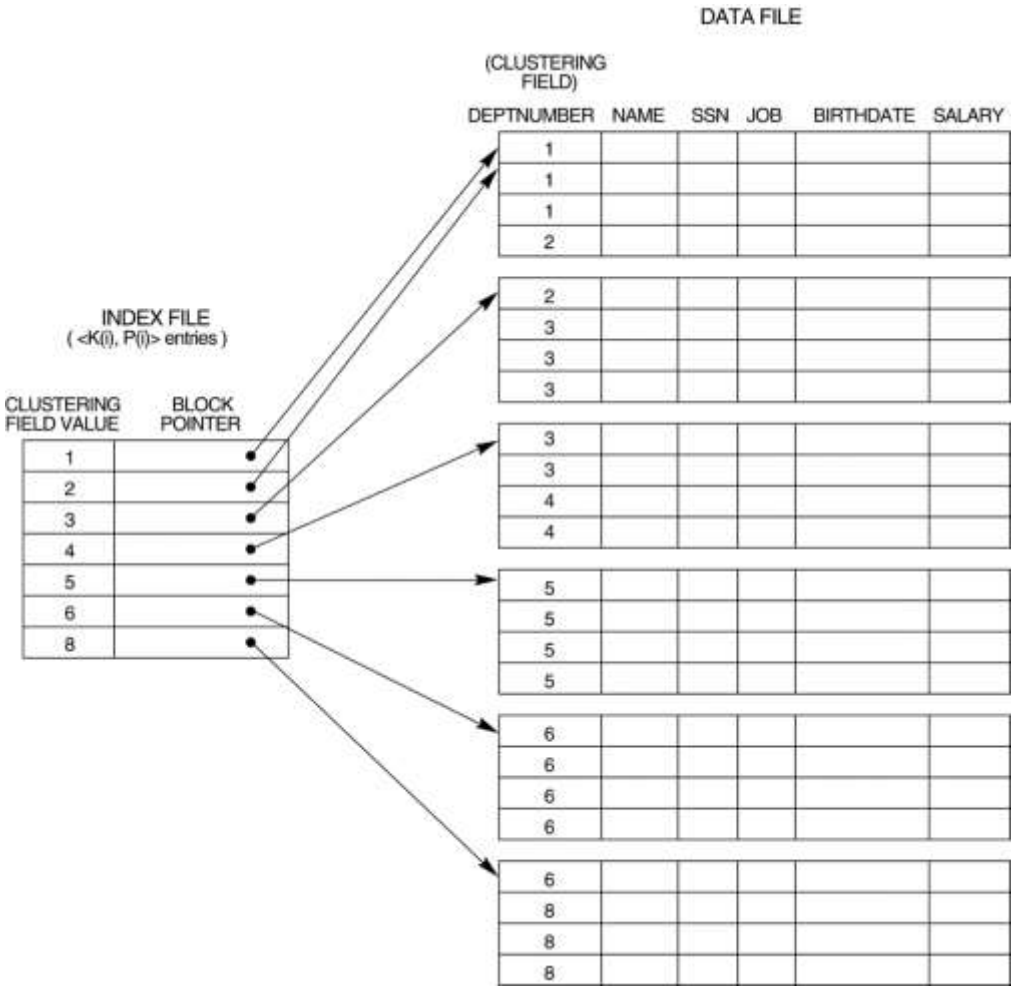


Types of Single-Level Indexes

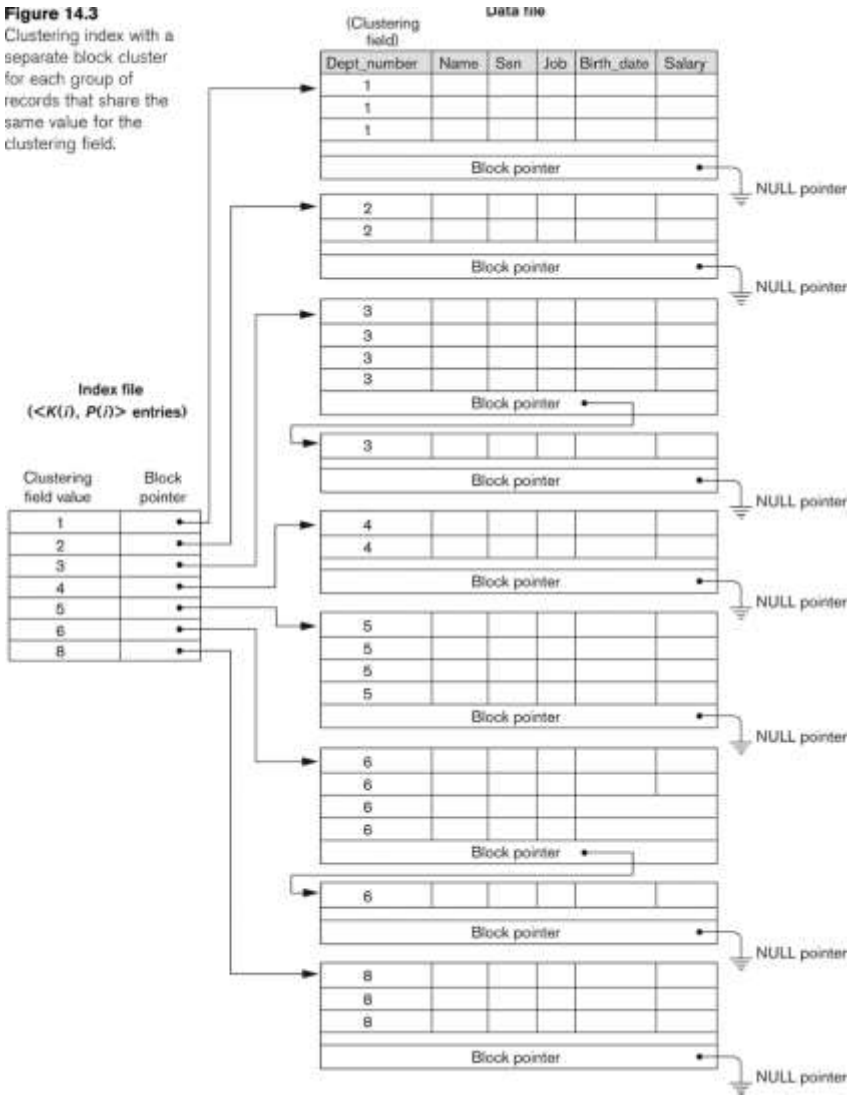
- Clustering Index
  - Defined on an ordered data file
  - The data file is ordered on a ***non-key field*** unlike primary index, which requires that the ordering field of the data file have a distinct value for each record.
  - Includes *one index entry for each distinct value of the field*; the index entry points to the first data block that contains records with that field value.
  - It is another example of *non-dense index* where Insertion and Deletion is relatively straightforward with a clustering index.

A Clustering Index Example

A clustering index on the DEPTNUMBER (ordering non-key field of an EMPLOYEE file).



Another Clustering Index Example

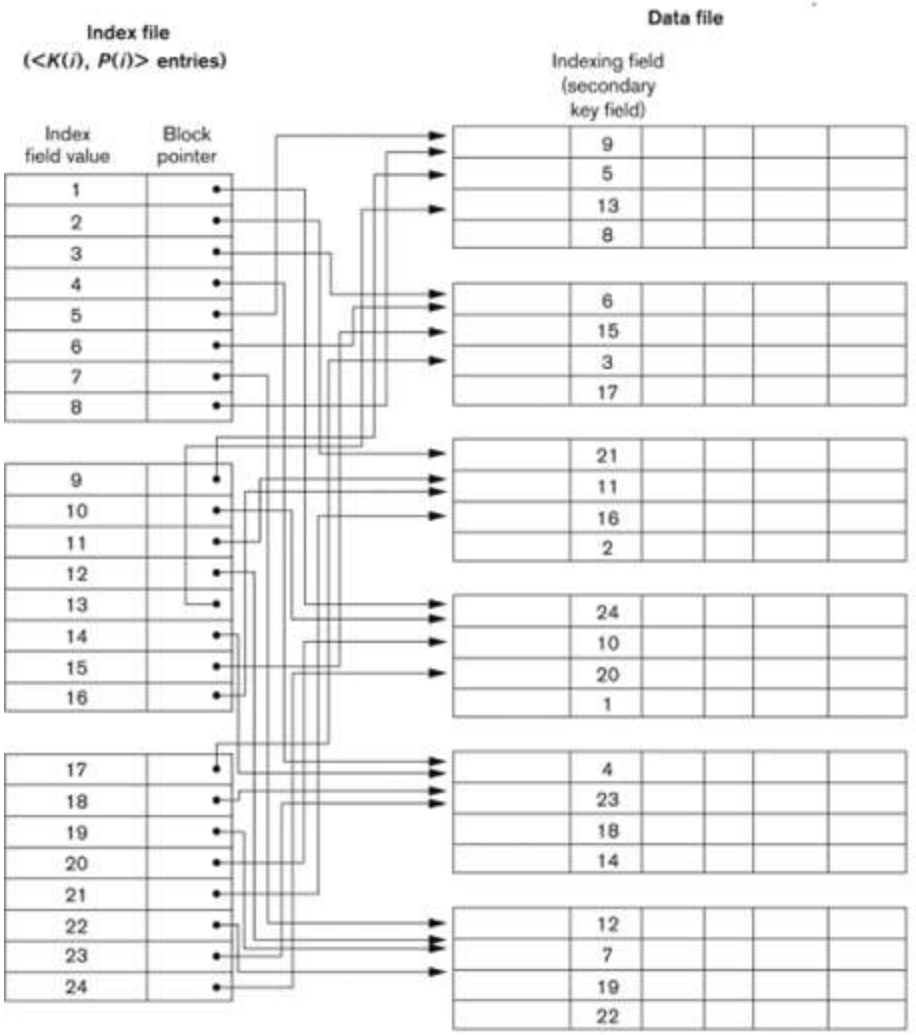


Types of Single-Level Indexes

- Secondary Index
  - A secondary index provides a secondary means of accessing a file for which some primary access already exists.
  - The secondary index may be on a field which is a candidate key and has a unique value in every record, or a non-key with duplicate values.
  - The index is an ordered file with two fields.
    - The first field is of the same data type as some **non-ordering 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 (and hence, indexing fields) for the same file.
  - Includes one entry *for each record* in the data file; hence, it is a *dense index*

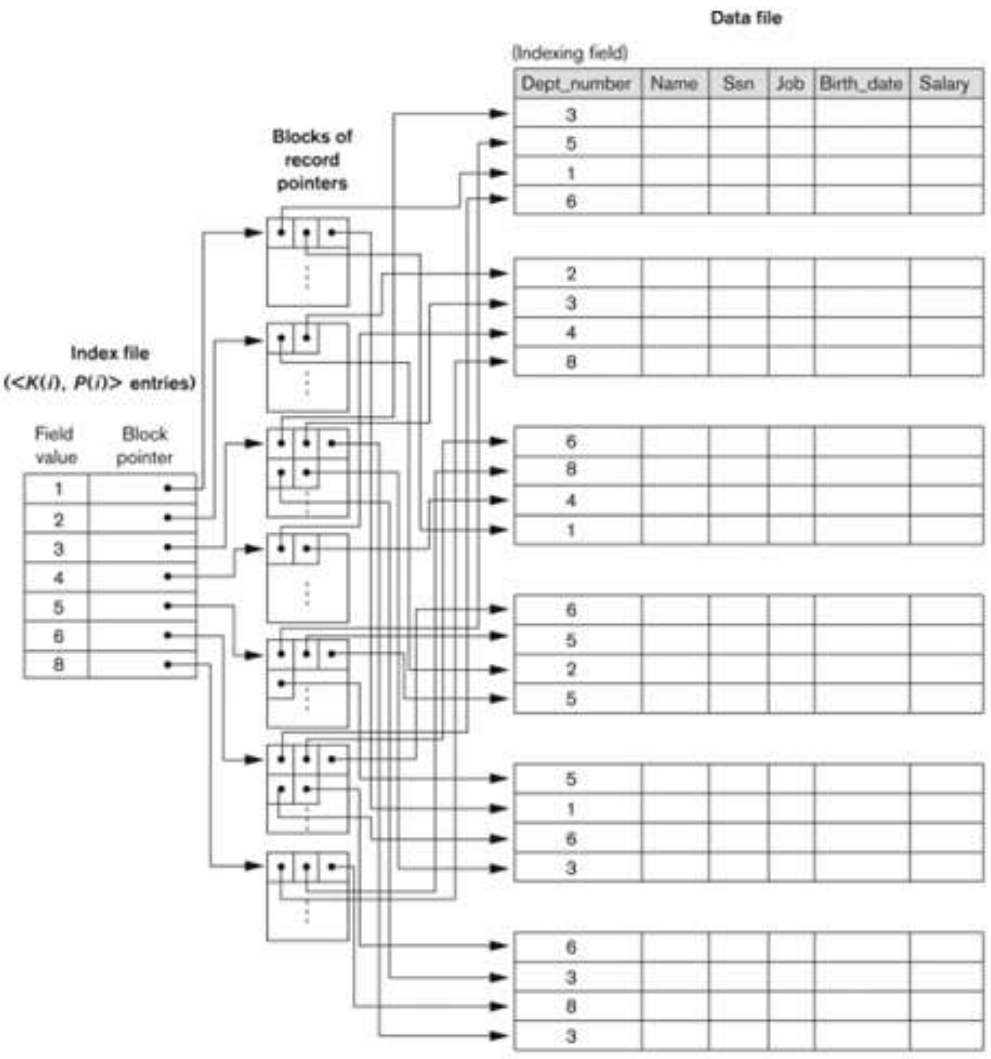
Example of a Dense Secondary Index

A dense secondary index with block pointers on a *unordered key field*



An Example of a Secondary Index

A dens secondary index with record pointers on a *unordered non-key field*



Properties of Index Types

TABLE 14.2 PROPERTIES OF INDEX TYPES

TYPE OF INDEX	NUMBER OF (FIRST-LEVEL) INDEX ENTRIES	DENSE OR NONDENSE	BLOCK ANCHORING ON THE DATA FILE
Primary	Number of blocks in data file	Nondense	Yes
Clustering	Number of distinct index field values	Nondense	Yes/no[a]
Secondary (key)	Number of records in data file	Dense	No
Secondary (nonkey)	Number of records[b] or Number of distinct index field values[c]	Dense or Nondense	No

[a]Yes if every distinct value of the ordering field starts a new block; no otherwise.
[b]For option 1.
[c]For options 2 and 3.

Multi-Level Indexes

- Because a single-level index is an ordered file, we can create a primary index *to the index itself*;
  - In this case, the original index file is called the *first-level index* and the index to the index is called the *second-level index*.
- We can repeat the process, creating a third, fourth, ..., top level until all entries of the *top-level* fit in one disk block
- A multi-level index can be created for any type of first-level index (primary, secondary, clustering) as long as the first-level index consists of *more than one* disk block

A Two-level Primary Index

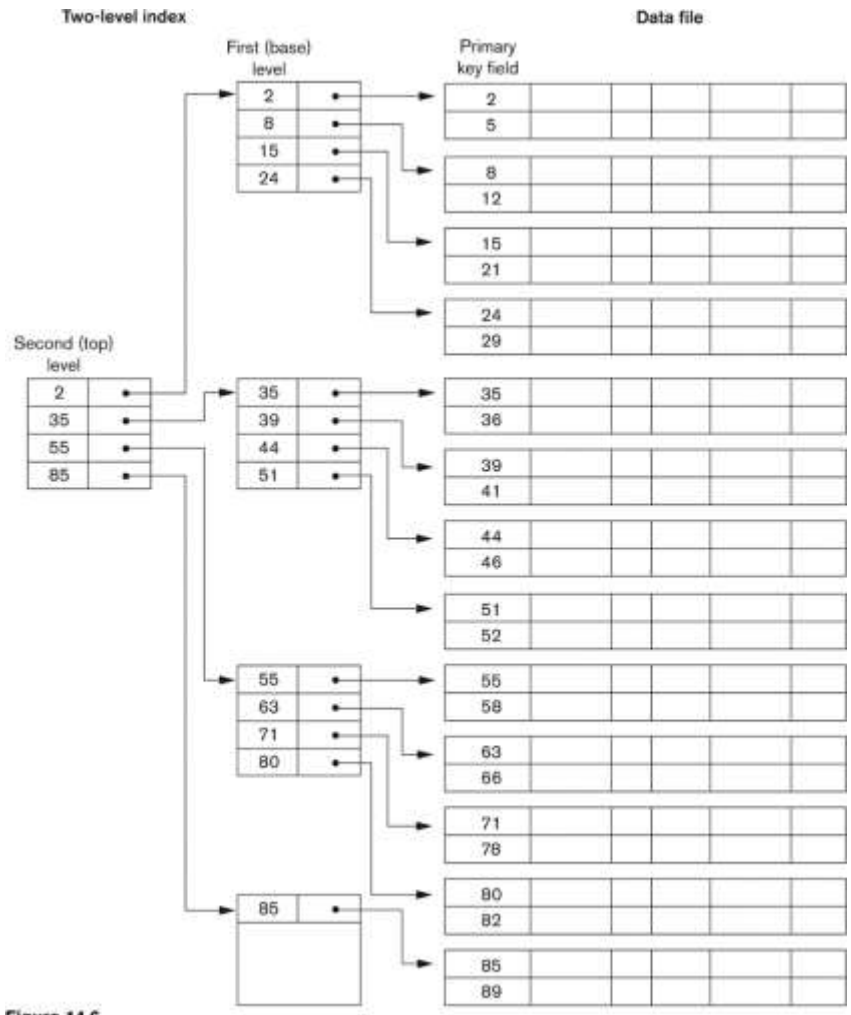


Figure 14.6
A two-level primary index resembling ISAM (Index Sequential Access Method) organization.

Multi-Level Indexes

- Such a multi-level index is a form of *search tree*
  - However, insertion and deletion of new index entries is a severe problem because every level of the index is an *ordered file*.

A Node in a Search Tree with Pointers to Subtrees below It

- FIGURE 14.8

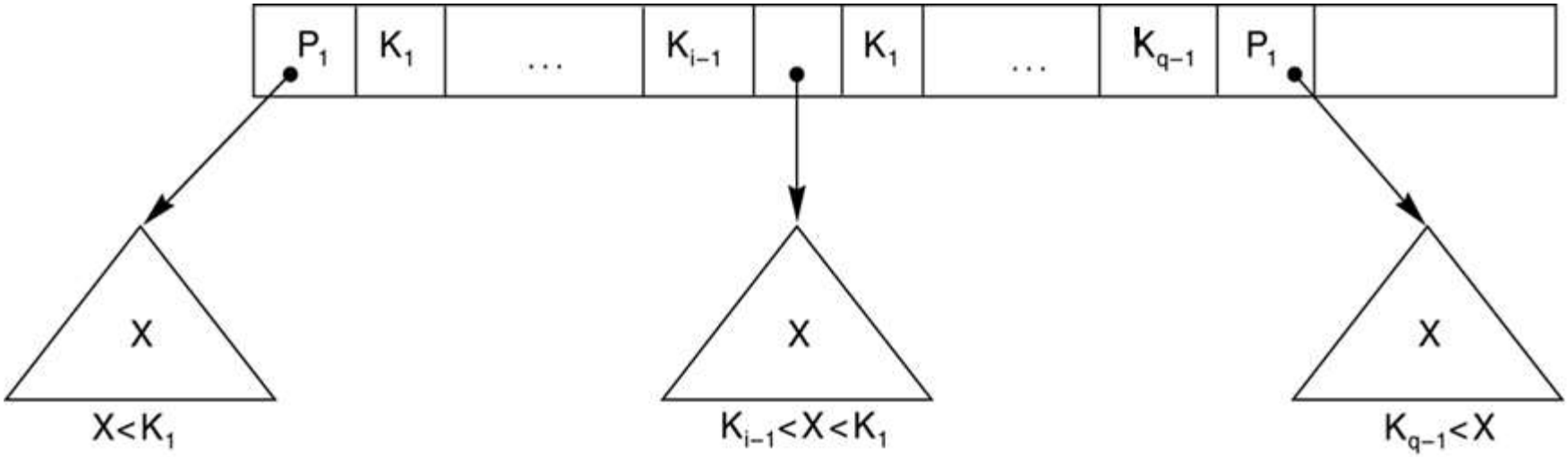
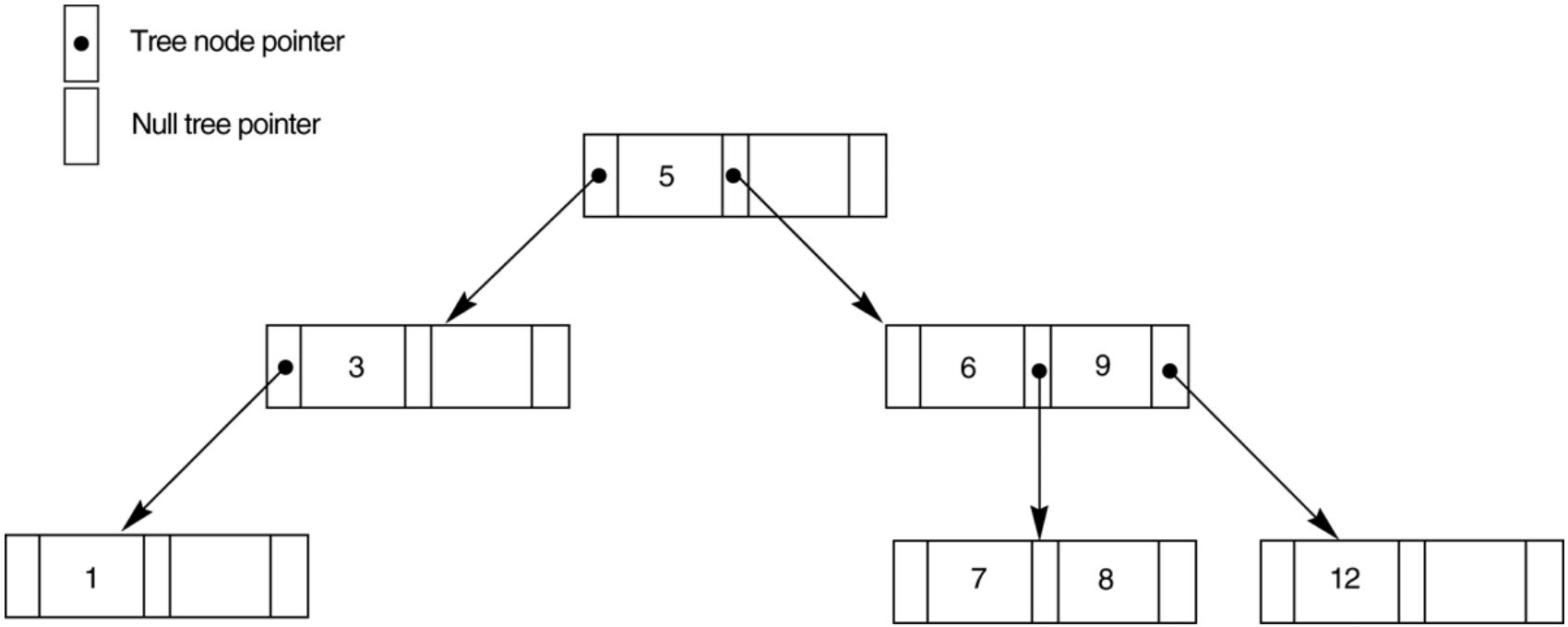


FIGURE 14.9
A search tree of order p = 3.



Dynamic Multilevel Indexes Using B Trees and B+ Trees

- An insertion into a node that is not full is quite efficient
  - If a node is full the insertion causes a split into two nodes
- Splitting may propagate to other tree levels
- 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 neighboring nodes

Difference between B-tree and B+-tree

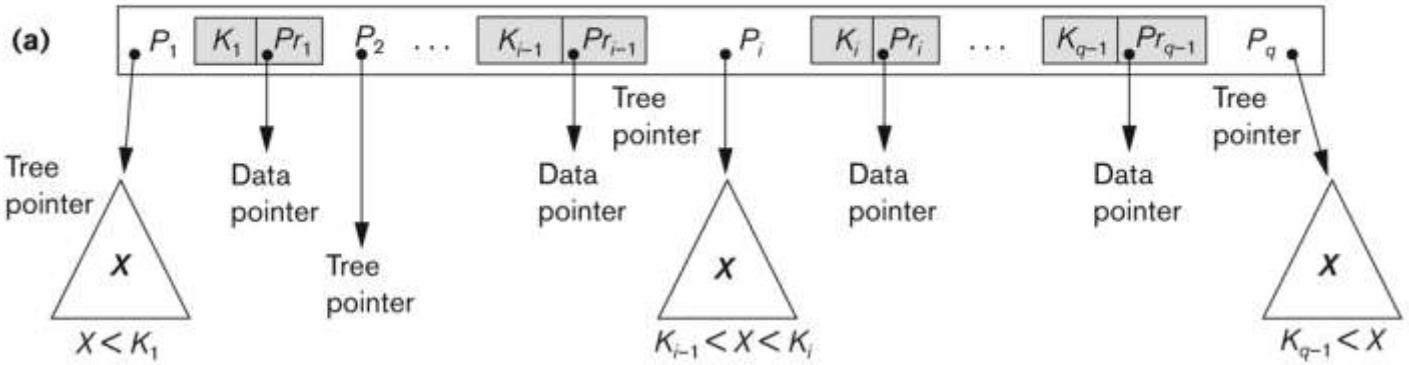
- In a B Tree, pointers to data records exist at all levels of the tree
- In a B+ Tree, all pointers to data records exists at the leaf-level nodes
- A B+ Tree can have less levels (or higher capacity of search values) than the corresponding B Tree

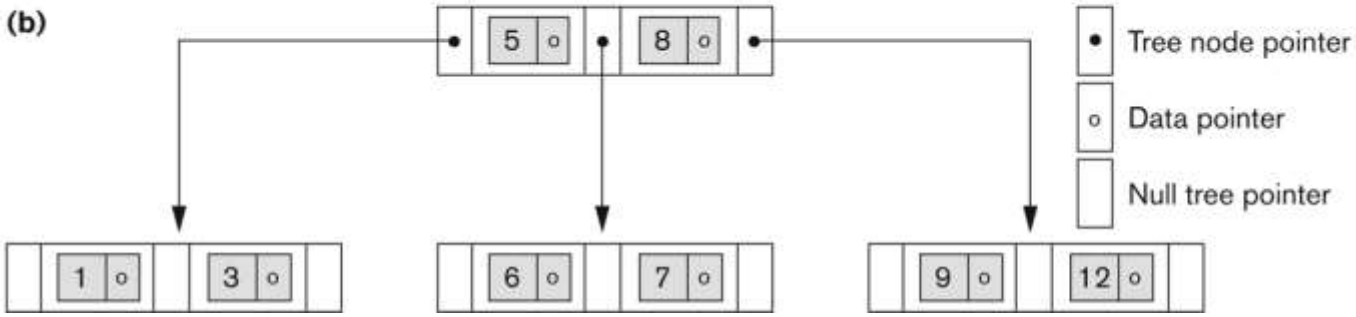
Dynamic Multilevel Indexes Using B Trees and B+ Trees

- Most multi-level indexes use B Tree or B+ Tree data structures because of the insertion and deletion problem
  - This leaves space in each tree node (disk block) to allow for new index entries
- These data structures are variations of search trees that allow efficient insertion and deletion of new search values.
- In B Tree and B+ Tree data structures, each node corresponds to a disk block
- Each node is kept between half-full and completely full

B Tree Structures

Figure 14.10
B-Tree structures. (a) A node in a B-tree with $q - 1$ search values. (b) A B-tree of order $p = 3$.The values were inserted in the order 8, 5, 1, 7, 3, 12, 9, 6.





B+ Tree Structures

- FIGURE 14.11 The nodes of a B+-tree
  - (a) Internal node of a B+-tree with q –1 search values.
  - (b) Leaf node of a B+-tree with q – 1 search values and q – 1 data pointers.