CI-5313
Arquitectura y Administración de Bases de Datos

Clase 3 – Indices (I)

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Cost of Operations

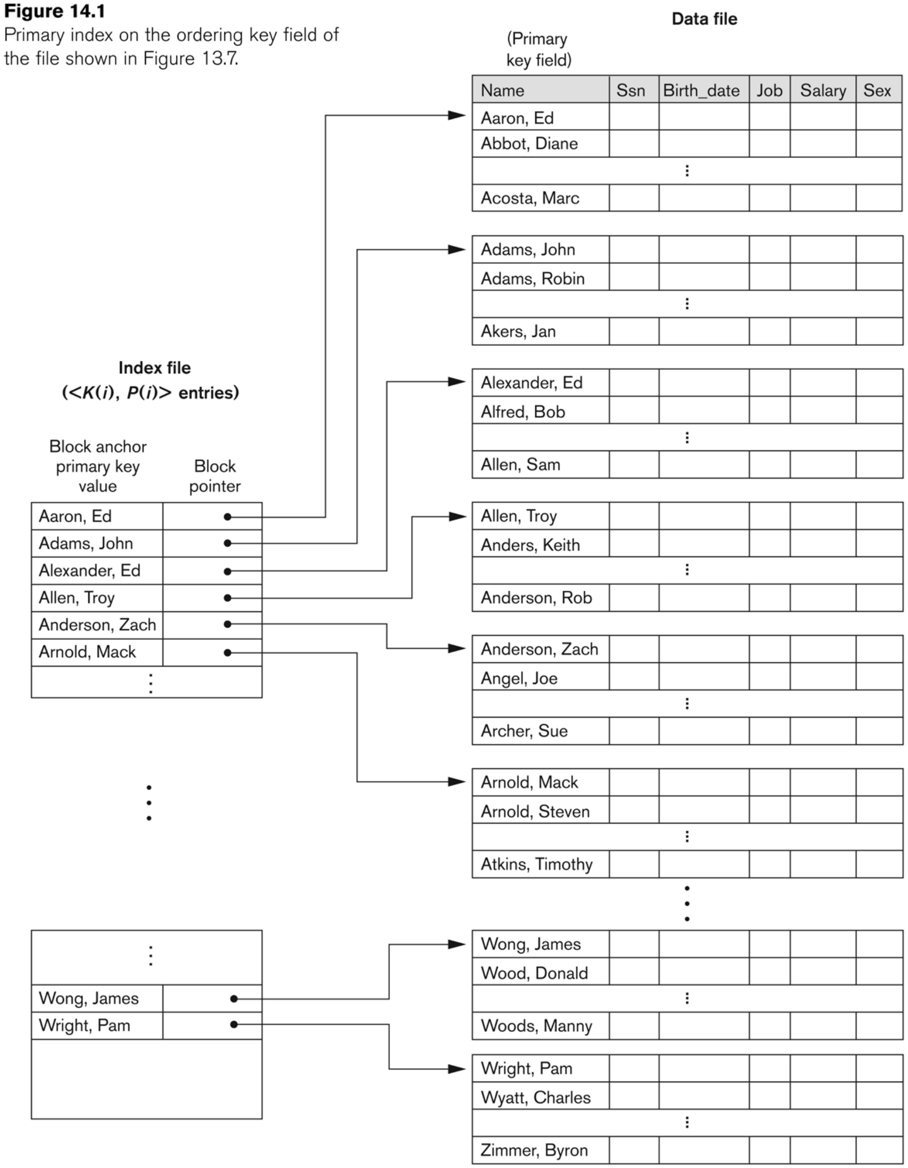
	Heap File	Sorted File
Scan all recs	**BD**	**BD**
Equality Search	**0.5 BD**	**D $\log_2$B**
Range Search	**BD**	**D ($\log_2$B + # of pages with matches)**
Insert	**2D**	**Search + BD**
Delete	**Search + D**	**Search + BD**

Index

- Data structure that organizes data records on disk.
- 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.
  - 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.

Primary index on the ordering key field

Figure 14.1
Primary index on the ordering key field of the file shown in Figure 13.7.



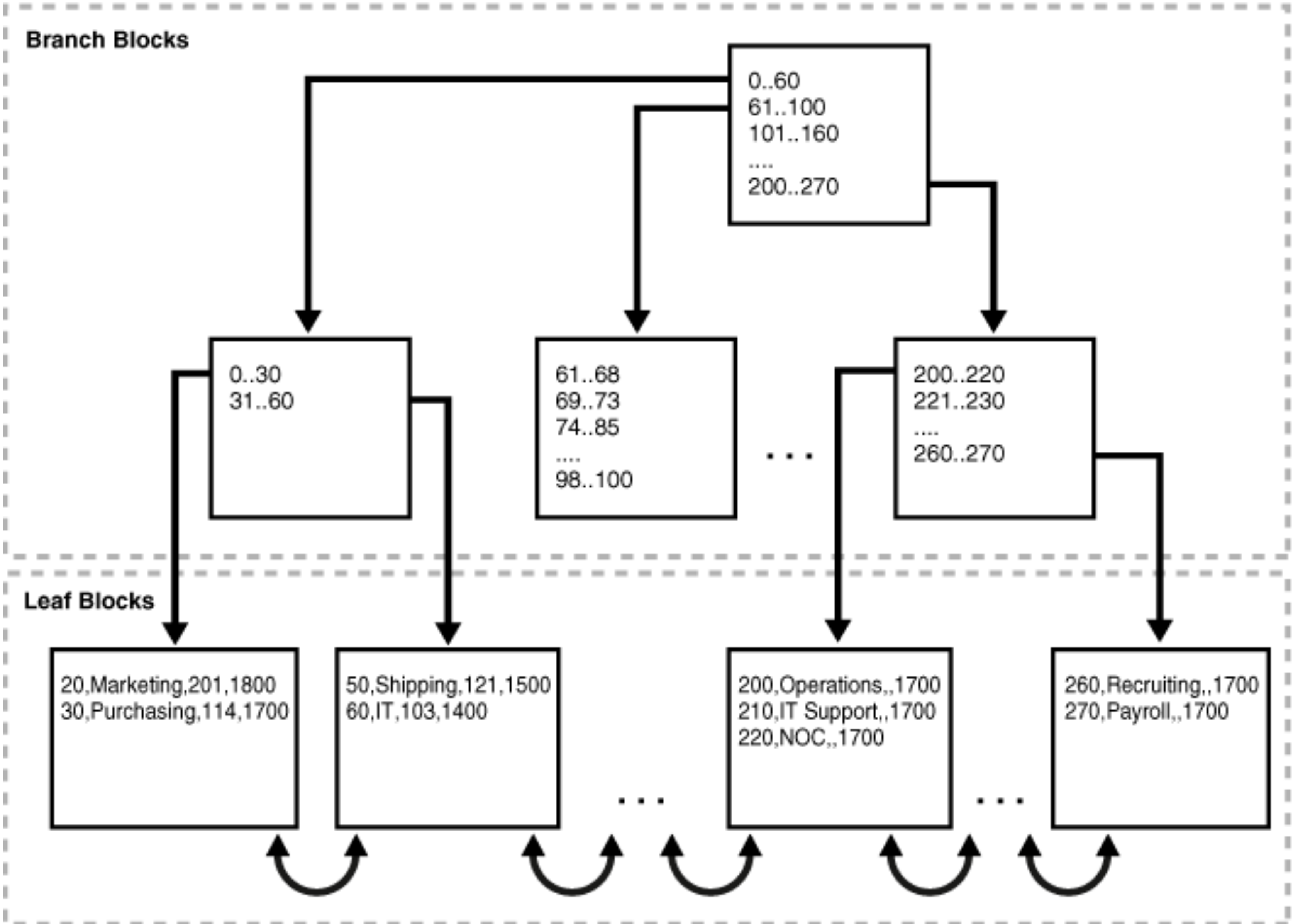
Index

- Three alternatives:
  - ① Data record with key value **k**
  - ② <**k**, rid of data record with search key value **k**>
  - ③ <**k**, list of rids of data records with search key **k**>
- 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+ trees, hash-based structures
  - Typically, index contains auxiliary information that directs searches to the desired data entries

Archivo "Clustered" - Primera alternativa

- If this is used, index structure is a file organization for data records (like Heap files or sorted files).
- At most one index on a given collection of data records can use Alternative 1. (Otherwise, data records duplicated, leading to redundant storage and potential inconsistency.)
- If data records very large, # of pages containing data entries is high. Implies size of auxiliary information in the index is also large, typically.

Archivo "Clustered" - Primera alternativa



Index – Alternatives 2 and 3 – separate file for index

- The index file usually occupies considerably less disk blocks than the data file because its entries are much smaller
- A binary search on a single-level index yields a pointer to the file record
- 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, on the other hand, has index entries for only some of the search values

Index example

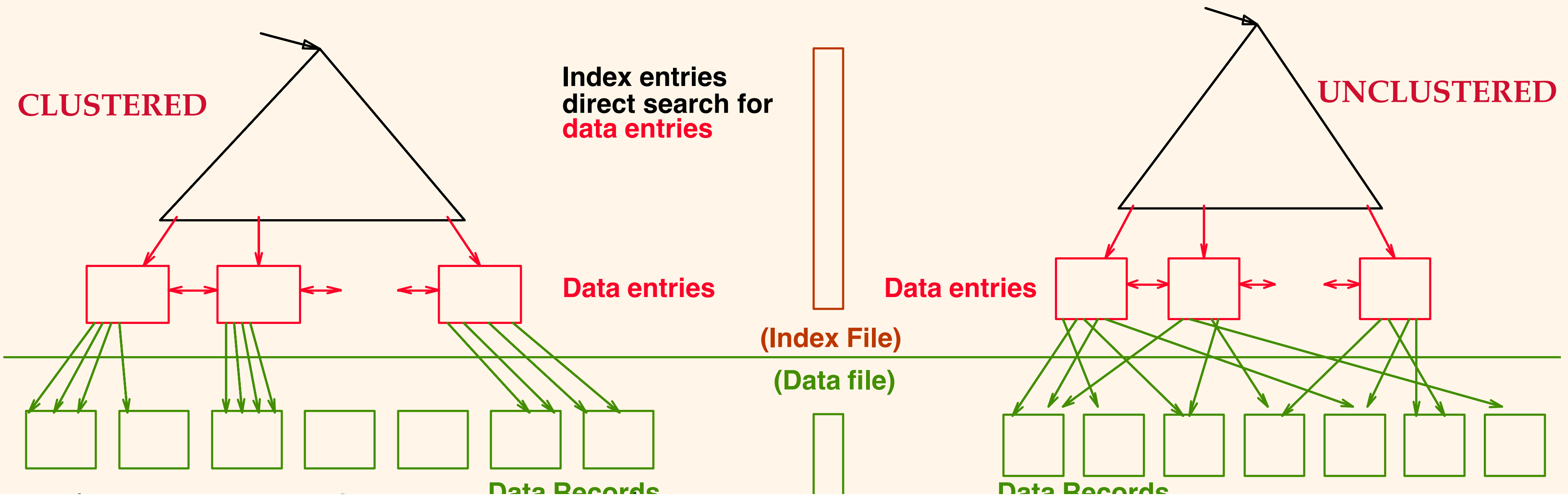
- Example: Given the following data file EMPLOYEE(NAME, SSN, ADDRESS, JOB, SAL, ...)
- Suppose that:
  - record size R=150 bytes   block size B=512 bytes r=30000 records
- Then, we get:
  - blocking factor Bfr= B div R= 512 div 150= 3 records/block
  - number of file blocks b= (r/Bfr)= (30000/3)= 10000 blocks
- For an index on the SSN field, assume the field size V_{SSN}=9 bytes, assume the block pointer size P_B=7 bytes. Then:
  - index entry size $R_I=(V_{SSN}+P_B)=(9+7)=16$ bytes
  - index blocking factor Bfr_I= B div R_I= 512 div 16= 32 entries/block
  - number of index blocks $b_I= (r/ Bfr_I)= (30000/32)= 938$ blocks
  - binary search needs $\log_2 b_I= \log_2 938=$ 10 block accesses
  - This is compared to an average linear search cost of:
    - (b/2)= 10000/2= 5000 block accesses
  - If the file records are ordered, the binary search cost would be:
    - $\log_2 b= \log_2 10000=$ 14 block accesses

Index taxonomies

- Dense vs. Sparse.
- Simple vs. Composite
- Single-level vs. Multi-level (trees).
- Primary vs. Secondary.
  - Primary is index on a key (unique).
  - A secondary index provides a secondary means of accessing a file for which some primary access already exists.
- Clustered vs. Unclustered.
  - If order of data records is the same as, or `close to', order of data entries, then called clustered index.
  - Alternative 1 implies clustered, but not vice-versa.
  - A file can be clustered on at most one search key.
  - Cost of retrieving data records through index varies greatly based on whether index is clustered or not!
- Points to record vs. Points to block

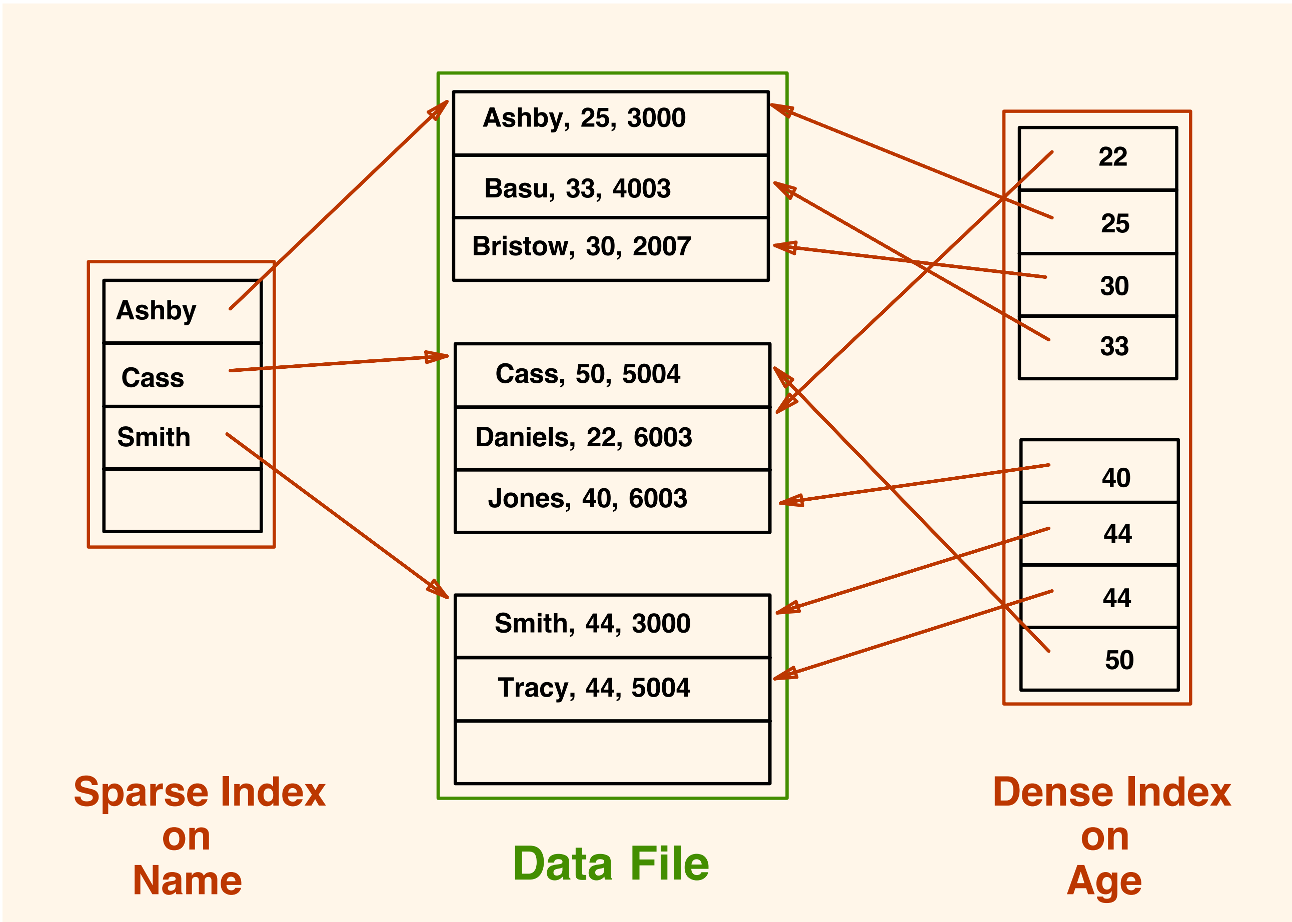
Clustered vs. Unclustered

- 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.)



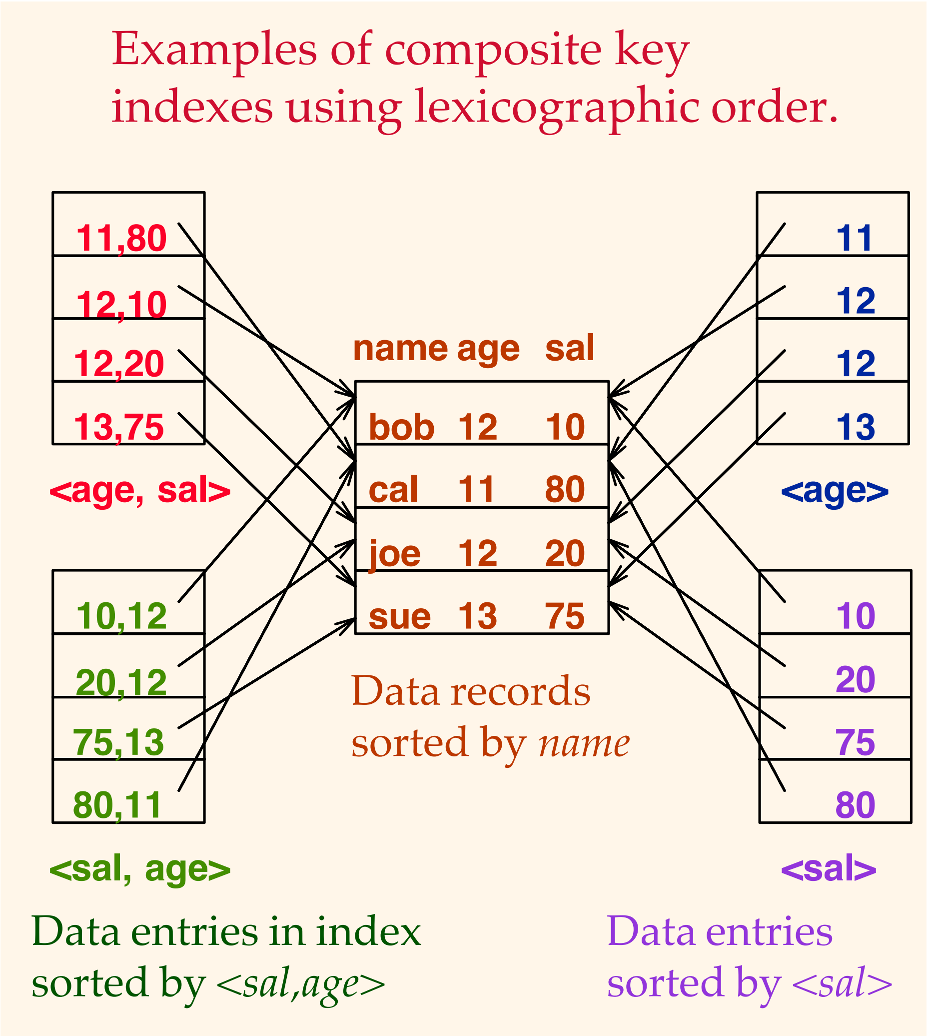
Dense vs. Sparse

- Dense vs. Sparse.



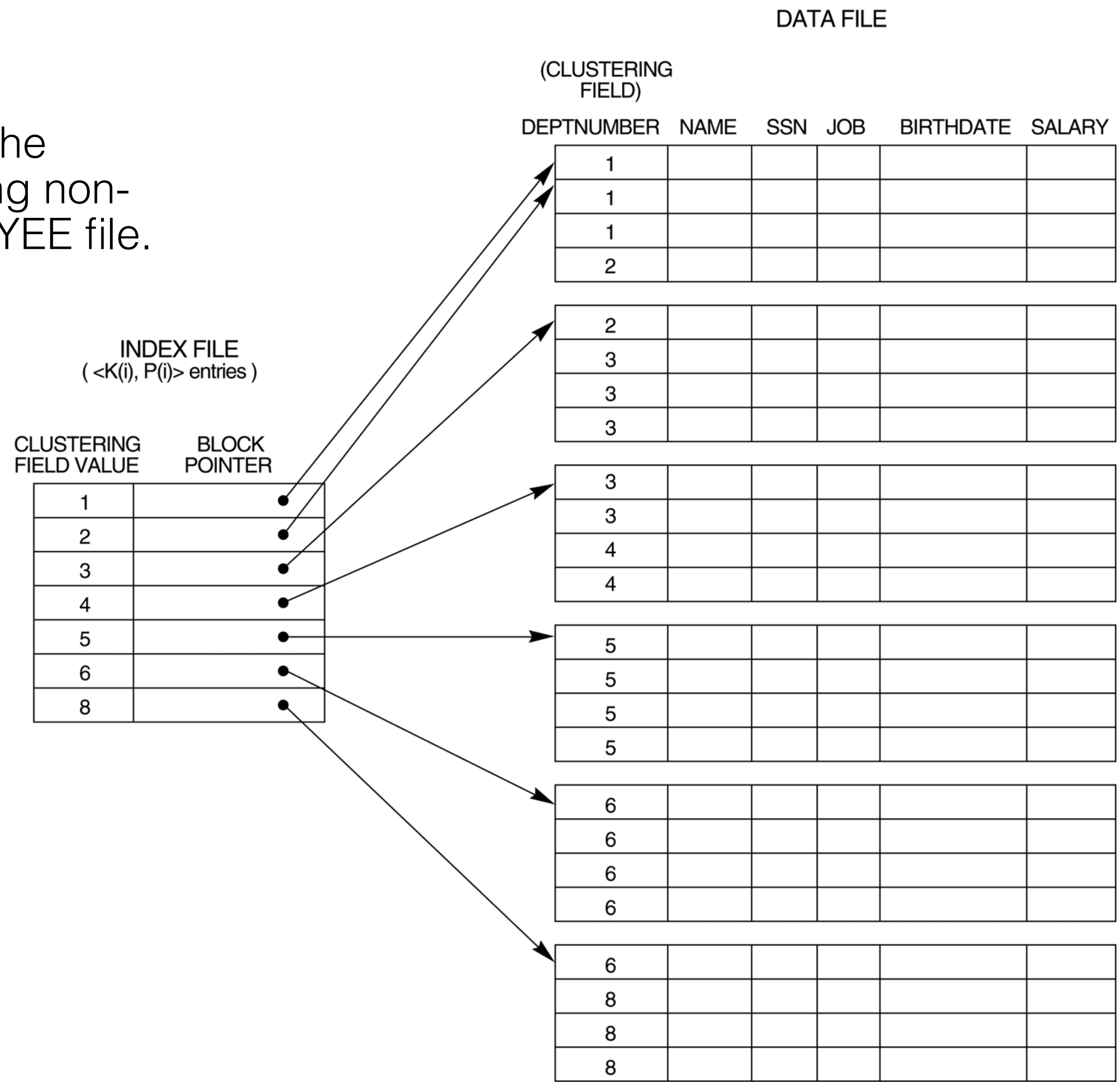
- Alternative 1 is sparse or dense?
- A sparse index is clustered or unclustered?

Example – Category in each taxonomy?



Example – Category in each taxonomy?

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



Another Clustering Index Example

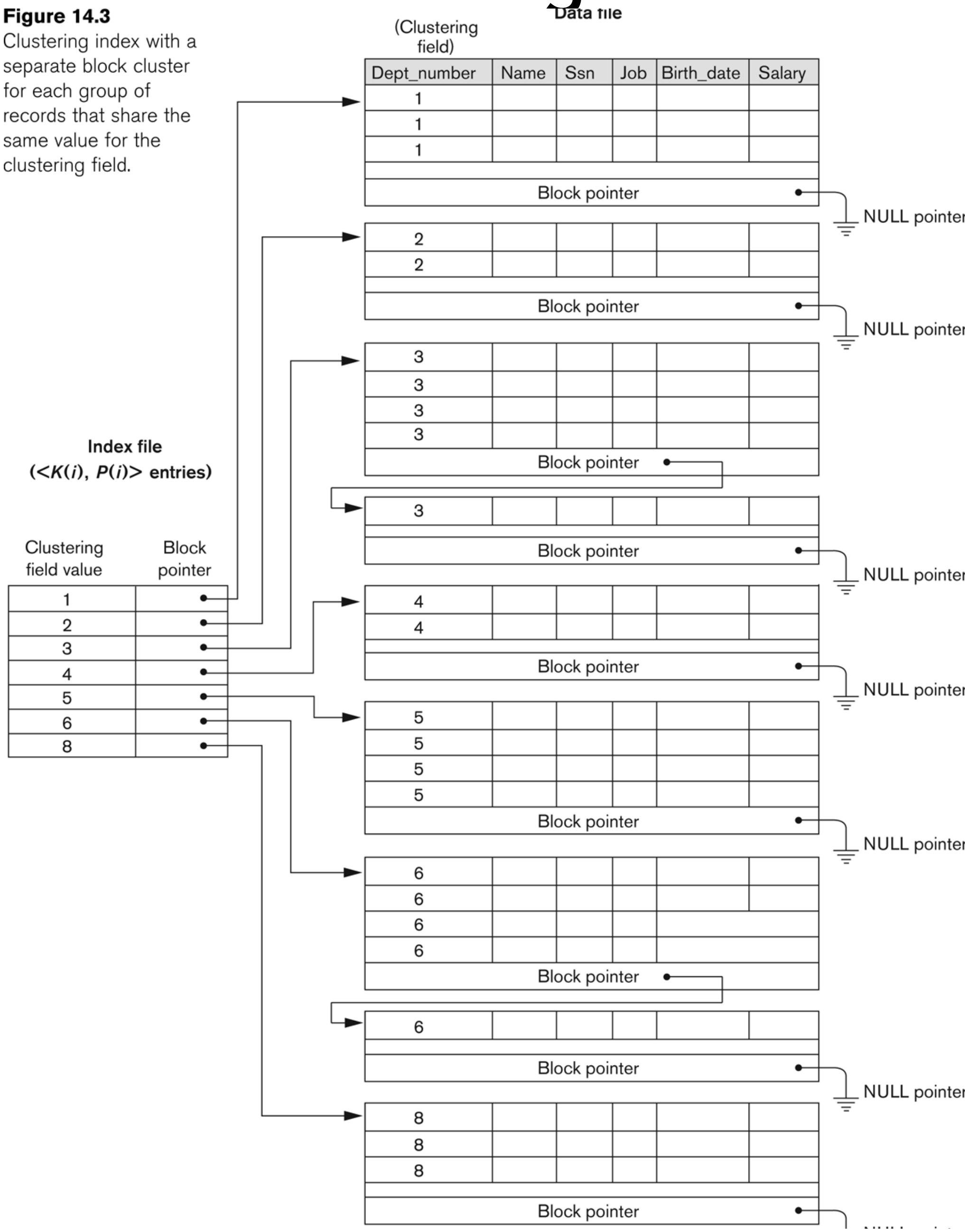
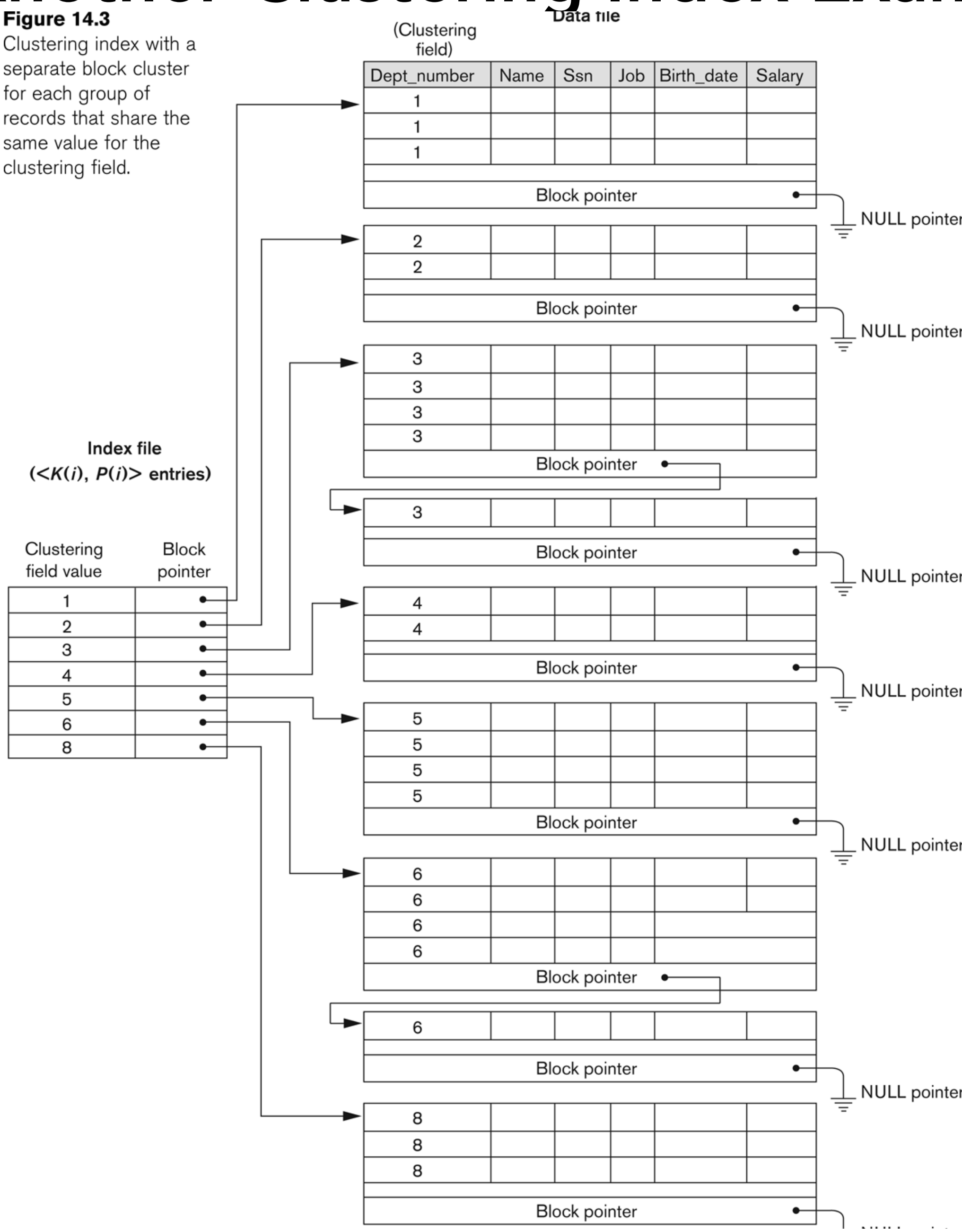


Figure 14.3
Clustering index with a separate block cluster for each group of records that share the same value for the clustering field.

Another Clustering Index Example

Figure 14.3
Clustering index with a separate block cluster for each group of records that share the same value for the clustering field.



Dense Scondary Index Example

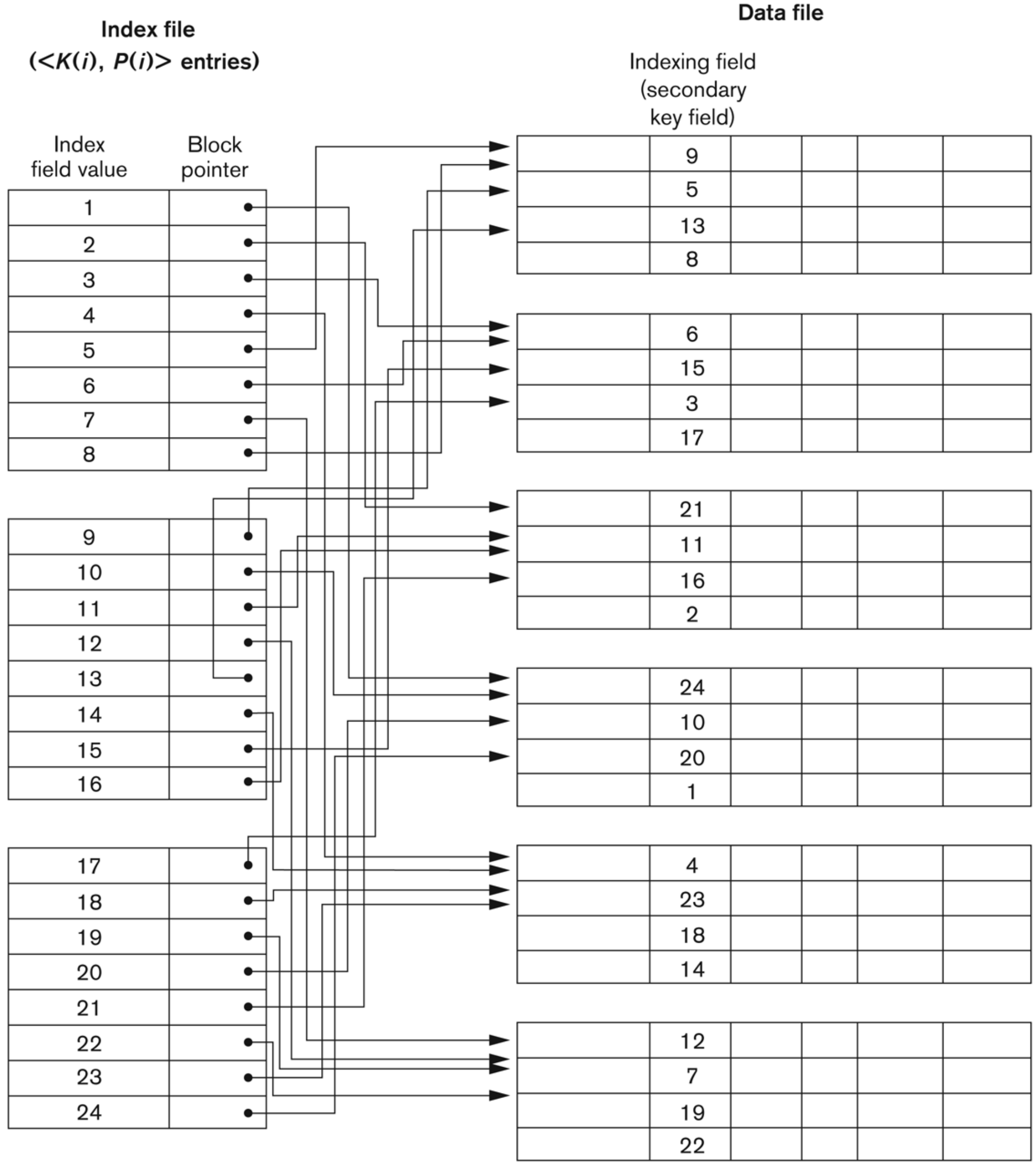


Figure 14.4
A dense secondary index (with block pointers) on a nonordering key field of a file.

Secondary Index Example

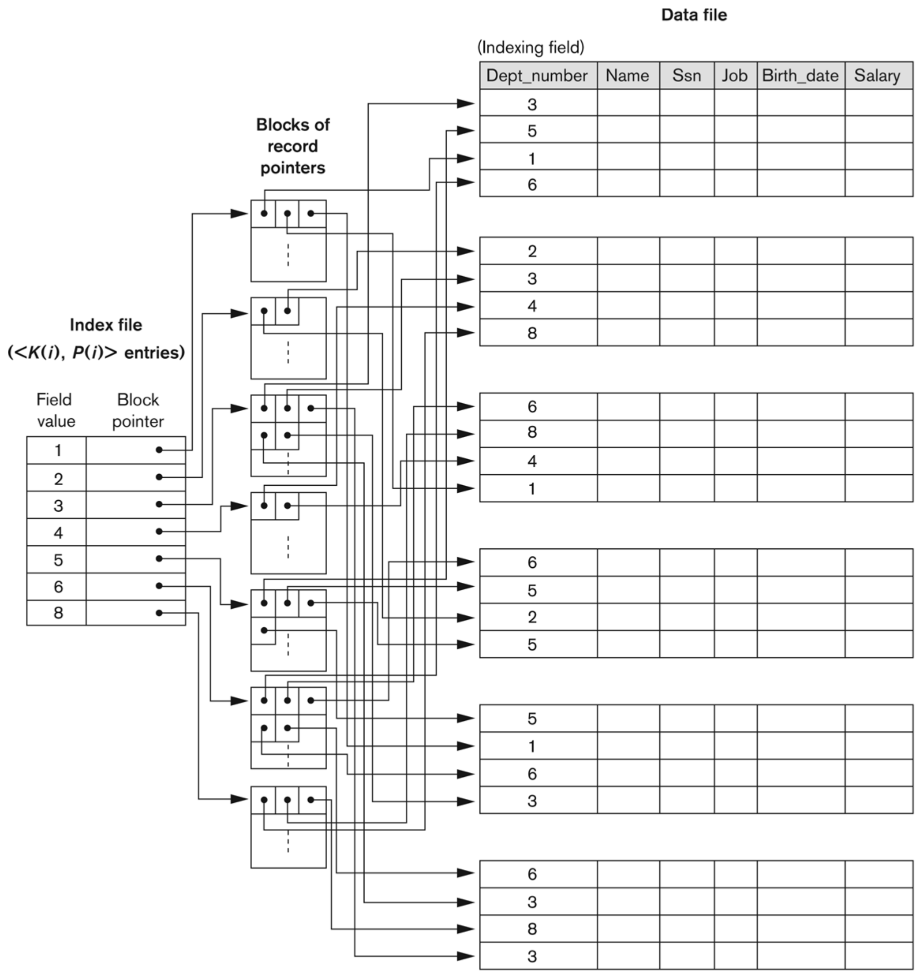
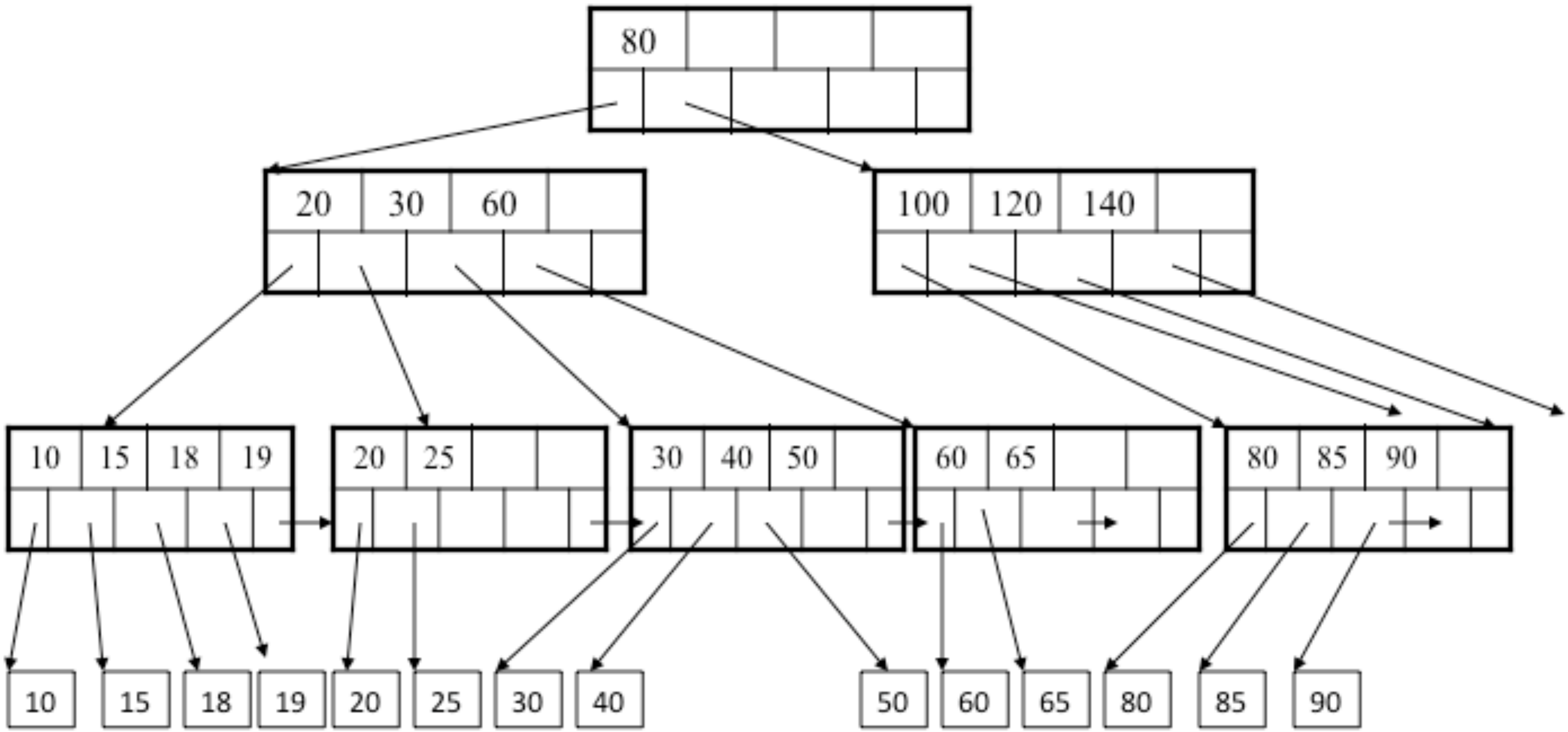


Figure 14.5
A secondary index (with record pointers) on a nonkey field implemented using one level of indirection so that index entries are of fixed length and have unique field values.

B+ Tree



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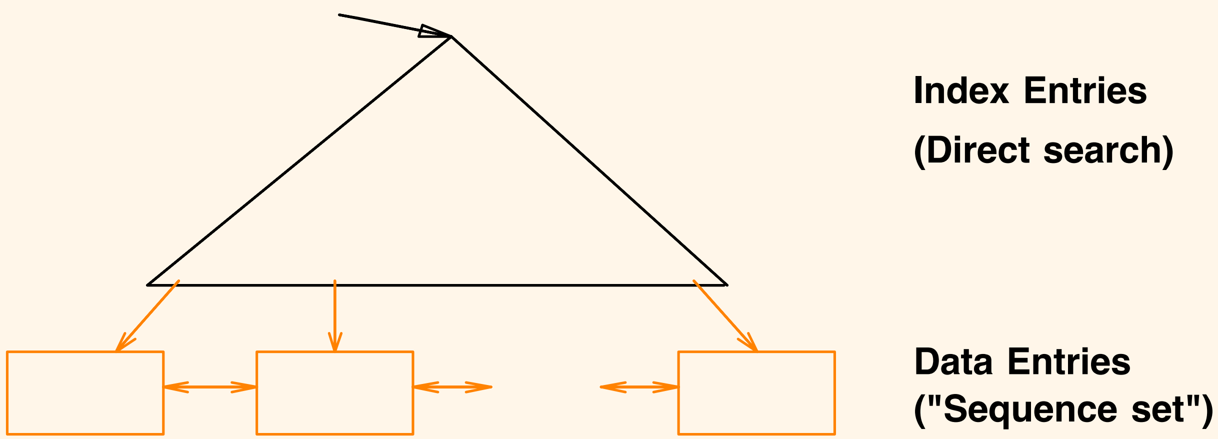
90

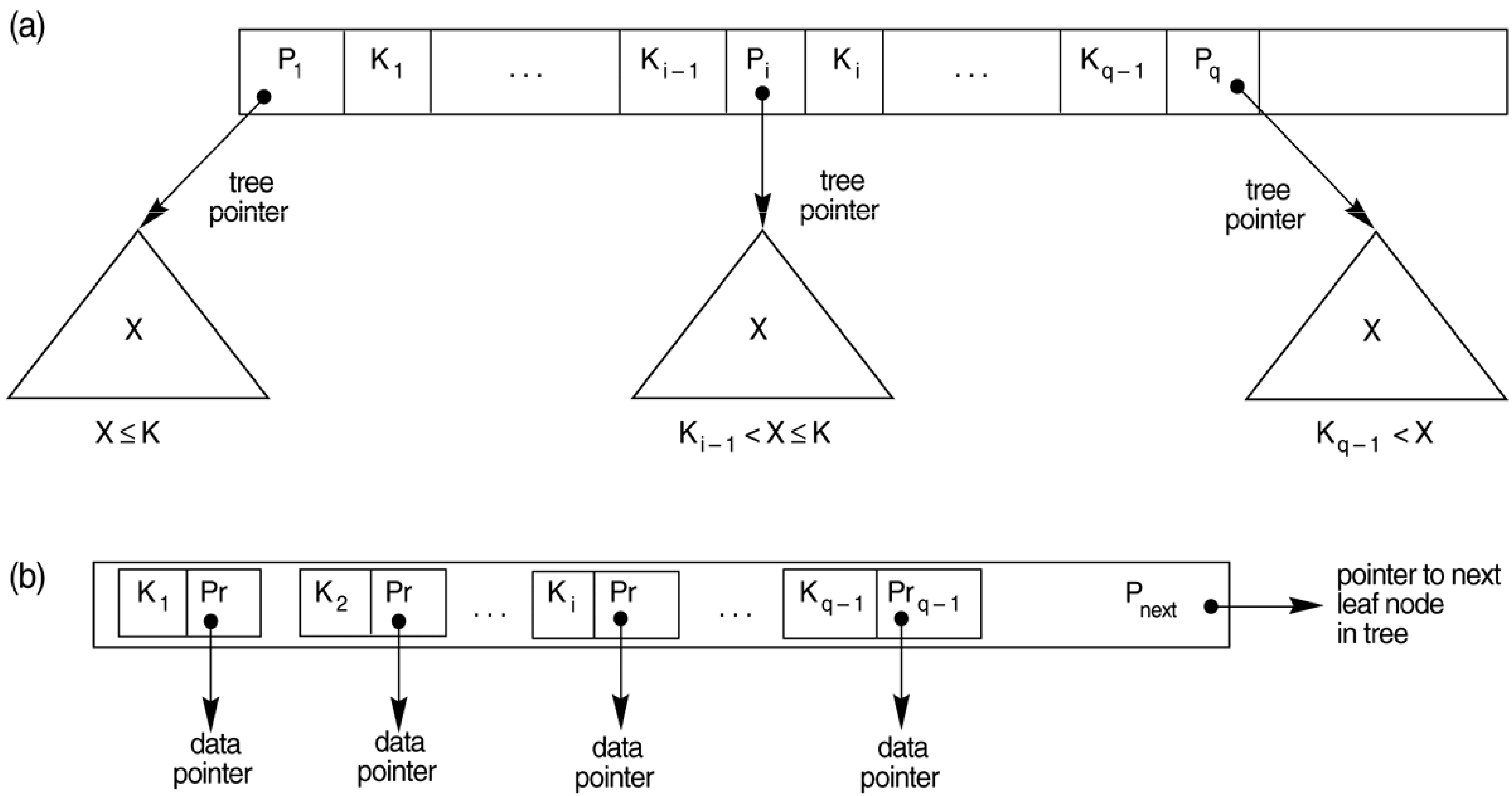
B+ Tree

- Insert/delete at $\log_F N$ cost; keep tree *height-balanced*. (F = fanout, N = # leaf pages)
- Minimum 50% occupancy (except for root). Each node contains **d** <= *m* <= 2**d** entries. The parameter **d** is called the *order* of the tree.
- Supports equality and range-searches efficiently.



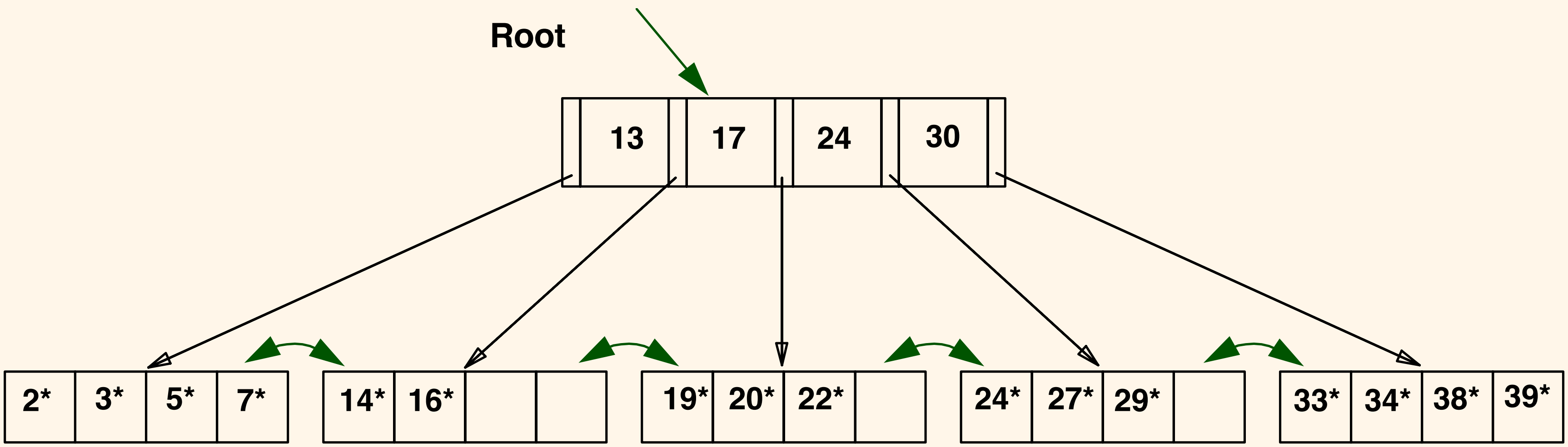
B+ Tree

- 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.



B+ Tree Search

- Search begins at root, and key comparisons direct it to a leaf (as in ISAM).
- Search for 5*, 15*, all data entries >= 24* ...



☛ *Based on the search for 15*, we <u>know</u> it is not in the tree!*

B+ Tree in practice

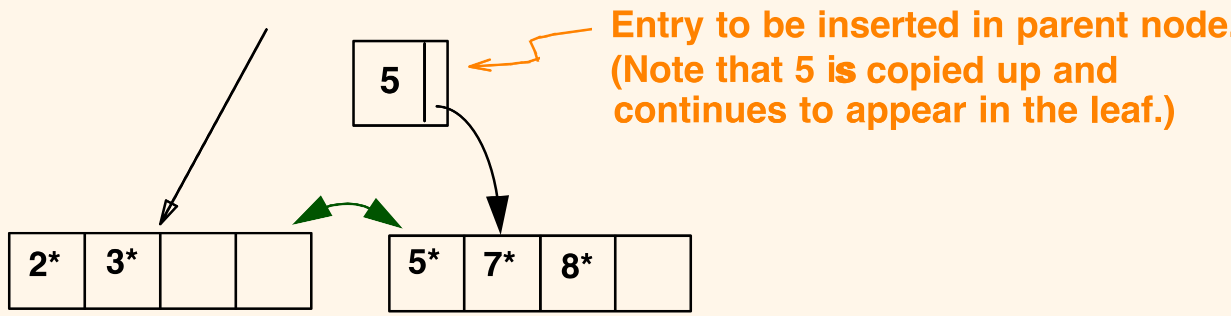
- Typical order: 100. Typical fill-factor: 67%.
  - average fanout = 133
- Typical capacities:
  - Height 4: 133^4 = 312,900,700 records
  - Height 3: 133^3 = 2,352,637 records
- Can often hold top levels in buffer pool:
  - Level 1 = 1 page = 8 Kbytes
  - Level 2 = 133 pages = 1 Mbyte
  - Level 3 = 17,689 pages = 133 MBytes

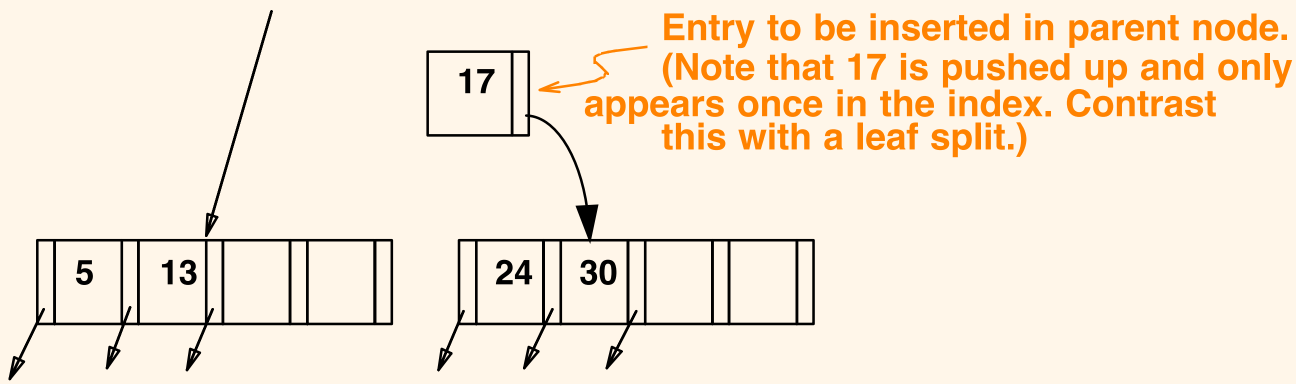
Inserting B+ Tree

- Find correct leaf *L.*
- Put data entry onto *L*.
  - If *L* has enough space, *done*!
  - Else, must *split* *L (into L and a new node L2)*
    - Redistribute entries evenly, **copy up** middle key.
    - Insert index entry pointing to *L2* into parent of *L*.
- This can happen recursively
  - To split index node, redistribute entries evenly, but **push up** middle key. (Contrast with leaf splits.)
- Splits "grow" tree; root split increases height.
  - Tree growth: gets *wider* or *one level taller at top.*

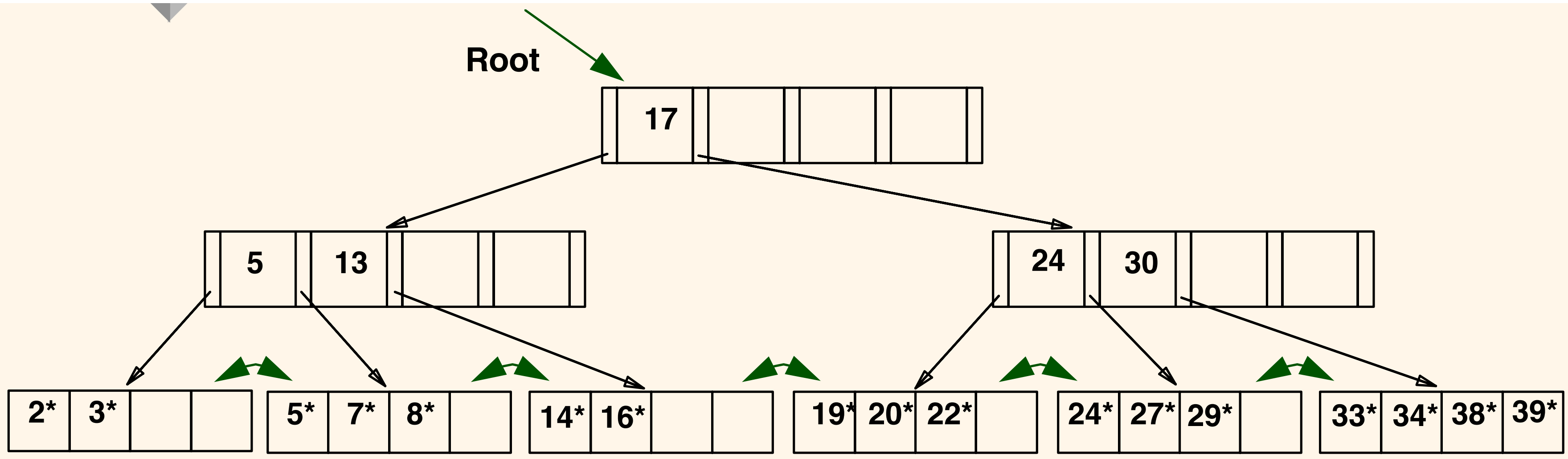
Inserting B+ Tree

- Observe how minimum occupancy is guaranteed in both leaf and index pg splits.
- Note difference between *copy-up* and *push-up*; be sure you understand the reasons for this.





Inserting node 8 B+ Tree



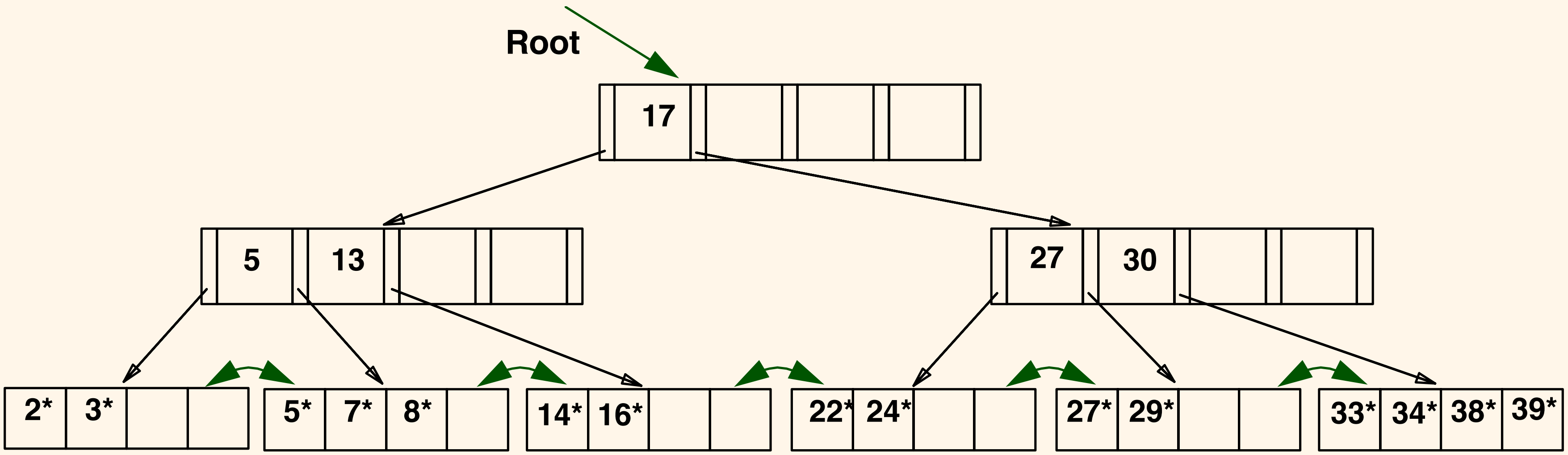
❖ Notice that root was split, leading to increase in height.

❖ In this example, we can avoid split by re-distributing entries; however, this is usually not done in practice.

Deleting B+ Tree

- Start at root, find leaf *L* where entry belongs.
- Remove the entry.
  - If L is at least half-full, *done!*
  - If L has only **d-1** entries,
    - Try to re-distribute, borrowing from *sibling* *(adjacent node with same parent as L)*.
    - If re-distribution fails, *merge* *L* and sibling.
- If merge occurred, must delete entry (pointing to *L* or sibling) from parent of *L*.
- Merge could propagate to root, decreasing height.

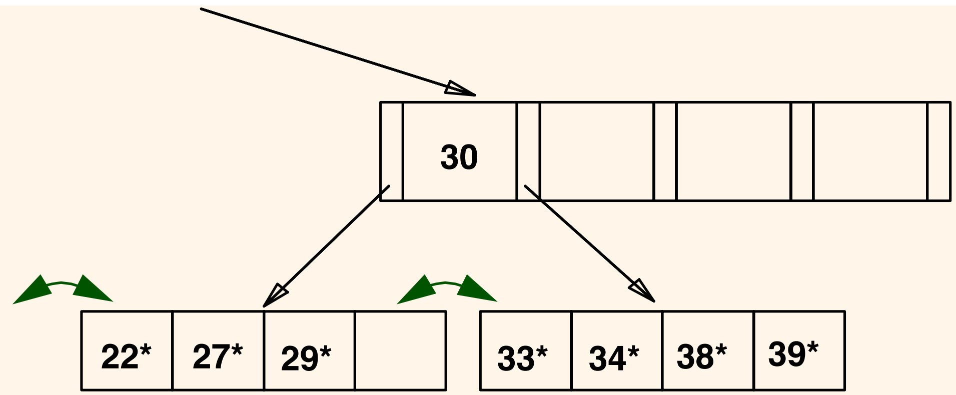
Deleting B+ Tree

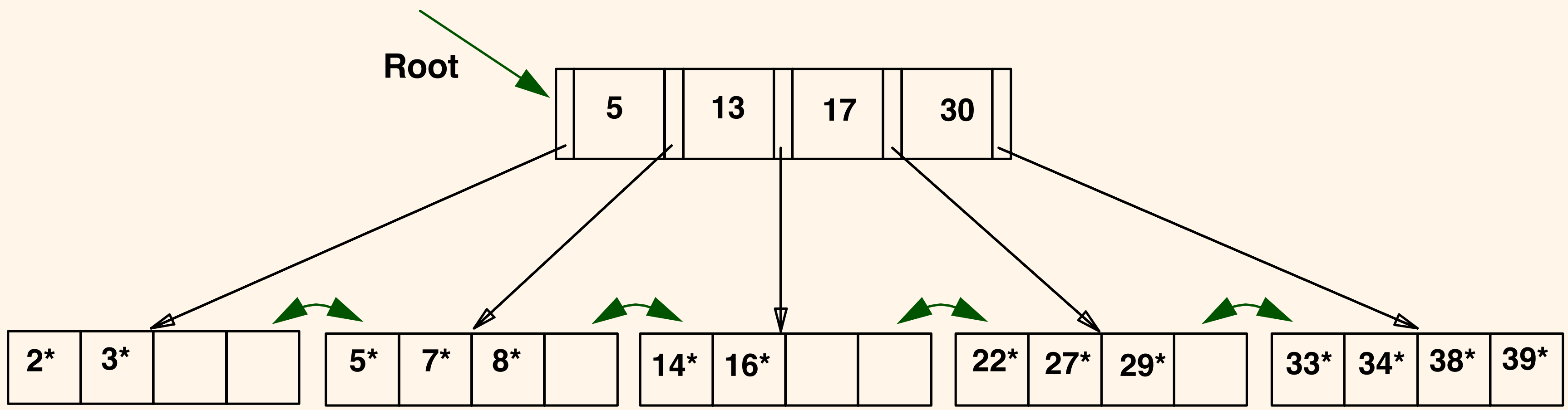


- Deleting 19* is easy.
- Deleting 20* is done with re-distribution. Notice how middle key is *copied up*.

Deleting 24 B+ Tree
toss 27, pull down 17

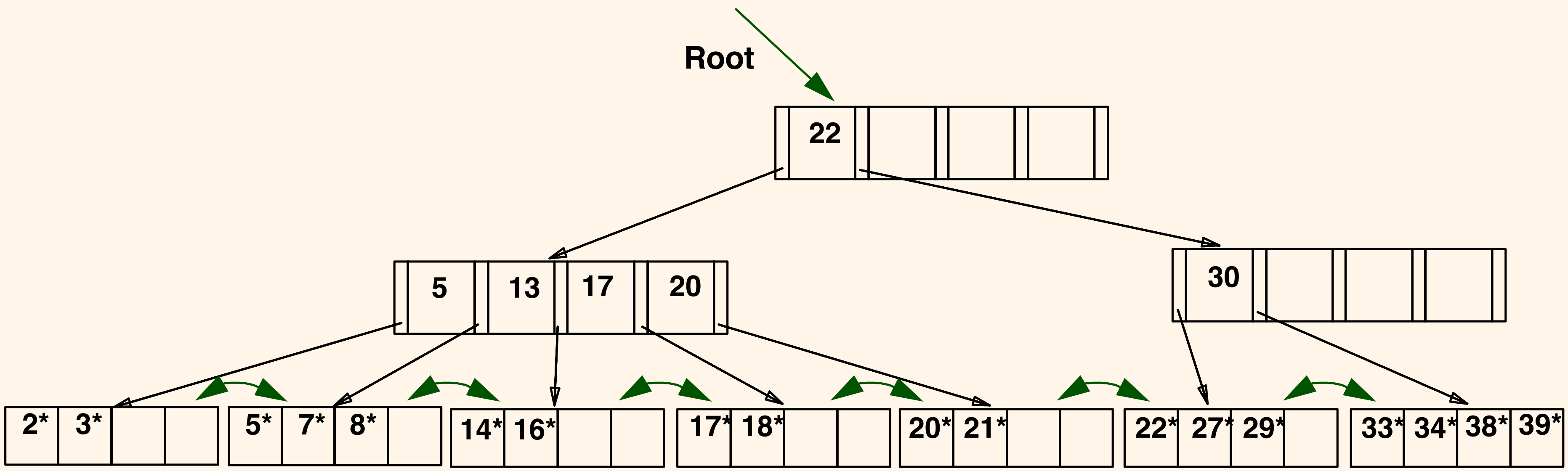
- Must merge.
- Observe *`toss'* of index entry (on right), and *`pull down'* of index entry (below).





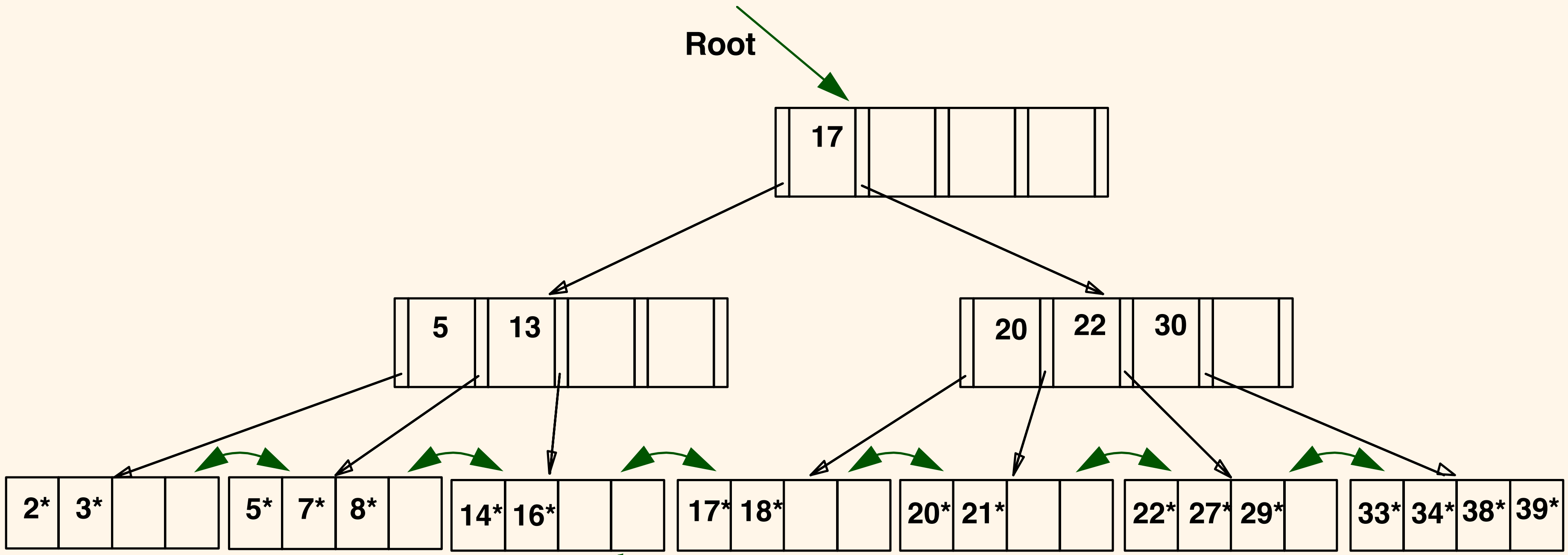
Example of non-leaf redistribution

- Tree is shown below *during deletion* of 24*. (What could be a possible initial tree?)
- In contrast to previous example, can re-distribute entry from left child of root to right child.



After redistribution

- Intuitively, entries are re-distributed by `*pushing through*' the splitting entry in the parent node.
- It suffices to re-distribute index entry with key 20; we've re-distributed 17 as well for illustration.



http://www.cs.usfca.edu/~galles/visualization/BPlusTree.html