• locate the record
• delete the pointed-to record from the data file
• delete the key-pointer pair from the B-tree...

Deletion: The No-Combining Pages Case

• recall that \( n=4 \), i.e., each internal node has at least \( n=2 \) keys and \( m+1 = 3 \) pointers (at most \( 4 \) keys, \( 5 \) pointers)
• if the node from which was deleted is still have full (has \( n=2 \) keys):
  – DONE (lookup still works), or
  – update parent if deleted leftmost key
• otherwise (Delete 22 ??)

Deletion: The No-Combining Pages Case

• if the node from which was deleted is still have full:
  – DONE, or
  – update parent if deleted leftmost key
• otherwise (Delete 22 ??)
• if the node N from which is deleted has minimum (m=2) items:
  • if there is a neighbor N’ (left or right) with >m items then
    • transfer the first (or last) item of N’ to N, and
    • update the appropriate ancestors of N
  • else ... (Delete 28: next page)

* transfer the last element of the left neighbor or the first of the right neighbor

---

... else combine N with a neighbor N’, and
• update the parent

* a deletion from parent may ripple recursively

---

When the root is left with two children a deletion may cause removal of a level
Deletions in Practice

- Oracle 8:
  - mark as deleted, then rebuild index online, or
  - coalesce underfull pages ("borrow from neighbors")
- Informix:
  - mark as deleted
- IBM DB2, MS SQL Server, Sybase:
  - delete and merge pages if below minimum
  - (Sybase alternative: mark as deleted and garbage-collect)

B-Tree Summary

- B-trees automatically maintain as many index levels as appropriate (no overflow blocks necessary!)
- a node (block/page) holds up to \( n \) keys and \( n+1 \) pointers
- nodes are maintained to be between half-full and full
- range queries are supported (as for indexed sequential files)

B-Tree Indexes in Practice

- The SQL standard does not talk about indexes!
- But every real DBMS allows statements like
  
  ```sql
  CREATE INDEX IndexName ON Students
  WITH STRUCTURE = BTREE,
  KEY = (dept, dpn)
  
  ```
- fan-out should be maximized \( \Rightarrow \) use key compression to ensure that many index entries fit into a node:

  ![Diagram of B-tree index]

  compress "David" as "Davi"? No, since Davey \( \preceq \) "Davi"