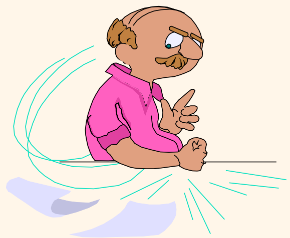
Introduction to Data Management

Lecture 20
(Storage and Indexing, cont.)



Instructor: Mike Carey
mjcarey@ics.uci.edu

It's time again for....

Friday Nights with Databases...!

Brought to you by...

Announcements

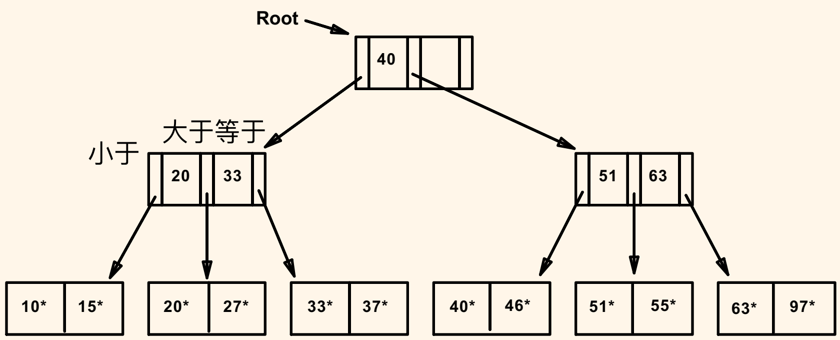
- Midterm #2 is **Wednesday (5/22) at 5 PM**
  - Relational languages (see syllabus!)
  - Sample exam from last year is available
  - Assigned seating, similar to last time
- HW #6 is due on **Monday at 7 PM**
  - One late "day" (*22 hours*) will be available
  - Solution coming Tuesday right after **5 PM** (*really*)
- Today's lecture plan
  - More about database indexes
  - (Not on Midterm #2, of course)

***Tree**-Structured Indexes: Over(re)view*

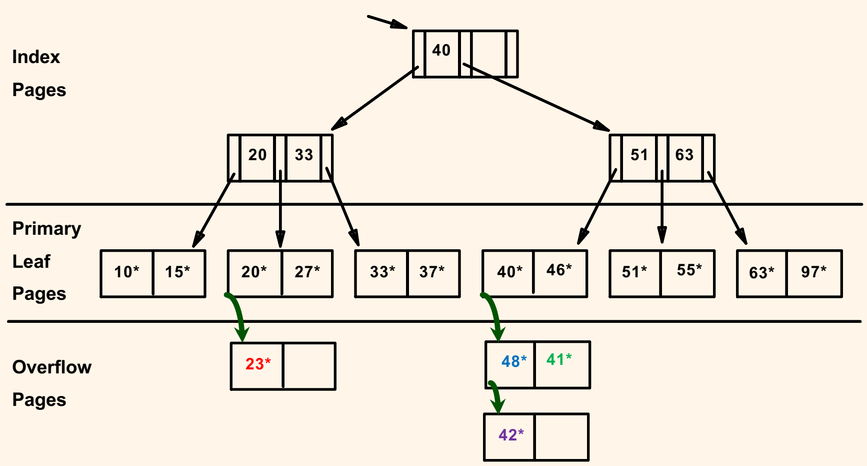
- *As for any index, 3 alternatives for data entries (**k***):*
  - Record with key **k**
  - <**k**, rid of record with key **k**>
  - <**k**, list of rids of records with key **k**>
- This data entry choice is orthogonal (⊥) to the *indexing technique* used to locate the data entries.
- Tree-structured indexing techniques can support both ***range searches*** and ***equality searches***.
- *ISAM*: static structure; *B+ tree*: dynamic, adjusts gracefully under inserts and deletes.

Example ISAM Tree

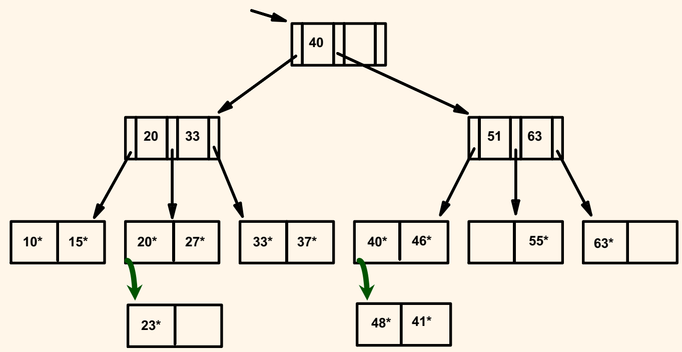
- Suppose each node can hold 2 entries (really more like 200, since nodes are disk pages!)



After Inserting 23, 48*, 41*, 42* ...*



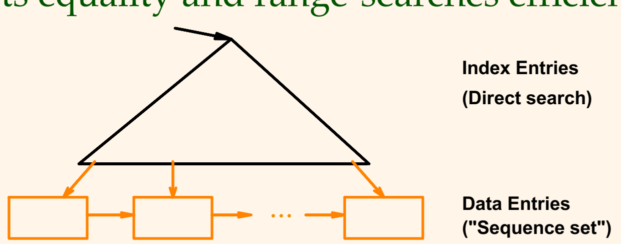
... Then Deleting 42*, 51*, 97*



☛ *Note that 51* still appears in index levels, but **not** in leaf!*

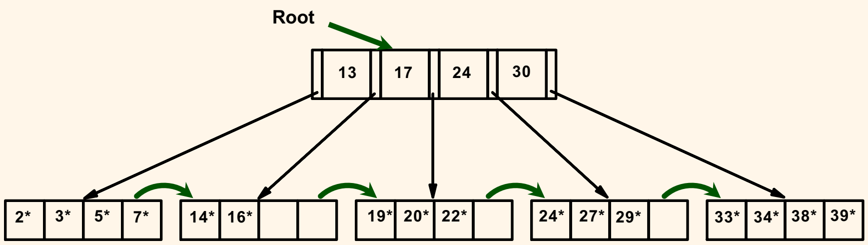
B+ Tree: Most Widely Used Index!

- 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 (mythical) **d** is called the *order* of the B+ tree.
- Supports equality and range-searches efficiently.



Example B+ Tree

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



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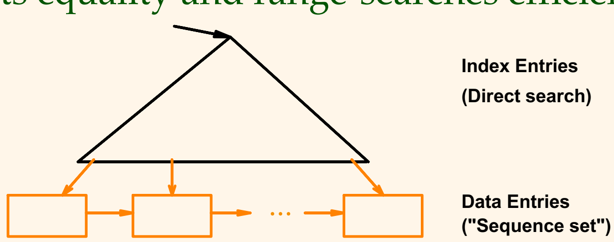

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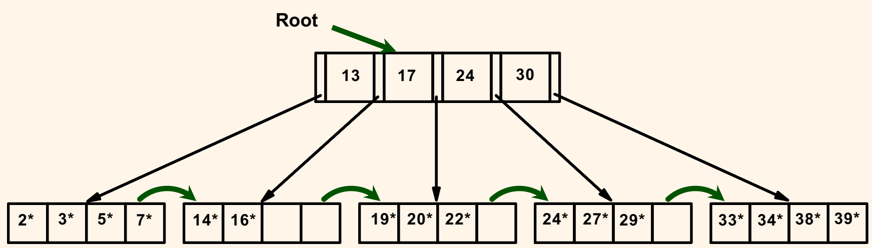

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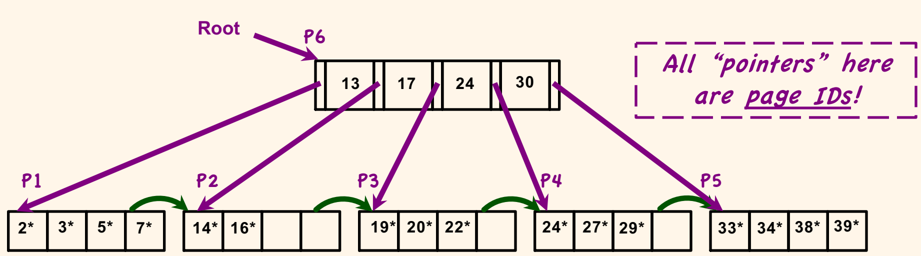
Example B+ Tree (a **clarification**)

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



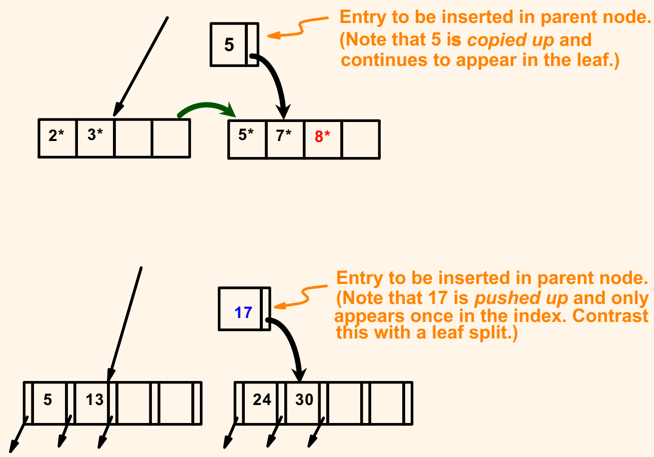
☛ *Based on the search for 15*, we <u>know</u> it is not in the tree!*

Inserting a Data Entry into a B+ Tree

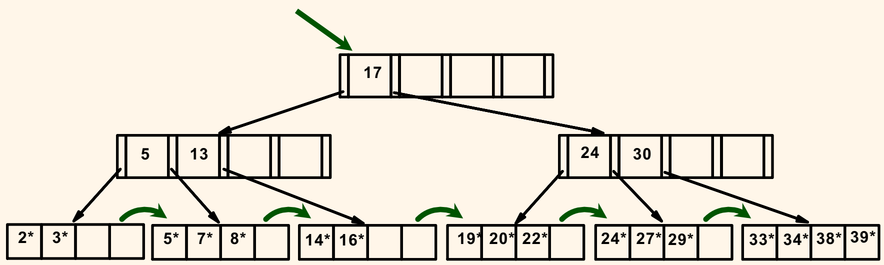
- Find correct leaf *L* (by ***searching*** for the new k).
- Put new data entry (k*, *a.k.a.* (k, I(k)) in leaf *L*.
  - If *L* has enough space, *done*! (Most likely case!)
  - Else, must *split* *L (into L and a new node L2)*
    - Redistribute entries evenly and **copy up** middle key.
    - Insert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

Inserting 8 into Example 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!



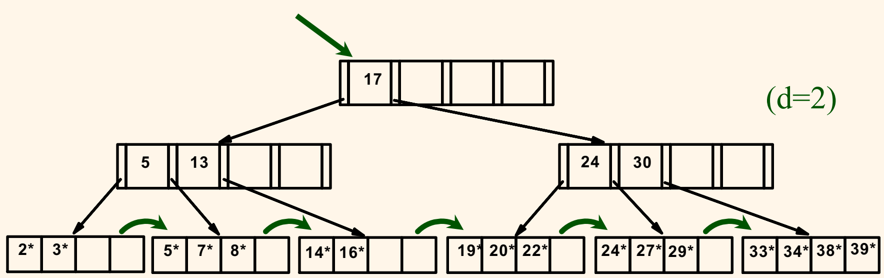
*Example B+ Tree **After** Inserting 8**



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

❖ In this example, could avoid split by redistributing entries; however, not usually done in practice. (Q: Why is that?)

Let's Go Live…! (Demo Time!)



(d=2)

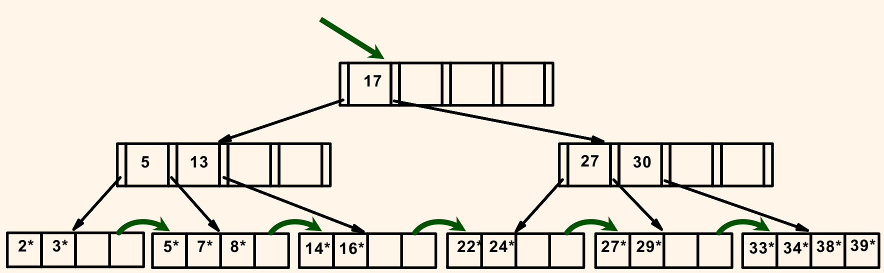
Note *(see Piazza)*: Very cool online B+ tree viz tool available (☺)

- https://www.cs.usfca.edu/~galles/visualization/BPlusTree.html
- Only slight differences from our defs (e.g., key 13 above → 14)
- Their "*Max. Degree*" is our 2d+1 (limit of 5 ptrs/node above)

Deleting a Data Entry from a B+ Tree

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

Example Tree After (Inserting 8, Then) Deleting 19* and 20* ...*



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

... *And Then Deleting 24**

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