

B-Trees

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Generalizes multilevel index.

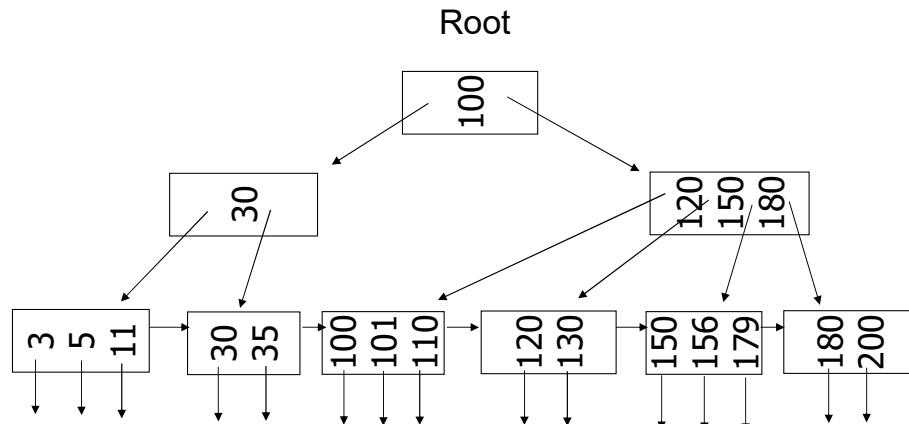
Number of levels varies with size of data file, but is often 3.

Different variants, we start with B+-trees.

Useful for primary, secondary indexes, primary keys, nonkeys.

Each node in the tree represents a block.

B+Tree Example



Nodes of B+ Tree

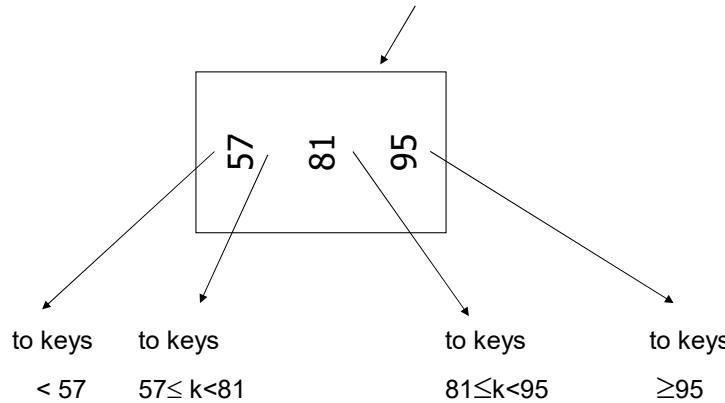
Leaves

- One pointer to next leaf.
- keypointer pairs for records of data file.
- At least half of these (round up) occupied.

Interior Nodes

- k keys form the divisions among $k+1$ subtrees.
- Key i is least key reachable from $(i + 1)$ st child.

Sample non-leaf



Don't want nodes to be too empty

Trees have an order that determines the maximal number of keys in a node

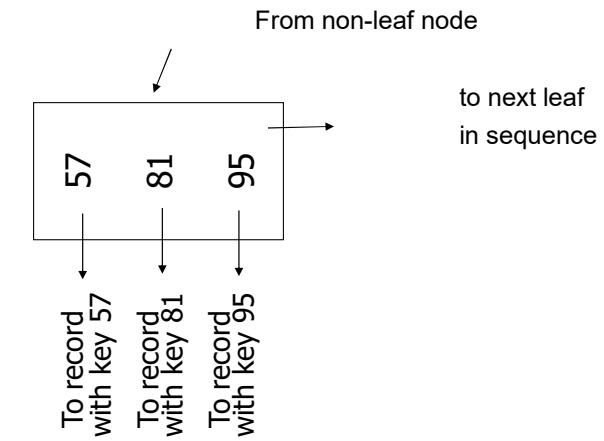
Use in a tree of order n at least

Non-leaf: $\lceil (n+1)/2 \rceil$ pointers to children

Leaf: $\lfloor (n+1)/2 \rfloor$ pointers to records

Root is a special Case

Sample Leaf Node



$n=3$

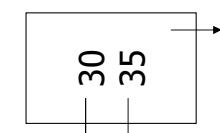
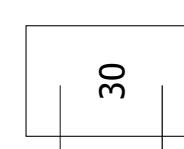
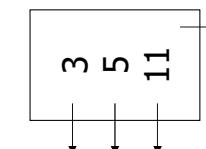
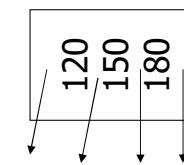
node

Non-leaf

Leaf

Full node

min.



B+ Tree rules (Tree of order n)

- (1) All leaves at same lowest level
(balanced tree)
- (2) Pointers in leaves point to records
except for “sequence pointer”
- (3) Number of pointers/keys for B+ tree (except for sequence pointers)

	Max ptrs	Max keys	Min ptrs \rightarrow data	Min keys
Non-leaf (non-root)	$n+1$	n	$\lceil (n+1)/2 \rceil$	$\lceil (n+1)/2 \rceil - 1$
Leaf (non-root)	n	n	$\lfloor (n+1)/2 \rfloor$	$\lfloor (n+1)/2 \rfloor$
Root	$n+1$	n	1 (if leaf)	1

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Lookup

Lookup in B+ Tree

- Start at root.
- Until you reach a leaf, follow the pointer that could lead to the key you want.
- Search that leaf (and leaves to the right if duplicates are possible).

B+ Tree Insertion

Search for the key being inserted.

If there is room for another key-pointer pair at that leaf,
insert there.

If no room, split leaf.

- Split of leaf results in insert of key-pointer pair at level above.
 - key is **copied** to level above
- Thus, recursive splitting all the way up the tree is possible.
 - split of non-leaf results in **moving** one key to level above
- Convention: If the number of keys in the two nodes resulting from the split is uneven, put one more key in the left node.
Otherwise: both nodes get the same number of keys