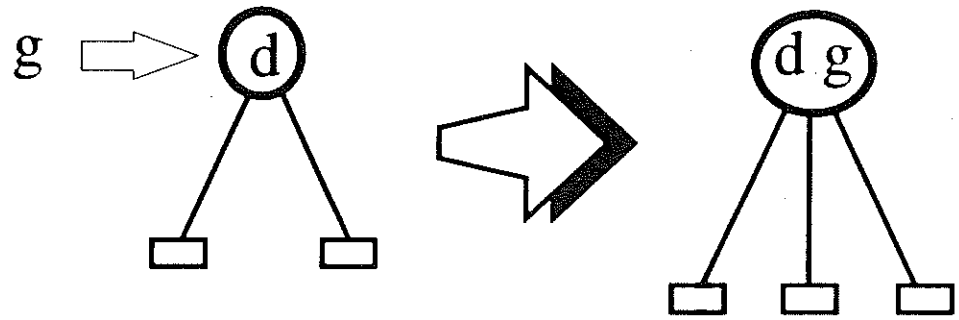
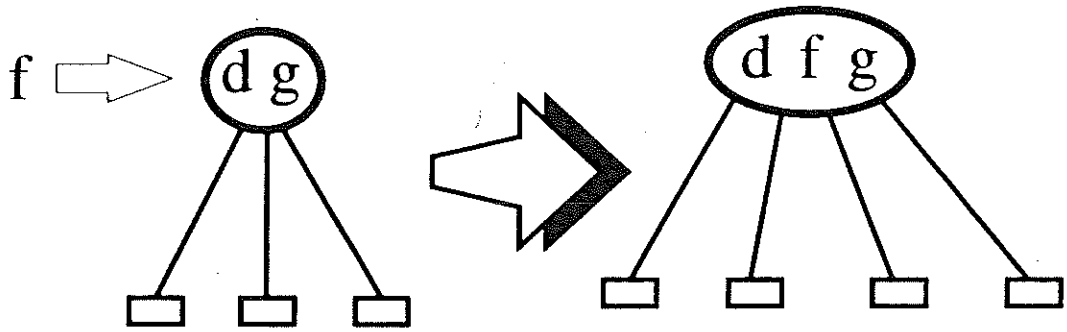
Insertion into (2,4) Trees

- Insert the new key at the lowest internal node reached in the search
  - ***2-node*** becomes ***3-node***



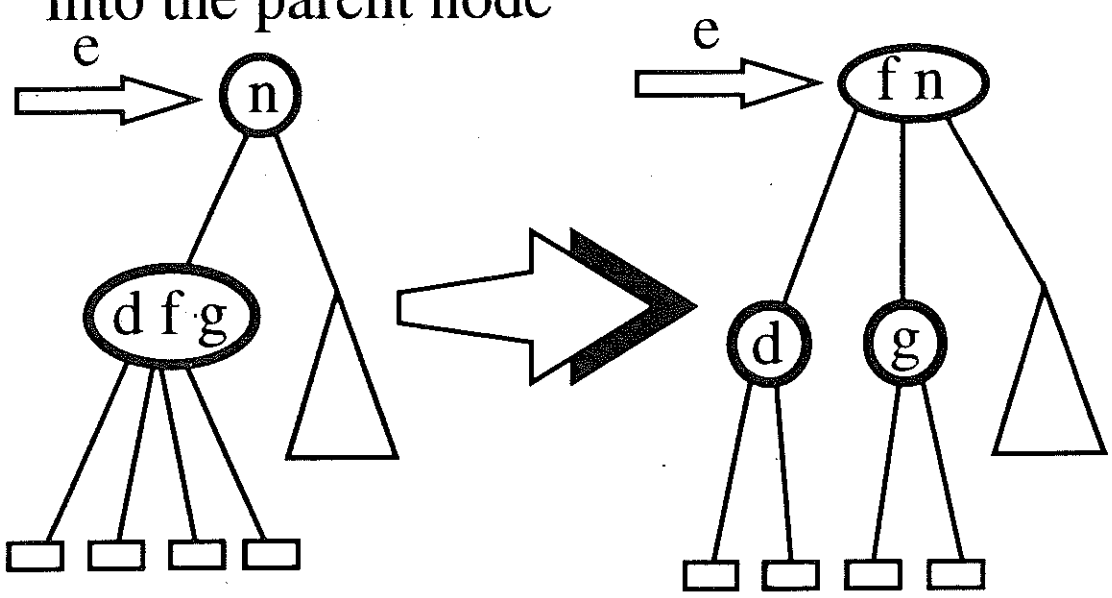
  - ***3-node*** becomes ***4-node***

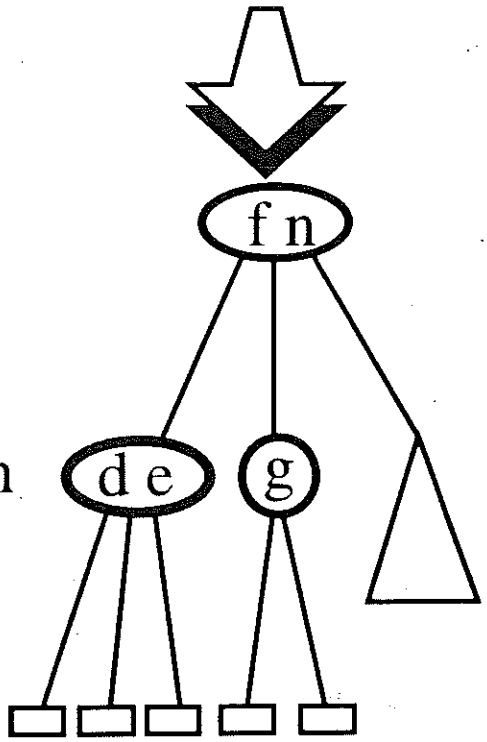


- What about a ***4-node***?
  - We can't insert another key!

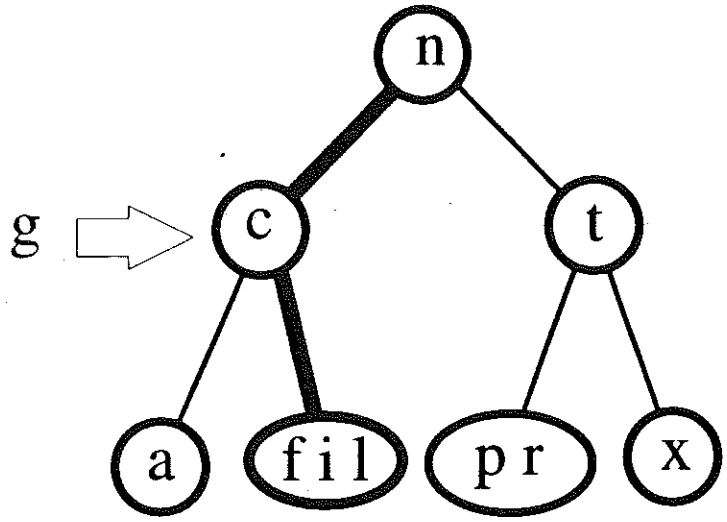
Top Down Insertion

- In our way down the tree, whenever we reach a ***4-node***, we break it up into two ***2-nodes***, and move the middle element up into the parent node

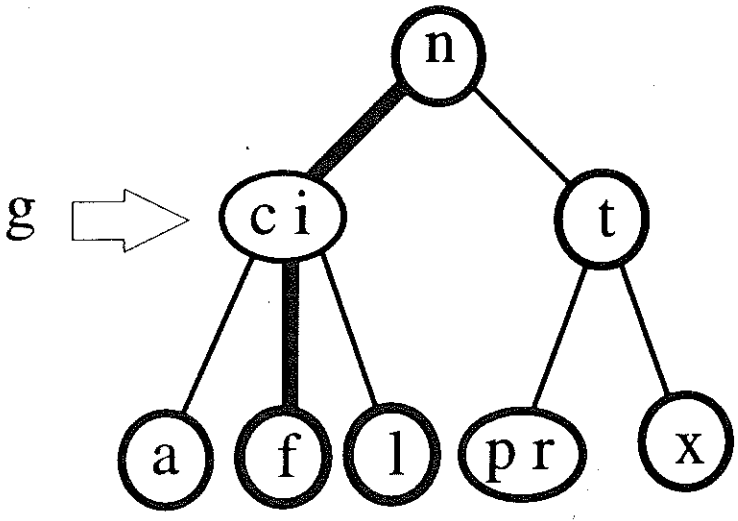


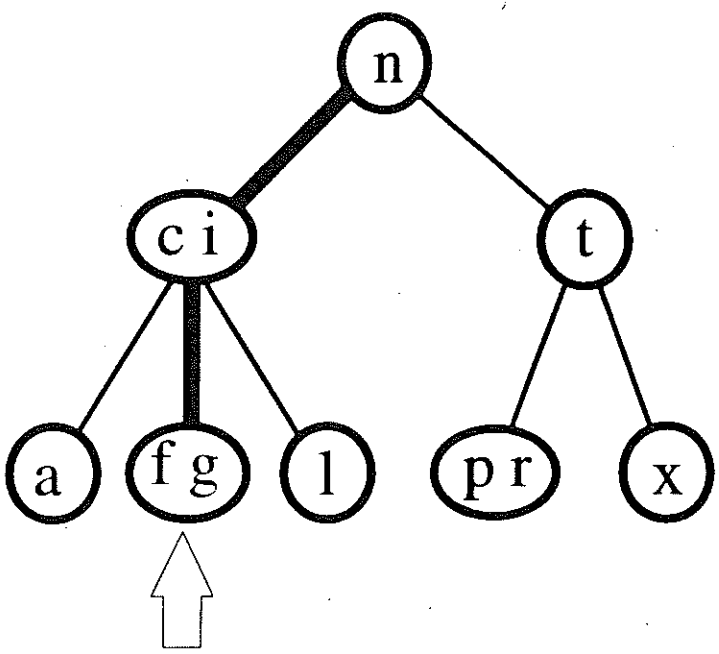


- Now we can perform the insertion using one of the previous two cases
- Since we follow this method from the root down to the leaf, it is called ***top down insertion***

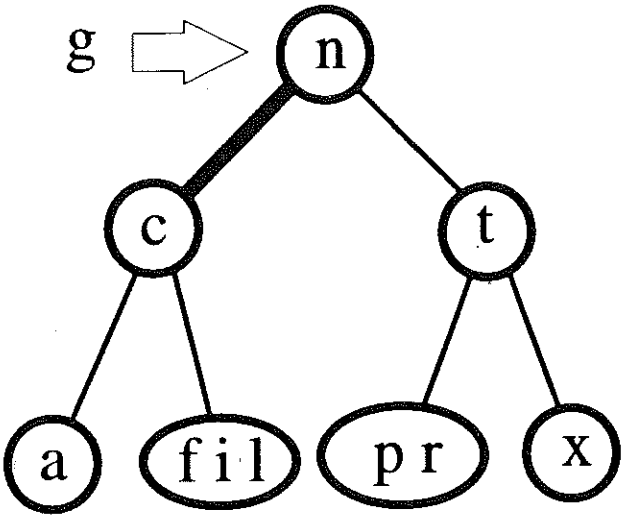


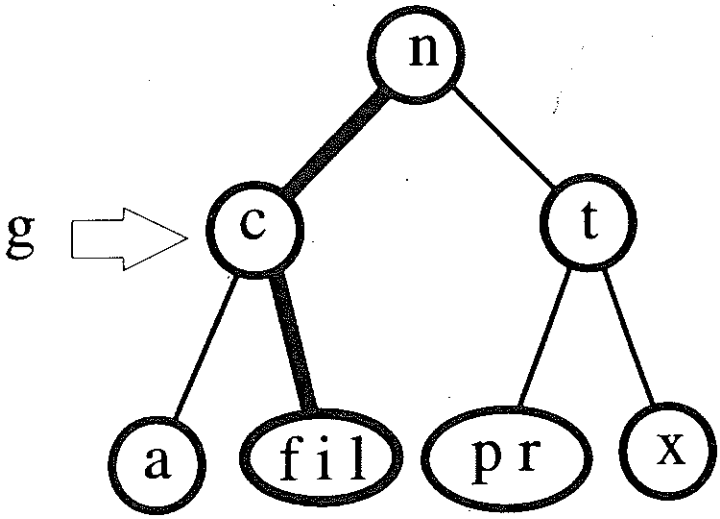
Whoa, cowboy





An Example

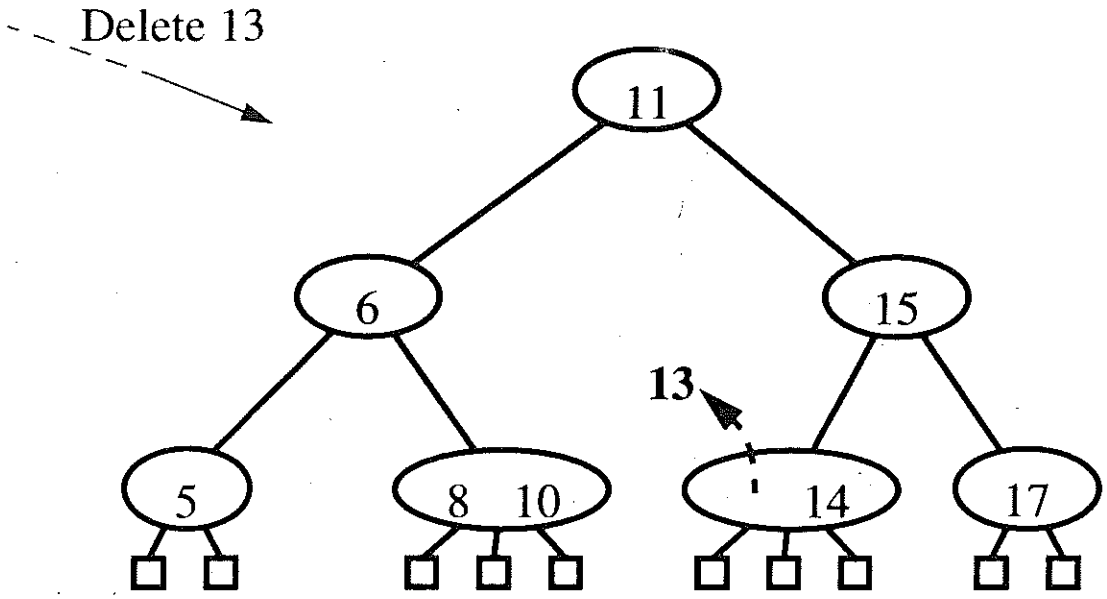




Whoa, cowboy

(2,4) Deletion

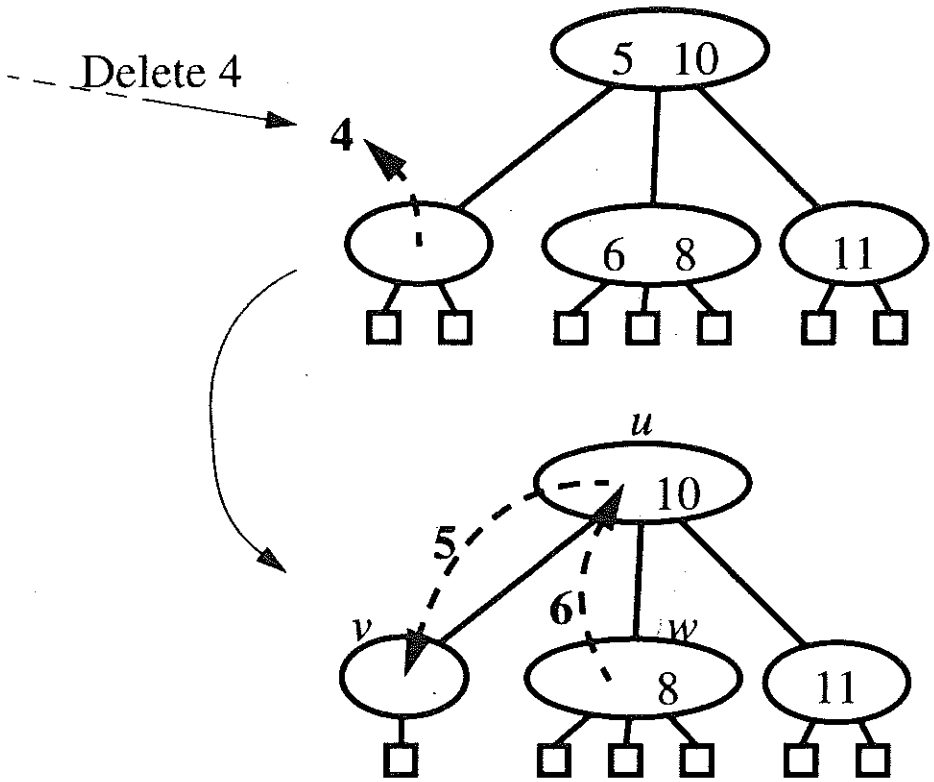
- A little trickier
- First of all, find the key
  - simple multi-way search
- If the item to delete has non-external children
  - reduce to the case where deletable item is at the bottom of the tree:
  - Find item which precedes it in in-order traversal
  - Swap them
- Remove the item



- Easy, right?
- ...but what about removing from 2-nodes?

(2,4) Deletion (cont.)

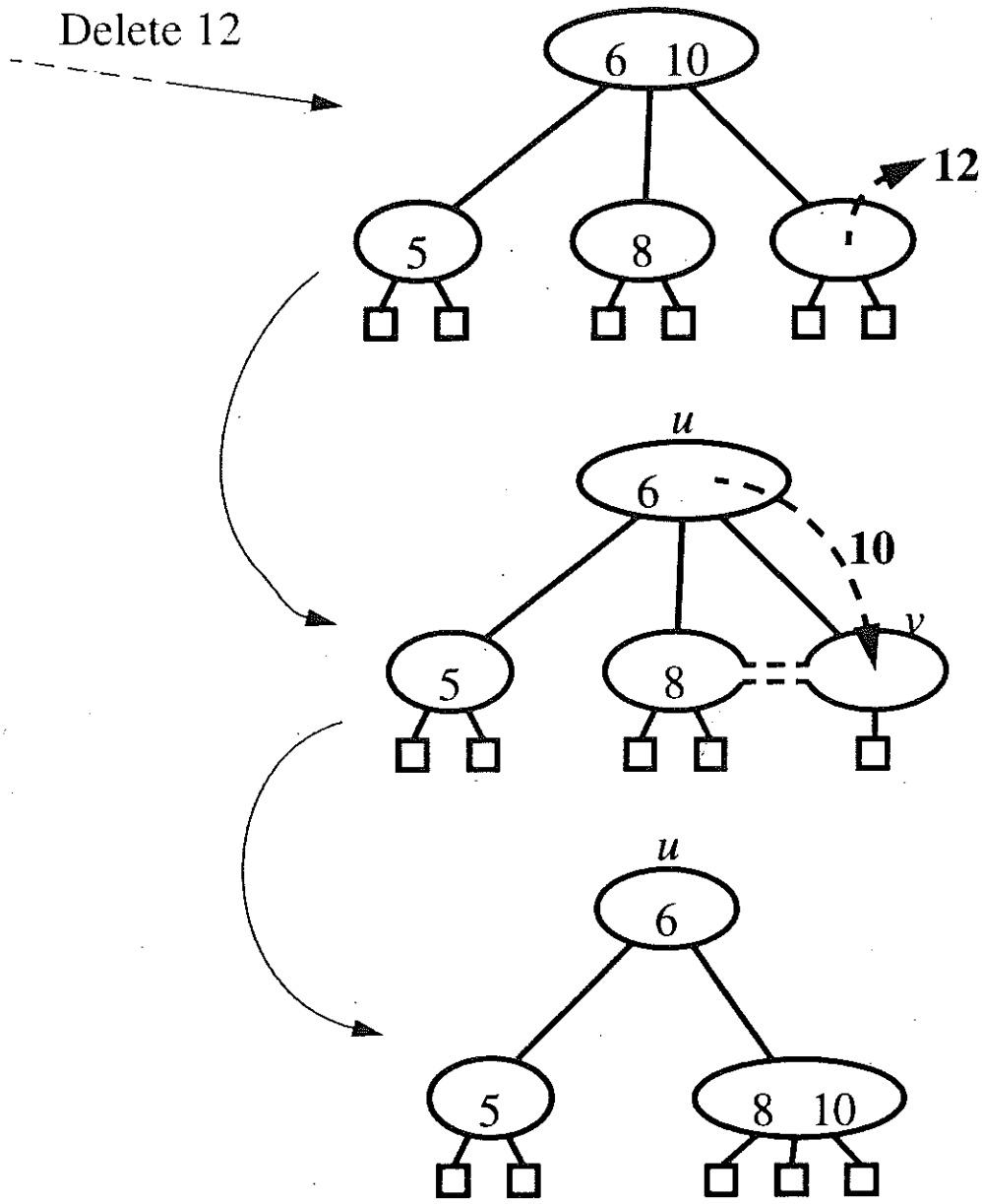
- Not enough items in the node
  - *underflow*
- Pull an item from the parent, replace it with an item from a sibling
  - called *transfer*



- Still not good enough! What happens if siblings are 2-nodes?
- Could we just pull one item from the parent?
  - too many children
- But maybe...

(2,4) Deletion (cont.)

- We know that the node's sibling is just a 2-node
- So we *fuse* them into one
  - after stealing an item from the parent, of course



- Last special case, I promise: what if the parent was a 2-node?

(2,4) Deletion (cont.)

- Underflow can cascade up the tree, too.