

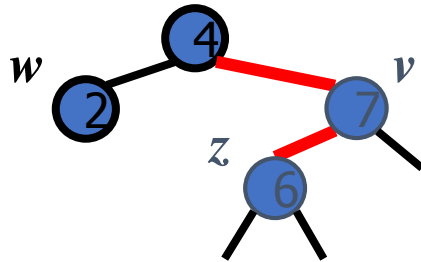
Red-Black Tree Example

Remedying a Double Red

- Consider a double red with child z and parent v , and let w be the sibling of v

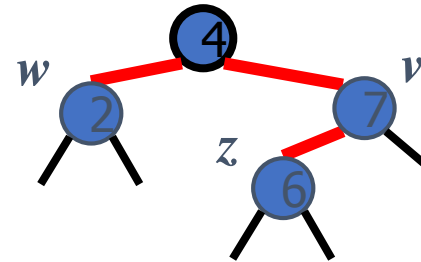
Case 1: *sibling of first red is black*

- The double red is an incorrect replacement of a 4-node
- Restructuring:** we change the 4-node replacement

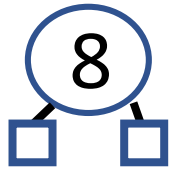


Case 2: *sibling of first red is red*

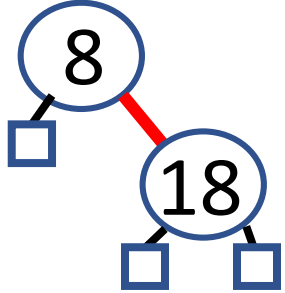
- The double red corresponds to an overflow
- Recoloring:** we perform the equivalent of a **split**



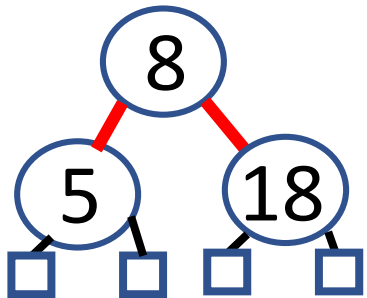
insert 8



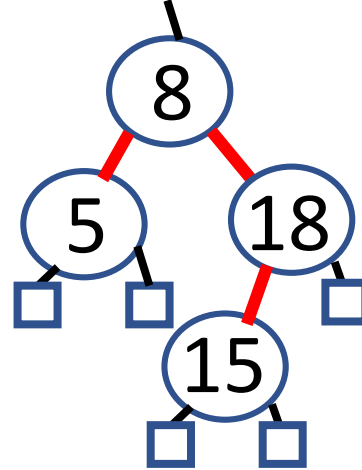
insert 18



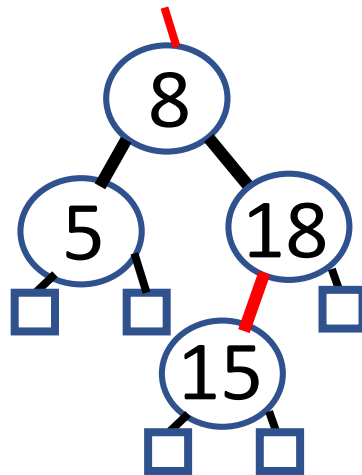
insert 5



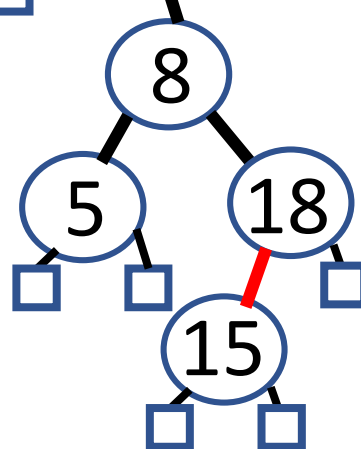
insert 15



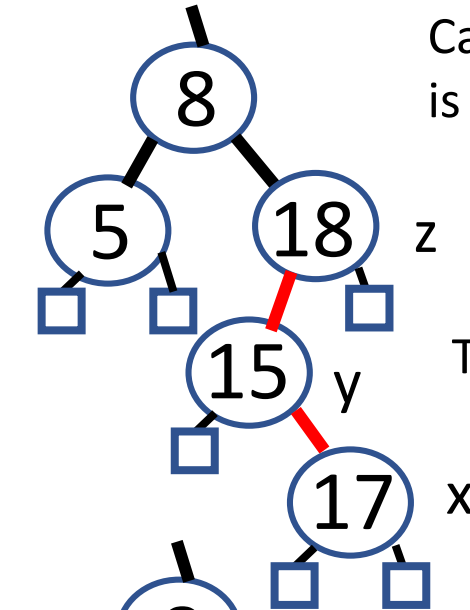
Case 1: Sibling
of first red is
red: Recolor



Recolor



insert 17



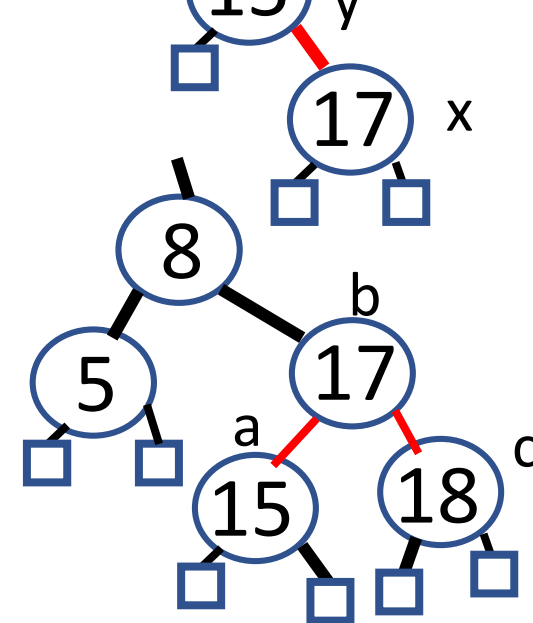
Case 2: Sibling of first red
is black: Rotate.

z – before first red

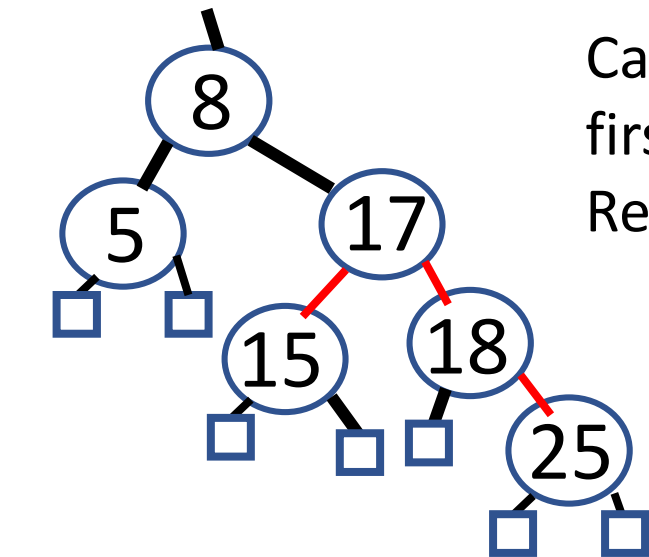
z y – between reds

x – after second red.

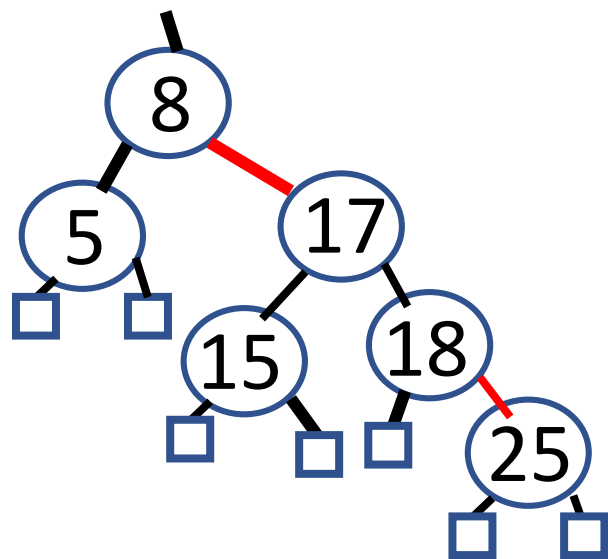
Transform z,y,x to a, b, c



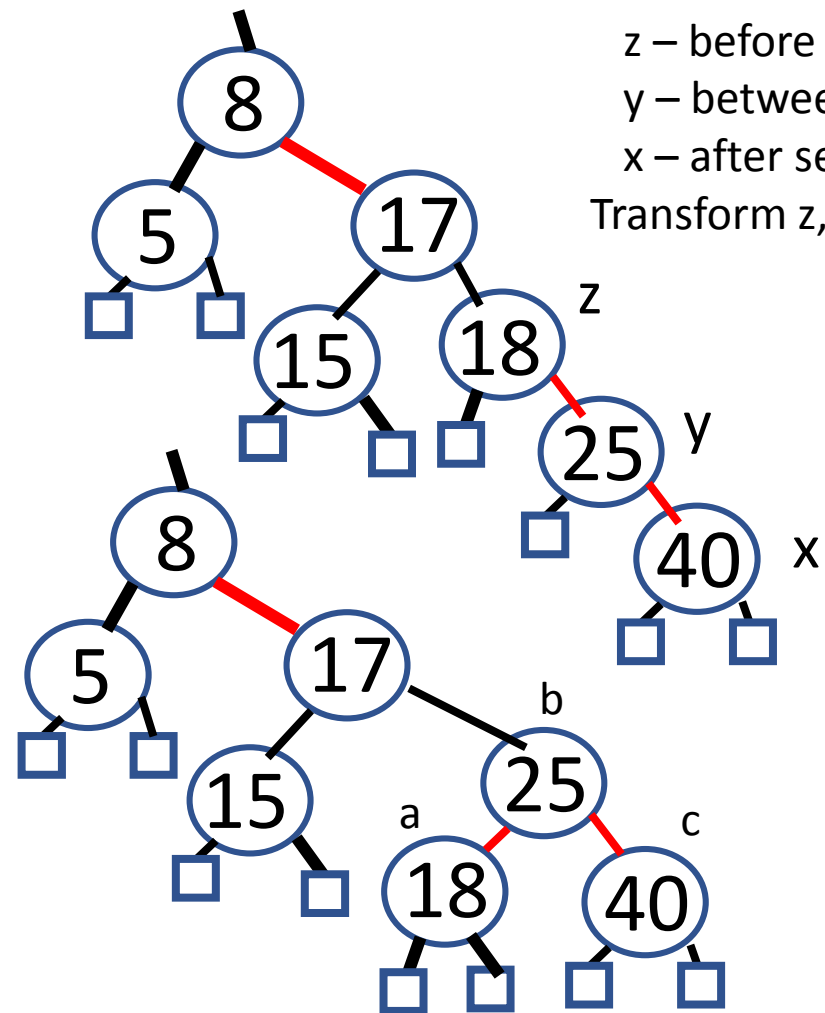
insert 25



Case 1: Sibling of first red is red:
Recolor



insert 40



Case 2: Sibling of first red is black:
Rotate.

z – before first red

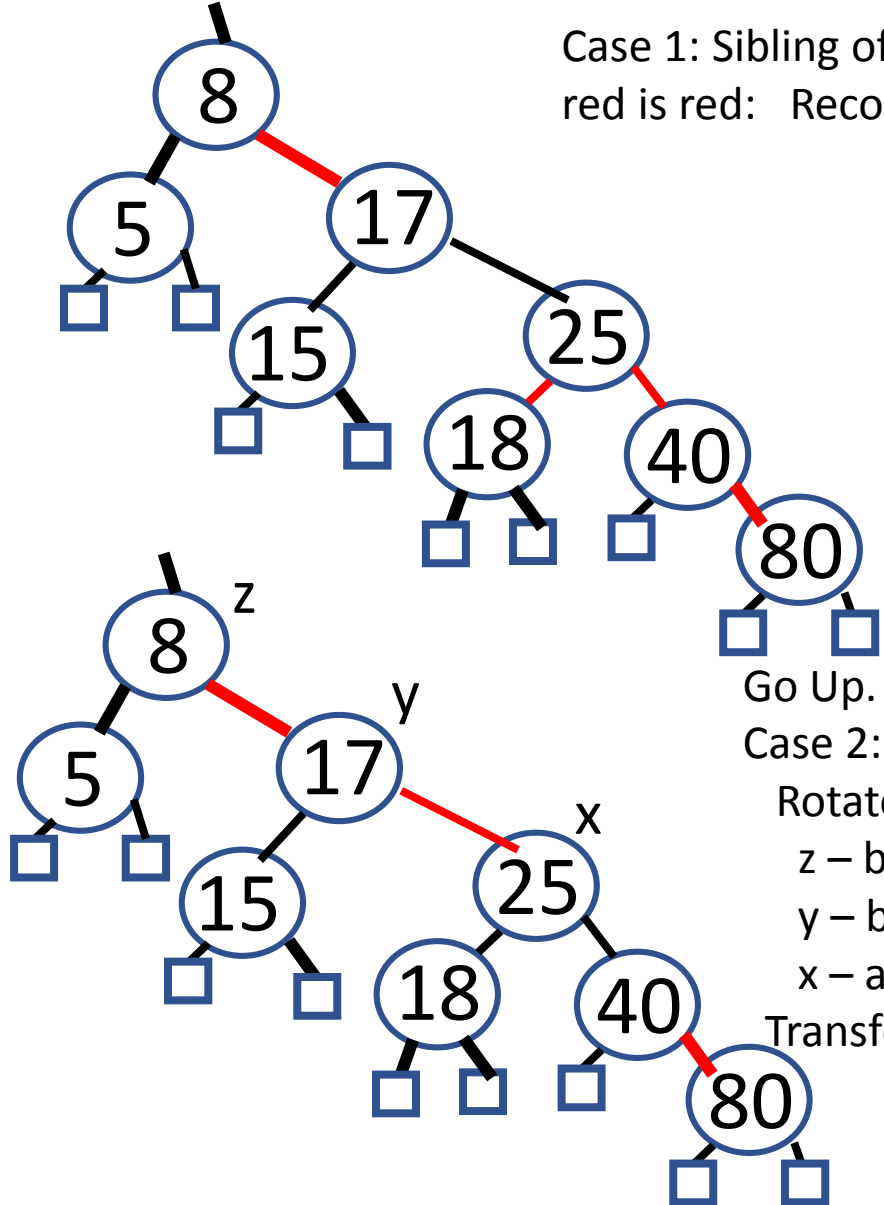
y – between reds

x – after second red.

Transform z,y,x to a, b, c

insert 80

Case 1: Sibling of first red is red: Recolor



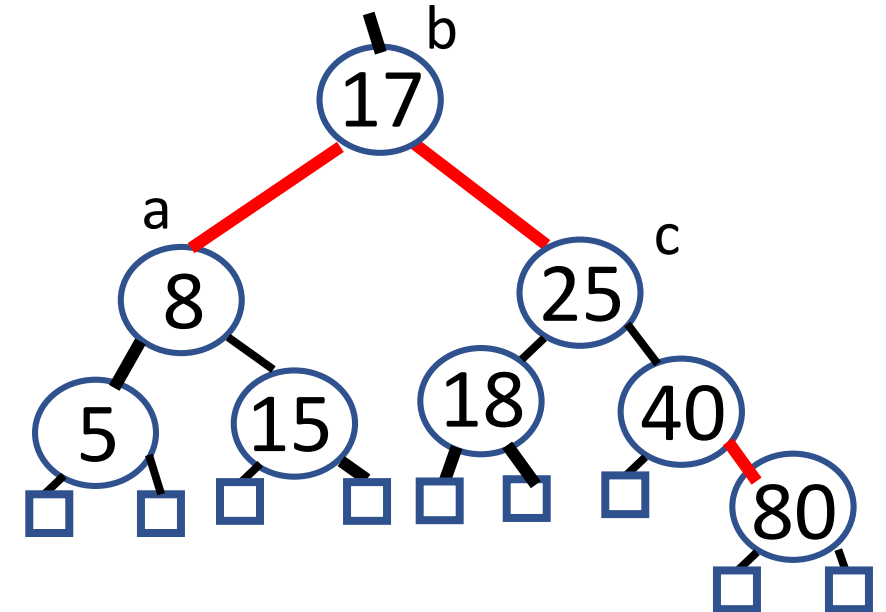
Case 2: Sibling of first red is black
Rotate.

z – before first red

y – between reds

x – after second red.

Transform z,y,x to a, b, c



Remedying a Double Black

- The algorithm for remedying a double black node w with sibling y considers three cases

Case 1: y is black and has a red child

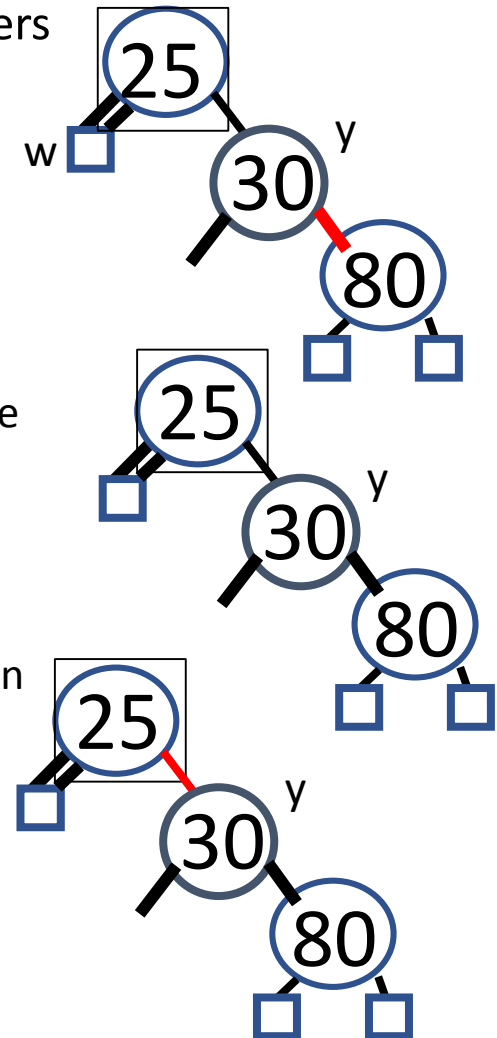
- We perform a **restructuring**, equivalent to a **transfer**, and we are done

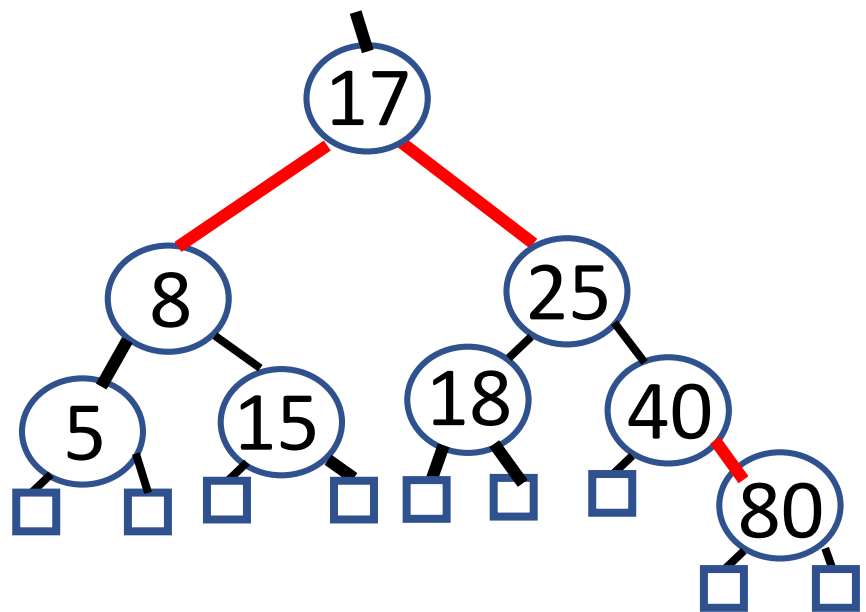
Case 2: y is black and its children are both black

- We perform a **recoloring**, equivalent to a **fusion**, which may propagate up the double black violation

Case 3: y is red

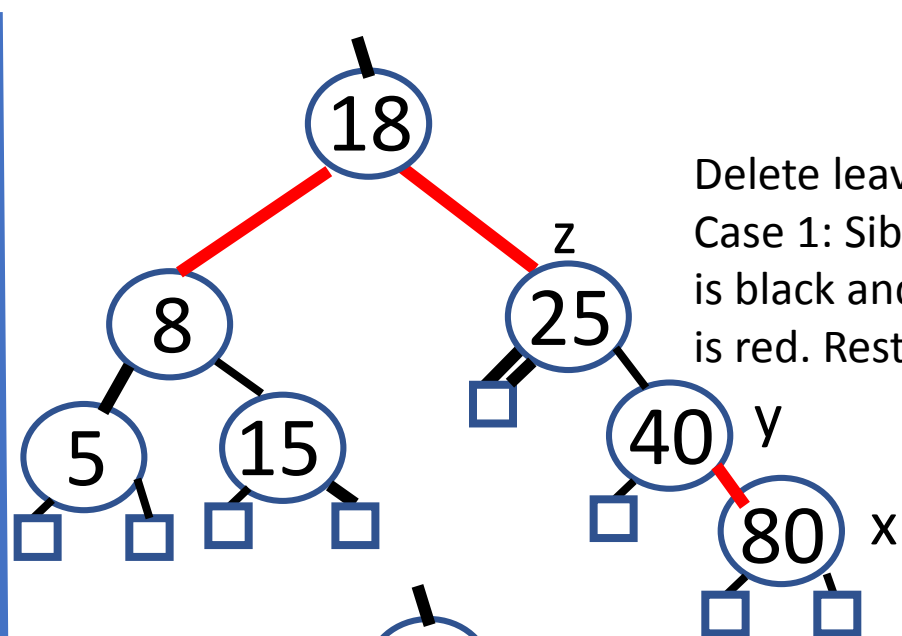
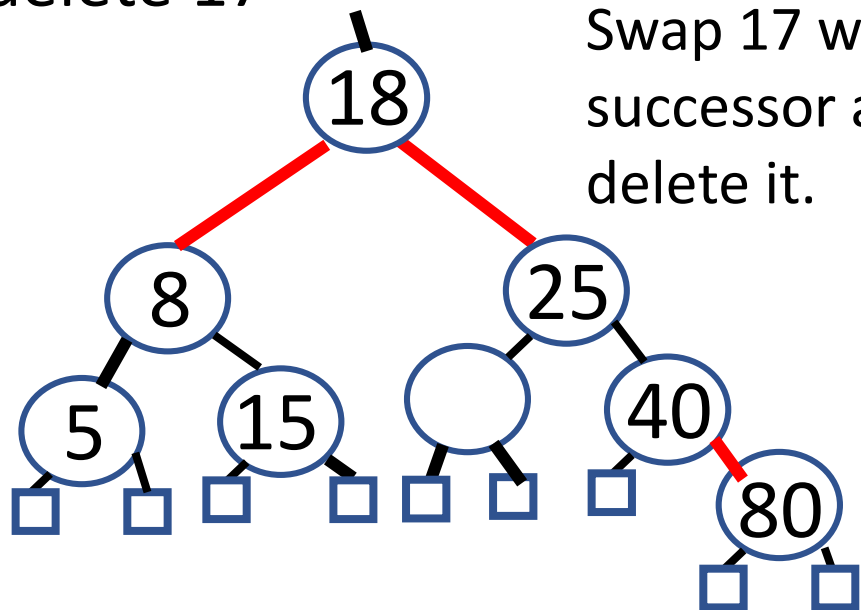
- We perform an **adjustment**, equivalent to choosing a different representation of a 3-node, after which either Case 1 or Case 2 applies
- Deletion in a red-black tree takes $O(\log n)$ time



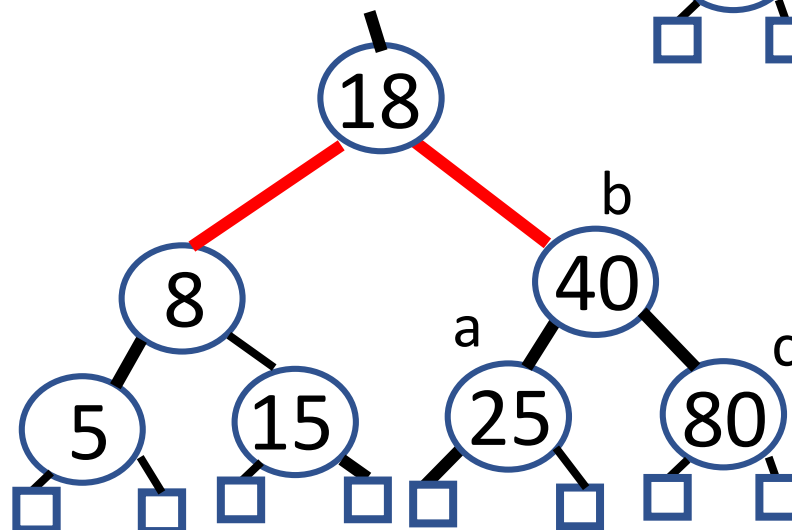


delete 17

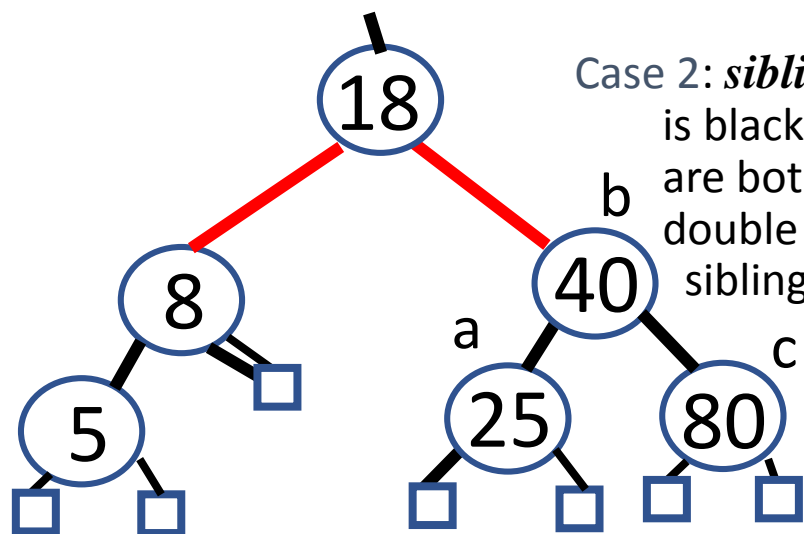
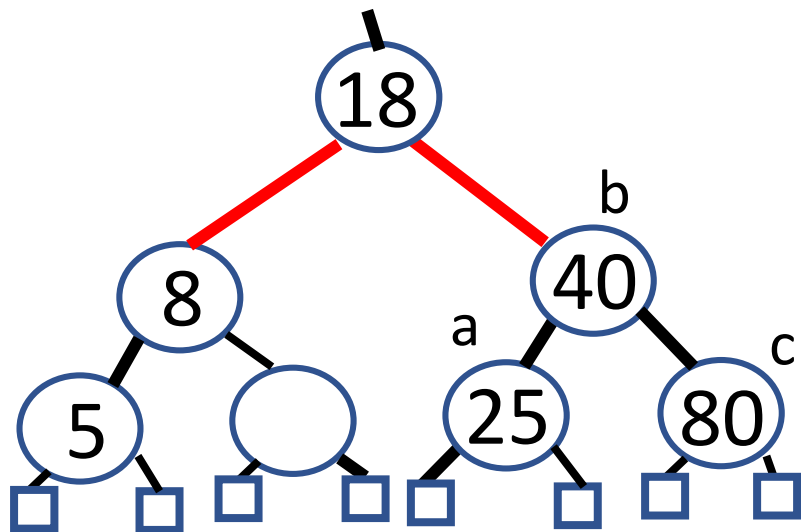
Swap 17 with
successor and
delete it.



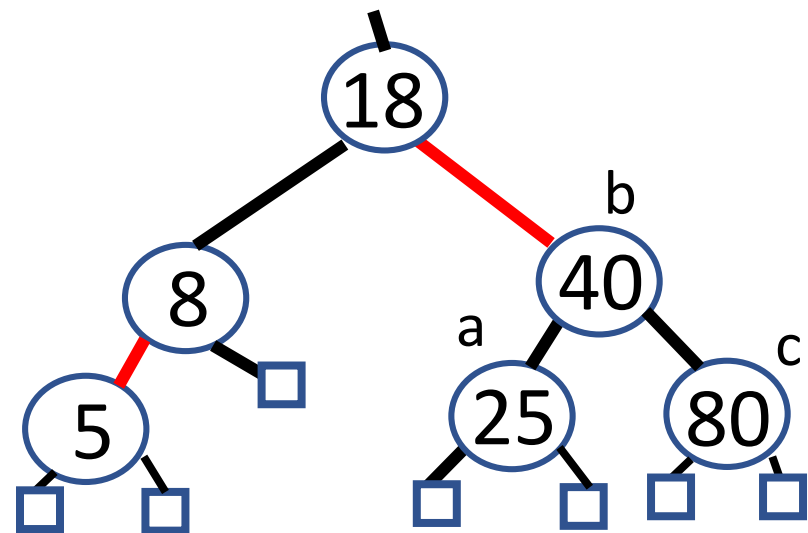
Delete leaves a double black
Case 1: Sibling of double black
is black and at least one child
is red. Restructure.



delete 15



Case 2: *sibling of double black*
is black and its children
are both black: Recolor.
double black turns into single and
sibling turns to red. parent turns to
black. Propagate double
black if necessary.



delete 5

