(4) Insert procedure:

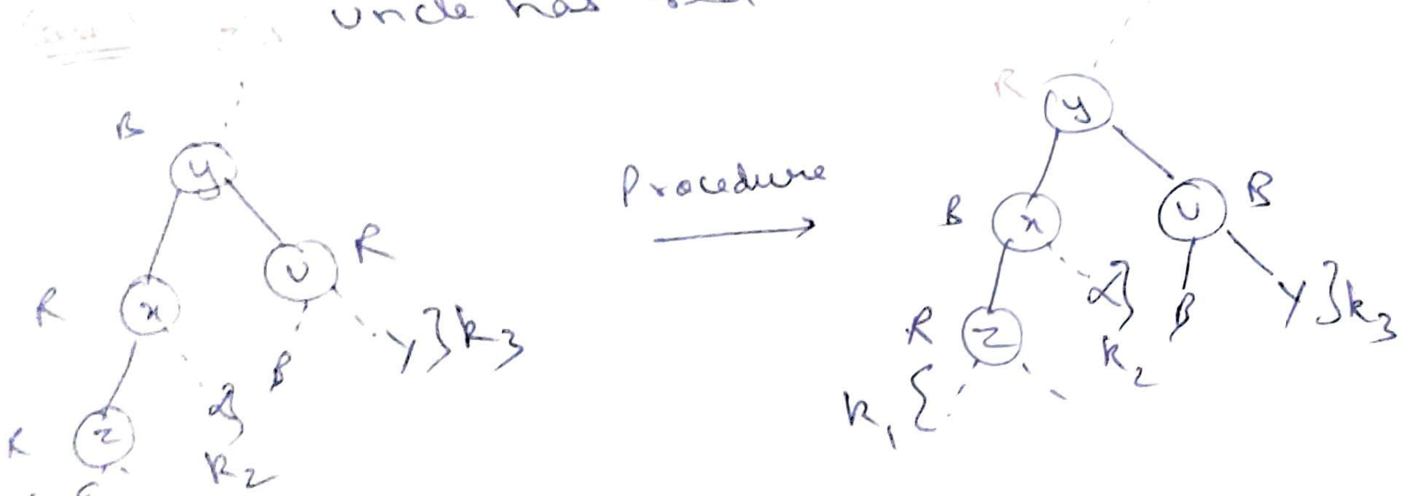
Insert (T, z)

Insert1 (T, z)

No change in these procedures is required as the inserted node is red which does not affect the black height of Tree (i.e. T.bh)

Ifixup (T, z) // we will look at various cases.

Case 1 → uncle has red colour



~~After~~

~~Before~~

Property → ~~No. of black nodes from y to any descendant leaf is~~ ~~(...)~~

~~after →~~

~~Before →~~

If y is root → Case 1 (a)

(referring to figure on previous page)

Before

Black nodes $y - z \cdots = 1 + k_1$

$y - \alpha \cdots = 1 + k_2$

$y - \beta \cdots = 1 + k_3$

After →

$y \cdots \alpha = 1 + k_2$

$y - z \cdots = 1 + k_1$

$y - \beta \cdots = 1 + k_3$

But to preserve property 2, the colour of y is made black. so T.bh increases by 1.

Conclusion:

We only need to change the code in RBfixUP(T,x) in Case 1

if y ~~becomes~~ is the root.

① if (u.col == red) → uncle is red

if(y == T.root) → y is root

y.col = black

T.bh = T.bh + 1

elif

}

Conclusion

We only need to change the code in Case 1 if y is the root.

① if (v.col == red)

```
    if (y == T.root)                root
        y.col = black
                          bh + 1

    elif
```

Delete procedure

z → node being deleted

y → node which was at the position in T, which got deleted

x → is the node that comes in place of y after deletion

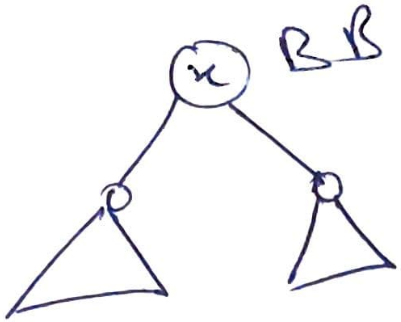
<u>Case</u> → When y is red (then R-B properties are still satisfied and T.bh does not change as a red node is removed from the position in T.

Delete (T, z)

→ No change is required in Delete(T, z) as ~~its~~ a ~~~~ if the black height of the tree changes we will get to know it while restoring the R.B properties as for the time being we have conserved the property 5, by denoting colour of x to Red-Black or Black-Black to maintain property 5 in case y was coloured black.

D fixUp(T, z)

Case-1 (b) when $x == T.root$ and x is $\begin{bmatrix} \text{black} \\ \text{black} \end{bmatrix}$

→ 

As x is root we drop off a Black from x hence the black height of Tree decreases by 1.

[T.bh = T.bh−1]

Psuedo code

→ Splited the Code given in lecture notes.

```
1) fix Up(T, x).
   If(x.coll == red)
       x.col = black
       return

   If (x.col == black) and (x == T.root)
       T.bh = T.bh - 1
       return

   .
   .
   .

}
```

Time complexity

We have just added O(1) operation [T.bh = T.bh - 1] if x.col == black and x == T.root which does not change the complexity.