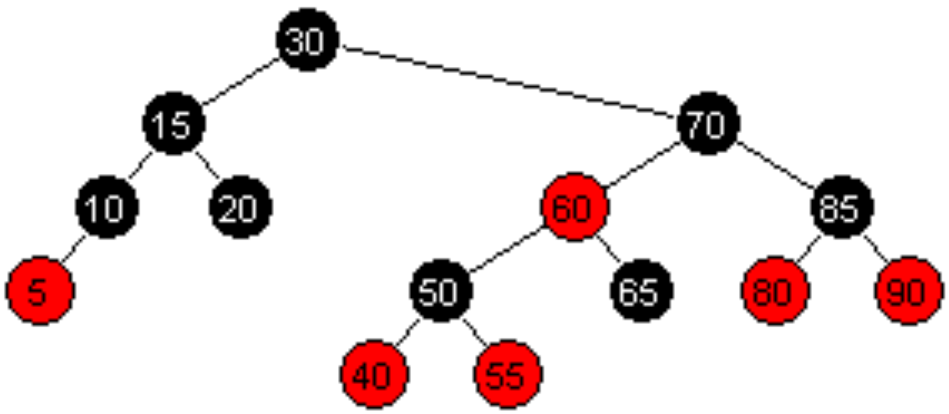


CSSE 230

Red-black trees

After today, you should be able to…
…determine if a tree is a valid red/black tree
…perform top-down insertion in a red/black tree

Do Midterm feedback survey on Moodle

Questions about

- The course: $+$ Δ
- Your study habits: $+$ Δ
- 5 minutes, please do now

EditorTrees Milestone 1 due tonight

- If submitted early, all will earn a late day.
- If submitted late, everyone is charged a late day.
  - Does everyone on my team have a late day?
  - See link from Moodle
- Tomorrow's class will be project work time
  - Don't let your team down! Be here and be on time.

Feedback to help as you move on…

- Milestone 1 is graded on unit tests only.

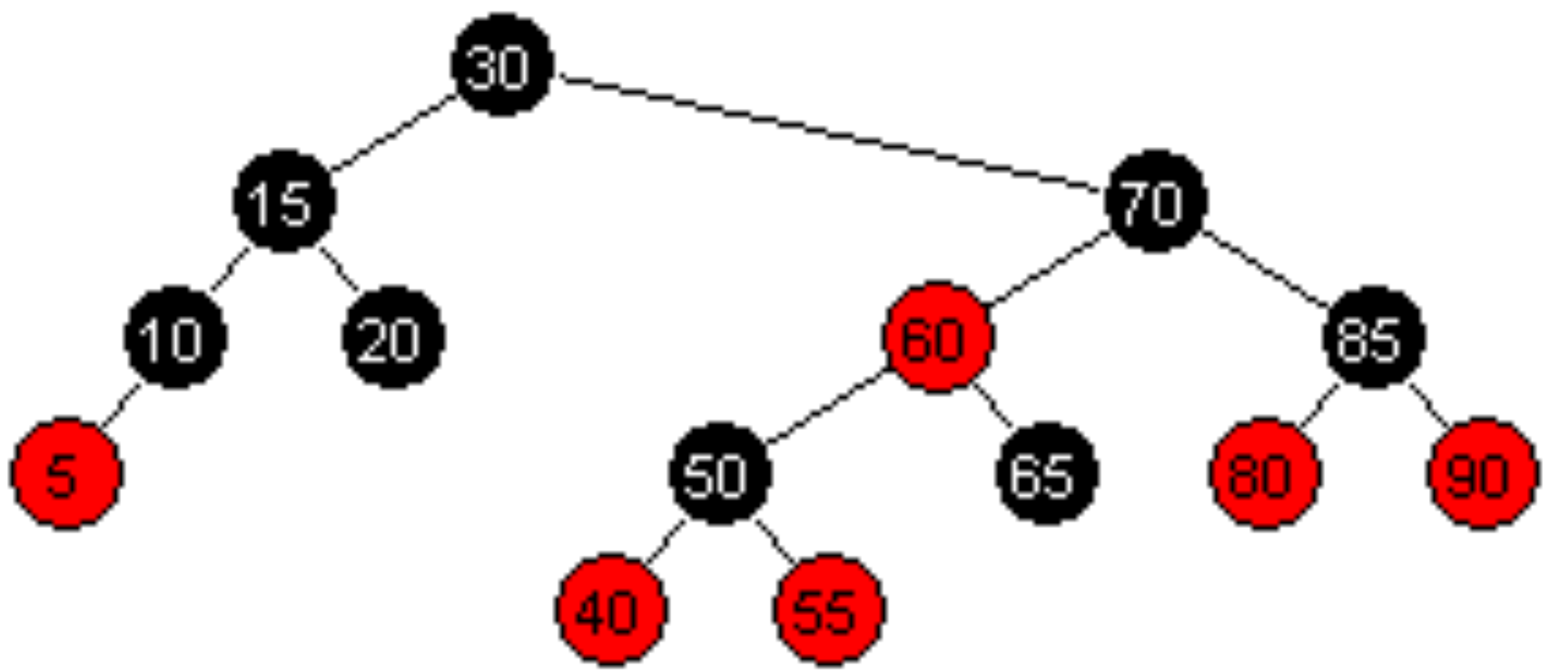
- But…be sure to fix efficiency issues for the future
  - See final notes in specification
  - Cannot recalculate size or height to update balance codes or handle rotations.
  - You can recalculate **rank and balance codes**: these are O(1) computations per node.
    - Suggestion: update rank (++) on the way down the tree.
    - Update balance codes and do rotations (which change rank and balance codes) on the way back up.
    - So each is O(log n) total
    - Know when you can stop! (day 14 slides have the algorithm for insertion, you'll have to think about deletion)

Red-Black Trees

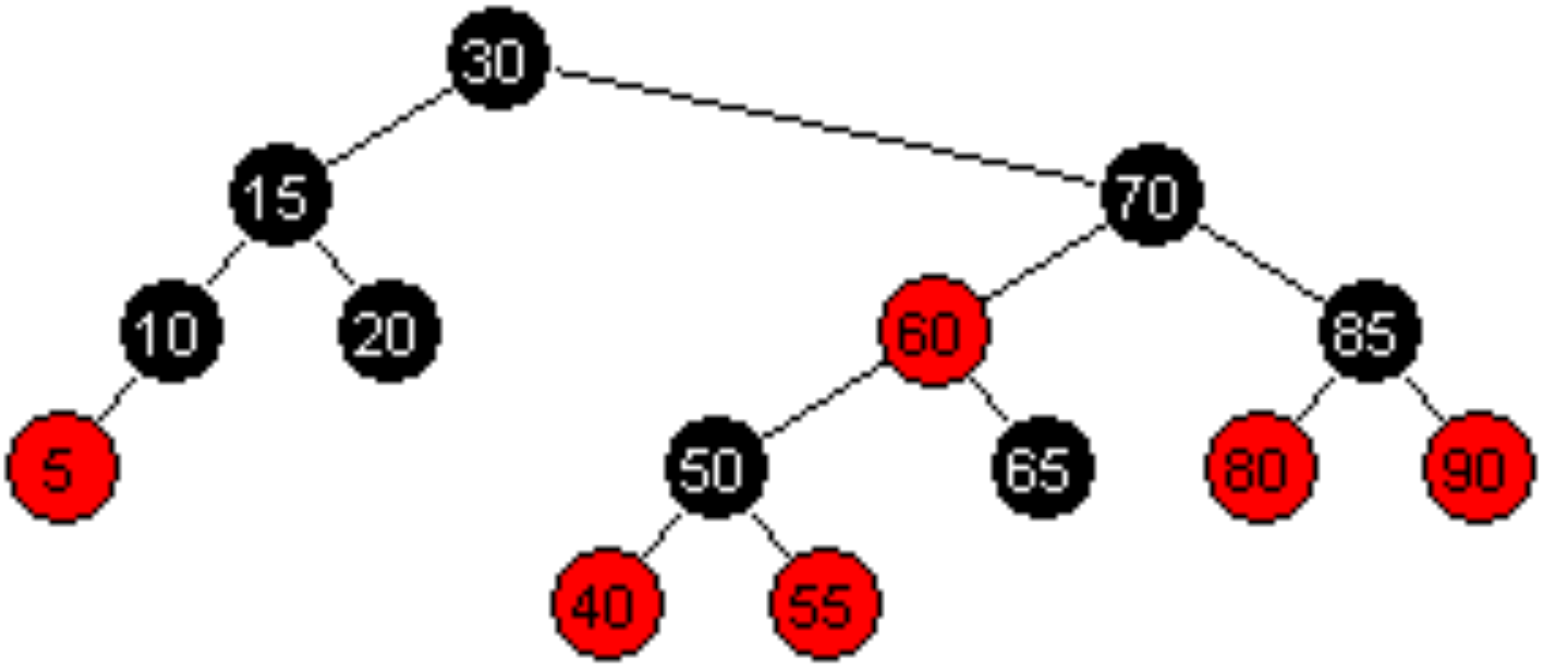
Another type of self-balancing search tree
with O(log N) performance

A red-black tree is a binary tree with 5 properties: 1

1. It is a BST
2. Every node is either colored red or black.
3. The root is black.
4. No two successive nodes are red.
5. **Every path from the root to a null node** has the same number of black nodes ("perfect black balance")



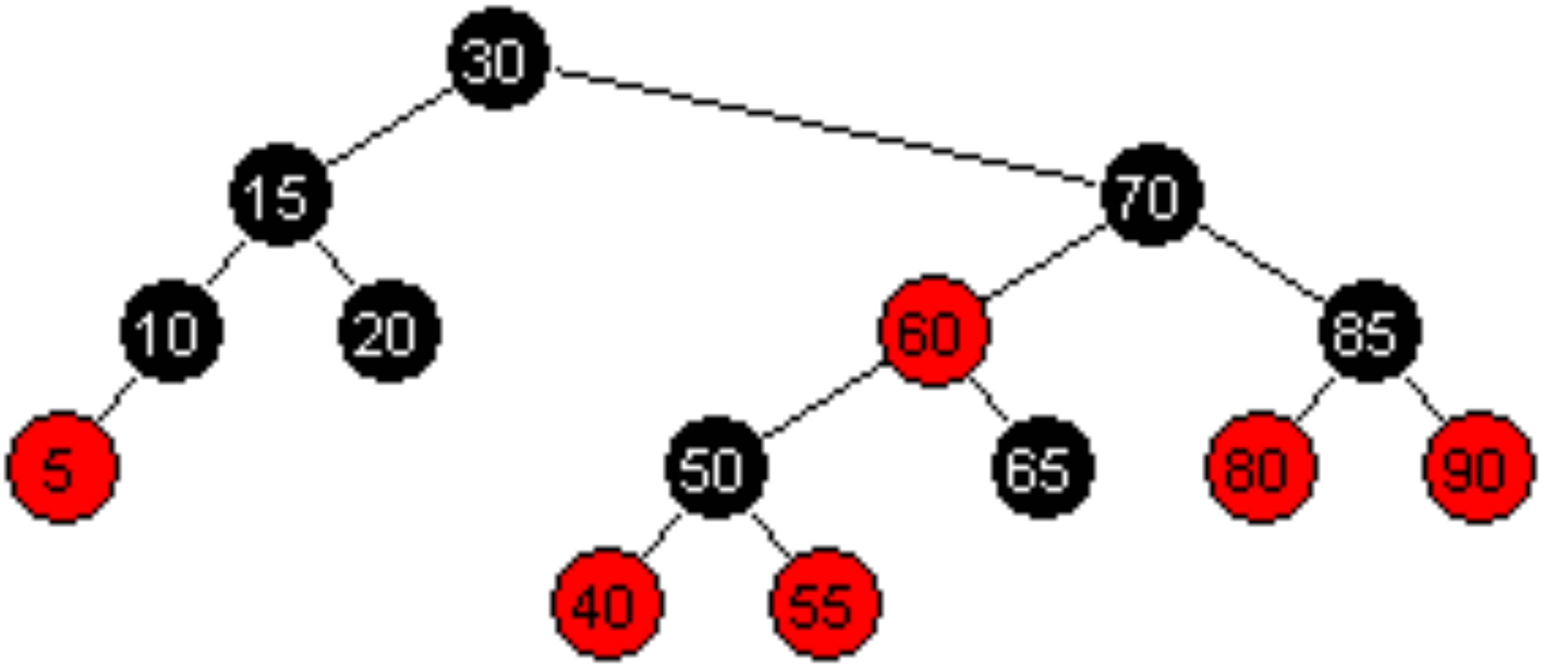
To search a red-black tree, just ignore the colors



Runtime is O(height)

Since it's a BST, runtime of insert and delete should also be O(height)

How tall is a red-black tree?



Best-case: if all nodes black, it is ~log n.

Worst case: every other node on the longest path is red. Height ~2 log n.

Note: **Not height-balanced:**
Sometimes taller but often shorter on average.

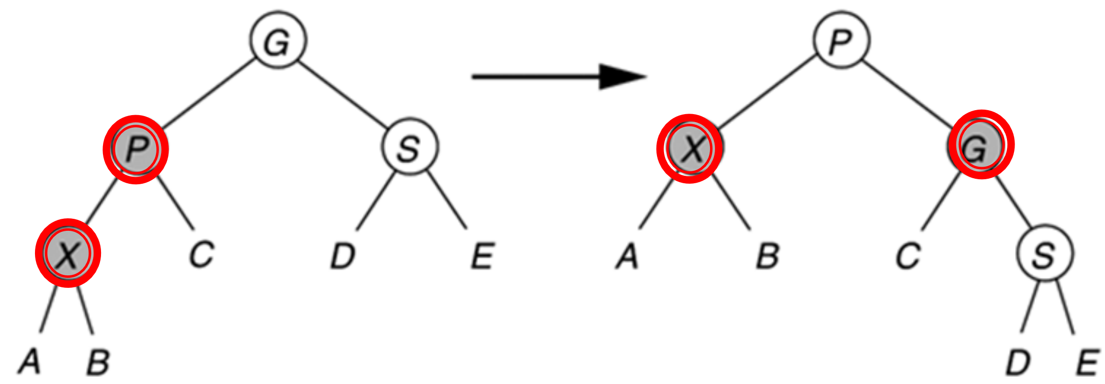
Bottom-Up Insertion Strategy

- Like BST:
  - Insert at leaf
  - Color it red (to keep perfect black balance)
- But could make two reds in a row?
  - On the recursive travel back up the tree (like AVL),
    - **rotate** (single- and double-, like AVL)
    - and **recolor** (new)
    - Show now that various “rotation+recoloring”s fix two reds in a row while maintaining black balance.
- At end of insert, always make root **of the entire tree** black (to fix property 3).

2 Reds in a row, with red outer grandchild and black sibling

figure 19.35

If S is black, a single rotation between parent and grandparent, with appropriate color changes, restores property 3 if X is an outside grandchild.



(a) Before rotation

(b) After rotation

2 Reds in a row, with red inner grandchild and black sibling

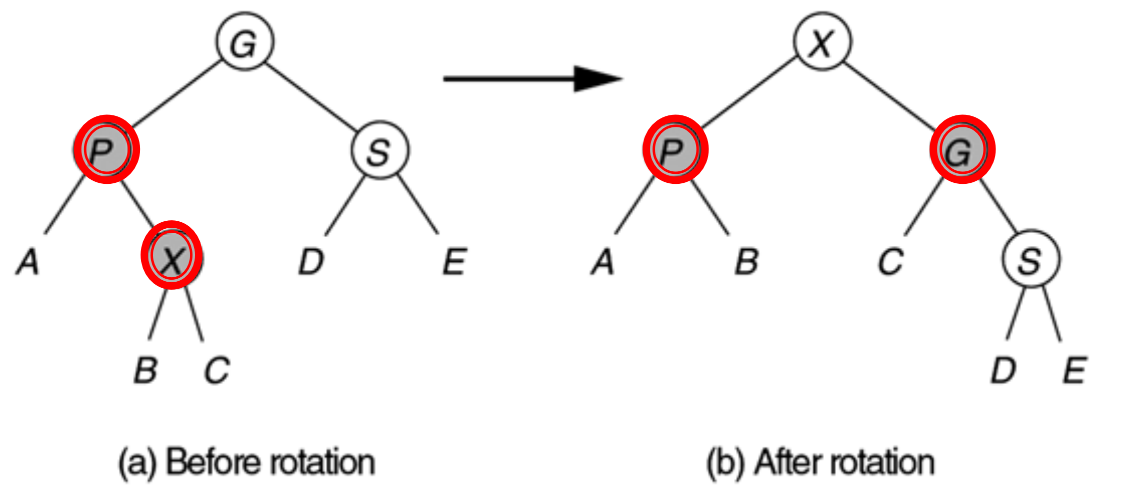


figure 19.36

If *S* is black, a double rotation involving *X*, the parent, and the grandparent, with appropriate color changes, restores property 3 if *X* is an inside grandchild.

2 Reds in a row, with red outer grandchild and red sibling

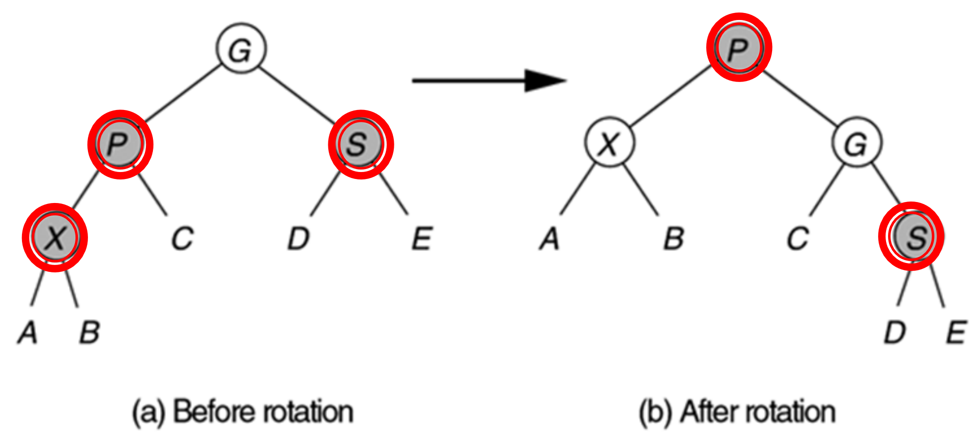


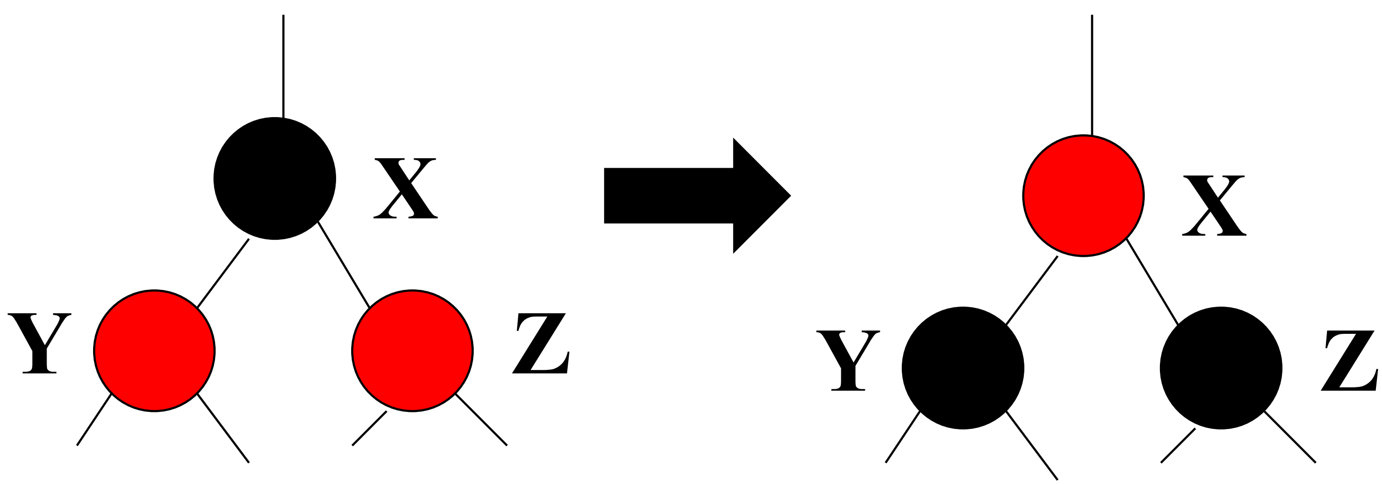
figure 19.37

If S is red, a single rotation between parent and grandparent, with appropriate color changes, restores property 3 between X and P.

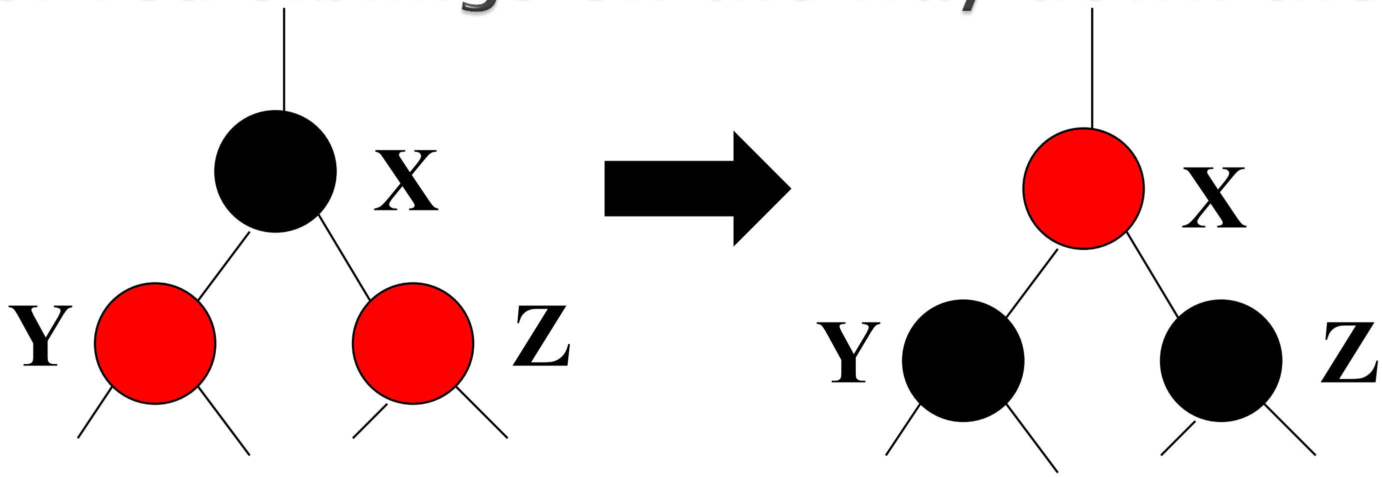
Case 3 (red sibling) can force us to do multiple rotations recursively

- Bottom-Up insertion strategy must be recursive.

- An alternative:
  - If we ever had a black node with two red children, swap the colors and black balance stays.
  - Details next…



Top-down insertion strategy:
Recolor red siblings on the way down the tree

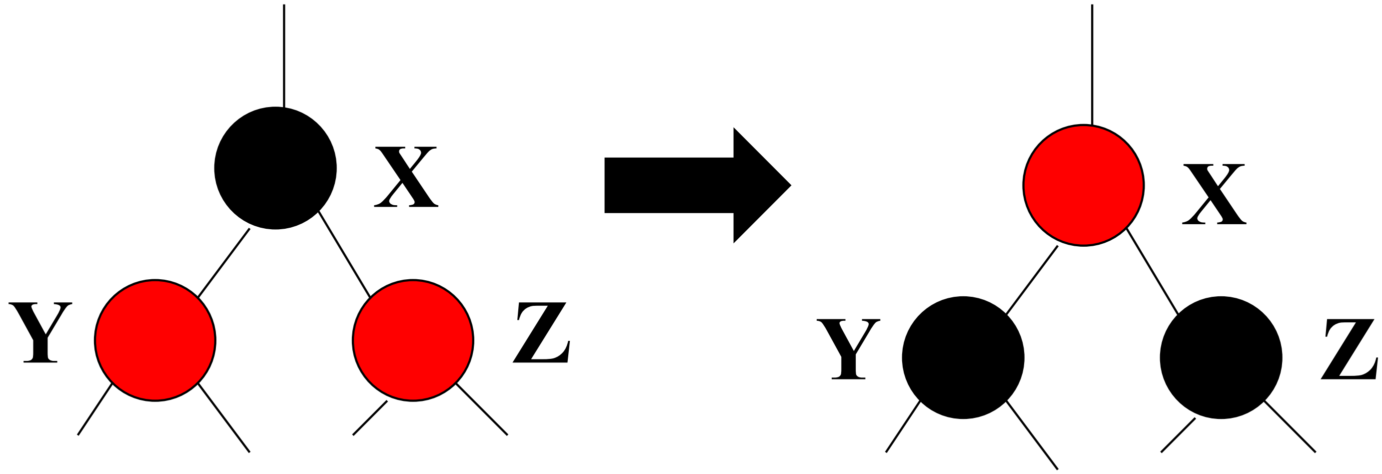


Situation: A black node with two red children.

Action: – Recolor the node red and the children black (if root, make black).
– If the parent is red, perform rotations, otherwise continue down the tree

Does this change black balance? No.

Top-Down Insertion Strategy



- On the way down the tree to the insertion point, if ever see a black node with two red children, swap the colors.
  - If X's parent is red, perform a rotation,
  - otherwise continue down the tree

- (All but possibly one of) the rotations are done **while traversing down the tree** to the insertion point.
  - Avoid rotating into case (c) (2 red siblings) altogether.

- Top-Down insertion is slightly "leaner" than bottom-up:
  - Never requires a (recursive) chain-reaction of rotations
  - No need for parent pointers

Insertion summary

- Rotate when an insertion or color flip produces two successive red nodes.
- Rotations are just like those for AVL trees:
  - If the two red nodes are both left children or both right children, perform a *single rotation*.
  - Otherwise, perform a *double rotation*.
- Except we recolor nodes instead of adjusting their heights or balance codes.

Testing

1. Insert: 1, 2, 3, 4, 5, 6, 7, 8
2. Insert: 7, 6, 5, 4, 3, 2, 1, 1
   - Relationship with (1)?
   - Duplicates not inserted.
3. Insert: 10, 85, 15, 70, 20, 60, 30, 50, 65, 80, 90, 40, 5, 55
4. Use applet [linked to in Schedule for today] to check your work.

Summary

- Java uses:
- Slightly faster than AVL trees
- What's the catch?
  - Need to maintain pointers to lots of nodes (child, parent, grandparent, great-grandparent, great-great-grandparent)
  - The deletion algorithm is *nasty*.

java.util

Class TreeMap<K,V>

java.lang.Object
    java.util.AbstractMap<K,V>
        java.util.TreeMap<K,V>

Type Parameters:

K - the type of keys maintained by this map

V - the type of mapped values

All Implemented Interfaces:

Serializable, Cloneable, Map<K,V>, NavigableMap<K,V

```
public class TreeMap<K,V>
extends AbstractMap<K,V>
implements NavigableMap<K,V>, Cloneable, Se
```

A Red-Black tree based NavigableMap implementation. T

This implementation provides guaranteed log(n) time cost fc