Lab 7

Left-Leaning Red Black Trees (LLRBs)

Announcements

Project 2A is due Wednesday, 3/06 at 11:59 pm.

Project 2B will be due Monday, 4/01 at 11:59 pm (this is the Monday after spring break!).

2-3 Trees (Balanced Search Trees)

Binary Search Trees

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We can't guarantee that binary search trees will always have a "bushy" structure. In the worst case, we would have a "spindly" tree.

- As a reminder, a bushy structure would have a worst case of O(logN) and a spindly tree would have a worst case runtime of O(N) (and this applies for insertion and lookup).

Balanced Search Trees

Main Idea: Instead of adding a new node for each inserted element, we want to put multiple elements into a single node.

- Simply put, we always insert an element into an **existing node** and if the node becomes too big, we "split" the node.

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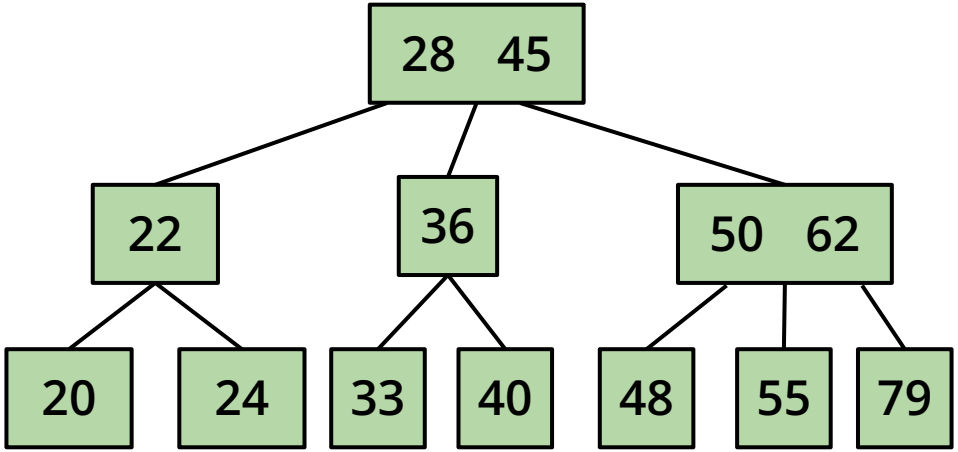
While there are several variants of a balanced search tree, we'll go with a 2-3 tree for this lab. What this means is that:

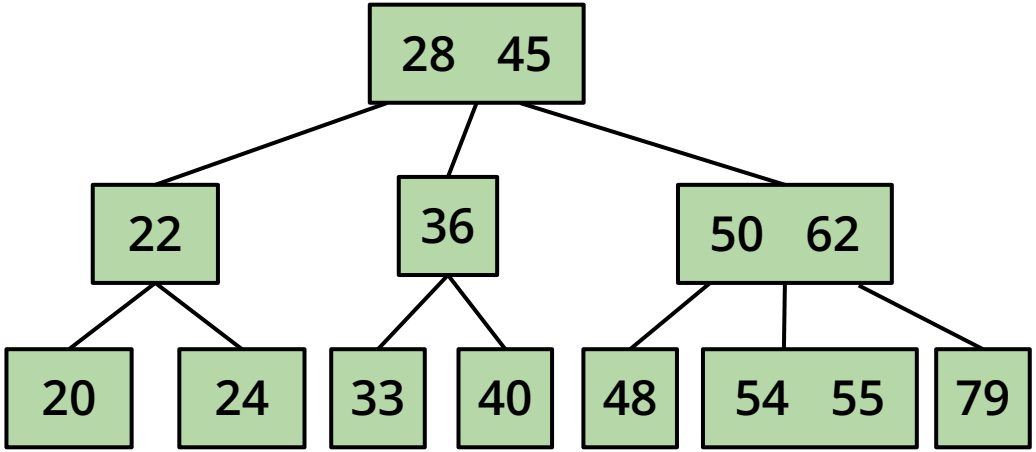
- We can only have **2 items max per node**.
- And each node can have **3 children max**.

Balanced Search Trees



If we insert 54, where would that go?

Balanced Search Trees



It would go into the same node as 55!

Left-Leaning Red Black Trees

Now that we have balanced search trees down, let's introduce the left-leaning red black trees. In practice, balanced search trees are actually kind of hard to implement.

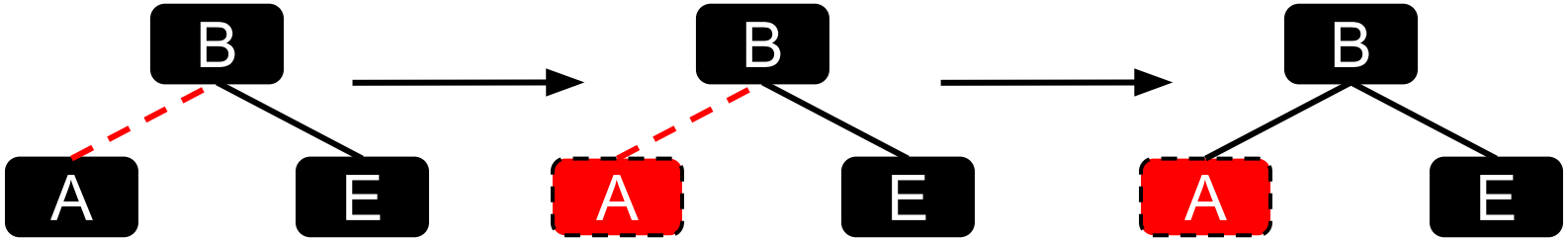
Left-Leaning Red Black Trees (LLRBs)

LLRBs

LLRBS are:

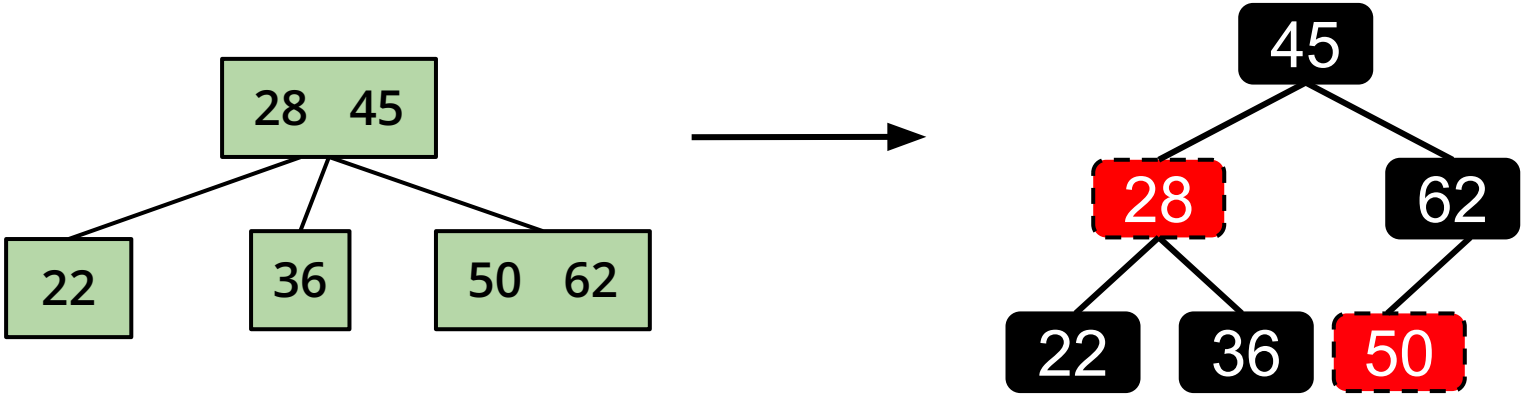
- A 2-3 tree represented in a binary search tree format (one item per node)
- This data structure is represented by two different types of nodes:
  - A **red** node means that the node is squished in the same node as the parent (in the 2-3 tree representation)
  - A **black** node means just a regular node in the 2-3 tree.

Links vs Nodes (Disclaimer)



Disclaimer: You may have wondered at this point why we're using colored nodes. In lecture, we introduce LLRBs with links. That is to say, if two nodes are connected with a red link, we say that the child node belongs in the same node as the parent in its 2-3 tree representation. For ease of implementation, the lab uses nodes instead (for the rest of lab, we'll use colored nodes).

LLRBs



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- This means that we can't have two left-leaning red nodes (as mentioned in lecture)
- Or a red right child of a red node (which is effectively no right-leaning red node).

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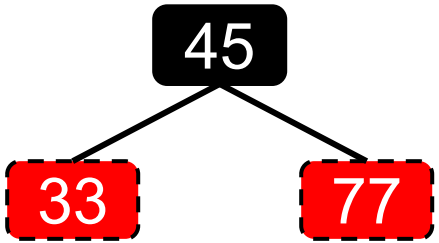
- Or a red right child of a red node (which is effectively no right-leaning red node).

As an important note, these red nodes come from insertion - whenever we insert a node into an LLRB, it's always as a red node.

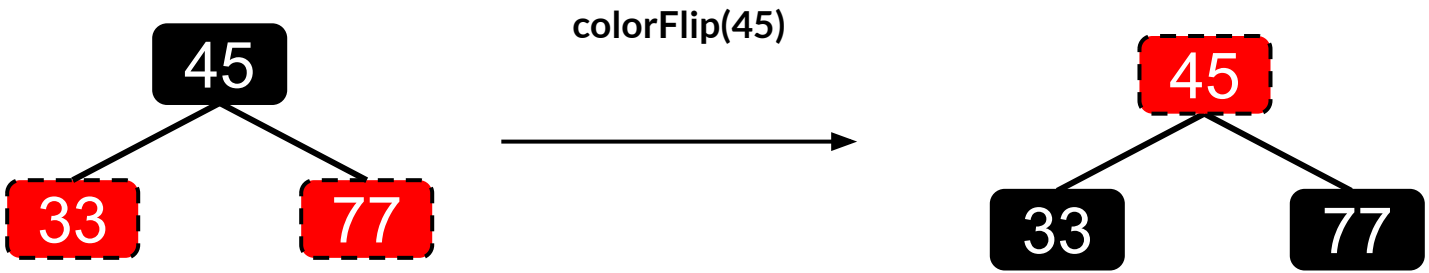
LLRB Operations

colorFlip



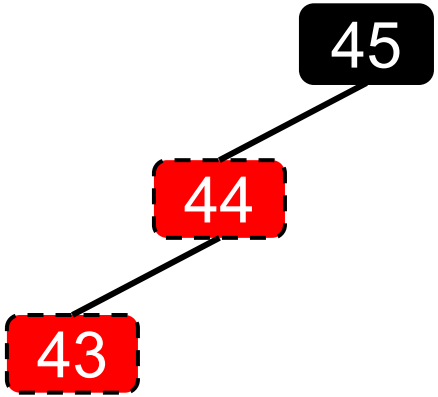
Which invariant is broken?

colorFlip



Invariant: No node can have two **red** children.

rotateRight



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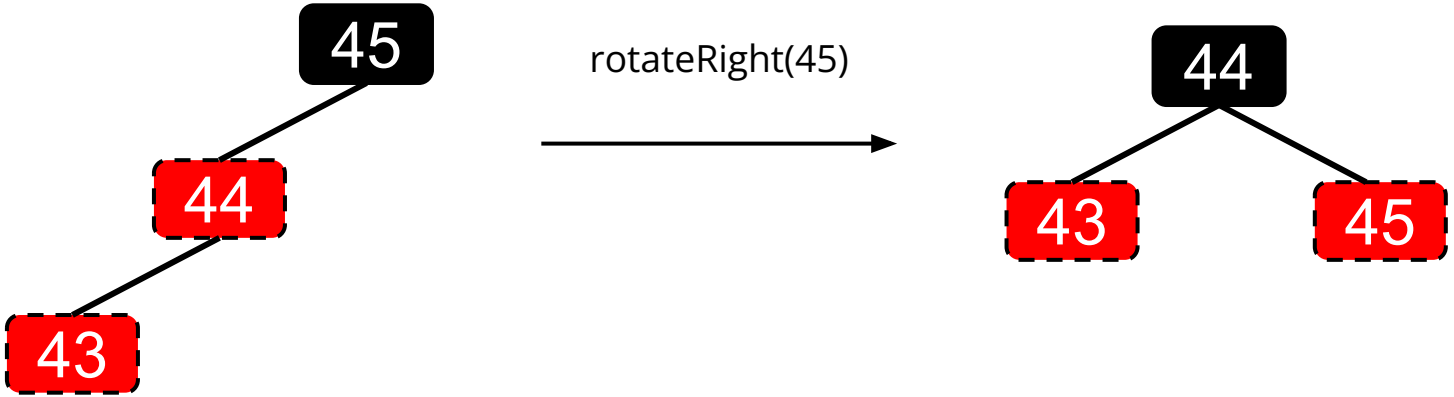
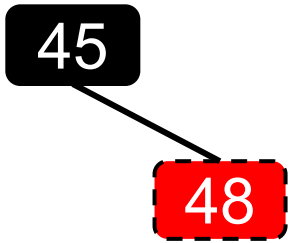
rotateRight



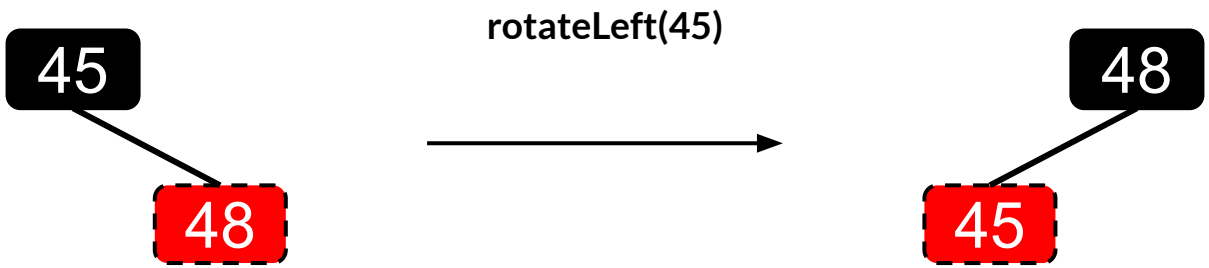
Invariant: The parent of a red node must be black (this means that we can not have two left-leaning red nodes).

rotateLeft



Which invariant is broken?

rotateLeft



Invariant: All red nodes must be left-leaning.

Lab Overview

An Overview

Lab 08 is due Friday, 3/08 at 11:59 pm.

Deliverables:

- Complete the following methods in `RedBlackTree.java`
  - `flipColors`
  - `rotateRight` and `rotateLeft`
  - `insert`

Lab Notes

The lab provides a Node class for you to use (`static class RBTreeNode<T>`). Make sure to read through it first to understand what it encompasses before starting on the lab! It is in `RedBlackTree.java`.

The syntax to declare the node object is not the same as Proj1A, but should be like below:

```
RBTreeNode<T> node = ...;
```