CS 106B, Lecture 19
Binary Search Trees

reading:

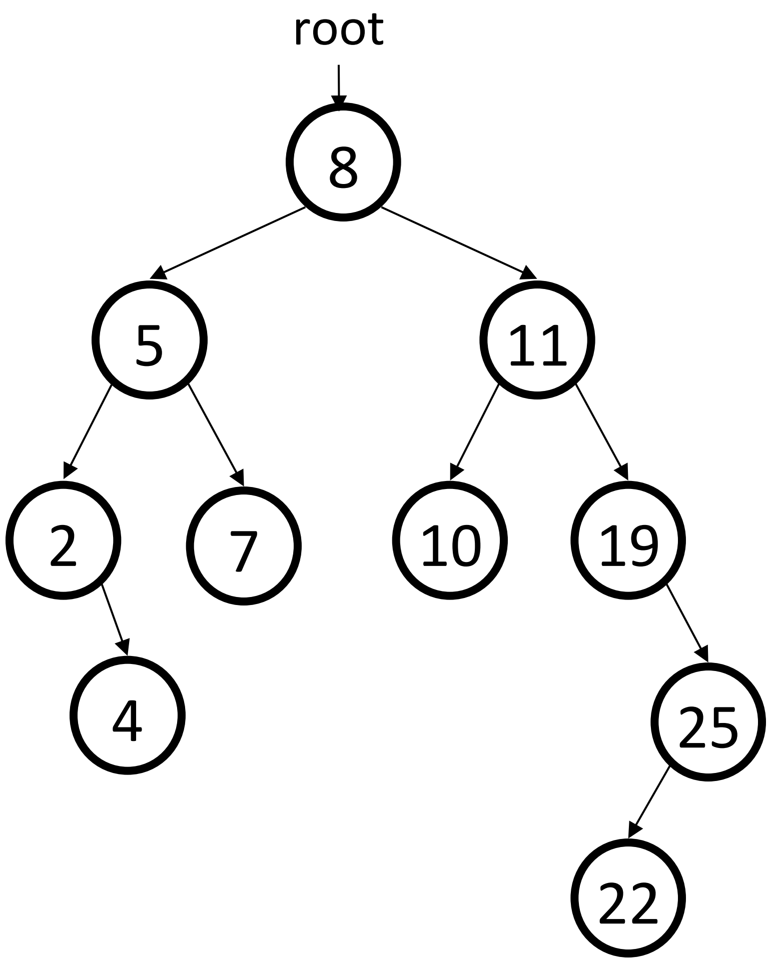
Programming Abstractions in C++, Chapter 16

Plan for Today

- Continue our discussion of Binary Search Trees
  - Implement add
  - Discuss remove
- MiniBrowser! New Assignment!

Adding to a BST

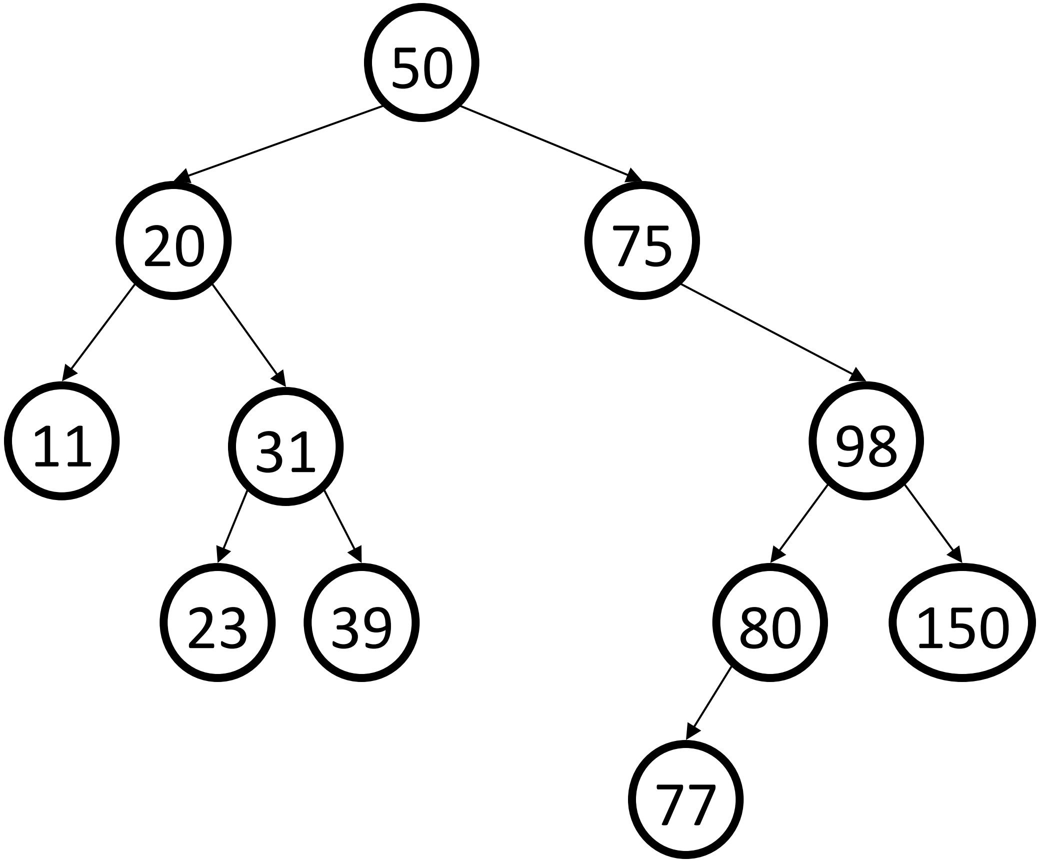
- Suppose we want to add new values to the BST below.
  - Where should the value 14 be added?
  - Where should 3 be added? 7?
  - If the tree is empty, where should a new value be added?
- What is the general algorithm?



Adding exercise

- Draw what a binary search tree would look like if the following values were added to an initially empty tree in this order:

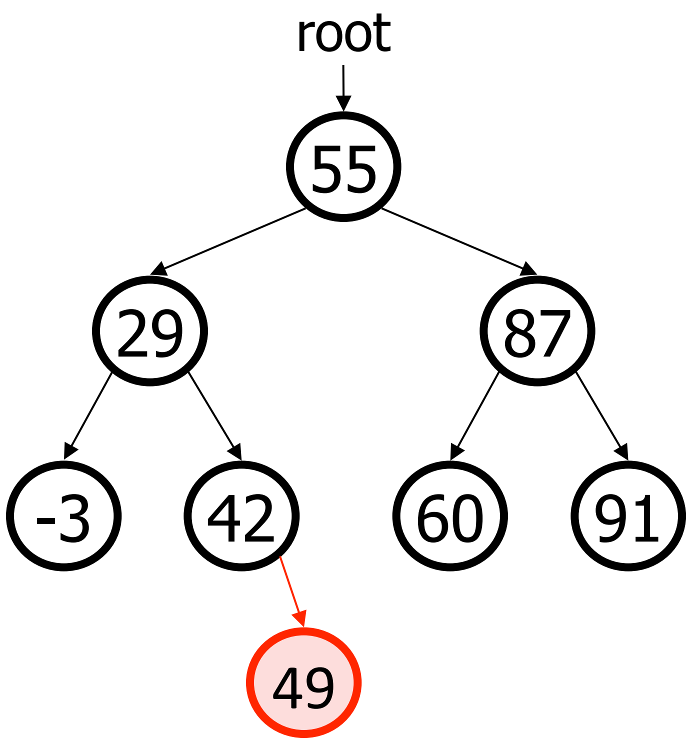
50
20
75
98
80
31
150
39
23
11
77



Exercise: add

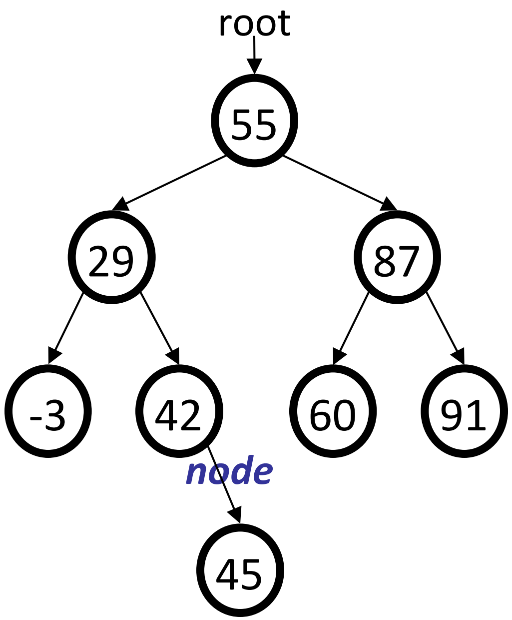
bstAdd

- Write a function **add** that adds a given integer value to the BST.
  - Add the new value in the proper place to maintain BST ordering.
    - `tree.add(root, 49);`



Add Solution

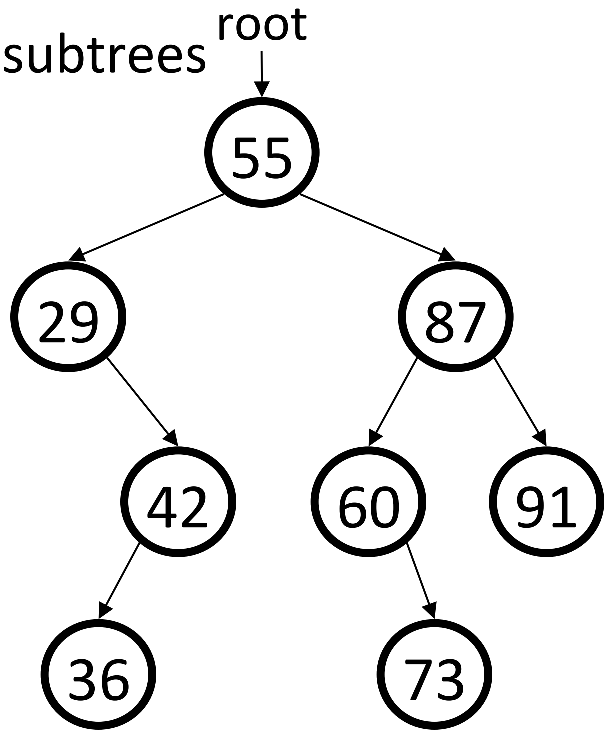
```
void add(TreeNode*& node, int value) {
    if (node == nullptr) {
        node = new TreeNode(value);
    } else if (node->data > value) {
        add(node->left, value);
    } else if (node->data < value) {
        add(node->right, value);
    }
}
```



- Must pass the current node *by reference* for changes to be seen.

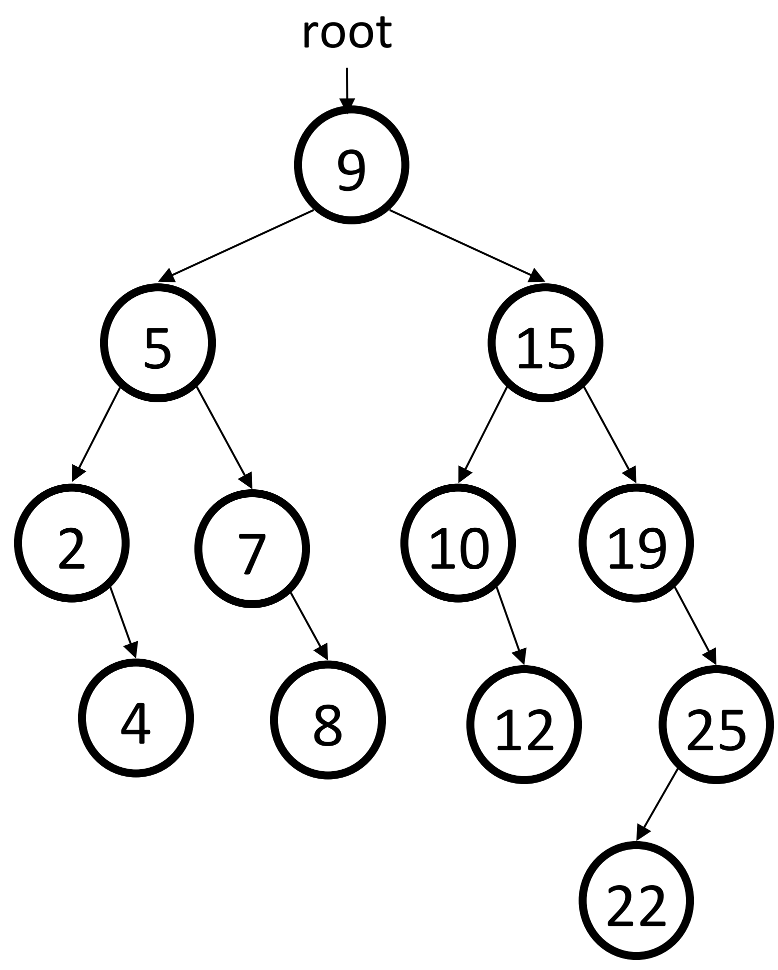
Free Tree

- To avoid leaking memory when discarding a tree, we must free the memory for every node.
  - Like most tree problems, often written *recursively*
  - must free the node itself, and its left/right subtrees
  - this is another *traversal* of the tree
    - should it be pre-, in-, or post-order?



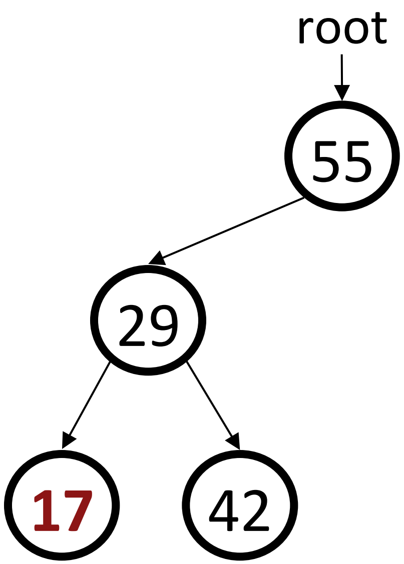
Removing from a BST

- Suppose we want to **remove** values from the BST below.
  - Removing a leaf like 4 or 22 is easy.
  - What about removing 2? 19?
  - How can you remove a node with two large subtrees under it, such as 15 or 9?
- What is the general algorithm?

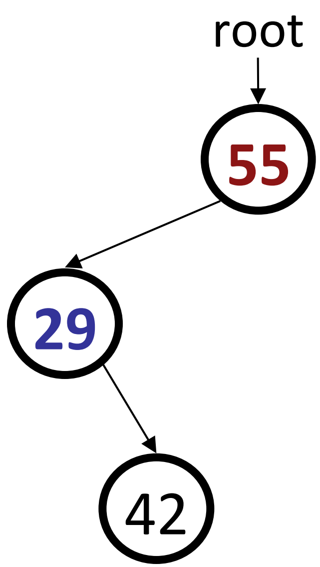


Cases for removal

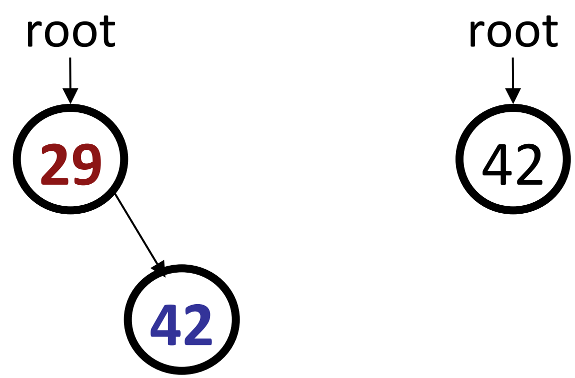
1. a **leaf**: Replace with `nullptr`
2. a node with a **left child only**: Replace with left child
3. a node with a **right child only**: Replace with right child



`remove(root, 17);`



`remove(root, 55);`

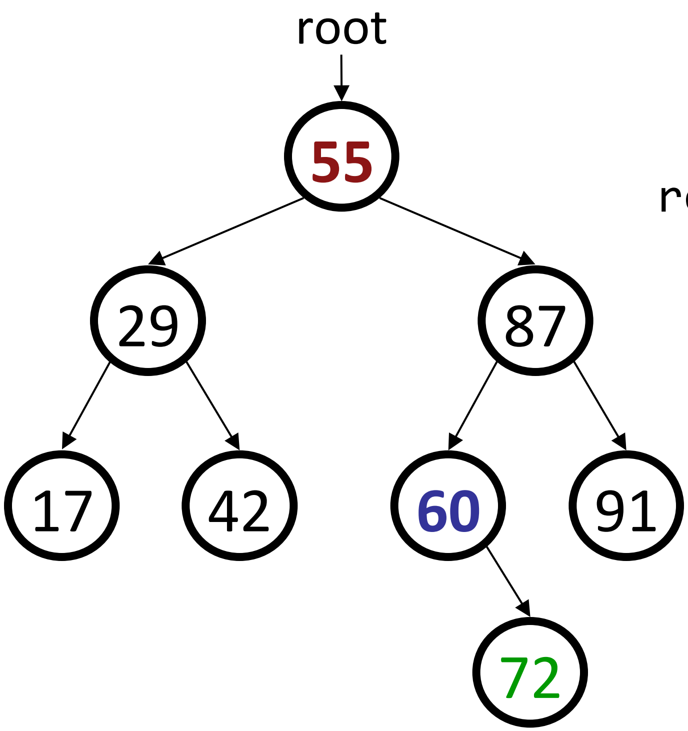


`remove(root, 29);`

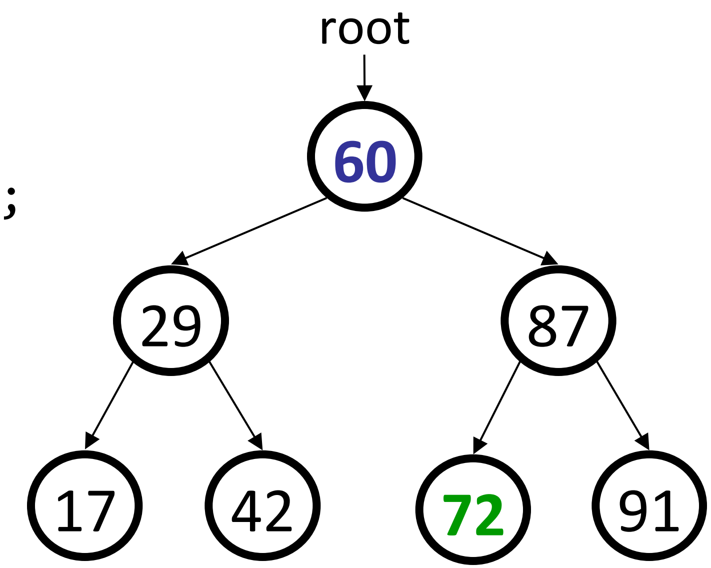
Cases for removal

4. a node with **both** children:

replace with **min from right**
(replacing with **max from left** would also work)




```
remove(root, 55);
```

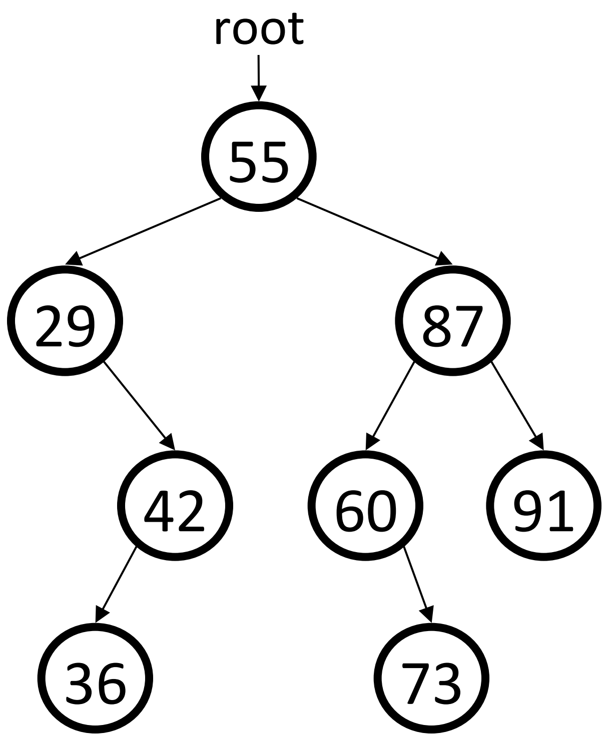


Exercise: remove

bstRemove

- Add a function **remove** that accepts a root pointer and removes a given integer value from the tree, if present. Remove the value in such a way as to maintain BST ordering.

  - `remove(root, 73);`
  - `remove(root, 29);`
  - `remove(root, 87);`
  - `remove(root, 55);`



remove solution

```
// Removes the given value from this BST, if it exists.
// Assumes that the given tree is in valid BST order.
void remove(TreeNode*& node, int value) {
    if (node == nullptr) {
        return;
    } else if (value < node->data) {
        remove(node->left, value);    // too small; go left
    } else if (value > node->data) {
        remove(node->right, value);   // too big; go right
    } else {
        // value == node->data; remove this node!
        // (continued on next slide)
        ...
```

remove solution

```
        // value == node->data; remove this node!
        if (node->right == nullptr) {
            // case 1 or 2: no R child; replace w/ left
            TreeNode* trash = node;
            node = node->left;
            delete trash;
        } else if (node->left == nullptr) {
            // case 3: no L child; replace w/ right
            TreeNode* trash = node;
            node = node->right;
            delete trash;
        } else {
            // case 4: L+R both; replace w/ min from right
            int min = getMin(node->right);
            remove(node->right, min);
            node->data = min;
        }
    }
}
```

Announcements

- Assignment 4 is due **today**
- Assignment 5 will be released later today
  - More time to complete it, but this assignment will be significantly longer than the others you've seen this quarter
  - As a rough guide, part c took SLs about four times as long to solve as part a, so don't wait until the last minute
- You will get assignment 3 feedback on today
- Please give feedback (if you have the next 30 minutes free): cs198.stanford.edu
- Exam logistics
  - Midterm today, July 25, from 7:00-9:00PM in Hewlett 200