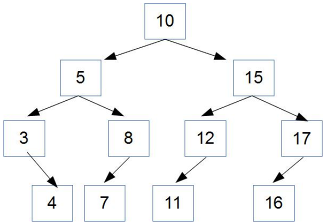
Outline

Binary Search Trees in C++

Let's recall Binary Search Trees (BST):
binary trees where every node has the following property:

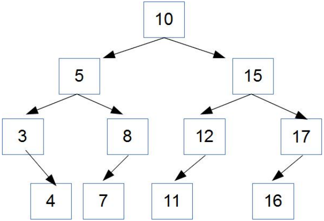
- Each value in the left subtree is less than the value at the node.
- Each value in the right subtree is greater than the value at the node. No duplicates!



Binary Search Trees in C++

Binary Search With A Binary Tree

- Start at the root
- If the value is there, we are done
- If the value is less than the node value, search the left subtree
- If the value is greater than the node value, search the right subtree



Binary Search Trees in C++

Performance (Running Time) To Find A Value

- Average Performance is $\Theta(\log n)$.
  If the tree is not too unbalanced, then we divide the number of items to search in half at each node. This is actually a binary search.

- Worst-Case Performance is $\Theta(n)$.
  If the tree branches only to one side (left or right) this is the same as linear search.

TreeNode Class

Recursive Definition Of A TreeNode Class in Python

```
class TreeNode:

   def __init__(self, data = None, left=None, right=None):

      self.item = data
      self.left = left # TreeNode or None
      self.right = right # TreeNode or None
```

TreeNode Class

Recursive Definition of a TreeNode Class in C++

```
//TreeNode.h
class TreeNode{
public:
   TreeNode(int item, TreeNode *left = NULL, TreeNode
*right = NULL);
private:
   TreeNode(const TreeNode &tnode); // no Copy Constructor
   void operator=(const TreeNode &tnode); // no assignment
operator
   int _item;
   TreeNode* _left;
   TreeNode* _right;
};
```

See the files TreeNode.h, TreeNode.cpp, and usingTreeNode.cpp.

Implementing a BST

in Python: __init__ (Constructor)

```
from TreeNode import TreeNode

class BST:

  def __init__(self):

    """ creates empty binary search tree """

    self.root = None
```

Implementing a BST

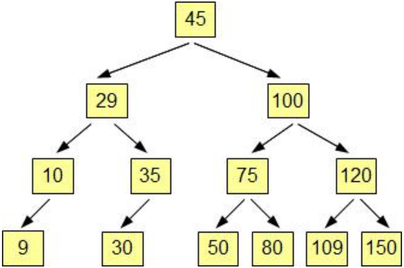
in C++ : BST.h

```
// BST.h
class BST{

public:
   BST() { _root = NULL; } // creates empty tree
   ~BST(); // destructor

private:
   TreeNode *_root;
};
```

Insertion into BST

Inserting into BST

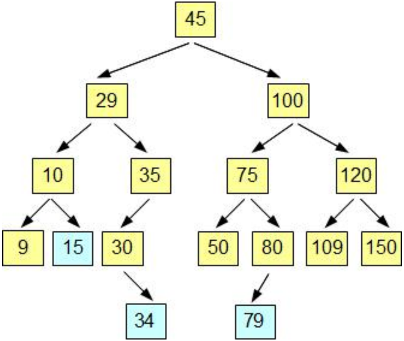
For the following BST, let's insert values 15, 34, and 79.



Insertion into BST

Inserting into BST

After insertion of 15, 34, and 79:



Insertion into BST

Insertion: iterative or recursive

Trees are a naturally recursive data structure, therefore it makes sense to implement insertion recursively, but we also have iterative version in Python's implementation.

In C++ implementation, you can find an iterative implementation only, but check out the overloaded **cin** method...

See the file BST.cpp.

Insertion into BST

Search: iterative or recursive

Trees are a naturally recursive data structure, therefore it makes sense to implement search recursively as well. In Python's implementation we had both (the recursive implementation was a HW assignment).

In C++ implementation, you can find an iterative implementation only.

See the file BST.cpp.

Deletion from BST

Removing nodes from the tree

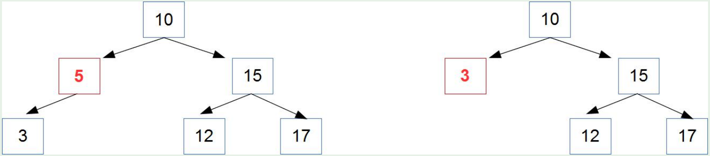
Removing a specific item from a BST is a bit tricky. List of cases:

- the node to be removed is a leaf:
  then we can simply drop it off the tree
  (reference in its parent node is set to None)
- the node to be removed has a single child:
  then we can simply reset the reference from its parent to the reference to the node's child instead.
- the node to be removed has two children:
  leave the node in place, but replace its contents (i.e. value), i.e. find an easily deletable node whose contents can be transferred into the target node, while maintaining the tree's binary search property.
  (Two options there: rightmost node of the left subtree (our book), or leftmost node of the right subtree)

Deletion from BST

Example 1

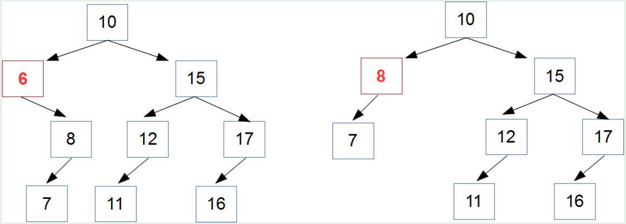
Let's delete 5 from a BST:



Deletion from BST

Example 2

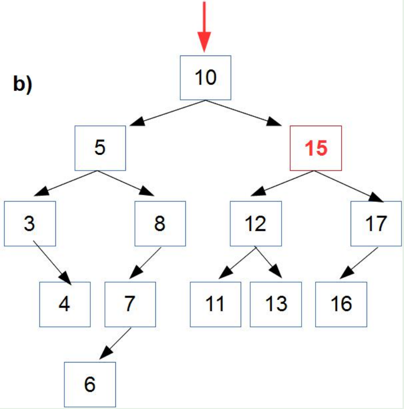
Let's delete 6 from a BST:



Deletion from BST

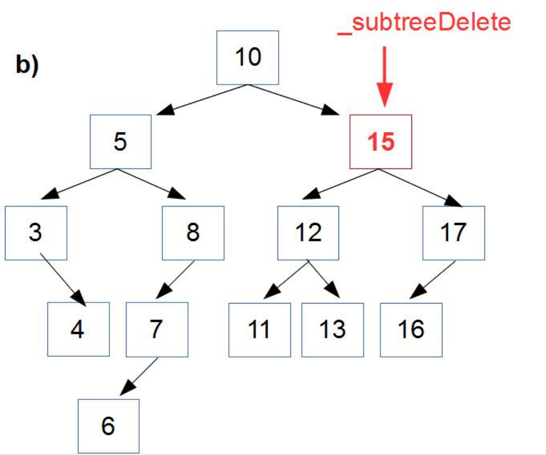
Example 3

Let's delete 15 from the given BST:



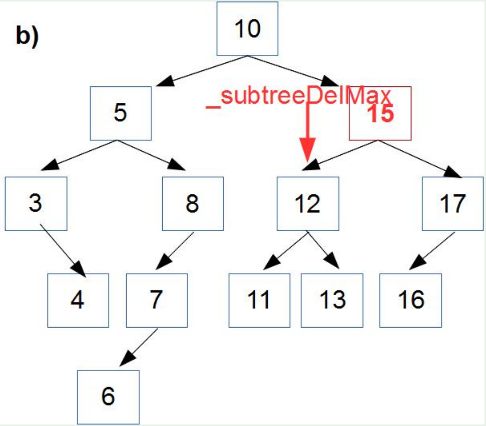
Deletion from BST

Example 3



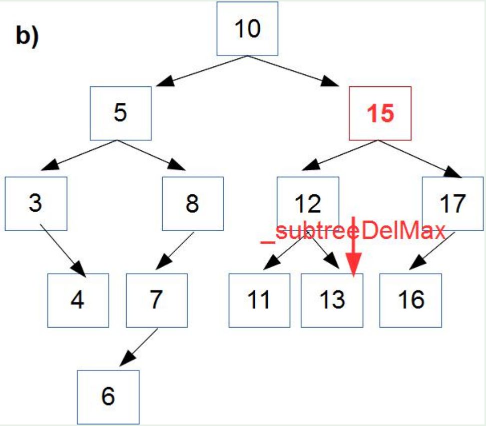
Deletion from BST

Example 3



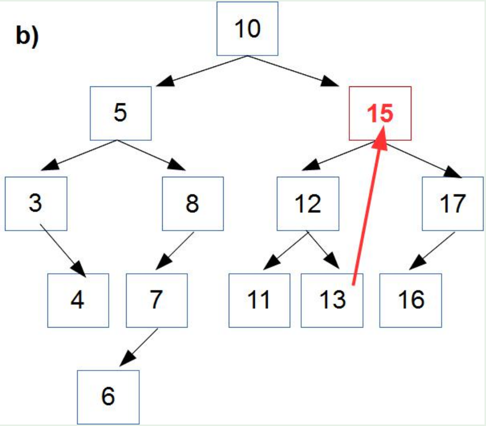
Deletion from BST

Example 3



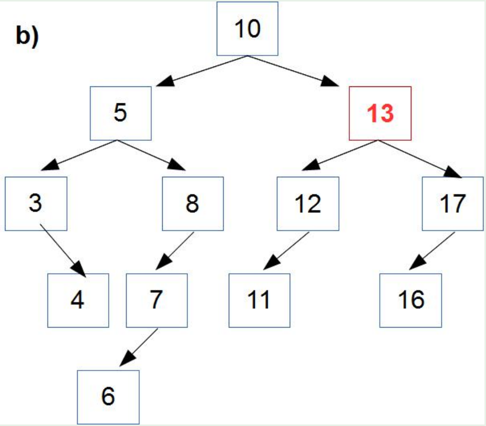
Deletion from BST

Example 3



Deletion from BST

Example 3



Deletion from BST

Conclusion

In conclusion, we can say that when deleting a value from BTS, which is represented by a node with two children, our book follows the following procedure:

- step to the left sub-tree,
- locate the rightmost node(or a leaf) in it,
- and place its value in to the node with value to be deleted, making necessary adjustments of the references.

We implemented the deletion in Python, but don't have its implementation in BST.cpp yet. This is a suggested practice.

Run-Time Analysis Of BST Methods

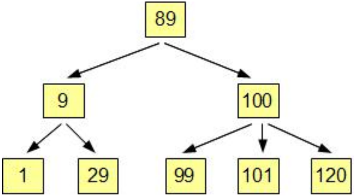
Methods

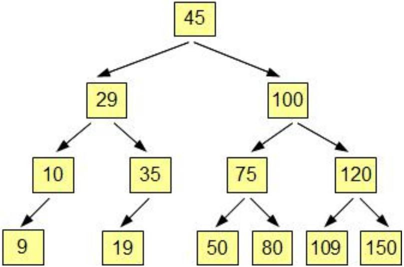
- asList is $\Theta(n)$.
- insert, delete, find have $\Theta(\log n)$ average behavior.
- insert, delete, find have $\Theta(n)$ worst-case behavior.

In-class work

In-class work - Part 1

For the following, state whether each of them is a binary tree, a binary search tree (BST), or just a tree.





In-class work

In-class work - on your own, part 2

Using class BST, insert the following numbers, one by one: 25, 5, 58, 1, 7, 17, 21, 32, 90, 6, 4, and 2.

1) Draw this BST as you think it should look.

2) What will be its array representation?

3) How will the tree look like if 5 is deleted?