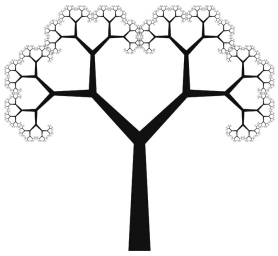
CSE 143

Computer Programming II

Binary Search Trees (BSTs)



Outline

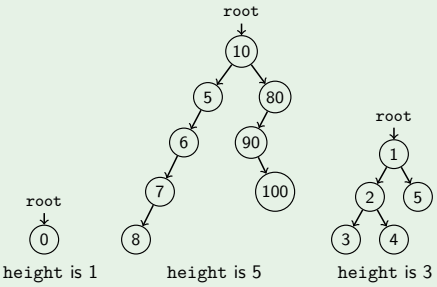
Another Tree Method

height

Write a tree method called `height` (inside the `IntTree` class) with the following method signature:

```
public int height()
```

that returns the number of nodes on the **longest path** from the root to any leaf. For example,



`height` Solution


```
1  public int height() {
2     return height(this.root);
3  }
4
5  private int height(IntTreeNode current) {
6     // A null tree has height 0
7     if (current == null) {
8        return 0;
9     }
10    else {
11       // Find the largest path by taking the max
12       // of both branches recursively (and adding 1 for this node)
13       return 1 + Math.max(
14          height(current.left),
15          height(current.right)
16       );
17    }
18 }
```

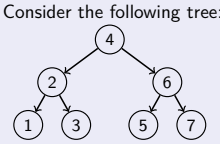
Back to `contains`

Recall `contains()`

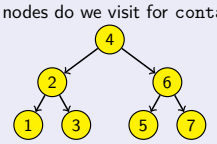
```
1  private boolean contains(IntTreeNode current, int value) {
2     /* If the tree is null, it definitely doesn't contain value... */
3     if (current == null) { return false; }
4
5     /* If current *is* value, we found it! */
6     else if (current.data == value) { return true; }
7
8     else {
9        return contains(current.left, value) ||
10              contains(current.right, value);
11    }
12 }
```

Runtime of `contains(7)`

Consider the following tree:



Which nodes do we visit for `contains(7)`



That makes the code $\mathcal{O}(n)$. Can we do better?

Doing Better! 4

In general, **we can't do better**. BUT, sometimes, we can!

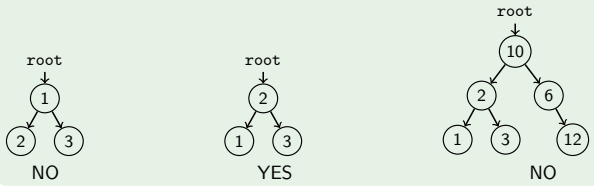
Definition (Binary SEARCH Tree (BST))

A binary tree is a **BST** when an **in-order traversal of the tree** yields a sorted list.

To put it another way, a binary tree is a **BST** when:

- All data "to the left of" a node is less than it
- All data "to the right of" a node is greater than it
- All sub-trees of the binary tree are also BSTs

Example (Which of the following are BSTs?)



contains (AGAIN!) 5

Write contains() for a BST

Fix contains so that it takes advantage of the BST properties.

Recall contains()

```
1  private boolean contains(IntTreeNode current, int value) {
2     /* If the tree is null, it definitely doesn't contain value... */
3     if (current == null) { return false; }
4
5     /* If current *is* value, we found it! */
6     else if (current.data == value) { return true; }
7
8     else if (current.data < value) {
9        return contains(current.right, value);
10    }
11    else {
12       return contains(current.left, value);
13    }
14 }
```

Tracing the new contains 6

Runtime of (better) contains(7)

Consider the following tree: Which nodes do we visit for contains(**7**)

That makes the code $\log n$. Much better!

WARNING!

Consider the following tree:

This is the same tree, but now **we have to visit all the nodes!**

Adding to a BST! 7

add

Write a method add in the BST class with the following signature:

```
public void add(int value);
```

that preserves the BST property.

Example (tree.add(49))

Adding to a BST (Attempt #1) 8

Attempt #1

```
1  public void add(int value) {
2     add(this.root, value);
3  }
4  private void add(IntTreeNode current, int value) {
5     if (current == null) {
6        current = new IntTreeNode(value);
7     }
8     else if (current.data > value) {
9        add(current.left, value);
10    }
11    else if (current.data < value) {
12       add(current.right, value);
13    }
14 }
```

What's wrong with this solution?

Just like with LinkedLists where we must change front or .next, we're not actually changing anything here. We're discarding the result.

x = change(x) 9

Consider the following code:

```
1  public static void main(String[] args) {
2     String s = "hello world";
3     s.toUpperCase();
4     System.out.println(s);
5  }
```

OUTPUT

```
>> hello world
```

```
1  public static void main(String[] args) {
2     String s = "hello world";
3     s = s.toUpperCase();
4     System.out.println(s);
5  }
```

OUTPUT

```
>> HELLO WORLD
```

We must USE the result; otherwise, it gets discarded

x = change(x) 10

If you want to write a method that can change the object that a variable refers to, you must do three things:

1. Pass in the original state of the object to the method
2. Return the new (possibly changed) object from the method
3. Re-assign the caller's variable to store the returned result

```
1    p = change(p); // in main
2    public static Point change(Point thePoint) {
3       thePoint = new Point(99, -1);
4       return thePoint;
5    }
```

Adding to a BST (Fixed) 11

Fixed Attempt

```
1  public void add(int value) {
2     this.root = add(this.root, value);
3  }
4  private IntTreeNode add(IntTreeNode current, int value) {
5     if (current == null) {
6        current = new IntTreeNode(value);
7     }
8     else if (current.data > value) {
9        current.left = add(current.left, value);
10    }
11    else if (current.data < value) {
12       current.right = add(current.right, value);
13    }
14    return current;
15 }
```

This works because we **always update the result**, **always return the result**, and **always update the root**.

BST Tips! 12

- BSTs can make searching/inserting/etc. much faster.
- Make sure that you can figure out if a tree is a BST or not.
- Whenever you are writing a BST method, you **must** use the `x = change(x)` pattern. It won't work otherwise.