Building Java Programs

Binary Search Trees

reading: 17.3 – 17.4
Binary search trees

- **binary search tree** ("BST"): a binary tree where each non-empty node R has the following properties:
  - elements of R's left subtree contain data "less than" R's data,
  - elements of R's right subtree contain data "greater than" R's,
  - R's left and right subtrees are also binary search trees.

- BSTs store their elements in sorted order, which is helpful for searching/sorting tasks.
 BST examples

- Which of the trees shown are legal binary search trees?
Searching a BST

- Describe an algorithm for searching a binary search tree.
  - Try searching for the value 31, then 6.

- What is the maximum number of nodes you would need to examine to perform any search?
Exercise

- Convert the `IntTree` class into a `SearchTree` class.
  - The elements of the tree will form a legal binary search tree.

- Write a `contains` method that takes advantage of the BST structure.
  - `tree.contains(29) → true`
  - `tree.contains(55) → true`
  - `tree.contains(63) → false`
  - `tree.contains(35) → false`

```
overall root
```
```
55
  29
  -3  42
```
```
87
  60  91
```
Exercise solution

// Returns whether this BST contains the given integer.
public boolean contains(int value) {
    return contains(overallRoot, value);
}

private boolean contains(IntTreeNode node, int value) {
    if (node == null) {
        return false; // base case: not found here
    } else if (node.data == value) {
        return true; // base case: found here
    } else if (node.data > value) {
        return contains(node.left, value);
    } else { // root.data < value
        return contains(node.right, value);
    }
}
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 a method `add` to the `SearchTree` class that adds a given integer value to the BST.
  - Add the new value in the proper place to maintain BST ordering.
    - `tree.add(49);`
An incorrect solution

// Adds the given value to this BST in sorted order.
public void add(int value) {
    add(overallRoot, value);
}

private void add(IntTreeNode node, int value) {
    if (node == null) {
        node = new IntTreeNode(value);
    } else if (node.data > value) {
        add(node.left, value);
    } else if (node.data < value) {
        add(node.right, value);
    } else node.data == value, so // it's a duplicate (don't add)
}

• Why doesn't this solution work?
The $x = \text{change}(x)$ pattern

read 17.3
A tangent: Change a point

- What is the state of the object referred to by \( p \) after this code?

```java
public static void main(String[] args) {
    Point p = new Point(1, 2);
    change(p);
    System.out.println(p);
}

public static void change(Point thePoint) {
    thePoint.x = 3;
    thePoint.y = 4;
}

// answer: (3, 4)
```
What is the state of the object referred to by \( p \) after this code?

```java
class Point { // x, y coordinates }  
public static void main(String[] args) {  
    Point p = new Point(1, 2);  
    change(p);  
    System.out.println(p);  
}

public static void change(Point thePoint) {  
    thePoint = new Point(3, 4);  
}

// answer: (1, 2)
```
Changing references

- If a method *dereferences a variable* (with . ) and modifies the object it refers to, that change will be seen by the caller.

```java
public static void change(Point thePoint) {
    thePoint.x = 3;  // affects p
    thePoint.setY(4);  // affects p
}
```

- If a method *reassigns a variable to refer to a new object*, that change will not affect the variable passed in by the caller.

```java
public static void change(Point thePoint) {
    thePoint = new Point(3, 4);  // p unchanged
    thePoint = null;  // p unchanged
}
```

- What if we want to make the variable passed in become null?
What is the state of the object referred to by \( p \) after this code?

```java
public static void main(String[] args) {
    Point p = new Point(1, 2);
    change(p);
    System.out.println(p);
}

public static Point change(Point thePoint) {
    thePoint = new Point(3, 4);
    return thePoint;
}

// answer: (1, 2)
```
What is the state of the object referred to by \( p \) after this code?

```java
public static void main(String[] args) {
    Point p = new Point(1, 2);
    p = change(p);
    System.out.println(p);
}

public static Point change(Point thePoint) {
    thePoint = new Point(3, 4);
    return thePoint;
}
```

// answer: (3, 4)
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

```java
p = change(p); // in main

public static Point change(Point thePoint) {
    thePoint = new Point(99, -1);
    return thePoint;
}
```

We call this general algorithmic pattern **x = change(x)**;
- also seen with strings: **s = s.toUpperCase();**
The problem

- Much like with linked lists, if we just modify what a local variable refers to, it won't change the collection.

```
private void add(IntTreeNode node, int value) {
    if (node == null) {
        node = new IntTreeNode(value);
    }
}
```

- In the linked list case, how did we actually modify the list?
  - by changing the `front`
  - by changing a node's `next` field
Applying $x = \text{change}(x)$

- Methods that modify a tree should have the following pattern:
  - input (parameter): old state of the node
  - output (return): new state of the node

- In order to actually change the tree, you must reassign:
  
  node before $\rightarrow$ parameter $\rightarrow$ your method $\rightarrow$ return $\rightarrow$ node after

  ```
  node = \text{change}(node, \text{parameters});
  node.left = \text{change}(node.left, \text{parameters});
  node.right = \text{change}(node.right, \text{parameters});
  overallRoot = \text{change}(overallRoot, \text{parameters});
  ```
A correct solution

// Adds the given value to this BST in sorted order.
public void add(int value) {
    overallRoot = add(overallRoot, value);
}

private IntTreeNode add(IntTreeNode node, int value) {
    if (node == null) {
        node = new IntTreeNode(value);
    } else if (node.data > value) {
        node.left = add(node.left, value);
    } else if (node.data < value) {
        node.right = add(node.right, value);
    } // else a duplicate; do nothing
    return node;
}

- What happens when node is a leaf?