Assignment 5: Binary Search Tree (BST)

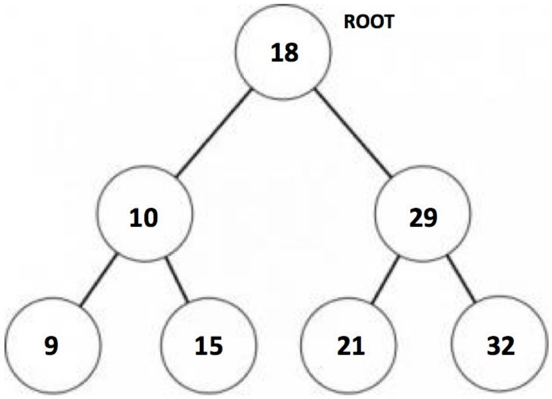
In this assignment, you will be creating a binary search tree (BST). The tree will be storing words (`Strings`), which you will insert, as well as delete, recursively. You will also be implementing tree traversals, which are different orders in which you recursively visit the items in a tree.

Point Breakdown:

- 10 points: `BinarySearchTree` class containing `BSTNode` class with constructors, `isEmpty()` and `makeEmpty()`.
- 30 points: `put()` and `contains()`
- 35 points: `delete()`
- 25 points: `inOrder()`, `preOrder()`, `postOrder()`
- 15 points (BONUS): balanceBST()

Introduction to Binary Search Trees

A binary search tree (BST) is an abstract data type, containing operations that enable users to add, remove, and traverse through nodes organized into a tree-like structure. BSTs begin with a node called the root. The root is the first item in your tree, and what your other nodes will be organized around. Below is an example of a BST with integers.



Every node can have up to two children, the left subtree and the right subtree. The data items in the left subtree are all smaller (in our case, earlier in alphabetical order) than the parent. The data items in the right subtree are all larger (in our case, later in alphabetical order) than the parent. There is no duplicate data - every data item is unique (e.g. we don't store the same word multiple times). More information on BSTs can be found in the textbook starting on page 570.

To test your BST, the main() in TestBST.java creates an instance of your BST and tests it. It makes use of the `printTreeStructure()` method that we've provided on `BinarySearchTree`. This prints out the internal structure of the tree so you can verify your operations are behaving correctly.

Implementing a BST

You will be creating a BST using a BST class called `BinarySearchTree`. It implements the interface `BSTInterface`. Along with implementing the methods in the `BSTInterface`, you will need to define a `BSTNode` class, which is similar to the `Node` class you implemented in previous assignments. `BSTNodes` will be used to store an item (the textbook calls these keys) which in this assignment are `Strings`. It will also contain references to its left and right subtrees (which as also `BSTNodes`). The `BSTNode` constructor will initialize the item to a value and the left and right nodes to `null`. `BSTNode` should be defined as an *inner class inside of* `BinarySearchTree`. The fields of BSTNode are:

- `String item`
- `BSTNode left`
- `BSTNode right`

The `BinarySearchTree` class itself only has one field, the root of the BST. The constructor for the `BinarySearchTree` only has to set the root to `null`.

We will be using `MyQueue` to store elements from traversals. That is, instead of preorder, inorder and postorder traversals printing out the elements of the tree, they will each return a `MyQueue` containing the elements in that order. The `MyQueue` class and methods will be provided for you, but you may feel free to use your own.

You will be implementing the following methods for your BST:

- `public boolean isEmpty()`

  Returns true if BST is empty, false otherwise
- `public void makeEmpty()`

  Clears BST so that it is empty

- `public MyQueue inOrder()`

  Returns a queue with the elements in-order
- `public MyQueue preOrder()`

  Returns a queue with the elements in pre-order
- `public MyQueue postOrder()`

  Returns a queue with the elements in post-order
- `public boolean contains(String s)`

  Returns true if the BST contains the string, otherwise returns false
- `public void put(String s)`

  If the string is already in the BST, then put will do nothing. If the string is not in the BST, then put will add the string to the BST.
- `public void delete(String s)`

  Removes the specified string from the BST, if the string cannot be found, then delete does nothing

Below under each operation are listed page numbers in the book that provide more information on the operation. Additionally, from pages 615-619 you can find source code for a BST, though it's a more complex implementation than we're doing. It's using Java generics with type variables, is using dictionary-style nodes with keys and values, and builds on other classes we haven't talked about. But the algorithms in the code on those pages might be helpful.

Implementing `public void put(String s)`

Implementing `put(String s)` will require creating a recursive helper method to assist with searching through the BST to find the appropriate place to put the new node. In your `put(String s)` method, you will need to call `recursiveInsert()` with the `root` of your BST as one argument and the `String` to insert as the other. Set `root` equal to the node returned from `recursiveInsert()`. The way to think about this is that you're setting the root equal to the new tree that results from doing the recursive insert.

For more information in the book, pages 602-605 describe inserting into a BST.

```
protected BSTNode recursiveInsert(BSTNode node, String s)
```

- You will have two cases to consider: 1) if `node` is `null` or 2) when `node` is not `null`.
- When `node` is `null`, this means that you've come to an empty subtree. This is where you will create the new node. Return a new `BSTNode` containing the `String`.
- If `node` is not `null`, then you need to compare the `String` argument to the item in the node.
    - If the `String s` is alphabetically before `node.item`, then we want to set the left subtree of `node` (`node.left`) equal to recursively inserting `s` into the left subtree.
    - Similarly, if the `String s` is alphabetically after `node.item`, then we want to set the right subtree of `node` (`node.right`) equal to recursively inserting `s` into the right subtree.
        - In both these cases the recursive call continues searching down the tree looking for the appropriately place to do an insert.
    - If `String s` is equal to `node.item`, we don't need to do anything. This means the `String` is already in the BST. In fact, we don't even have to explicitly test for this case since we're not going to do anything other than return the `node`.
- Return the `node`. The way to think about this is that you're returning the subtree rooted at `node` into which you've inserted the `String`.

Implementing `public boolean contains(String s)`

This method allows you to search through the BST for a specified string, `String s`. It will return true if the string is stored within the BST, false otherwise. All the work is done by the recursive helper function, `recursiveSearch()`. All that `contains()` does is return the result of calling `recursiveSearch()` with the root and the `String` as arguments.

For more information in the book, pages 600-602 describe searching a BST.

`protected boolean recursiveSearch(BSTNode node, String s)`
This helper function searches the subtree rooted at `node` for the `String s`, returning `true` if it finds it, `false` otherwise.

- If `node` is `null` we haven't found the `String`. Return `false`.
- If the `item` stored in `node` is equal to `s`, we've found the string. Return `true`.

- If `String s` is alphabetically before `node.item`, return the result of recursively searching the left subtree of `node`.
- If `String s` is alphabetically after `node.item`, return the result of recursively searching the right subtree of `node`.

Implementing `public void delete(String s)`

This method searches for `String s` and deletes the node in the BST containing it. If it does not find the specified string, then the method will do nothing.

For more information in the book, pages 605-613 describe deleting items from a BST.

The implementation of `delete(String s)` will require the assistance of three helper functions.

- `protected BSTNode recursiveRemove(BSTNode node, String s)` - given a subtree rooted at `node` and a `String s`, returns the node that is the root of the new subtree that results from removing `s` from the subtree.
- `protected BSTNode deleteNode(BSTNode node)` - given a node to remove, returns the new subtree that results from removing that node. This is the method that handles the four cases for deleting nodes: leaf nodes (no children), just a left child, just a right child, and two children (the most complicated case).
- `protected String getSmallest(BSTNode node)` - returns the alphabetically smallest (first in alphabetical order) `String` in the subtree whose root is the `node` argument.

All `delete()` does is set the root equal to the result of calling `recursiveRemove()` with the root and string as arguments.

`protected Node recursiveRemove(BSTNode node, String s)`

- This function is somewhat similar to the recursive helper functions for `put()`. If the `node` is not equal to `null`, then we need to compare `node.item` with the string.
    - If the `String s` is alphabetically before `node.item`, then we want to set the left subtree of `node` (`node.left`) equal to recursively removing `s` from the left subtree.
    - If the `String s` is alphabetically after `node.item`, then we want to set the right subtree of `node` (`node.right`) equal to recursively removing `s` from the right subtree.

    - If `String s` equals `node.item`, we want to set the `node` equal to the result of calling `deleteNode()`. This can be thought of as setting `node` equal to the new subtree that results when you delete the root of this subtree.
- If the `node` is `null` that means that we never found the string and there's nothing we have to do. So we don't even have to explicitly test for this case. We just need to skip over the tests above if the `node` is `null` (which is why there's first a test to make sure it isn't `null`).
- Return the `node`. This is the modified subtree after removing the string (or null if the node is null).

`protected BSTNode deleteNode(BSTNode node)`

`deleteNode()` handles the four cases of removing a node.

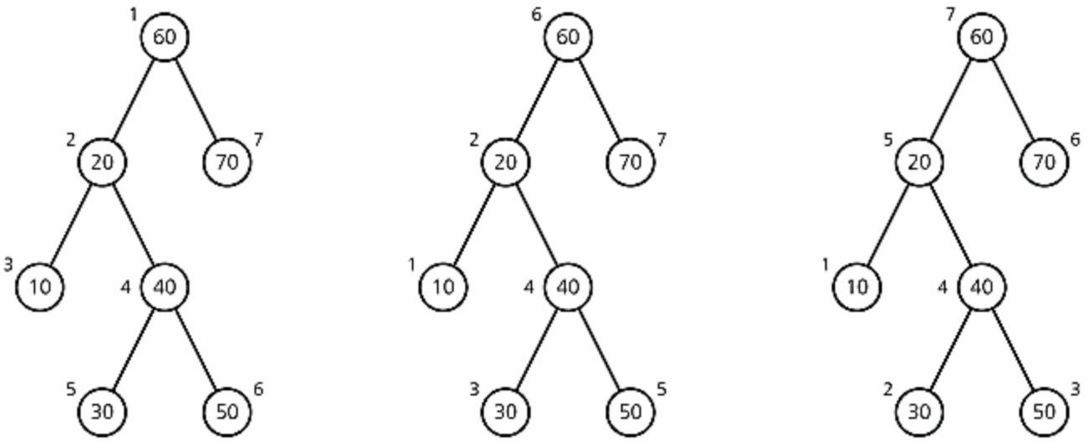
- Case 1: No children. If both the left and right children are `null` this means it is a leaf node and we can just remove it. Set `node` equal to `null`.
- Case 2: Just a left child. If there's only a left child, then set `node` equal to `node.left`. The one child is "promoted" into being the root of the subtree.
- Case 3: Just a right child. If there's only a right child, then set `node` equal to `node.right`. The one child is "promoted" into being the root of the subtree.
- Case 4: Two children. With two children we have to do something more complicated to rearrange the subtree.
    - Call `getSmallest()` on the subtree `node.right` to get the in-order successor. This is the smallest value that is larger than the current `node.item` (the next item in alphabetical order stored in the tree).
    - Set `node.item` equal to this in-order successor. The left and right child relationships will still hold: everything to the left will still be alphabetically before the new item and everything to the right will still be alphabetically after the new item (since the new item is the smallest value from the right subtree).
    - Set `node.right` equal to recursively removing the in-order successor from the right subtree. Since you've moved this value into the current node, you can now delete the value from the right subtree. When `recursiveRemove()` ends up calling `deleteNode()` again, the in-order successor is guaranteed to be one of the "easy" cases (0 or 1 child).
- Return `node`.

`protected String getSmallest(BSTNode node)`

- To start the process for finding the smallest string in the subtree rooted at `node`, define a `String` variable `smallest` and set it equal to `node.item`.

- Now we'll keep on following left branches in the tree (since things to the left are always smaller values), until we can't go left any more. Then we know we've found the smallest value.
    - While `node.left` is not null
        - Set `smallest` equal to `node.left.item`.
        - Set `node` equal to `node.left`.
- Return `smallest`.

Traversing BSTs



(a) Preorder: 60, 20, 10, 40, 30, 50, 70 (b) Inorder: 10, 20, 30, 40, 50, 60, 70 (c) Postorder: 10, 30, 50, 40, 20, 70, 60

(Numbers beside nodes indicate traversal order.)

In this portion of the assignment, you will be implementing these methods, which enable you to traverse through your BST:

`public MyQueue inOrder()`: Does an in-order traversal to return a queue of strings in-order. This is the strings in alphabetical order.

`public MyQueue preOrder()`: Does a pre-order traversal to return a queue of strings pre-order. This is the order in which you'd want to insert the strings into a new tree to replicate the tree structure.

`public MyQueue postOrder()`: Does a post-order traversal to return a queue of strings post-order. This is the order of strings from the leaves upward, starting from the left and going rightward.

For examples of how these traversals work and further information, you may visit the following links:

https://www.youtube.com/watch?v=gm8DUJJhmY4

https://www.youtube.com/watch?v=5dySuyZf9Qg

https://www.tutorialspoint.com/data_structures_algorithms/tree_traversal.htm

Each of the functions has a recursive helper function:

- `void inOrderRecursive(BSTNode node, MyQueue queue)`
- `void preOrderRecursive(BSTNode node, MyQueue queue)`
- `void postOrderRecursive(BSTNode node, MyQueue queue)`

Implementing `public MyQueue inOrder()`

- Create a new `MyQueue`.
- Call inOrderRecursive() with the `root` and the new `MyQueue` as arguments.
- Return the `MyQueue`.

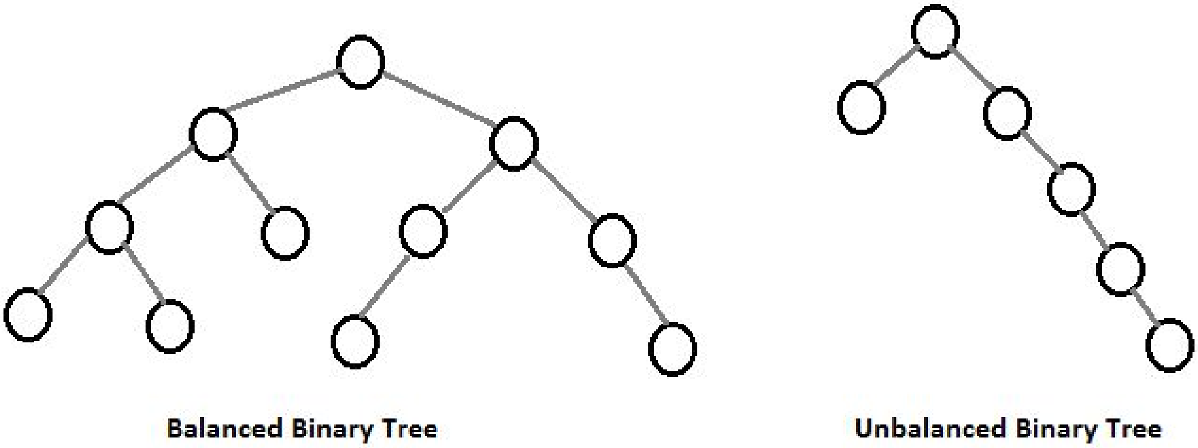
Implementing `preOrder()` and `postOrder()` follow the same pattern.

Implementing `protected void inOrderRecursive(BSTNode node, MyQueue queue)`

- If the node is not null
    - Recursively call `inOrderRecursive()` on the left subtree.
    - Add `node.item` to the queue.
    - Recursively call `inOrderRecursive()` on the right subtree.

Each of the other recursive helpers follow the same pattern. For pre-order, you add to the queue first, then recursively process the left and right subtrees, while for post-order you recursively process the left and right subtrees first, then add the current `node.item` to the queue at the end.

EXTRA CREDIT: Balancing Unbalanced BSTs



As an extra credit method, you can choose to implement `public void balanceBST()`, which will balance an unbalanced BST. An unbalanced BST contains right and left subtrees with a significantly different numbers of nodes in each subtree. This makes recursive searching operations inefficient.

Implementing `public void balanceBST()`

To balance a BST, you want to get the values into a sorted array. Then you can recursively divide the array into halves, inserting middle values of each of the recursive halves (kind of like a binary search algorithm) into a new tree.

- Use `inOrder()` to get a queue of the BST values in sorted order.
- Since `MyQueue` doesn't implement a size operation, you'll need to create a temporary queue and `dequeue()` elements into the temporary queue, counting them as you do so.
- Once you have a count, create a `String[]` of this size and copy values from the temporary queue into the array.
- Empty the BST.
- Call the recursive helper `BSTNode balanceRecursive(String[] array, int first, int last)`, where `first` and `last` are the initial and final index of the array, setting root equal to the return value.

```
protected BSTNode balanceRecursive(String[] array, int first, int
last)
```

Think about how binarySearch worked. You'll want to do something similar, except that the string at the mid value is what you'll use to make a new BSTNode. The left and right children should be set equal to recursive calls to balanceRecursive(), then you'll want to return the node you created. The base case should return null (this corresponds to a child of a leaf).

Turning the code in

- Create a directory with the following name: `<student ID>_assignment5` where you replace `<student ID>` with your actual student ID. For example, if your student ID is 1234567, then the directory name is `1234567_assignment5` .
- Put a copy of your edited files in the directory.
- Compress the folder using zip. Zip is a compression utility available on mac, linux and windows that can compress a directory into a single file. This should result in a file named `<student ID>_assignment5.zip` (with `<student ID>` replaced with your real ID of course).
- Upload the zip file through the page for Assignment 5 in canvas.