CSCI 136
Data Structures & Advanced Programming

Lecture 24

Fall 2018

Instructor: Bills

Administrative Details

- Lab 8 today!
- You can work with a partner
- Bring a design to lab
- Try to take advantage of
  - Abstract base classes/inheritance
  - Data structures you've learned

Last Time

- Heapifying an array
  - Top-Down vs Bottom-up
- Heapsort
- Skew Heaps: A Mergeable Heap Structure

Today' s Outline

- Lab 8
- Binary search trees (Ch 14)
  - Overview
  - Definition
  - Some Applications
  - The *locate* method
  - Further Implementation

Improving on OrderedVector

- The OrderedVector class provides O(log n) time searching for a group of n comparable objects
  - add() and remove(), though, take O(n) time in the worst case---and on average!
- Can we improve on those running times without sacrificing the O(log n) search time?
- Let's find out....

Binary Trees and Orders

- Binary trees impose multiple orderings on their elements (pre-/in-/post-/level-orders)
- In particular, in-order traversal suggests a natural way to hold comparable items
  - For each node v in tree
    - All values in left subtree of v are ≤ **v**
    - All values in right subtree of v are ≥ **v**
- This leads us to...

Binary Search Trees

- Binary search trees maintain a *total* ordering among elements (assumes comparability)
- Definition: A BST T is either:
  - Empty
  - Has root r with subtrees T_L and T_R such that
    - All nodes in T_L have smaller value than r
    - All nodes in T_R have larger value than r
    - T_L and T_R are also BSTs

BST Observations

- The same data can be represented by many BST shapes
- Searching for a value in a BST takes time proportional to the height of the tree
  - Reminder: trees have height, nodes have depth
- Additions to a BST happen at nodes missing at least one child (*a constraint!*)
- Removing from a BST can involve *any* node

BST Operations

- BSTs will implement the OrderedStructure Interface
  - `add(E item)`
  - `contains(E item)`
  - `get(E item)`
  - `remove(E item)`
  - Runtime of above operations?
    - All O(h) – where h is the tree height
  - `iterator()`
    - `This will provide an in-order traversal`

BST Implementation

- The BST holds the following items
  - BinaryTree root: the root of the tree
  - BinaryTree EMPTY: a static empty BinaryTree
    - To use for all empty nodes of tree
  - int count: the number of nodes in the BST
  - Comparator<E> ordering: for comparing nodes
    - Note: E must implement Comparable
- Two constructors: One takes a Comparator
  - Other creates a NaturalComparato

BST Implementation: locate

- Several methods search the tree
  - add, remove, contains
- We factor out common code: locate method
- *protected* locate(BinaryTree<E> *node*, E *v*)
  - Returns a BinaryTree<E> *n* in the subtree with root *node* such that either
    - *n* has its value equal to *v*, or
    - *v* is not in this subtree and *n* is the node whose child *v* should be
- How would we implement locate()?

BST Implementation: locate

```
BinaryTree locate(BinaryTree root, E value)
    if root's value equals value return root
    child ← child of root that should hold value
    if child is emptry tree, return root
        // value not in subtree based at root
    else //keep looking
        return locate(child, value)
```

BST Implementation: locate

- What about this line?

  child 🡐 *child of root that should hold value*
- If the tree can have multiple nodes with same value, then we need to be careful
- Convention: During *add* operation, only move to right subtree if value to be added is *greater than* value at node
- We'll look at *add* later
- Let's look at *locate* now....

The code : locate

```
protected BinaryTree<E> locate(BinaryTree<E> root, E value) {
       E rootValue = root.value();
       BinaryTree<E> child;

       // found at root: done
       if (rootValue.equals(value)) return root;

       // look left if less-than, right if greater-than
       if (ordering.compare(rootValue,value) < 0)
           child = root.right();
       else
           child = root.left();

       // no child there: not in tree, return this node,
       // else keep searching
       if (child.isEmpty()) return root;
       else
           return locate(child, value);
}
```

Other core BST methods

- locate(v) returns either a node containing v or a node where v can be added as a child
- locate() is used by
  - `public boolean contains(E value)`
  - `public E get(E value)`
  - `public void add(E value)`
  - `Public void remove(E value)`
- Some of these also use another utility method
  - `protected BT predecessor(BT root)`
- Let's look at contains() first...

Contains

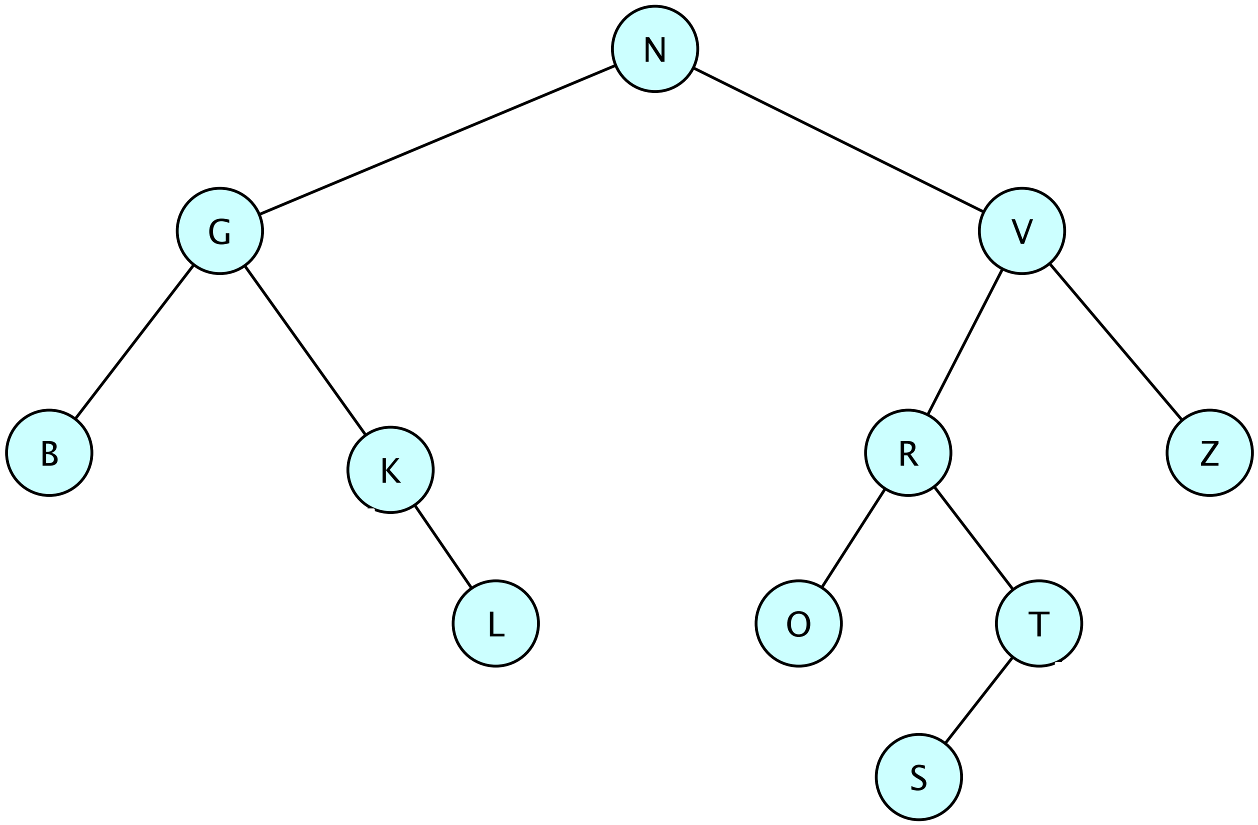
```
public boolean contains(E value){
   if (root.isEmpty()) return false;

   BinaryTree<E> possibleLocation = locate(root,value);

   return value.equals(possibleLocation.value());
}
```

First (Bad) Attempt: add(E value)

```
public void add(E value) {
        BinaryTree<E> newNode = new BinaryTree<E>(value,EMPTY,EMPTY);
        if (root.isEmpty()) root = newNode;
        else {
                BinaryTree<E> insertLocation = locate(root,value);
                E nodeValue = insertLocation.value();
        if (ordering.compare(nodeValue,value) < 0)
                insertLocation.setRight(newNode);
        else
                insertLocation.setLeft(newNode);
        }
        count++;
}
```

Problem: If repeated values are allowed, left subtree might not be empty when setLeft is called

Add: Repeated Nodes



Where would a new K be added?
A new V?