CS211, LECTURE 20
SEARCH TREES

ANNOUNCEMENTS:

OVERVIEW:

• motivation
• naive tree search
• sorting for trees and binary trees
• new tree classes
• search
• insert
• delete
1. Motivation

1.1 Search Structure

- continuing
- did linear; now want hierarchical
- so, use trees

1.2 Search Trees

- special trees organized for searching
- focus on binary search trees because of binary tree focus
- advanced topics later: balanced trees

1.3 Interface to implement

```java
interface SearchStructure {
    void insert(Object o);
    void delete(Object o);
    boolean search(Object o);
    int size();
}
```
2. Searching A Tree

2.1 Assume built “at random” (no sorting)

2.2 Tree Traversal

- visit each node and do something with it
- depth-first: pre, post, in (for binary trees)
- breadth-first (also, level-order): each level at a time

2.3 Searching

- could do a traversal for search
- expensive: might have to search every node
2.4 Example of “complete” traversal

- Algorithm:
  - if current node is null, return false
  - else if current node has data, return true
  - else search left branch and search right branch; return result of checking if data is at any node
- Use CONDITIONAL OR (||) to help
- Code:

```java
// In BinaryNode class:
public boolean naivefind(Object o, BinaryNode n) {
    if (n == null)
        return false;
    else if (o.equals(n.item))
        return true;
    else
        return naivefind(o, n.left) || naivefind(o, n.right);
}
```
2.5 Improvements

- use parent links (no recursion needed)
- sort the tree, as we did with arrays (rest of lecture!)

2.6 More info on traversal:

- free DS&A!
  http://www.brpreiss.com/books/opus5/html/
- see Chap 9 (Tree Traversal)

2.7 General Trees?

- using binary trees (see Lecture 18)
- searching general tree anyway? (Preiss: M-Way search tree in 10.6)
3. Binary Search Tree

3.1 Properties of BST:

- For given data at a node (root, root of subtree),
  - all nodes with data smaller than data are stored in the left subtree
  - all nodes with data bigger than data are stored in the right subtree
- What about nodes with data equal to data? no repeats
4. **Binary Search Tree Intuition**

- sort a list
- “grab middle” of list (search “halves” instead of whole)
- middle becomes root of tree
- sublists to left and right of root “flop” down
- detach the sublists and repeat process of grab & lift
- hook roots of the sublists to the previous root
- repeat until no more elements
5. Stubbed Out BST

abstract public class BinarySearchTree implements SearchStructure {
    private BinaryNode root;
    // more fields?

    public BinarySearchTree() { root = null; }
    public void insert(Object o);
    public void delete(Object o);
    public boolean search(Object o);
    public int size();

    // helper methods?
    // more methods?
}

Search Trees

Stubbed Out BST
6. Search

6.1 Algorithm:

- if tree is empty, return false
- if root object == search object, return true
- if root object < search object, search right subtree
- if root object > search object, search left subtree

6.2 Code:

```java
public boolean search(Object o) {
    BinaryNode n = mySearch(o, root);
    // no empty tree, double check data:
    return ( n!=null && n.getItem().equals(o) );
}

// search helper:
private BinaryNode mySearch(Object o, BinaryNode r) {
    if (r == null) return null;
    int test = ((Comparable) r.getItem()).compareTo(o);
    if (test > 0)
        return mySearch(o, r.getLeft());
    else if (test < 0)
        return mySearch(o, r.getRight());
    else
        return r;
}
```
7. Search for Max

7.1 Algorithm:

- If empty, return null
- Check right: if empty, return root value; otherwise, find rightmost leaf on the rightmost subtree

7.2 Code:

```java
public Comparable findMax() {
    return findMax(root);
}

public Comparable findMax(BinaryNode r) {
    if (r == null)
        return null;
    if (r.getRight() == null)
        return (Comparable) r.getItem();
    else
        return findMax(r.getRight());
}
```
8. Checking if Tree is BST

8.1 Algorithm:

- If tree is empty or leaf -> BST
- Else, internal node:
  - compute smallest and largest values in left and right subtrees
  - check if subtrees are also BSTs
  - BST if both subtrees are BSTs and
    largest object in left subtree is < root object and
    smallest object in right subtree is > root object

8.2 Advice

- perform post-order walk of tree:

```
56
33  67
8  60  80
```
9. Insertion

9.1 Algorithm:

- Search for object o in BST (assume no dupsl)
- if at leaf (and empty root) make a new node with o
- else, if o < subtree root item, insert into left subtree
- else, if o > subtree root item, insert into right subtree

9.2 Code:

```java
public void insert (Object o) {
    root = insert(o,root);
    size++;
}

private BinaryNode insert(Object o, BinaryNode r) {
    if (r == null)
        r = new BinaryNode(o);
    else if (((Comparable) r.getItem()).compareTo(o) > 0)
        r.setLeft(insert(o,r.getLeft()));
    else if (((Comparable) r.getItem()).compareTo(o) < 0)
        r.setRight(insert(o,r.getRight()));
    return r; // actually, not good (no dupsl)
}
```
9.3 Alternative Algorithm

- Search for o
- during search, set these cursors/fingers:
  - current: node where search ends
  - previous: parent of current node
- if at leaf or empty tree, make new node with o
- insert at previous node: based on o and root’s item,
  - insert left or
  - insert right
- see testBST.java for original version
9.4 Example (see TestBST.java)

public class TestBST {
    public static void main( String [] args ) {

        BST bst = new BST();

        BinaryNode b5 = new BinaryNode(new Integer(5));
        bst.setRoot(b5);

        BinaryNode b2 = new BinaryNode(new Integer(2));
        BinaryNode b3 = new BinaryNode(new Integer(3));
        BinaryNode b4 = new BinaryNode(new Integer(4));
        BinaryNode b6 = new BinaryNode(new Integer(6));
        BinaryNode b9 = new BinaryNode(new Integer(9));

        b5.setLeft(b3);
        b5.setRight(b6);
        b3.setLeft(b2);
        b3.setRight(b4);
        b6.setRight(b9);

        bst.insert(new Integer(0));
        bst.insert(new Integer(1));
        bst.insert(new Integer(7));
        bst.insert(new Integer(8));
        bst.insert(new Integer(10));

        System.out.println(bst.toTree());
    }
}
9.5 Session

Note: I modified `toTree()` in `BinaryNode`!

```
5
|___3
|   |___2
|   |   |___0
|   |   |   |___1
|   |   |   |___
|   |   |___
|   |___4
|   |___
|___6
|   |___9
|   |___
|___7
|   |___8
|   |___10
|   |___
```
9.6 Modified toTree

- now Tree-i-fying leaves
- can distinguish between left and right subtrees
- code could be cleaned up…
- Code:

```java
public String toTree(String blank, String spacing) {
    String s = "" + item + "\n";
    if (left == null)
        s += spacing + "\n";
    else
        s += spacing + left.toTree(blank, blank+spacing);
    if (right == null)
        s += spacing + "\n";
    else
        s += spacing + right.toTree(blank, blank+spacing);
    return s;
}
```
10. Deleting

10.1 Easy cases:

- leaf (9): change ref in parent (8) to null
- 1 child (6): change parent’s (3) child to child’s child (4) (so, 3’s child becomes 4)
10.2 Node has two children?

- a bit harder
- more general algorithm for deleting node N with item i:
  - walk down tree until you find N with i
  - let p be parent of N
  - if left subtree of N is null, make right subtree of N into subtree of p
  - if left subtree of N is not empty, extract max value from left subtree of N and stick that into N
11. Exercises

• Write a recursive \texttt{findMin}.
• Write iterative versions of \texttt{search}, \texttt{findMax}, \texttt{findMin}, and \texttt{insert}.
• Write method \texttt{checkBST} to check if a tree is a BST.
• Write \texttt{delete}... see \texttt{testBST} and textbooks for course.