

CS211, LECTURE 20

SEARCH TREES

ANNOUNCEMENTS:

OVERVIEW:

- motivation
- naive tree search
- sorting for trees and binary trees
- new tree classes
- search
- insert
- delete

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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

```
interface SearchStructure {  
    void insert(Object o);  
    void delete(Object o);  
    boolean search(Object o);  
    int size();  
}
```

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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

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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:

```
// 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);  
}
```

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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)

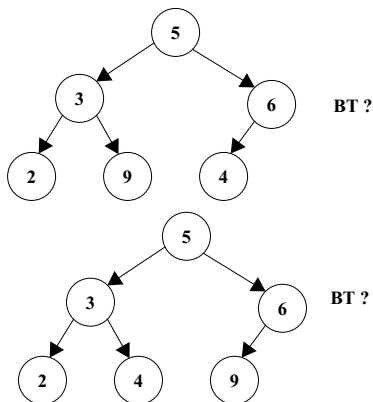
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3. Binary Search Tree

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



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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

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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?
}
```

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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:

```
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;
}
```

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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:

```
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());
}
```

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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
```

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9. Insertion

9.1 Algorithm:

- Search for object o in BST (assume no dups!)
- 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:

```
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 dups!)
}
```

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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

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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);

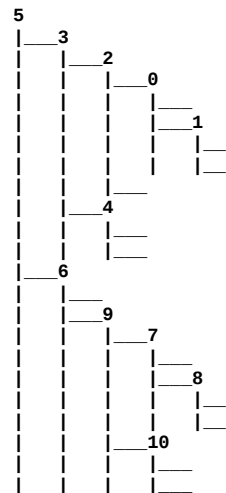
        bst.insert(new Integer(0));
        bst.insert(new Integer(1));
        bst.insert(new Integer(7));
        bst.insert(new Integer(8));
        bst.insert(new Integer(10));

        System.out.println(bst.toTree());
    }
}
```

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9.5 Session

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



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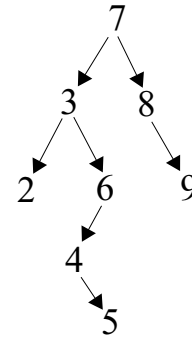
9.6 Modified toTree

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

```
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;
}
```

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10. Deleting



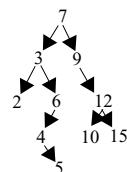
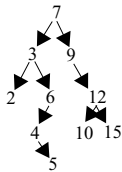
10.1 Easy cases:

- 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)

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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



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11. Exercises

- Write a recursive **findMin**.
- Write iterative versions of **search**, **findMax**, **findMin**, and **insert**.
- Write method **checkBST** to check if a tree is a BST.
- Write **delete**...see **testBST** and textbooks for course.

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