Election Day is TODAY! If you are eligible to vote, vote! Polls close at 7pm.
https://myvote.wi.gov/

Program 4 assigned yesterday

Midterm Exam 2: Tuesday, November 15th, 5:00 pm – 7:00 pm
- Lecture 1: Room 105 of Psychology Building
- Lecture 2: Room 6210 of Sewell Social Sciences
- Lecture 3: Room 132 of Noland Hall

Last Time
General Trees
- determining tree height
Binary Trees
- implementing
Tree Traversals
Categorizing ADTs Part 2
Binary Search Tree (BST)

Today
Binary Search Tree (BST)
- BSTnodes
- BST class
- implementing print
- implementing lookup, insert, delete
- complexities of BST methods

CS Options/Courses

Next Time
Read: Red-Black Trees
Classifying Binary Trees
Balanced Search Trees
Red-Black Trees
- tree properties
- print, lookup
- insert
Recall BSTs and BSTnodes

BST – Binary Search Tree
- is a key-value oriented collection of items where duplicate keys are not allowed
- goal: combine speed of binary search for access in an array $O(1)$
  with speed of linking/unlinking in a chain of nodes $O(n)$
- shape constraint: binary tree structure
- order constraint:

- in lecture, we’ll explore BSTs with items having only a key value
  see readings for items having a key value and an associated value

BSTnode Class

class BSTnode<K> {

    private K key;
    private BSTnode<K> left, right;

    public BSTnode(K key, BSTnode<K> left, BSTnode<K> right) {
        this.key = key;
        this.left = left;
        this.right = right;
    }

    public K getKey() { return key; }
    public BSTnode<K> getLeft() { return left; }
    public BSTnode<K> getRight() { return right; }

    public void setKey(K newK) { key = newK; }
    public void setLeft(BSTnode<K> newL) { left = newL; }
    public void setRight(BSTnode<K> newR) { right = newR; }
}

→ Draw a picture of the memory layout of a BSTnode.
import java.io.*;  //for PrintStream

public class BST<K extends Comparable<K>> { 
    private BSTnode<K> root;
    public BST() { root = null; }
    public void insert(K key)
        throws DuplicateException {
    
    }
    public void delete(K key) {
    
    }
    public boolean lookup(K key) {
    
    }
    public void print(PrintStream p) {
    
    }
    //add helpers ...
}
Implementing `print`

→ **Write a recursive definition** to print a binary tree given `n`, a reference to a BSTnode.

```
    37
   / \
 10   49
 / \
8 25 41 84
```

→ **Complete the print method based** on the recursive definition.

```java
public void print( PrintStream p ) {   print( root, p ); }

private void print( BSTnode<K> n, PrintStream p ) {
```
Implementing lookup and insert

Pseudo-Code Algorithm for lookup

private boolean lookup(BSTnode<K> n, K key) {

High-Level Algorithm for insert

private BSTnode<K> insert(BSTnode<K> n, K key)
    throws DuplicateException {
Practice - Inserting into a BST

→ Insert 5, 27, 90, 73, 57 into the tree above.

→ What is the shape of a BST when values are inserted in sorted order?

→ Will you get a bad shape only if values are inserted in sorted order?
Implementing delete

High-Level Algorithm

private BSTnode<K> delete( BSTnode<K> n, K key ) {
Practice - Deleting from a BST

→ Delete 90 from the tree above.
→ Delete 40 and 65 from the tree above.

→ Delete 10 and 70 from the tree above and redraw the tree.

→ How do you delete 50 or 30 from the tree above?
Implementing delete (cont.)
Practice - Deleting from a BST

→ Delete 30 from the tree above using the _____________ ____________.

→ Delete 50 from the tree above using the _____________ ____________.
Complexities of BST Methods

Problem size: $N =$

print:

lookup:

insert:

delete:
CS Options

CS Certificate

5 CS Courses (12 credits minimum)
- Data Structures – CS 367 (& possibly prereq 302)
- 2 CS Courses >=400 level
- 2 Other CS Courses

CS Major

Basic CS
- Discrete Math – CS 240
- Programming + Data Structures – CS 302, CS 367
- Basic Systems – CS 252, CS 354

Math
- Calculus – MA 221, MA 222
- 2 Beyond Calc – STATS 324 (intro applied stats), MA 340 (linear algebra)

Group A Theory
- Algorithms – CS 577

Group B Hardware/Software
- OS – CS 537

Group C Applications
- AI – CS 540

Group D Electives
- 2 CS Courses >=400 level

CS Double Major

- Must complete major requirements
- Easy for Computer Engineering Majors
CS Courses

Take Next

- CS 240 Introduction to Discrete Mathematics
- CS 252 Introduction to Computer Engineering (prereq for CS 354)
- CS 354 Machine Organization and Basic Systems (prereq for many group B)
- (CS 368) Learning a New Programming Language (C++ for CS 537)

- NOTE: CS 352 Digital Systems Fundamentals no longer required

>= 400 can take after CS 367

- CS 407 Foundations of Mobile Systems (spring, popular)
- CS 540 Introduction to Artificial Intelligence
- CS 570 Human Computer Interaction (spring)

>= 400 can take after CS 367 + Math

- CS 412 Introduction to Numerical Methods – MA 222 + MA 234 or CS 240
- CS 435 Introduction to Cryptography – MA 320 or MA 340
- CS 525 Linear Programming Methods – MA 320 or MA 340 or MA 443
- CS 533 Image Processing – MA 320 or MA 340 (fall)
- CS 559 Computer Graphics – MA 320 or MA 340
- CS 576 Introduction to Bioinformatics – MA 222 (fall)
- CS 577 Introduction to Algorithms – CS 240