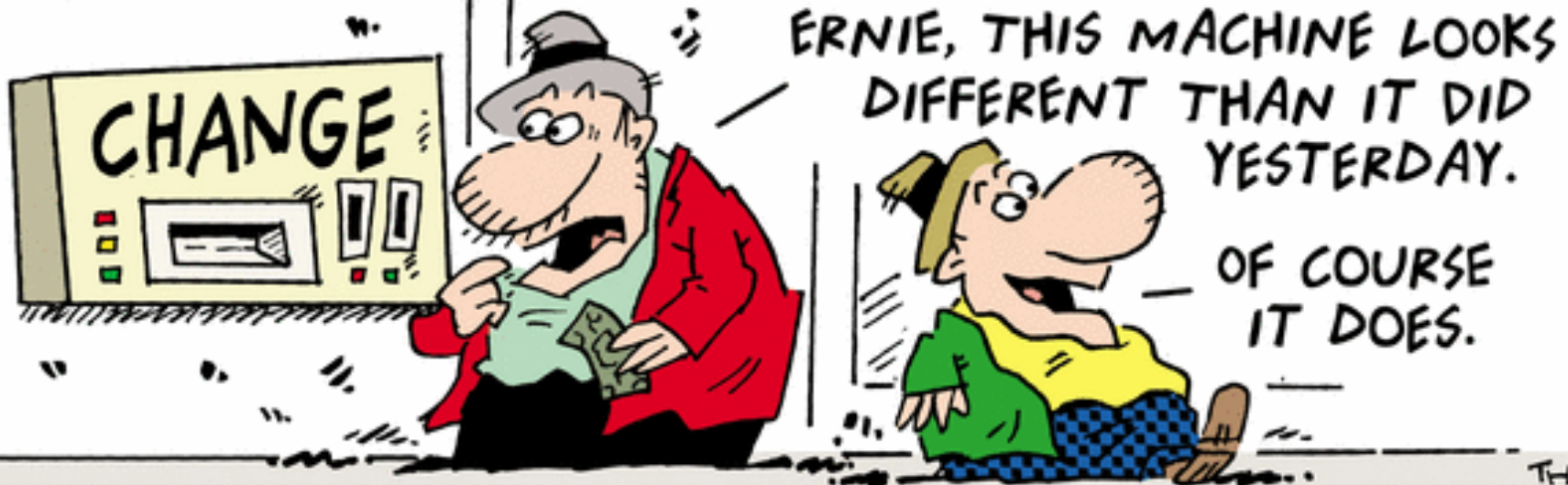


# CSSE 230 Day 10

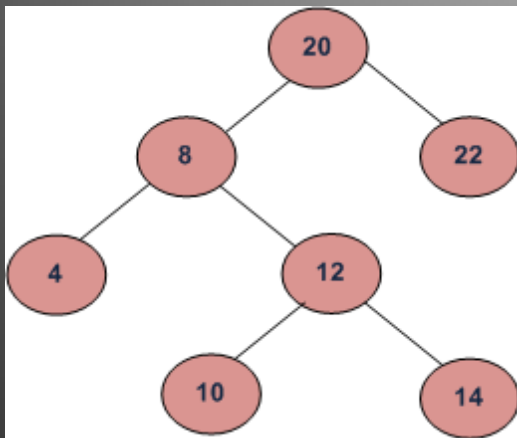
## Binary Search Tree intro BST with order properties

- After today, you should be able to...
- ... implement insertion into a BST
  - ... implement search (contains) in a BST
  - ... implement deletion from a BST

# Questions?



# Binary Search Trees



Binary Trees that store elements in increasing order

A Binary Search Tree (BST) allows easy and fast lookup of its items because it keeps them ordered

## Draw a "birthday BST"

- A BST is a Binary Tree  $T$  with these properties:
  1. Elements are Comparable, and non-null
  2. No duplicate elements (we implement TreeSet)
  3. All elements in  $T$ 's left subtree are less than the root element
  4. All elements in  $T$ 's right subtree are greater than the root element
  5. Both subtrees are BSTs
- **Advantage:** Lookup of items is  $O(\text{height}(T))$
- What does the inorder traversal of a BST yield?

# BST insert, contains, and delete need to maintain BST properties

```

public class BinarySearchTree<T extends Comparable<T>> {

    private BinaryNode root;

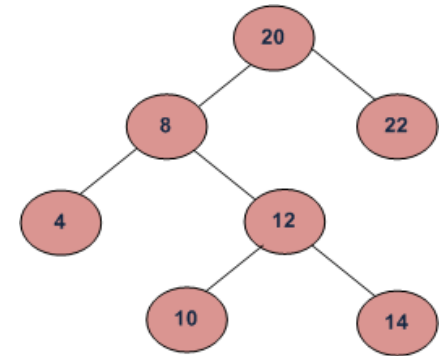
    public BinarySearchTree() {
        this.root = NULL_NODE; // or null;
    }
    // insert obj. If already there, return false
    public boolean insert(T obj)

    // delete obj. If not there, return false
    public boolean delete(T obj)
        // 3 cases (see text)

        https://en.wikipedia.org/wiki/Binary\_search\_tree#Deletion
        http://stackoverflow.com/questions/21800298/remove-a-node-in-binary-search-tree
        Hibbard deletion: http://dl.acm.org/citation.cfm?id=321108

    // Does this tree contain obj?
    public boolean contains(T obj)

```



# Implementation issues, part 1 (notes from spec)

- The **recursive BinaryNode** insert() and delete() in the text return BinaryNodes. So how do the BinarySearchTree methods return Booleans?
- Could let the Boolean be a tree field. But could encapsulate better.
- Can the helper method return 2 things?
  - Create a simple composite class to hold both a boolean and a BinaryNode.
- Can you pass a parameter to the helper method and mutate it?
  - Parameters are call-by-value, so primitives can't be mutated.
  - Pass a simple BooleanContainer object so you can mutate the Boolean inside.

# Implementation issues, part 2

- Modifying (inserting/deleting) from a tree should cause any current iterators to fail (throw a `ConcurrentModificationException`).
  - How do you detect this?
- How do you remove from an iterator?
  - Just call `BST remove()`.
  - But throw exceptions if `next()` hasn't been called, or if `remove` is called twice in a row. (Javadoc for `TreeSet` iterator has details.)