CSE 143
Lecture 20

Binary Search Trees continued; Tree Sets

read 17.3 - 17.5

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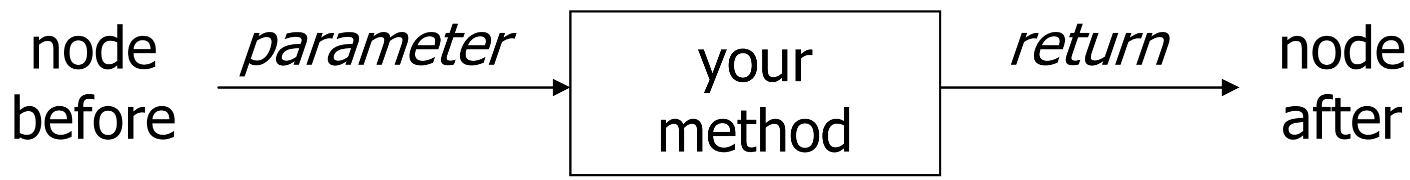
http://www.cs.washington.edu/143/

Recall: x = change(x)

- Methods that modify a tree should have the following pattern:
  - input (parameter): old state of the node
  - output (return): new state of the node

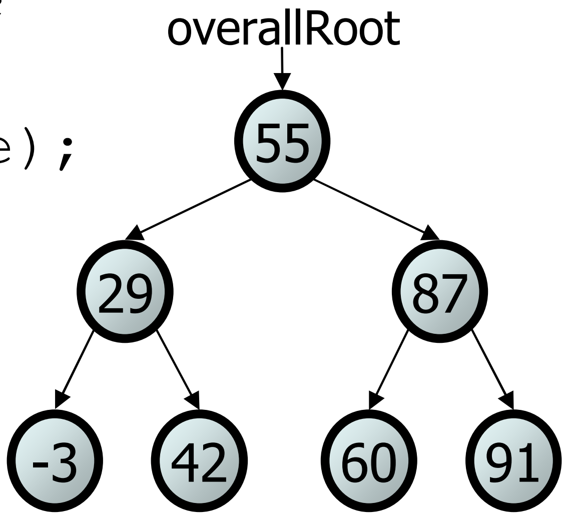


- In order to actually change the tree, you must reassign:

```
node        = change(node, parameters);
node.left   = change(node.left, parameters);
node.right  = change(node.right, parameters);
overallRoot = change(overallRoot, parameters);
```

Add method

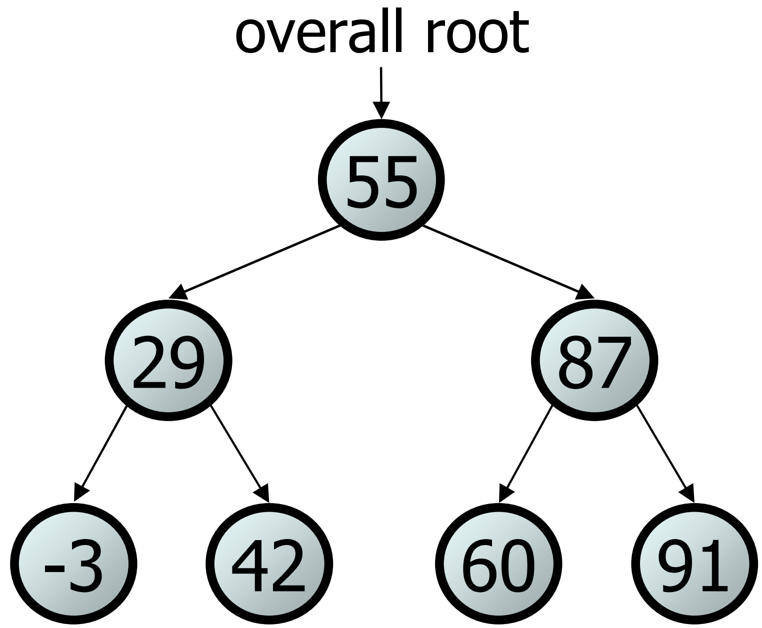
```
// Adds the given value to this BST in sorted order.
public void add(int value) {
    overallRoot = add(overallRoot, value);
}

private IntTreeNode add(IntTreeNode node, int value) {
    if (node == null) {
        node = new IntTreeNode(value);
    } else if (node.data > value) {
        node.left = add(node.left, value);
    } else if (node.data < value) {
        node.right = add(node.right, value);
    } // else a duplicate

    return node;
}
```



Exercise

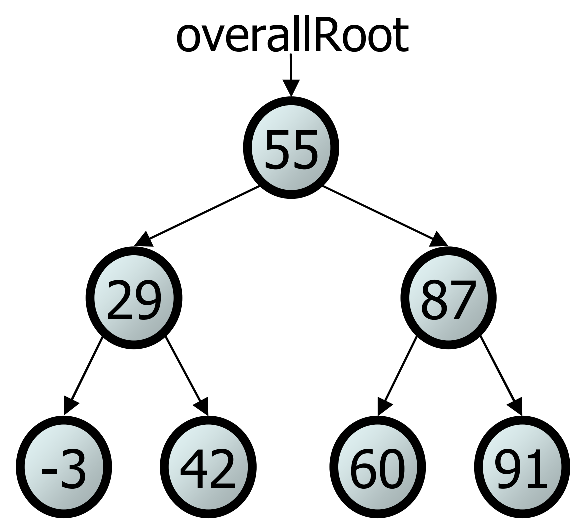
- Add a method `getMin` to the `IntTree` class that returns the minimum integer value from the tree. Assume that the elements of the `IntTree` constitute a legal binary search tree. Throw a `NoSuchElementException` if the tree is empty.

```
int min = tree.getMin();  // -3
```



Exercise solution

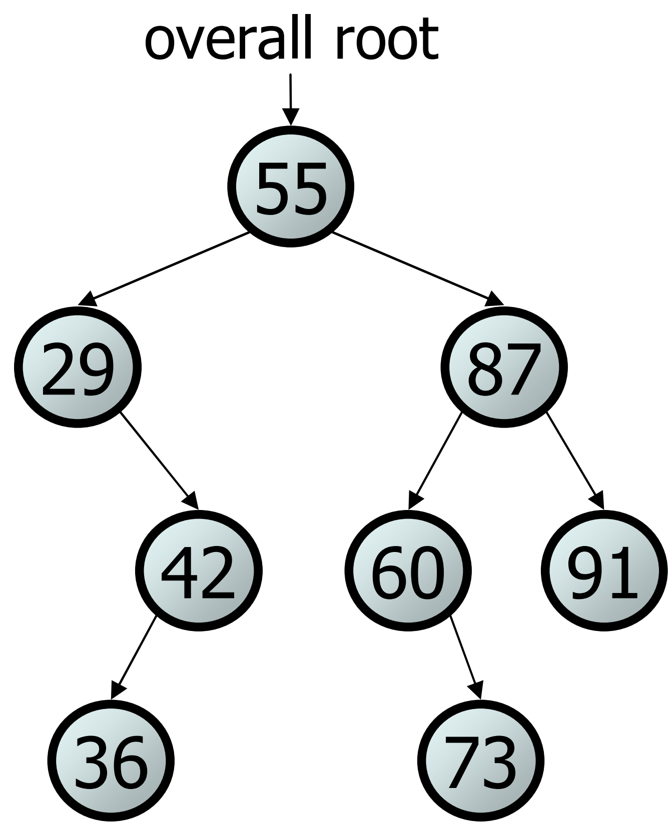
```
// Returns the minimum value from this BST.
// Throws a NoSuchElementException if the tree is empty.
public int getMin() {
    if (overallRoot == null) {
        throw new NoSuchElementException();
    }
    return getMin(overallRoot);
}

private int getMin(IntTreeNode root) {
    if (root.left == null) {
        return root.data;
    } else {
        return getMin(root.left);
    }
}
```



Exercise

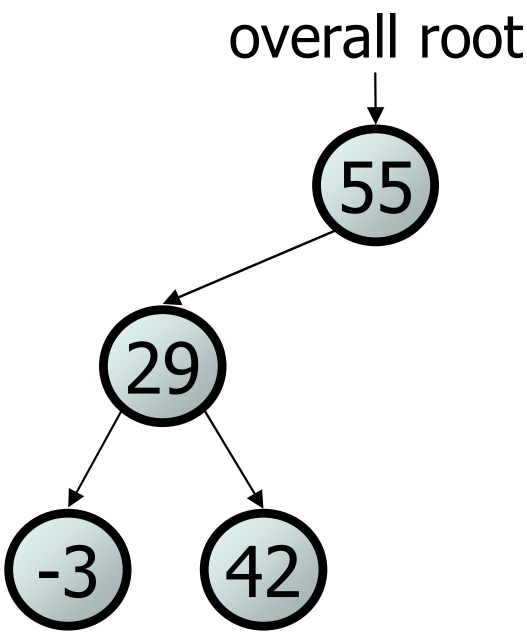
- Add a method `remove` to the `IntTree` class that removes a given integer value from the tree, if present. Remove the value in such a way as to maintain BST ordering.

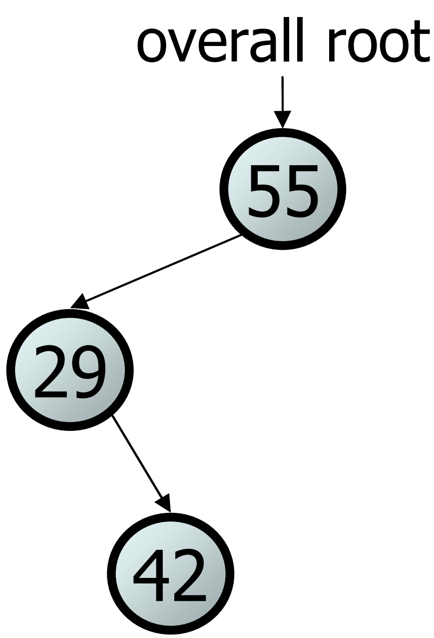
    - `tree.remove(73);`
    - `tree.remove(29);`
    - `tree.remove(87);`
    - `tree.remove(55);`

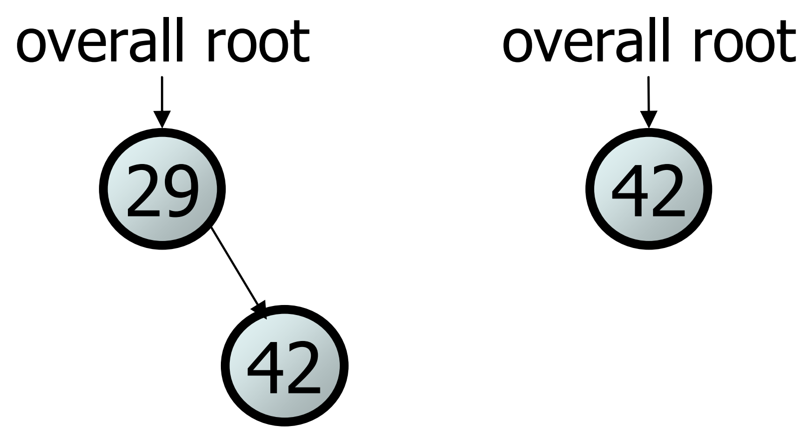


Cases for removal 1

1. a **leaf**: replace with `null`
2. a node with a **left child only**: replace with left child
3. a node with a **right child only**: replace with right child





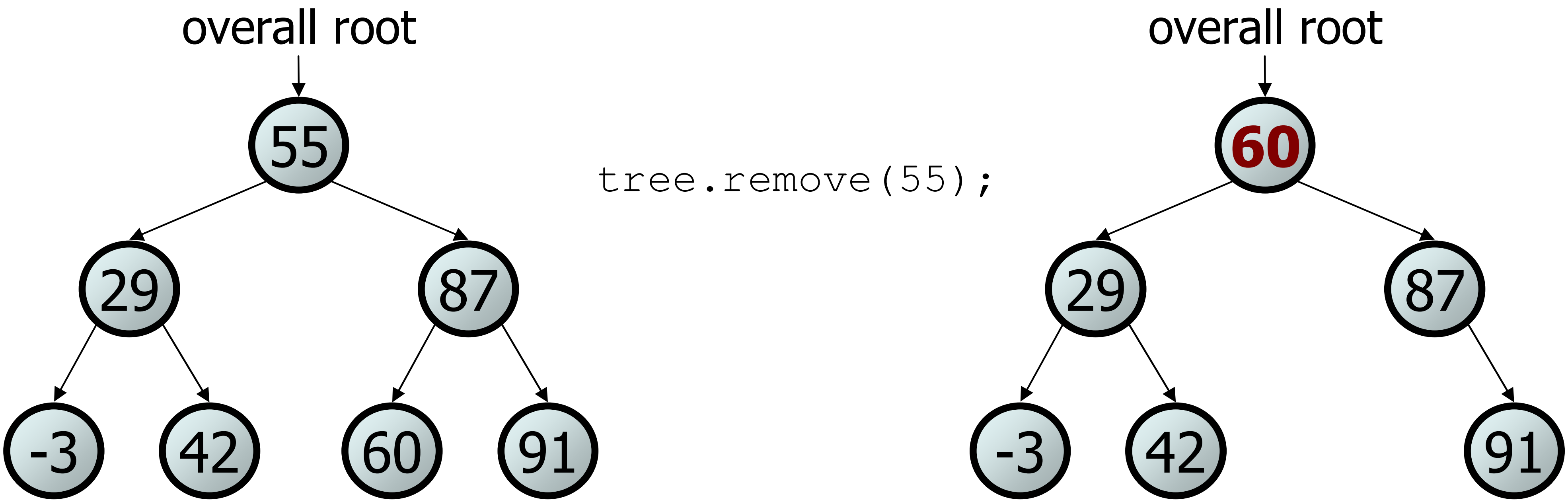


`tree.remove(29);`

`tree.remove(-3);` `tree.remove(55);`

Cases for removal 2

4. a node with **both** children: replace with **min from right**
   - (replacing with max from left would also work)

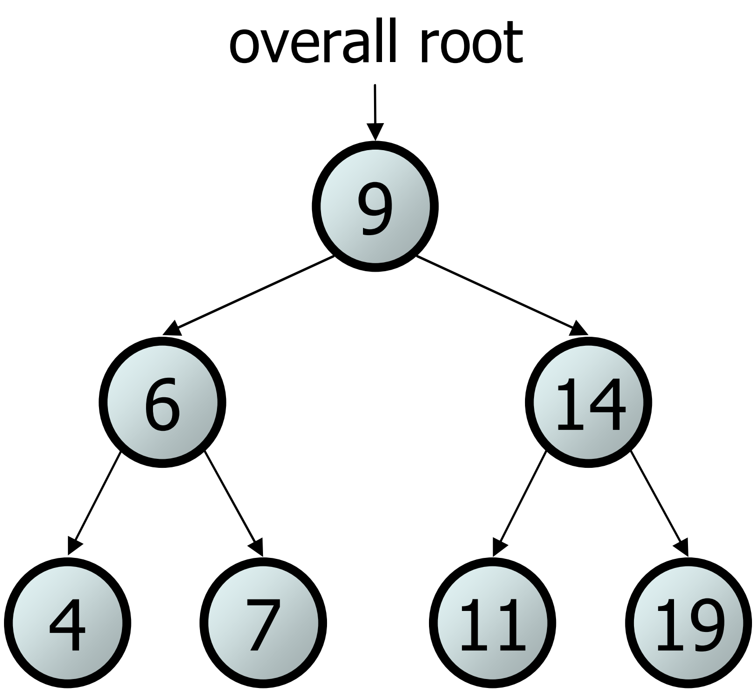


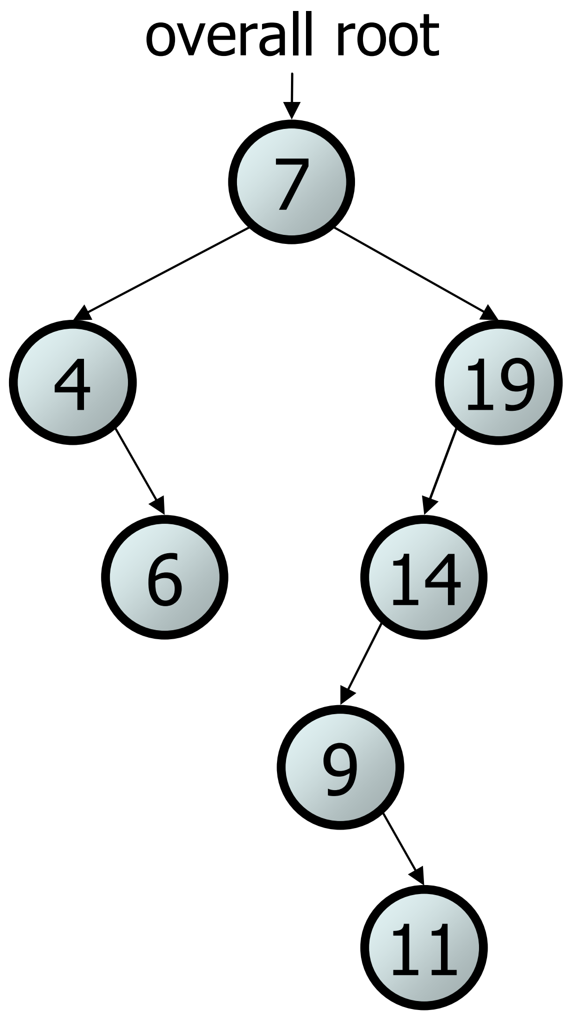
Exercise solution

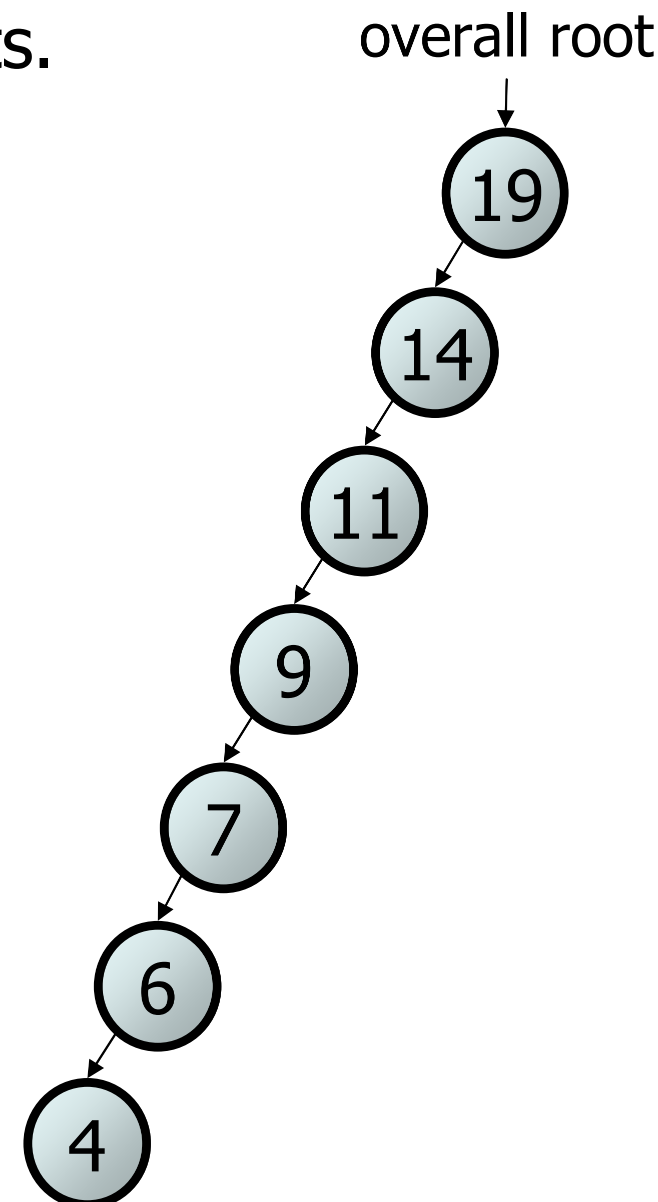
```
// Removes the given value from this BST, if it exists.
public void remove(int value) {
    overallRoot = remove(overallRoot, value);
}

private IntTreeNode remove(IntTreeNode root, int value) {
    if (root == null) {
        return null;
    } else if (root.data > value) {
        root.left = remove(root.left, value);
    } else if (root.data < value) {
        root.right = remove(root.right, value);
    } else {  // root.data == value; remove this node
        if (root.right == null) {
            return root.left;    // no R child; replace w/ L
        } else if (root.left == null) {
            return root.right;   // no L child; replace w/ R
        } else {
            // both children; replace w/ min from R
            root.data = getMin(root.right);
            root.right = remove(root.right, root.data);
        }
    }
    return root;
}
```

Searching BSTs

- The BSTs below contain the same elements.
  - What orders are "better" for searching?



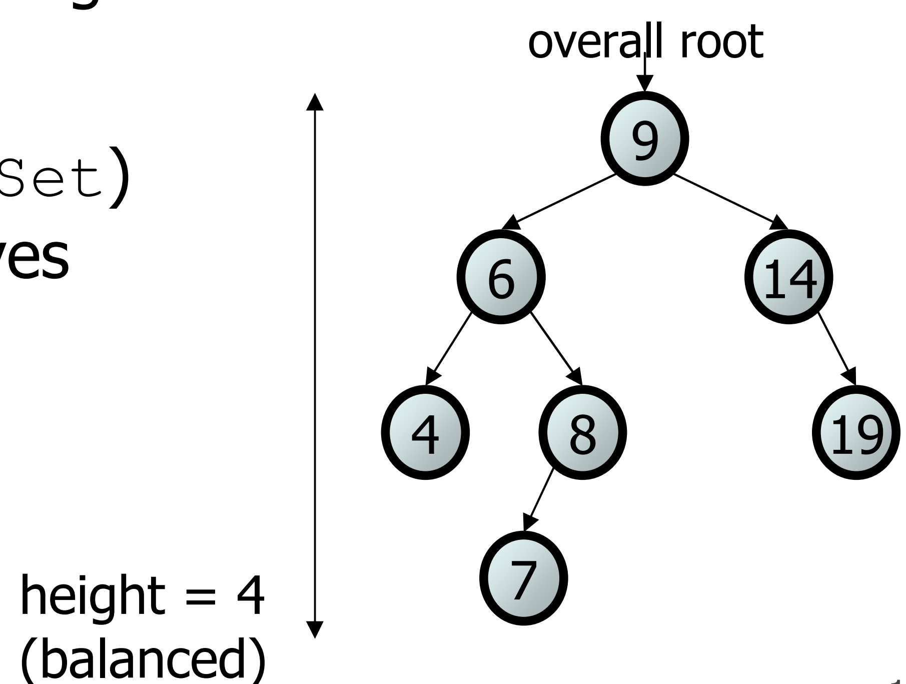




Trees and balance

- **balanced tree**: One whose subtrees differ in height by at most 1 and are themselves balanced.
  - A balanced tree of N nodes has a height of ~ $\log_2$ N.
  - A very unbalanced tree can have a height close to N.

  - The runtime of adding to / searching a BST is closely related to height.
  - Some tree collections (e.g. `TreeSet`) contain code to balance themselves as new nodes are added.



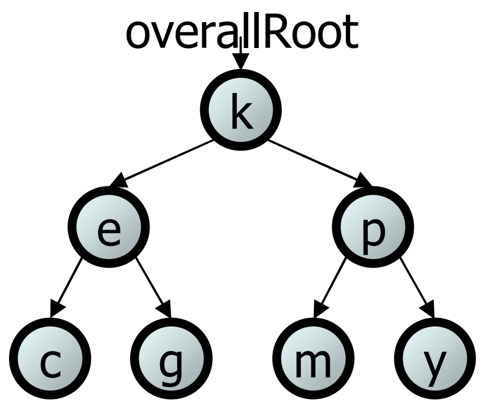
Implementing a Tree Set

read 17.4 - 17.5

A tree set

- Our `SearchTree` class is essentially a set.
  - operations: `add`, `remove`, `contains`, `size`, `isEmpty`
  - similar to the `TreeSet` class in `java.util`

- Let's actually turn it into a full set implementation.
  - *step 1:* create ADT interface; implement it
  - *step 2:* get rid of separate node class file
  - *step 3:* make tree capable of storing any type of data (not just `int`)



Recall: ADTs (11.1)

- **abstract data type (ADT)**: A specification of a collection of data and the operations that can be performed on it.
  - Describes *what* a collection does, not *how* it does it.

- Java's collection framework describes ADTs with interfaces:
  - `Collection`, `Deque`, `List`, `Map`, `Queue`, `Set`, `SortedMap`

- An ADT can be implemented in multiple ways by classes:
  - `ArrayList` and `LinkedList` implement `List`
  - `HashSet` and `TreeSet` implement `Set`
  - `LinkedList` , `ArrayDeque`, etc. implement `Queue`

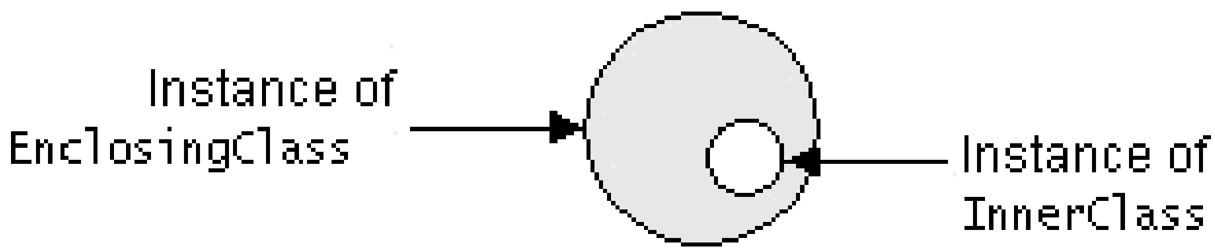
An `IntSet` interface

```
// Represents a list of integers.
public interface IntSet {
    public void add(int value);
    public boolean contains(int value);
    public boolean isEmpty();
    public void remove(int value);
    public int size();
}


public class IntTreeSet implements IntSet { ...
```

Inner classes

To get rid of our separate node file, we can use an *inner class*.

- **inner class**: A class defined inside of another class.
  - inner classes are hidden from other classes (encapsulated)
  - inner objects can access/modify the fields of the outer object



Inner class syntax

```
// outer (enclosing) class
public class name {
    ...

    // inner (nested) class
    private class name {
        ...
    }
}
```

- Only this file can see the inner class or make objects of it.
- Each inner object is associated with the outer object that created it, so it can access/modify that outer object's methods/fields.
  - If necessary, can refer to outer object as **OuterClassName**`.this`

Recall: Type Parameters

```
ArrayList<Type> name = new ArrayList<Type>();
```

- When constructing a `java.util.ArrayList`, you specify the type of elements it will contain in `<` and `>`.
  - `ArrayList` accepts a **type parameter**; it is a **generic** class.

```
ArrayList<String> names = new ArrayList<String>();
names.add("Marty Stepp");
names.add("Helene Martin");
names.add(42);  // compiler error
```

Implementing generics

```
// a parameterized (generic) class
public class name<Type> {
    ...
}
```

- Forces any client that constructs your object to supply a type.
  - Don't write an actual type such as String; the client does that.
  - Instead, write a type variable name such as `E` or `T`.
  - You can require multiple type parameters separated by commas.
- The rest of your class's code can refer to that type by name.

Generics and inner classes

```
public class Foo<T> {
    private class Inner<T> {...}    // incorrect
    private class Inner {...}       // correct
}
```

- If an outer class declares a type parameter, inner classes can also use that type parameter.
- The inner class should NOT redeclare the type parameter.
  - (If you do, it will create a second type param with the same name.)

Issues with generic objects

```
public class TreeSet<E> {
    ...
    public void example(E value1, E value2) {

        // BAD:  value1 == value2      (they are objects)
        // GOOD: value1.equals(value2)

        // BAD:  value1 < value2
        // GOOD: value1.compareTo(value2) < 0

    }
}
```

- When testing objects of type `E` for equality, must use `equals`
- When testing objects of type `E` for `<` or `>`, must use `compareTo`
  - Problem: By default, `compareTo` doesn't compile! What's wrong!

Type constraints

```
// a parameterized (generic) class
public class name<Type extends Class/Interface> {
    ...
}
```

- A **type constraint** forces the client to supply a type that is a subclass of a given superclass or implements a given interface.
  - Then the rest of your code can assume that the type has all of the methods in that superclass / interface and can call them.

Generic set interface

```
// Represents a list of values.
public interface Set<E> {
    public void add(E value);
    public boolean isEmpty();
    public boolean contains(E value);
    public void remove(E value);
    public int size();
}

public class TreeSet<E extends Comparable<E>>
                    implements Set<E> {
    ...
```