Inheritance and binary search

4/29/26

Administrivia

- HW 5 (sorting and search order) due Friday night (5/1)

Inheritance

- extends: makes class a subtype of another
  - terminology: subclass and superclass
  - subclass has all attributes and methods of superclass
    - subclass can override methods it wants to change
  - references to subclass can be stored in superclass-typed variables

Inheritance

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- access control
  - public: anyone can access it
  - private: can only access from within the class
  - protected: accessible from within class or a subclass

  As a general rule, be as restrictive as possible

Which of the following lines has a compile-time error?

```
class Person {  private String name;    }

class Student extends Person {                         //A
    private double credits;
    private double qualityPts;

    public double gpa() {   return qualityPts / credits;    }

    public String toString() {
        return name + " (GPA: " + gpa() + ")";     //B
    }
...
}
...
    Person p = new Student();                       //C
    System.out.println(p.gpa());                    //D
                                                    //E: Not exactly one of the above
```

Which of the following lines has a compile-time error?

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        public double gpa() {   return qualityPts / credits;    }

        public String toString() {
                return name + “ (GPA: “ + gpa() + “)”;      //B
        }
...
}
...
        Person p = new Student();                           //C
        System.out.println(p.gpa());                        //D
                                                            //E: Not exactly one of the above (B & D)
```

toString

- Method inherited from Object
  - Called when an object is printed
  - Comes with default implementation, but can be overridden by something more useful

Implementing contains (ints)

```
boolean contains(int key) {
    //returns whether value is in the set
    for(int i=0; i<size; i++)
        if(vals[i] == key)
            return true;
    return false;
}
```

Implementing contains (Objects)

```
boolean contains(E key) {
    //returns whether value is in the set
    for(int i=0; i<size; i++)
        if(vals[i].equals(key))
            return true;
    return false;
}
```

Aside: Implementing .equals

```
public class Pair {  //represents a pair of ints
    private int x;  private int y;
    ...
    public boolean equals(Object o) {
        if(o instanceof Pair) {
            Pair p = (Pair) o;
            return (x == p.x) && (y == p.y);
        }
        return false;
    }
}
```

Recall: Set ADT

- Represents unordered collection
  {“hello”, “there”, “=)”, “CS 142”}
- **No duplicate elements**

- Supports add, contains, iterator
  Maybe also: size, remove, clear

Map ADT: Add value attached to each item (key)
- Supports put, get, remove, …

Array-based implementation of Set

- Store the keys in arbitrary order in an array, keeping the size in another variable

  (Basically an ArrayList, but no duplicates)

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Fill in the following: With this implementation, add runs in ____ while contains runs in ____

A. O(1), O(1)
B. O(1), O(n)
C. O(n), O(1)
D. O(n), O(n)
E. None of the above

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C. O(n), O(1)
D. O(n), O(n)
E. None of the above

What if the list is kept sorted?

How can you search faster?

Binary search

```
int rank(E key) {        //returns where key goes in keys
    int lo = 0;          //lowest index that could have key
    int hi = size-1;     //highest index that could have key
    while(lo <= hi) {
        int mid = lo + (hi – lo) / 2;
        int cmp = key.compareTo(keys[mid]);
        if(cmp < 0)         hi = mid – 1;
        else if(cmp > 0) lo = mid + 1;
        else return mid;
    }
    return lo;
}
```

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How long does this take?

A) O(1)
B) O(log n)
C) O(n)
D) O(n^2)
E) None of the above

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How long does it take to add a new key into the sorted array?

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B. O(1) amortized
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D. O(n)
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Fill in the following: With a sorted linked list implementation of a set, add runs in ____ while contains runs in ____

A. O(1), O(1)
B. O(1), O(log n)
C. O(log n), O(1)
D. O(n), O(log n)
E. None of the above

Fill in the following: With a sorted linked list implementation of a set, add runs in _____ while contains runs in _____

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B. O(1), O(log n)
C. O(log n), O(1)
D. O(n), O(log n)
E. None of the above: O(n), O(n)

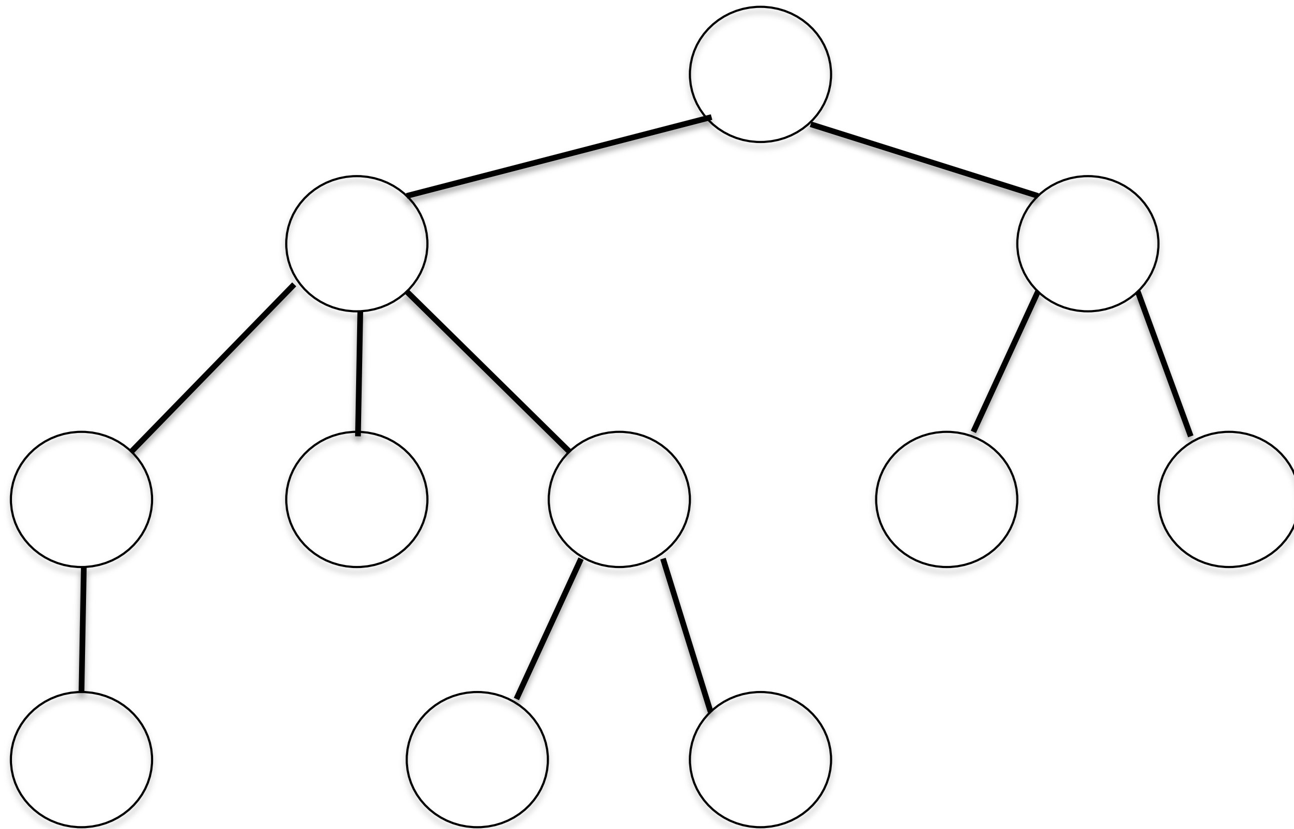
Overview of set implementations

- Array w/ vals in arbitrary order, but no duplicates
  - O(n) add, O(n) contains
- Array with values in sorted order
  - Allows binary search (O(log n)), but slow insertion (O(n))
- Linked list
  - Can more easily add in the middle, but contains is slow

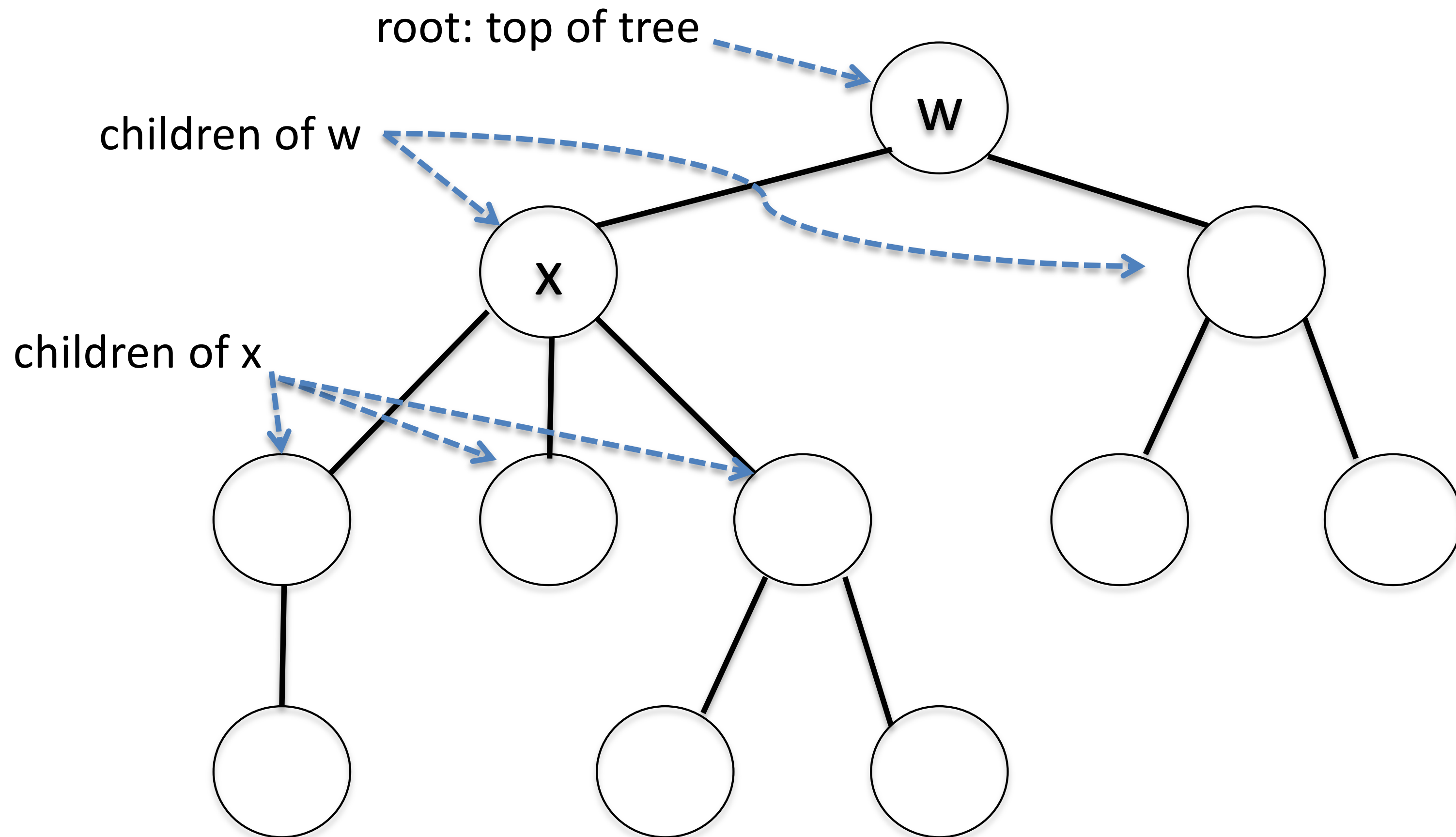
Desired properties

- Ability to quickly “jump” later in the sequence of keys (like binary search)
- Ability to easily add keys into the appropriate position (like linked lists)

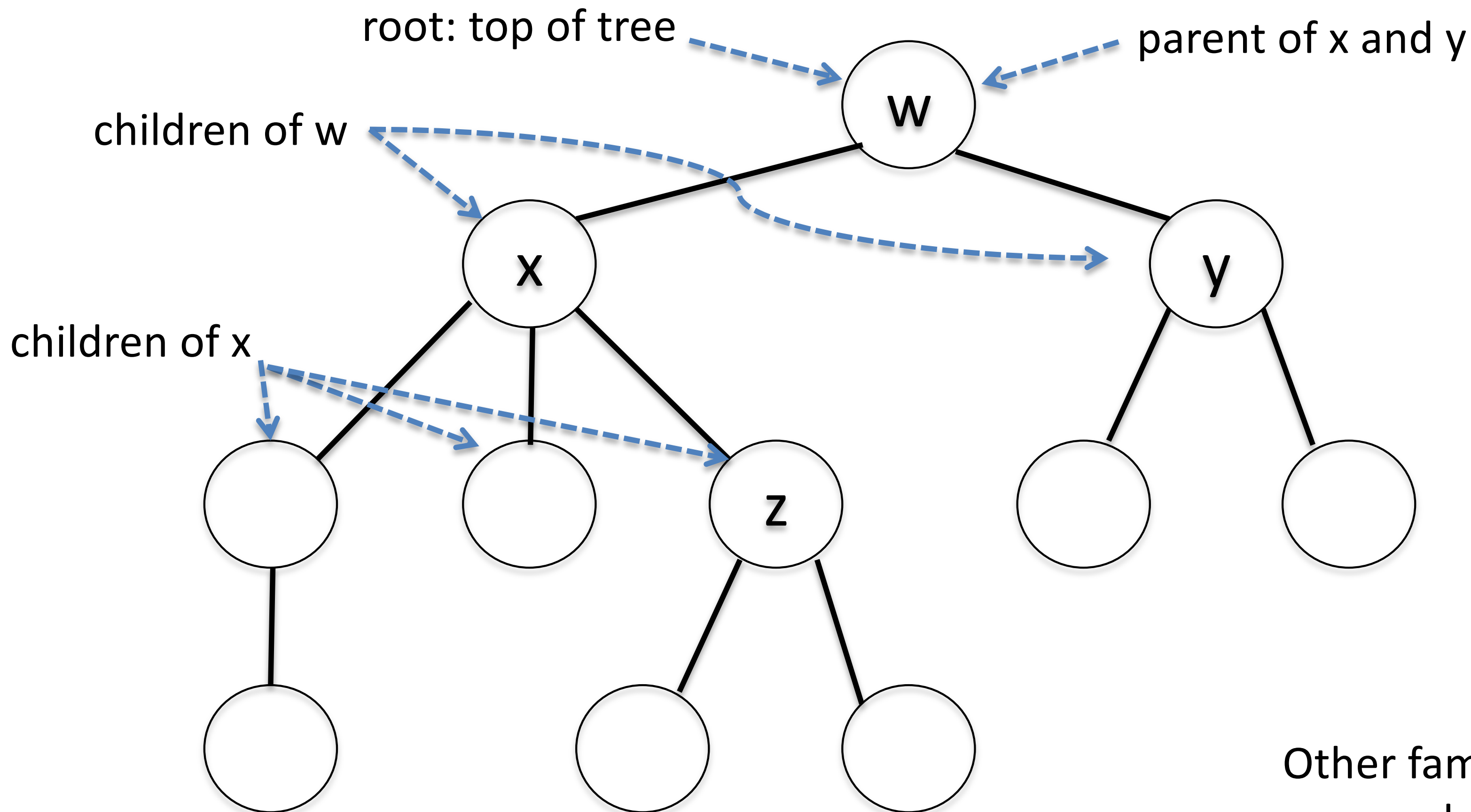
Trees



Trees



Trees



Other familial relationships:

x and y are siblings

w is grandparent of z

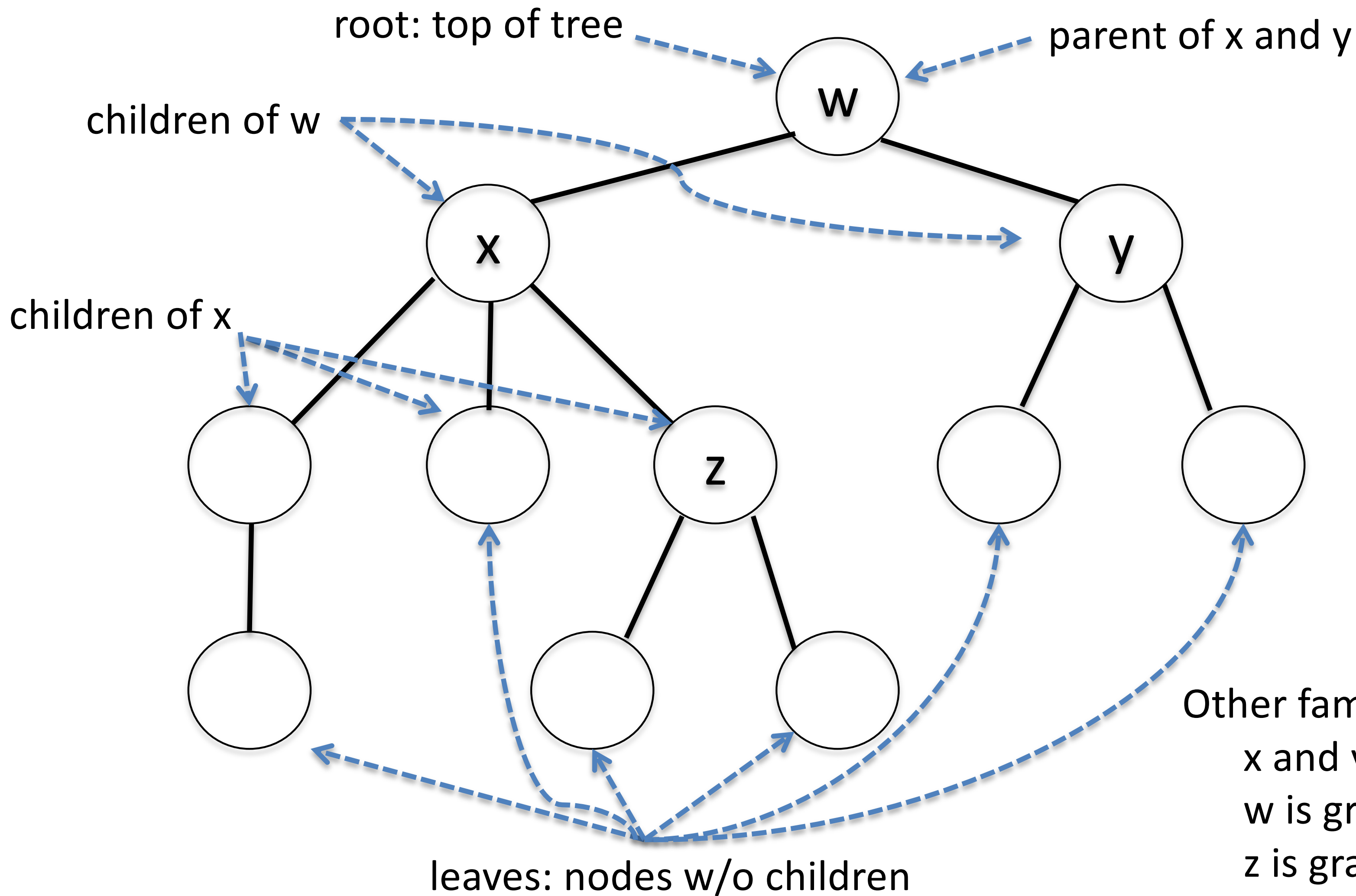
z is grandchild of w

y is uncle (or aunt) of z

ancestors are nodes toward root

descendants are nodes away from it

Trees



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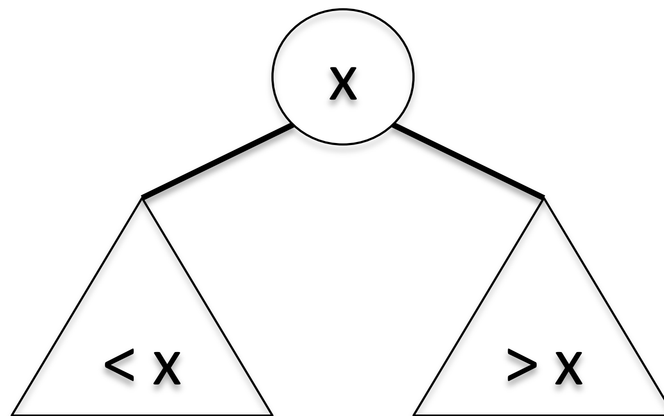
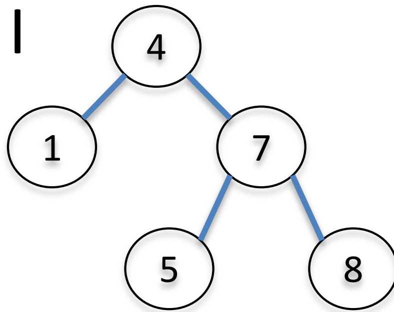
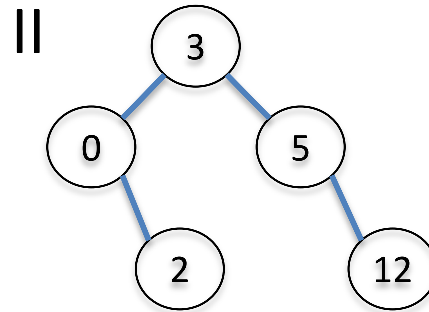
Binary Search Trees (BSTs)

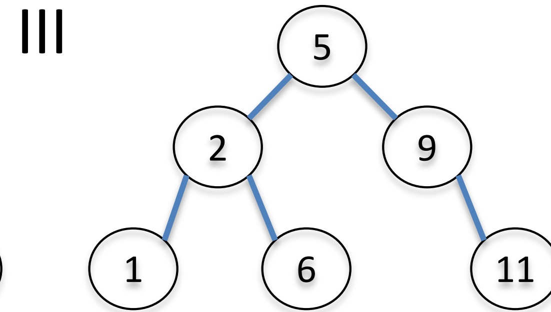
- Tree with key stored at each node such that
  - Every node has 2 children (left and right)
    - Children can be null (nodes have 0, 1, 2 actual children)
  - All keys in a node's right subtree are greater than its key and all in the left subtree are less



Which of the following is a legal BST?







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B. I and II only
C. II and III only
D. All of them
E. None of the choices above is correct

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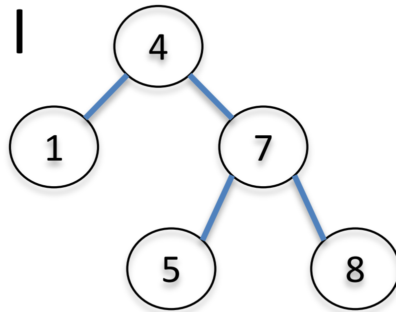

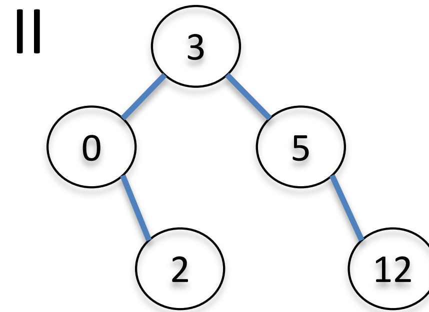

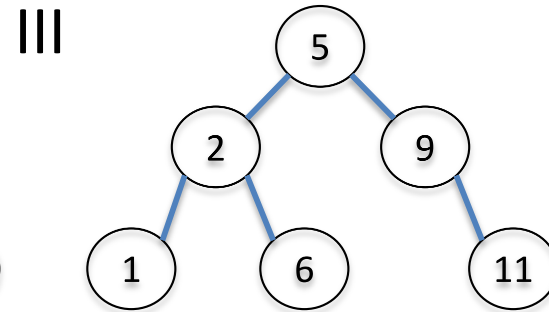

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Implementing a BST

```
public class BST<E extends Comparable<E>> {
    Node root;

    private class Node {
        Node left;
        Node right;
        E key;
    }
}
```

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```
boolean contains(E key) {
    Node curr = root;
    while(curr != null) {
        int cmp = key.compareTo(curr.key) ;
        if(cmp < 0) curr = curr.left;
        else if(cmp > 0) curr = curr.right;
        else return true;
    }
    return false;
}
```

Recursive implemention

```
boolean contains(E key) {
    return contains_helper(root, key);
}

boolean contains_helper(Node curr, E key) {
    if(curr == null) return false;
    int cmp = key.compareTo(curr.key) ;
    if(cmp < 0) return contains_helper(curr.left, key);
    else if(cmp > 0) returns contains_helper(curr.right, key);
    else return true;
}
```