CS206

Trees, continued

Shallow & deep copy (revisited)

```
public class DeepShallow
{
    private class Node {
      public int payload;
      public Node(int p) {
          this.payload = p;
      }
    }

    public void shde()
    {
      ArrayList<Node> arrOrig = new ArrayList<>();
      for (int i=0; i<10; i++) {
          arrOrig.add(new Node(i));
      }

      // Pointer Copy
      ArrayList arrpc = arrOrig;

      //Shallow Copy
      ArrayList<Node> arrShallow = new ArrayList<>();
      Collections.copy(arrShallow, arrOrig);

      //Deep Copy
      ArrayList<Node> arrDeep = new ArrayList<>();
      for (Node n : arrOrig)
          arrDeep.add(new Node(n.payload));
    }
    public static void main(String[] args)
    {
      new DeepShallow().shde();
    }
    }
}
```

Height / maxDepth

Recall: Depth == node property — distance from root
Height == tree property — max depth

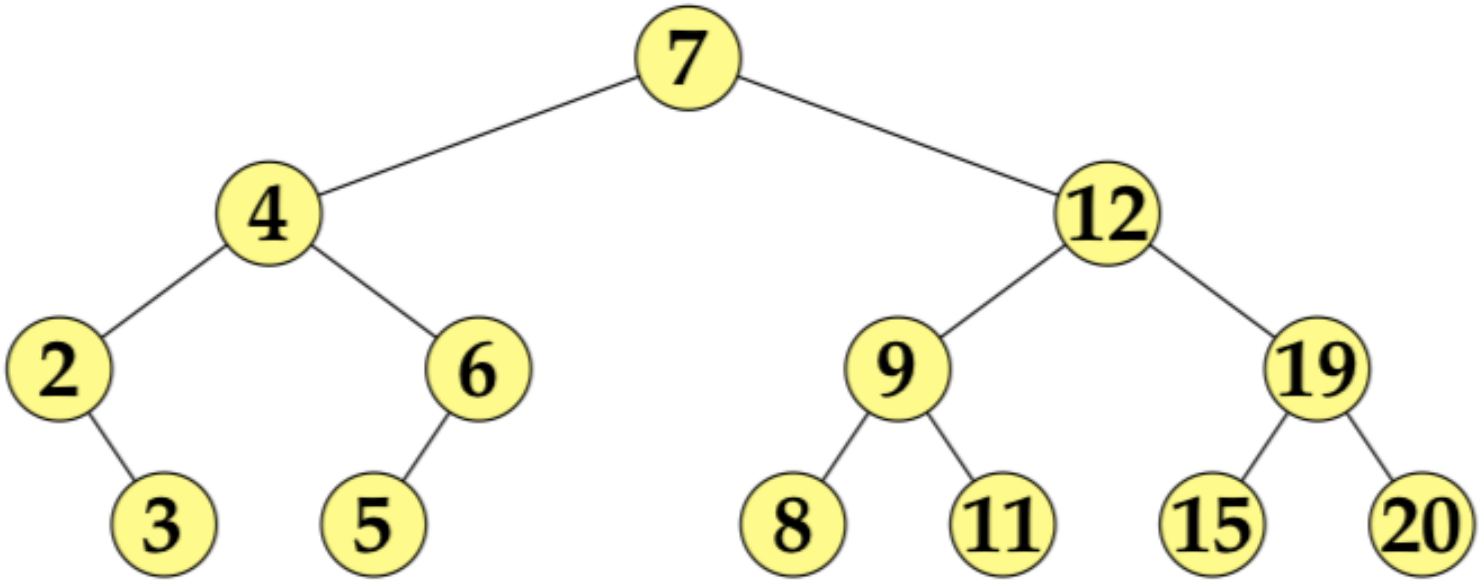
From Tuesday

```
private class Node
{
Comparable<E> payload;
Node right;
Node left;

public String toString()
{
    return payload.toString();
}
}
```

Again, use a recursive helper method

```
@Override
public int maxDepth()
{
    return iMaxDepth(root, 1);
}

int iMaxDepth(Node n,
                  int depth) {
   …}
```

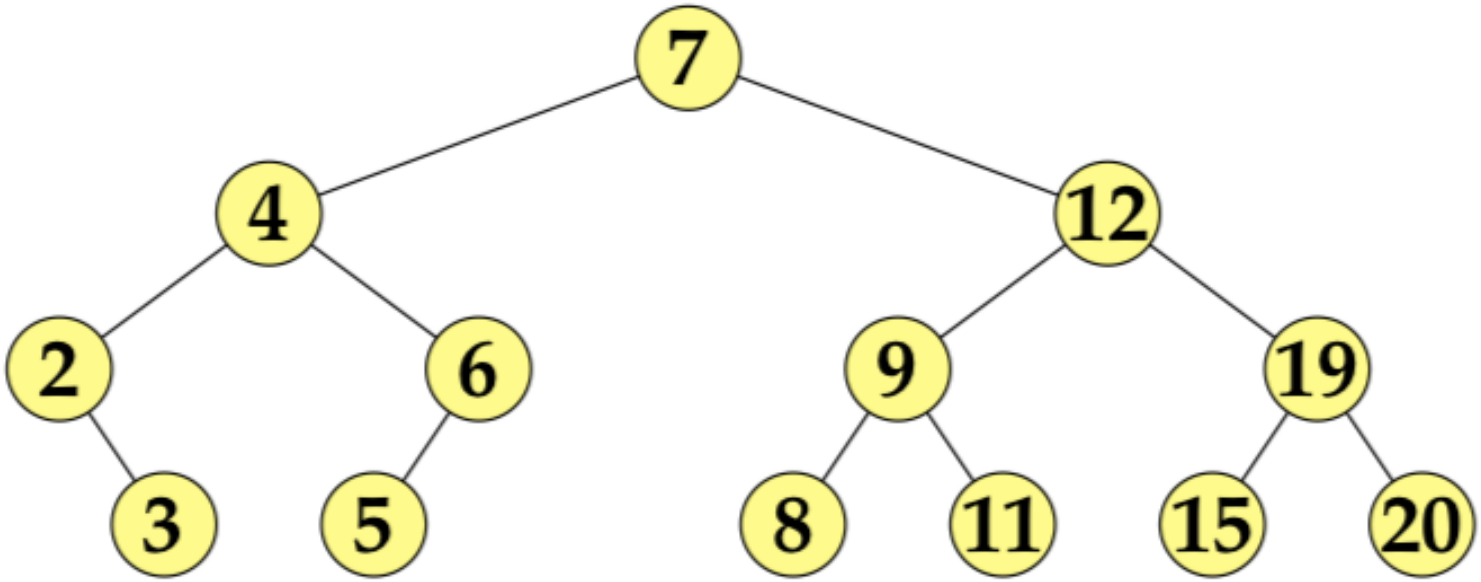
Terms



Binary Tree Traversals

- Traversal visits all nodes in a tree in some order
- Inorder: left subtree, current, right subtree
- Preorder: current, left subtree, right subtree
- Postorder: left subtree, right subtree, current

Traversals



toString inorder

Yet another recursive helper method

```
public String toString()
{
   return inorderString(root, 0);
}

private String inorderString(Node n, int depth)
```

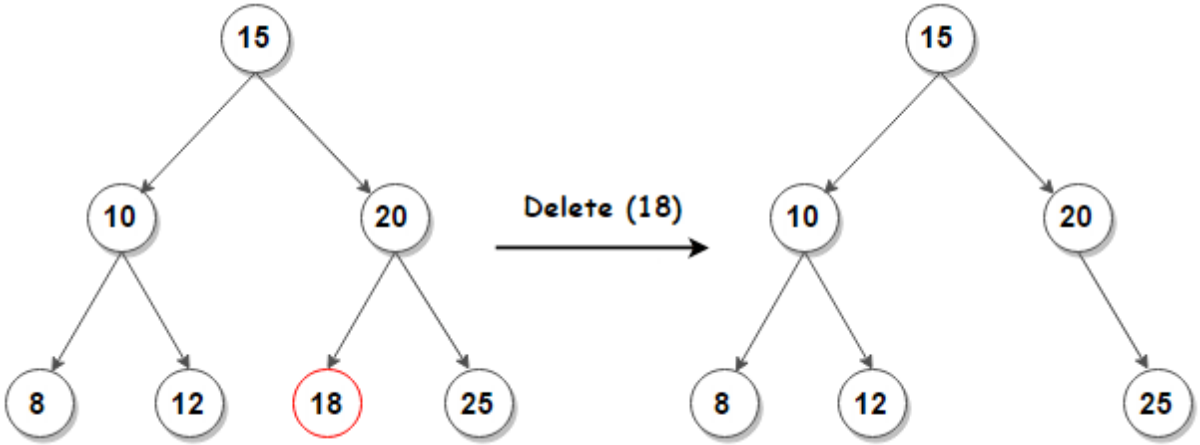
Chalkboard

Remove

- `boolean remove(E element);`
- returns true if element existed and was removed and false otherwise
- Cases
  - element not in tree
  - element is a leaf
  - element has one child
  - element has two children

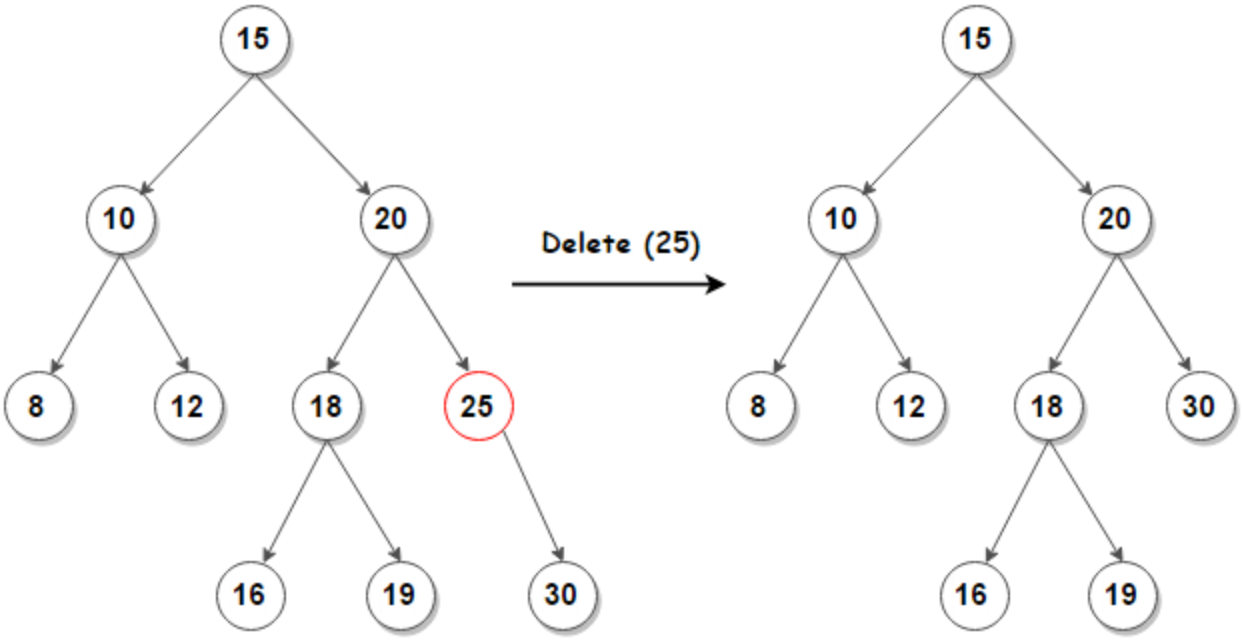
Leaf

- Just delete



One child

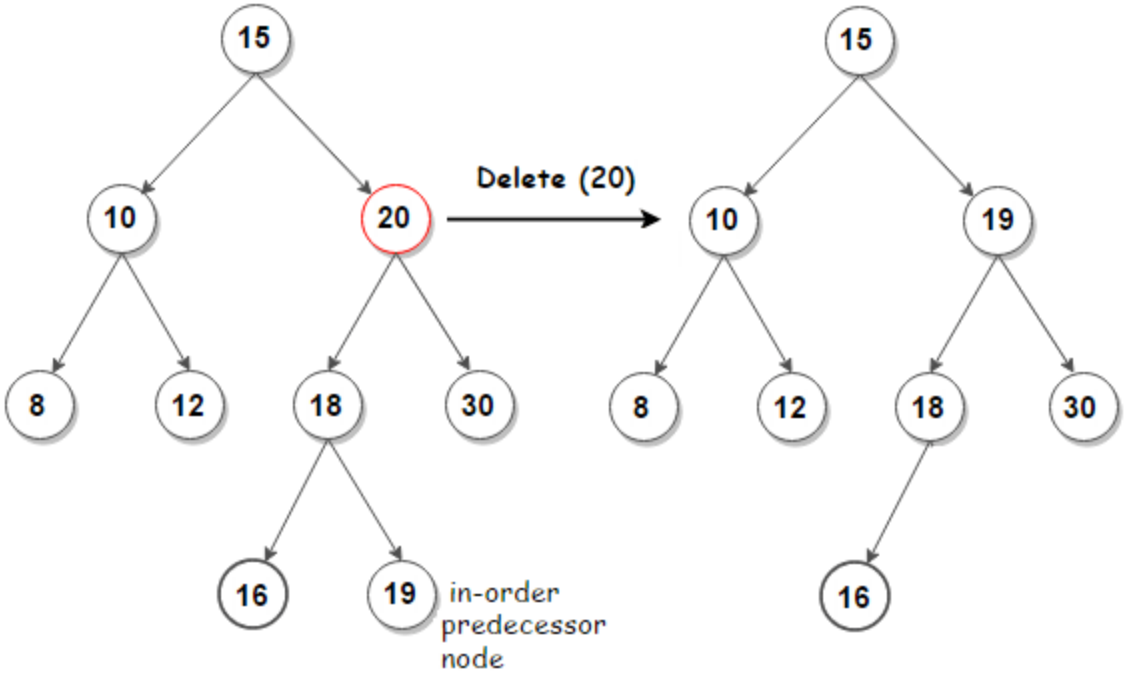
- Replace with child – skip over like in linked list



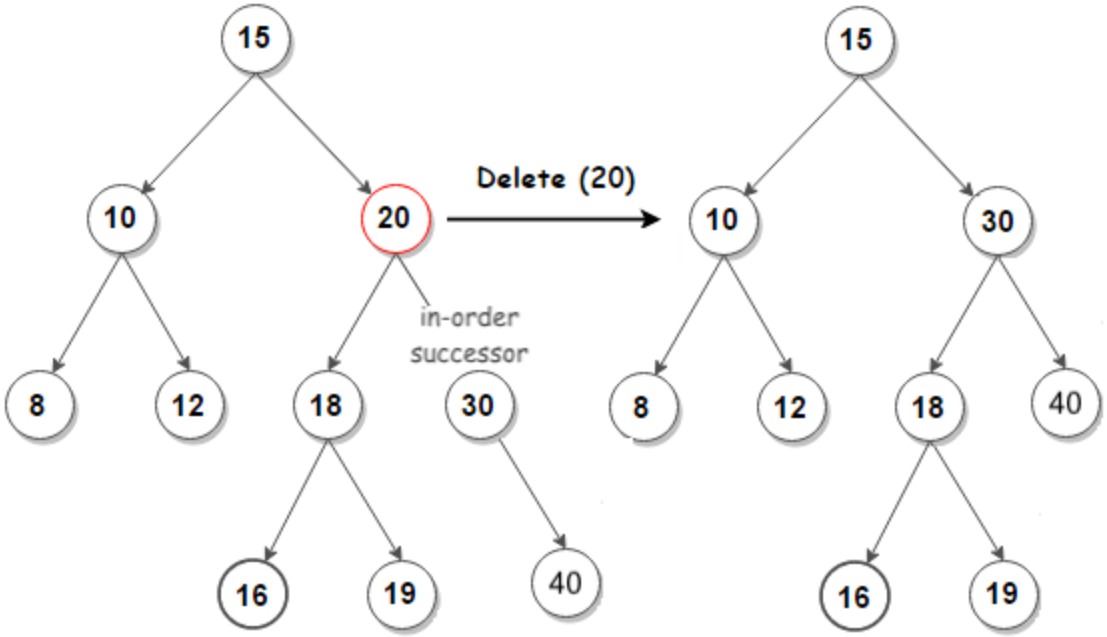
Two Children

- Replace with in-order predecessor or in-order successor
- in-order predecessor
  - rightmost child in left subtree
  - max-value child in left subtree
- in-order successor
  - leftmost child in right subtree
  - min-value child in right subtree

Replace with Predecessor



Replace with Successor



Pseudo code

```
minKey(sRoot):
  if sRoot.left == null:
    return sRoot.key
  else
    return minKey(sRoot.left)
```

```
removeRec(sRoot, key):
  if sRoot == null:
    return null
  if sRoot.key > key:
    sRoot.left = removeRec(sRoot.left, key)
    return sRoot
  else if sRoot.key < key:
    sRoot.right = removeRec(sRoot.right, key)
    return sRoot
  else  // found the one to delete!!!!
    if sRoot.left == null:
      return sRoot.right
    else if sRoot.right == null:
      return sRoot.left
    else
      // either two children OR no children
      sRoot.key = minKey(sRoot.right)  //change value!
      sRoot.right = removeRec(sRoot.right, sRoot.key)
      return sRoot
```

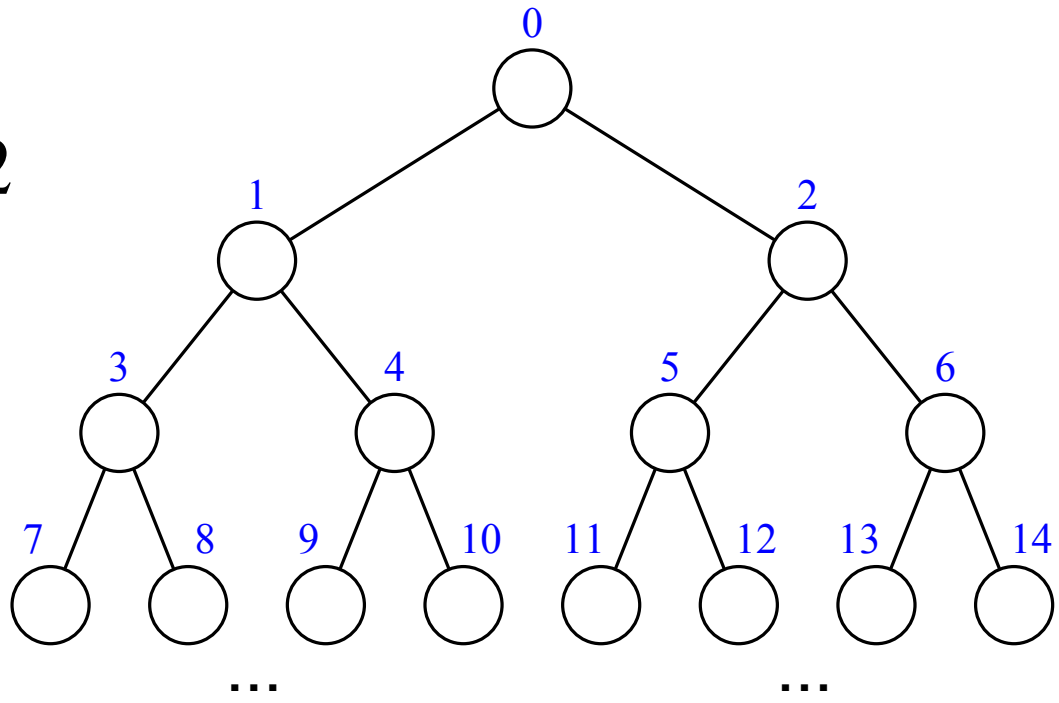
10/31: Question in class about coverage of the no links case. I reviewed and this is correct. I added two return statements to the version shown in class

Implementation

```
public boolean remove(E element) {
    int oSize=size;
    root = iRemoveRec(root, element);
    return oSize!=size;
}

private Comparable<E> iMinKey(Node sRoot) {
    if (sRoot.left==null)
        return sRoot.payload;
    else
        return iMinKey(sRoot.left);
}

private Node iRemoveRec(Node sRoot, Comparable<E> element) {
    if (sRoot==null) return null;
    ……
}
```

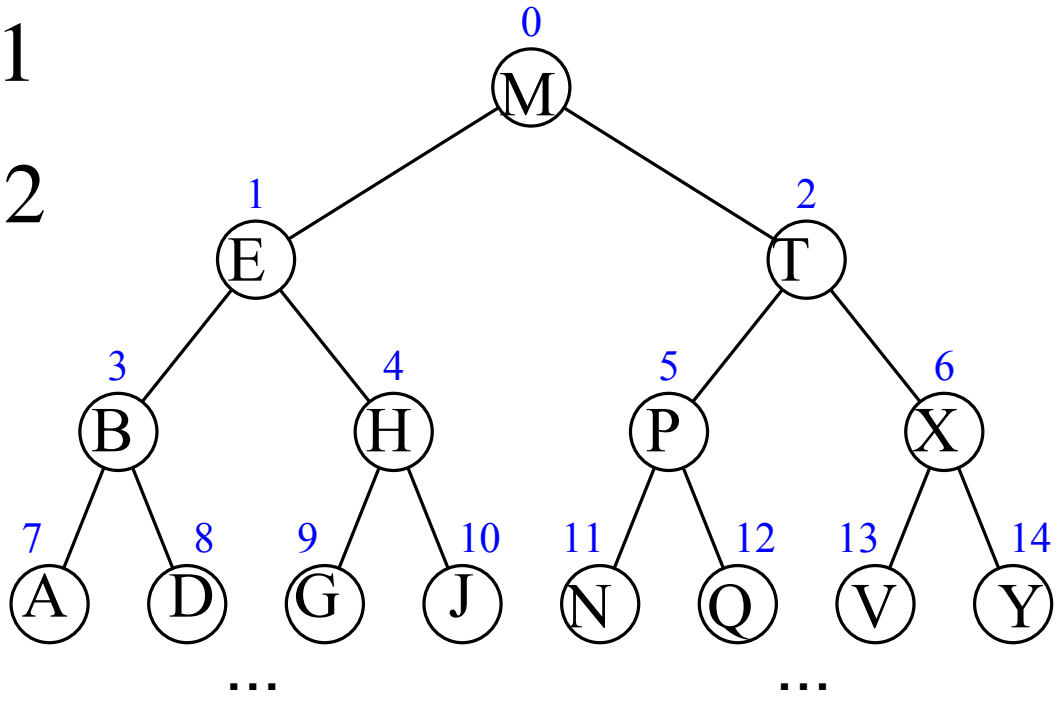
Array-based Binary Tree

- Number nodes level-by-level, left-to-right
- $f(root) = 0$
- $f(l) = 2f(p) + 1$
- $f(r) = 2f(p) + 2$
- Numbering is based on all positions, not just occupied positions



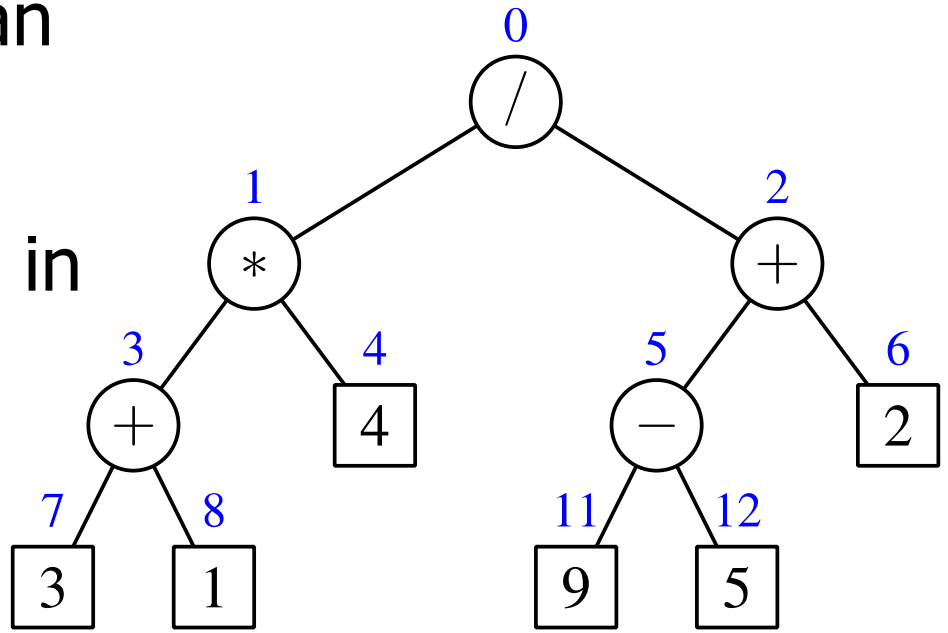
Level-numbering

- Number nodes level-by-level, left-to-right
- $f(root) = 0$
- $f(l) = 2f(p) + 1$
- $f(r) = 2f(p) + 2$



Array-based Binary Tree

- The numbering can then be used as indices for storing the nodes directly in an array



/	*	+	+	4	−	2	3	1			9	5		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14