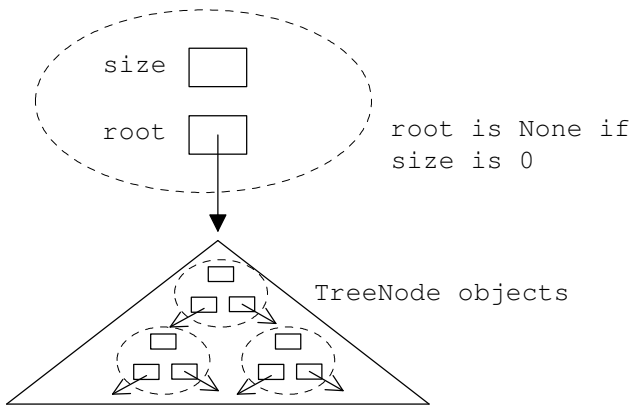
1. Consider the partial TreeNode class and partial BinarySearchTree class.

```
class TreeNode:
   def __init__(self,key,val,left=None,right=None,
            return True                parent=None):
        self.key = key
        self.payload = val
        self.leftChild = left
        self.rightChild = right
        self.parent = parent

    def hasLeftChild(self):
        return self.leftChild

    def hasRightChild(self):
        return self.rightChild

    def isLeftChild(self):
        return self.parent and \
               self.parent.leftChild == self

    def isRightChild(self):
        return self.parent and \
               self.parent.leftChild == self

    def isRoot(self):
        return not self.parent

    def isLeaf(self):
      return not (self.rightChild or self.leftChild)

    def hasAnyChildren(self):
        return self.rightChild or self.leftChild

    def hasBothChildren(self):
        return self.rightChild and self.leftChild

    def replaceNodeData(self,key,value,lc,rc):
        self.key = key
        self.payload = value
        self.leftChild = lc
        self.rightChild = rc
        if self.hasLeftChild():
            self.leftChild.parent = self
        if self.hasRightChild():
            self.rightChild.parent = self

    def __iter__(self):
       if self:
          if self.hasLeftChild():
               for elem in self.leftChild:
                  yield elem
          yield self.key
          if self.hasRightChild():
               for elem in self.rightChild:
                  yield elem
```

A BinarySearchTree object

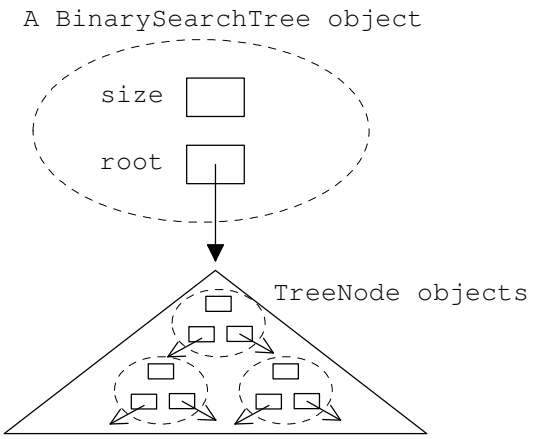



```
class BinarySearchTree:
  def __init__(self):
      self.root = None
      self.size = 0

  def length(self):
      return self.size

  def __len__(self):
      return self.size

  def __iter__(self):
      return self.root.__iter__()

  def __str__(self):
   """Returns a string representation of the tree
      rotated 90 degrees counter-clockwise"""

     def strHelper(root, level):
        resultStr = ""
        if root:
           resultStr += strHelper(root.rightChild,
                                  level+1)
           resultStr += "|  " * level
           resultStr += str(root.key) + "\n"
           resultStr += strHelper(root.leftChild,
                                  level+1)
        return resultStr

     return strHelper(self.root, 0)
```

a) How do the BinarySearchTree __iter__ and __str__ methods work?

More partial TreeNode class and partial BinarySearchTree class.

```
class BinarySearchTree:
   • • •
   def __contains__(self,key):
       if self._get(key,self.root):
           return True
       else:
           return False

   def get(self,key):
       if self.root:
           res = self._get(key,self.root)
           if res:
               return res.payload
           else:
               return None
       else:
           return None

   def _get(self,key,currentNode):
       if not currentNode:
           return None
       elif currentNode.key == key:
           return currentNode
       elif key < currentNode.key:
           return self._get(key,currentNode.leftChild)
       else:
           return self._get(key,currentNode.rightChild)

   def __getitem__(self,key):
       return self.get(key)

   def __setitem__(self,k,v):
       self.put(k,v)

   def put(self,key,val):
       if self.root:
           self._put(key,val,self.root)
       else:
           self.root = TreeNode(key,val)
       self.size = self.size + 1

   def _put(self,key,val,currentNode):
       if key < currentNode.key:
           if currentNode.hasLeftChild():



           else:



       else:
```



b) The `_get` method is the "work horse" of BST search. It recursively walks `currentNode` down the tree until it finds `key` or becomes `None`

In English, what are the base and recursive cases?

c) What is the `put` method doing?

d) Complete the recursive `_put` method. It has a precondition that `key` is not in the BST.

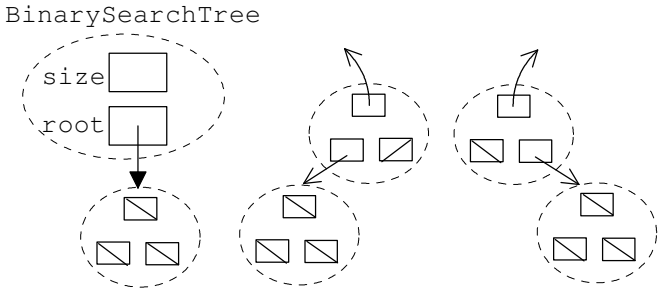
e) Draw the "shape" of the BST after `put`s of: 50, 60, 30, 70, 90, 40, 65

f) If "n" items are in the BST, what is `put`'s: Best-case *O*( )? Worst-case *O*( )? Average-case *O*( )?

2. More partial TreeNode class and partial BinarySearchTree class.

```
class BinarySearchTree:
   • • •
 def delete(self,key):
   if self.size > 1:
       nodeToRemove = self._get(key,self.root)
       if nodeToRemove:
           self.remove(nodeToRemove)
           self.size = self.size-1
       else:
           raise KeyError('Error, key not in tree')
   elif self.size == 1 and self.root.key == key:
       self.root = None
       self.size = self.size - 1
   else:
       raise KeyError('Error, key not in tree')

 def __delitem__(self,key):
     self.delete(key)


 def remove(self,currentNode):
   if currentNode.isLeaf(): #leaf
     if currentNode == currentNode.parent.leftChild:
         currentNode.parent.leftChild = None
     else:
         currentNode.parent.rightChild = None
   elif currentNode.hasBothChildren(): #interior
     succ = currentNode.findSuccessor()
     succ.spliceOut()
     currentNode.key = succ.key
     currentNode.payload = succ.payload

   else: # this node has one child
     if currentNode.hasLeftChild():
       if currentNode.isLeftChild():
           currentNode.leftChild.parent = currentNode.parent
           currentNode.parent.leftChild = currentNode.leftChild
       elif currentNode.isRightChild():
           currentNode.leftChild.parent = currentNode.parent
           currentNode.parent.rightChild = currentNode.leftChild
       else:
           currentNode.replaceNodeData(currentNode.leftChild.key,
                               currentNode.leftChild.payload,
                               currentNode.leftChild.leftChild,
                               currentNode.leftChild.rightChild)

     else:
       if currentNode.isLeftChild():
           currentNode.rightChild.parent = currentNode.parent
           currentNode.parent.leftChild = currentNode.rightChild
       elif currentNode.isRightChild():
           currentNode.rightChild.parent = currentNode.parent
           currentNode.parent.rightChild = currentNode.rightChild
       else:
           currentNode.replaceNodeData(currentNode.rightChild.key,
                               currentNode.rightChild.payload,
                               currentNode.rightChild.leftChild,
                               currentNode.rightChild.rightChild)
```

a) Update picture where we delete a leaf.



b) Where in the code is each handled?

c) Draw all pictures deleting all nodes with one child.

3. Yet even more partial TreeNode class and partial BinarySearchTree class.

```
class TreeNode:
   . . .
      def findSuccessor(self):
         succ = None
         if self.hasRightChild():
             succ = self.rightChild.findMin()
         else:
             if self.parent:
                 if self.isLeftChild():
                     succ = self.parent
                 else:
                     self.parent.rightChild = None
                     succ = self.parent.findSuccessor()
                     self.parent.rightChild = self
         return succ

      def findMin(self):
         current = self
         while current.hasLeftChild():
             current = current.leftChild
         return current

      def spliceOut(self):
         if self.isLeaf():
            if self.isLeftChild():
               self.parent.leftChild = None
            else:
               self.parent.rightChild = None
         elif self.hasAnyChildren():
            if self.hasLeftChild():
               if self.isLeftChild():
                  self.parent.leftChild = self.leftChild
               else:
                  self.parent.rightChild = self.leftChild
               self.leftChild.parent = self.parent
            else:
               if self.isLeftChild():
                  self.parent.leftChild = self.rightChild
               else:
                  self.parent.rightChild = self.rightChild
               self.rightChild.parent = self.parent
```