Binary Search Trees

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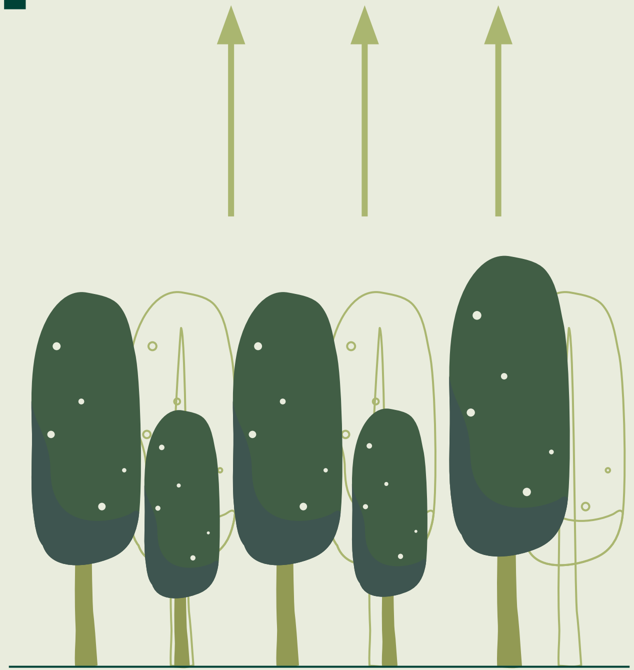

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Binary Search Tree Basics

Binary Search Tree
Basics

A **binary search tree (BST)** is a hierarchical data structure used for organizing keys in a sorted manner. In a BST, each node has at most two **child nodes**: a left child and a right child. The key in each node is greater than all keys in its left subtree and less than all keys in its right subtree.

Common Uses: Efficient Searching, Insertion, and Deletion; Dictionaries, Maintaining Ordered Data

Implementation

```
class TreeNode:

    def __init__(self, value):
        self.left = None
        self.right = None
        self.value = value

    def insert(self, value):
        if value < self.value:
            if self.left is None:
                self.left = TreeNode(value)
            else:
                self.left.insert(value)
        else:
            if self.right is None:
                self.right = TreeNode(value)
            else:
                self.right.insert(value)
```

My BST is implemented under a class called **TreeNode**

- **Initializes** with a value given by the user, and left and right set to None
- **Insert function** properly creates a BST by placing elements smaller to each node to the left of the node and each node larger to the right
    - Nodes that have the same value as their **parent node** are placed to the right
- **Find function** traverses tree following the same process as insertion
    - Complexity of O(logn) when balanced

Implementation (Cont.)

```
def inorder_traversal(self):
        if self.left:
            self.left.inorder_traversal()
        print(self.value)
        if self.right:
            self.right.inorder_traversal()

    def preorder_traversal(self):
        print(self.value)
        if self.left:
            self.left.preorder_traversal()
        if self.right:
            self.right.preorder_traversal()

    def postorder_traversal(self):
        if self.left:
            self.left.postorder_traversal()
        if self.right:
            self.right.postorder_traversal()
        print(self.value)
```

- The trees can be **displayed** in three separate ways:
  - **Inorder Traversal** prints the nodes in ascending order
  - **Preorder Traversal** prints the nodes as they appear always going left until there are no more left child, then going one node up then right
    - Most commonly used in testing
  - **Postorder Traversal** prints the nodes from the bottom most left note of the tree then goes up to the parent node, to the right node, and prints the lowest element there, following this pattern

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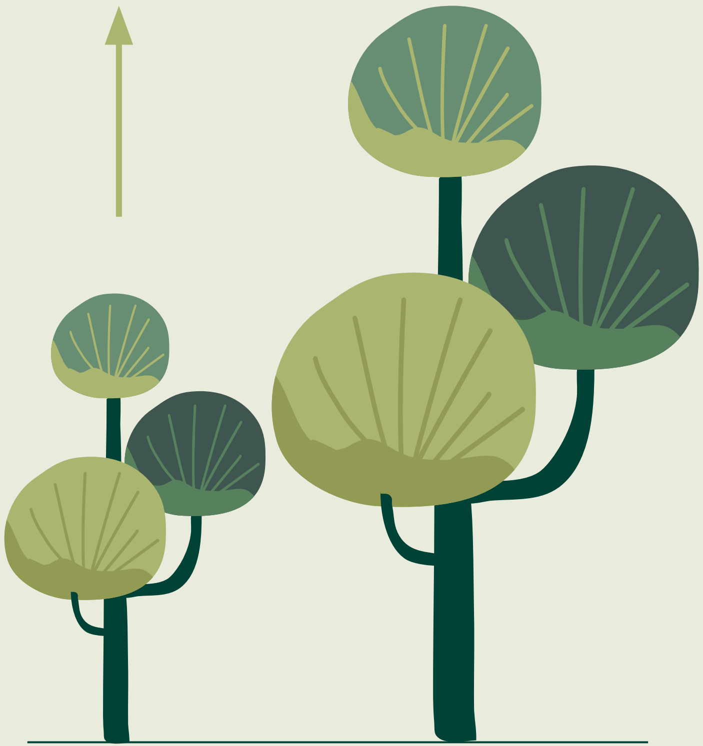
Interview Questions



Interview Questions

01 Deletion

Write a function to delete a given node from a BST while maintaining its BST properties.

02 In Order Successor

Write a function to find the in-order successor of a given node in a BST. The in-order successor is the node with the next higher key value in the in-order traversal of the BST.

03 Array to Tree

Given a sorted array, write a function to convert it into a height-balanced BST.

04 Tree Rotation

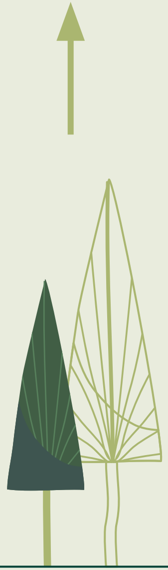
Give a node, write a function that can either rotate it right or left.

1. Deletion

Problem

Deleting a node off of a tree comes down from two main problems:

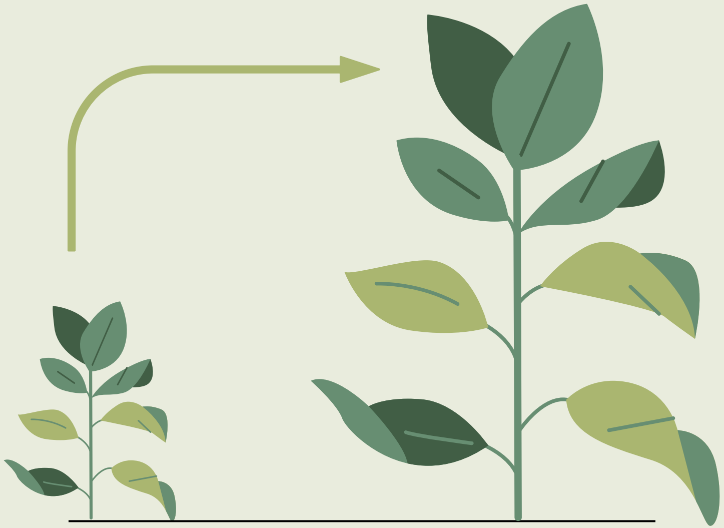
- Removing a node from the tree can leave its children without a parent
- Improperly removed nodes will leave floating trees that will get garbage collected



Implementation

- Create get_minimum_value_node function which will check to see if the left child exist
- Recursively create the deele_node function to call itself when a node is None
- Set nodes to none if their children (valuing left children more) are None

1. Deletion: Code Snippet



```
def get_min_value_node(self, node):
    current = node
    while current.left is not None:
      current = current.left
    return current
  def delete_node(self, value):
    if self is None:
      return self
    if value < self.value:
      self.left = self.left.delete_node(value)
    elif value > self.value:
      self.right = self.right.delete_node(value)
    else:
      if self.left is None:
        temp = self.right
        self = None
        return temp
      elif self.right is None:
        temp = self.left
        self = None
        return temp
      temp = self.get_min_value_node(self.right)
      self.value = temp.value
      self.right = self.right.delete_node(temp.value)
    return self
```

2. In Order Successor

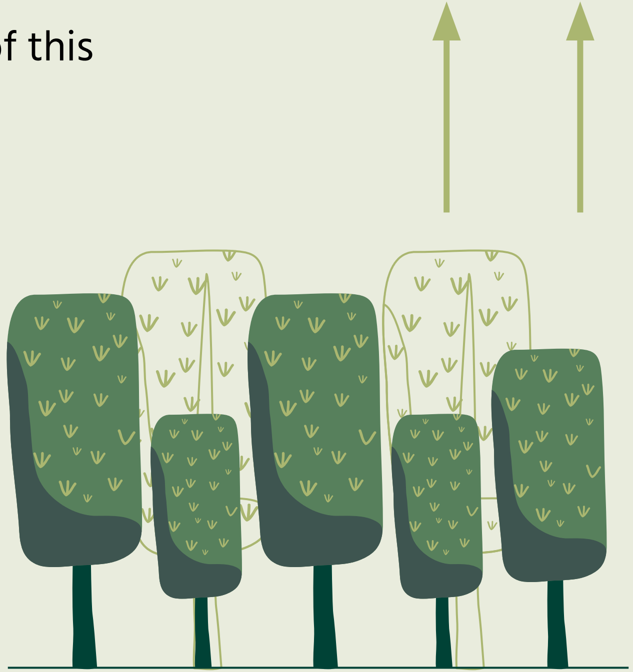
Problem

Tree traversal is complicated and poor implementations of this function will lead to complexities up to O(n)

Implementation

The function will remember the current best successor for the node and discard all parts of the tree that can no longer contain that successor:

- If the current node is less than or equal to the target, the function will continue exploring that tree
- If the current node is greater than the best, the tree will be discarded



2. In Order Successor: Code Snippet

```
def in_order_successor(self, target):
        if self.value <= target:
            if self.right:
                return self.right.in_order_successor(target)
            else:
                return None
        else:
            left_successor = None
            if self.left:
                left_successor =
self.left.in_order_successor(target)
            return left_successor if left_successor else self
```

3. Array to Tree

Problem

There are many ways to change an array to a tree but many of them will be inefficient in the amount of passes they take or they will create an imbalance tree

- Adding the elements in the order they appear will result in a tree with one really long leg

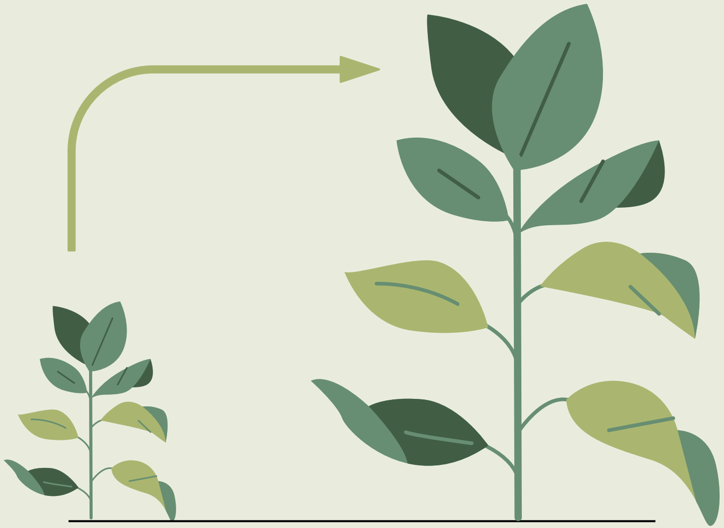
3. Array to Tree (cont.)

Implementation

Approach is based on the fact that for a balanced tree, the parent node should come from the middle of a sorted array

- ***This means a function that just adds all elements to on either side of the middle element will also be balanced, just really long
- A function will be called recursively that find the middle element of an array and inserts that into the tree
- Each consecutive next pass will explore either to the rest of the array to either the left or the right

3. Array to Tree: Code Snippet

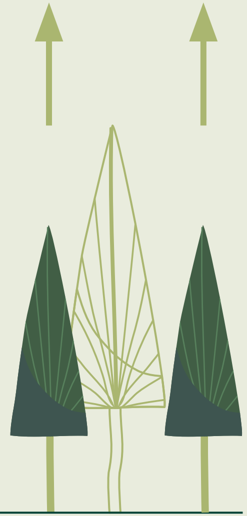


```
@staticmethod
    def array_to_tree_helper(array, start, end):
        if start > end:
            return None
        mid = (start + end) // 2
        root = TreeNode(array[mid])
        root.left = TreeNode.array_to_tree_helper(array, start, mid - 1)
        root.right = TreeNode.array_to_tree_helper(array, mid + 1, end)
        return root
    @staticmethod
    def array_to_tree(array):
        if not array:
            return None
        return TreeNode.array_to_tree_helper(array, 0, len(array) - 1)
```

4. Tree Rotation

Problem

Tree rotation can be a memory nightmare similar to deletion where massive parts of the tree can just be deleted if not careful



Implementation

Only the root and side wanting to be switched need to be fully altered, the rest of the trees can be rotated as subtrees [this explanation will be for rotate left]:

- Set the root node to root.right, set the root.left to be the original root node
- Add back subtrees under their new positions

4. Rotation: Code Snippet

```python
def rotate_left(self):
        if not self.right:
            return
        a = self.value
        b = self.right.value
        A = self.left
        B = self.right.left
        C = self.right.right
        self.value = b
        self.left = TreeNode(a)
        self.left.left = A
        self.left.right = B
        self.right = C
```

```python
def rotate_right(self):
        if not self.left:
            return
        a = self.value
        b = self.left.value
        A = self.left.left
        B = self.left.right
        C = self.right
        self.value = b
        self.right = TreeNode(a)
        self.right.left = B
        self.right.right = C
        self.left = A
```

03

Self Balancing Trees

Height and Height Factor

The get_height function is a recursive function that adds one to the height value very time it finds a node to go down deeper in the tree.

The height_factor is used to determine how unbalanced the tree is. A perfectly balanced tree will have a factor ranging from [-1, 1], though it's ideally at 0. Trees that have a negative factor have a longer left leg and positive factors mean a longer right leg.

Height and Height Factor: Code Snippet

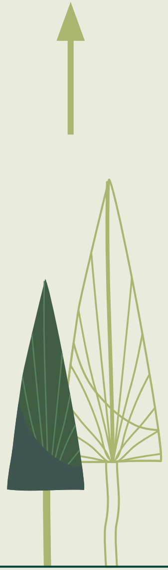
```
def get_height(self):
        left_height = self.left.get_height() if self.left else 0
        right_height = self.right.get_height() if self.right else 0
        return 1 +max(left_height, right_height)

    def height_factor(self):
        right_height = self.right.get_height() if self.right else 0
        left_height = self.left.get_height() if self.left else 0
        return right_height - left_height
```

Self Balancing

Self balancing is as checking the height_factor after every insertion and deletion. If its is greater than | 1 |, rotate the tree in the appropriate direction.

Insertion: Snippet

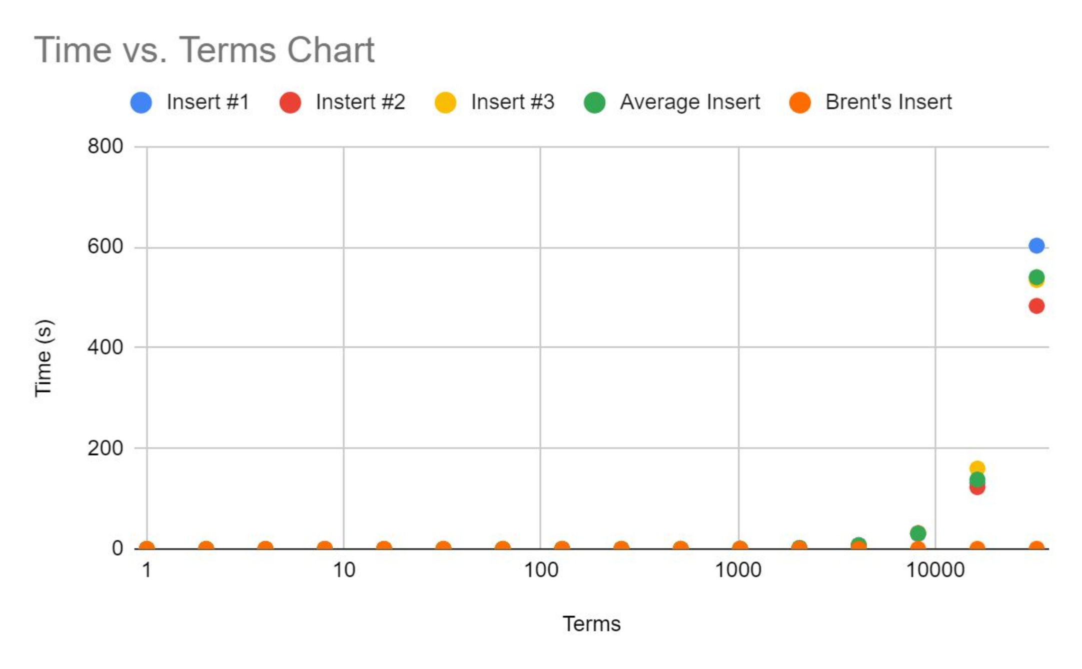
```
def insert(self, value):
        if value < self.value:
            if self.left is None:
                self.left = TreeNode(value)
            else:
                self.left.insert(value)
        else:
            if self.right is None:
                self.right = TreeNode(value)
            else:
                self.right.insert(value)
        if self.height_factor() > 1:
            self.rotate_left()
        if self.height_factor() <= -1:
            self.rotate_right()
```



End of Deletion: Snippet

```
self.right.delete_node(temp.value)
        if self.height_factor() > 1:
            self.rotate_left()
        if self.height_factor() <= -1:
            self.rotate_right()
        return self
```

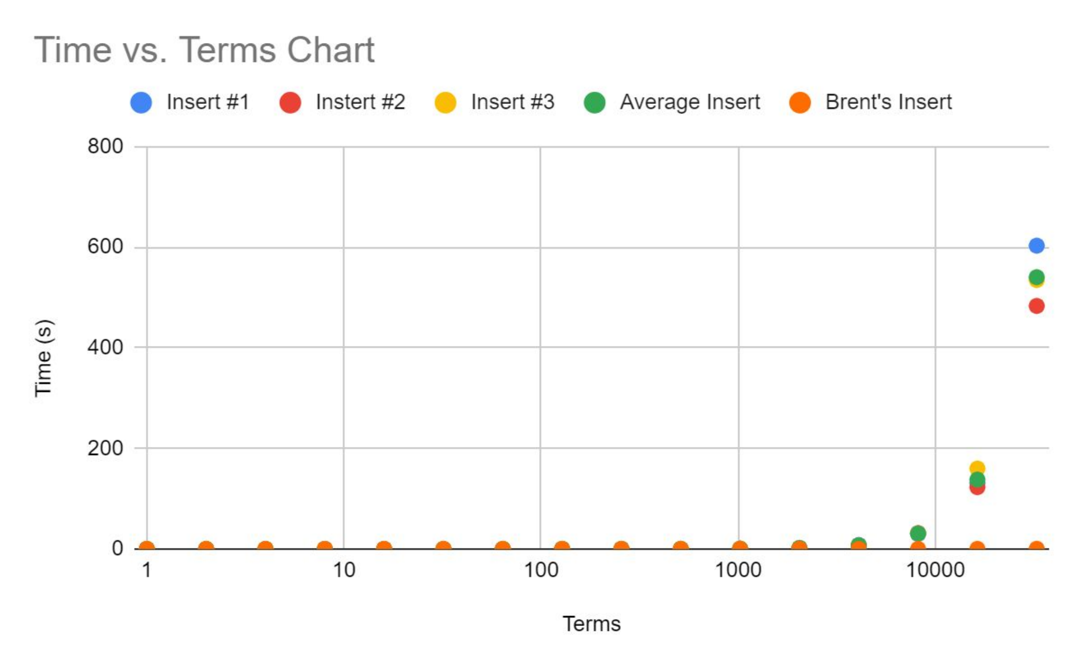
Speed Comparison: Insertion



Other BST was taken from Brent Orlina: GitHub

Not log scaled in time to show how ridiculous Brent's times are

Speed Comparison: Insertion



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Future Implementations

Future Implementations

Visualization

Currently all models are being tested using preorder traversal and USFCA's visualizer. Implementing my own visualizer would really help with the debugging process

Currently looking into: HTML/JavaScript, PYQT, pygame

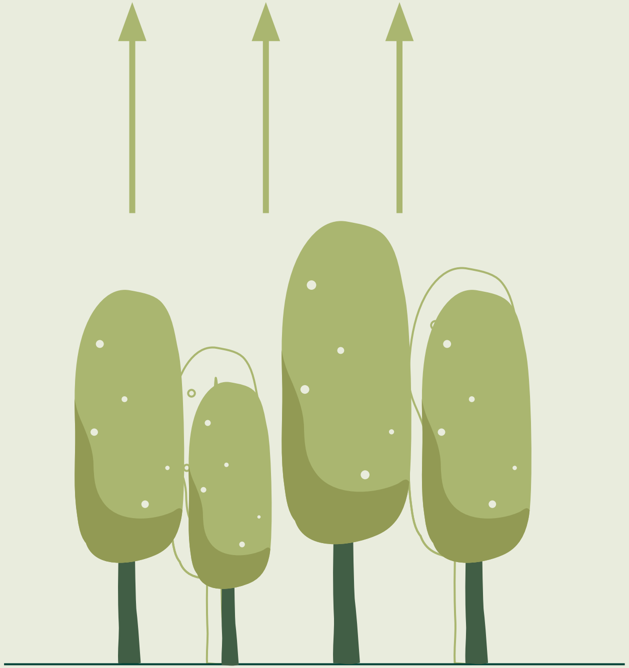
Brent Rotation Speed

I need to figure out how Brent got his times so low. I believe it's due to their four rotation functions and the different use cases each function has but getting times as low as under a second for over 32,000 terms is incredible and something I want to achieve.

Faster Balancing

Currently the tree loses a lot of time by rebalancing after every insert/delete. Better implementation would detect when they tree is no longer in action and call a balancine function then that would work until the tree is balanced instead of adding after every call.

Thanks!



Do you have any questions?

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