Previous Next

404. Sum of Left Leaves

April 17, 2020 | 2.5K views

★★★★★
Average Rating: 5 (4 votes)

Find the sum of all left leaves in a given binary tree.

Example:

```
    3
   / \
  9  20
    /  \
   15   7

There are two left leaves in the binary tree, with values 9 and 15 respectively. Retur
```

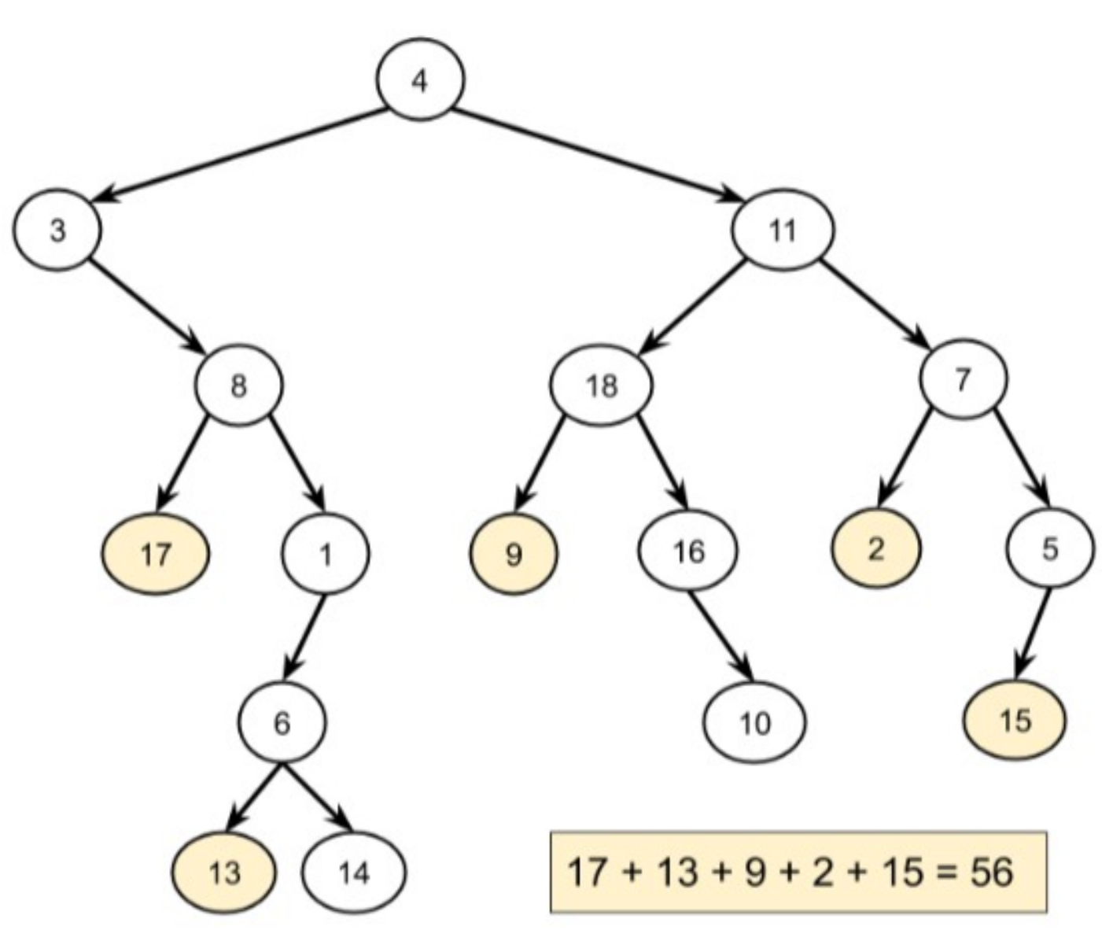
Solution

Recall that a binary tree is made up of *linked tree nodes*, where each node has a reference to its *left child* and to its *right child*. We access the child nodes by using `root.left` and `root.right`. Tree traversal algorithms are used to explore all nodes in the tree. If you're completely confused now, we recommend checking out our Binary Tree Explore Card and then coming back to this question.

Approach 1: Iterative Tree Traversal (Pre-order)

Intuition

Here is an example of a binary tree. The left-leaf nodes are highlighted. Our task is to find all of these left-leaf nodes, add together their values, and return the final sum we get.



To get each left-leaf node's value, we need to "visit" each one. Note that because it is a *sum* we need, the order we visit the left-leaf nodes in doesn't matter. As such, we can pick any algorithm that visits all nodes of the tree. The simplest such algorithm is an **iterative pre-order traversal** (if you're not sure what this is, check out the Binary Tree Explore Card).

When we visit each node, we'll need to know whether or not it *is* a left-leaf node: this is the main challenge in this problem. Remember that once we're on a node, there is no link back up to its parent. This means that given a node, it is impossible to check whether or not it is a *left* node unless we have an existing reference to its parent. There are a couple of strategies for handling this problem:

1. While we're at a node, we can check if its *left-child* is a leaf node (instead of trying to check if the node itself is a left child).
2. When we're ready to visit the children of a node, we can pass some extra information down telling the left child that it is a left child.

The second strategy works well for the recursive implementation (Approach 2), but the first strategy is the best for the iterative, so is what we'll go with here.

Anyway, to do an iterative pre-order traversal, we start by putting the `root` onto a `stack`. Then, while the `stack` is non-empty, we take a node off the top, check if the node's *left child is a leaf node* and then add that child's value to a `total` if it is. Finally, we put the node's left child and right child onto the `stack` so that they can be visited too. Here is the algorithm in pseudocode.

```
define function sum_of_left_leaves(root):

    stack = a new stack
    push root to stack
    total = 0

    while the stack is non-empty:
        node = pop a node of stack
        if node.left exists and node.left is a leaf:
            total = total + node.left.value
        if node.right exists:
            push node.right to stack
        if node.left exists:
            push node.left to stack

    return total
```

Note that it doesn't matter whether we put the left or right child on the stack first. We just chose to put right and then left so that left is the next off, thus matching the standard pre-order traversal code template.

Here is an animation of this approach in action!

A pre-order traversal is a type of depth-first tree traversal. This is because it uses a *stack* to keep track of unvisited nodes. Alternatively, we could have used a breadth-first tree traversal; using a *queue* to keep track of unvisited nodes instead of a stack. This works because while the nodes are visited in a different order, this doesn't matter, as discussed above. In fact, we could have used any data structure that allowed us to put an unvisited node in and take a node out to visit.

Algorithm

This code uses a *stack* to keep track of the unvisited nodes. You could, however, replace it with a *queue* and the algorithm would still work (but would process the nodes in a different order). In Java, we use a `Deque` like a stack, instead of using `Stack` (`Stack` is deprecated).

Java | Python | Copy

```python
class Solution:

    def sumOfLeftLeaves(self, root: TreeNode) -> int:

        if root is None:
            return 0

        def is_leaf(node):
            return node is not None and node.left is None and node.right is None

        stack = [root]
        total = 0
        while stack:
            sub_root = stack.pop()
            # Check if the left node is a leaf node.
            if is_leaf(sub_root.left):
                total += sub_root.left.val
            # If the right node exists, put it on the stack.
            if sub_root.right is not None:
                stack.append(sub_root.right)
            # If the left node exists, put it on the stack.
            if sub_root.left is not None:
                stack.append(sub_root.left)

        return total
```

Complexity Analysis

Let N be the number of nodes in the tree.

- Time complexity : $O(N)$.

  Each node is put onto the stack *once*, by its parent node. We know each node only has one parent because this is a tree. Therefore, each node is only taken off, and processed, once. Processing a node is an $O(1)$ operation. Therefore, we get a total time complexity of $N \cdot O(1) = O(N)$.

- Space complexity : $O(N)$.

  Remember that in complexity analysis, we're always looking at the worst case. The worst-case tree is one where we have a long "strand" of left nodes, with each having a single right node. On one of these trees, the algorithm will work its way down the left nodes first, having at most one of them on the stack at a time. However, every right node that it encounters will be placed on the stack. With half of the nodes being these right nodes, the space used is proportional to the number of nodes in the tree, giving us a space complexity of $O(N)$.

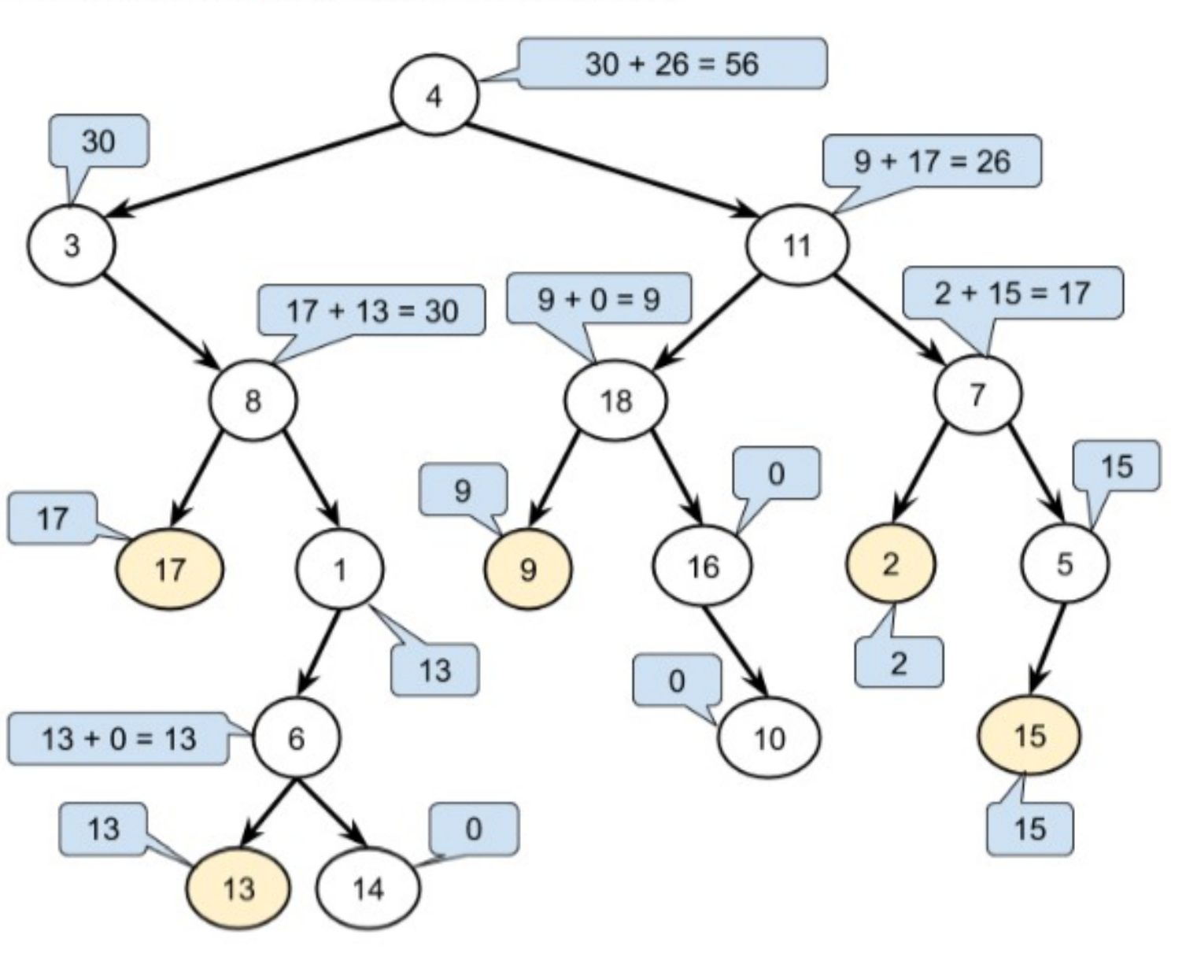
For the problem we've been given here on LeetCode, we haven't been told whether or not the input tree is *balanced* (most non-leaf nodes having 2 children, thus minimizing the maximum depth). Therefore, we have to assume it is *not*. **However**, in an interview, you *might* be asked what the time and space complexity are if the input *was* guaranteed to be a balanced tree. If it is, balanced, then the time complexity remains the same (we still have to visit all N nodes), but the space complexity becomes $O(D)$, where D is the maximum depth. This is equivalent to $O(\log N)$.

Approach 2: Recursive Tree Traversal (Pre-order)

Intuition

Another way of traversing a tree is to use recursion to visit each node. If you're not familiar with recursion on trees, check out the Binary Trees Explore Card.

Recall that recursive tree algorithms work by treating each node of the tree as the root of a *subtree*. The answer (i.e. the sum of left leaf node values) is then found for each *subtree* by finding the answers for the left and right subtrees and combining (adding) them together.



To implement a recursive function, we need to identify the base cases and recursive cases.

The **base case** is that this subtree is a leaf node (i.e. the subtree only contains a single node; its root node). The value we return for it depends on whether this subtree was to the left or the right of its parent. If it was to the left, we return its value. If it was to the right, we return zero.

The **recursive** case is that this subtree contains a left and/or right subtree (i.e. the subtree has more than just the root node in it). We call the recursive function on the left and right subtrees, add their results together and return the added result.

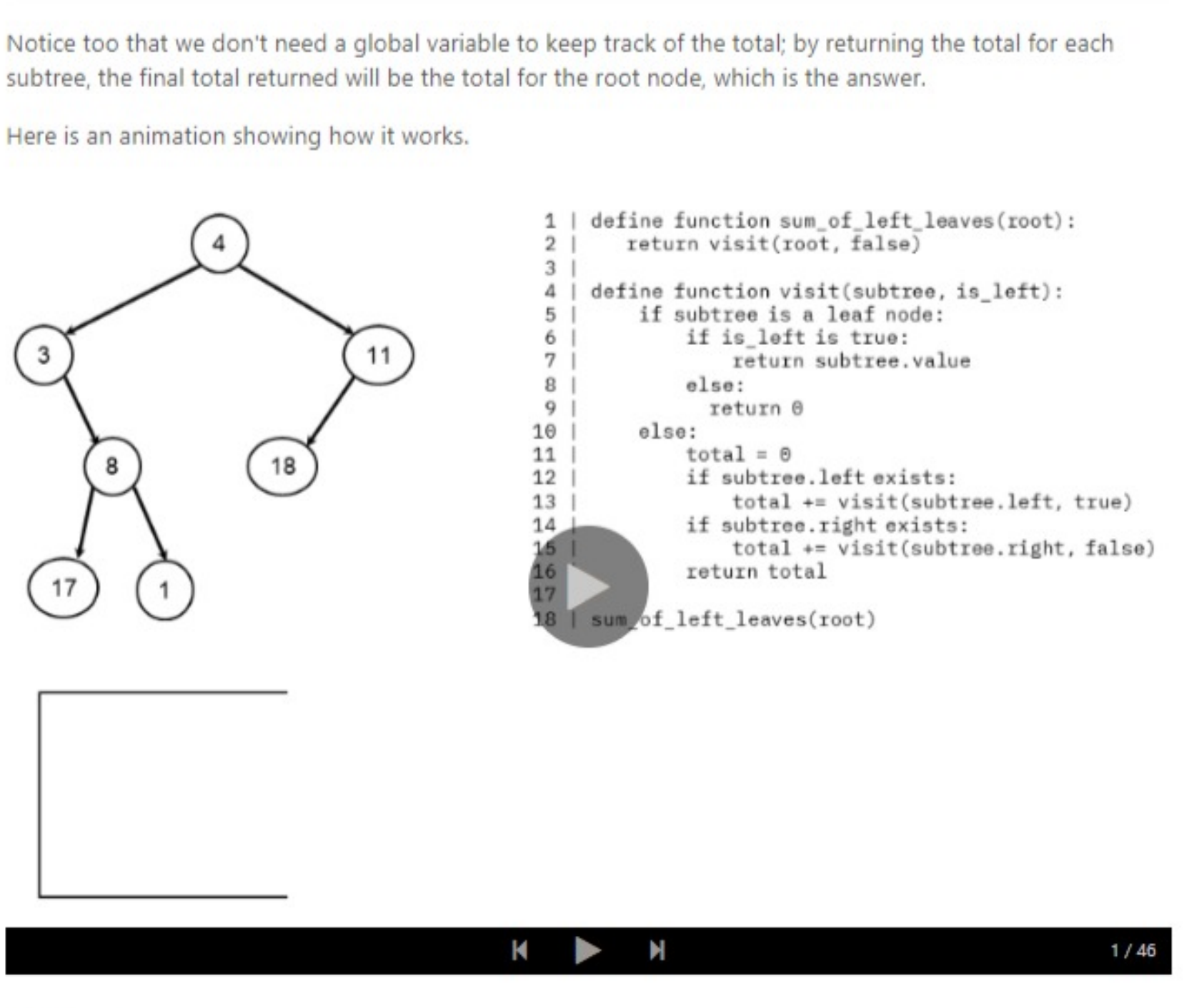
Like before though, we still have the problem of knowing whether or not the current subtree was to the left of its parent. With recursion though, there is a far more elegant solution than before: we can simply have an additional boolean parameter on our recursive function, specifying whether or not the subtree is a left one! Note that the *top* subtree is neither a left node, nor a right node, but we pass in false for it, as the purpose of the parameter is to specify whether or not it *is a left subtree*.

```
define function sum_of_left_leaves(root):
    return process_subtree(root, false)

define function process_subtree(subtree, is_left):
    if subtree is a leaf node:
        if is_left is true:
            return subtree.value
        else:
            return 0
    else:
        total = 0
        if subtree.left exists:
            total = total + process_subtree(subtree.left, true)
        if subtree.right exists:
            total = total + process_subtree(subtree.right, false)
        return total
```

Notice too that we don't need a global variable to keep track of the total; by returning the total for each subtree, the final total returned will be the total for the root node, which is the answer.

Here is an animation showing how it works.



```
define function sum_of_left_leaves(root):
   return visit(root, false)

define function visit(subtree, is_left):
    if subtree is a leaf node:
        if is_left is true:
            return subtree.value
        else:
          return 0
    else:
        total = 0
        if subtree.left exists:
            total += visit(subtree.left, true)
        if subtree.right exists:
            total += visit(subtree.right, false)
        return total

sum_of_left_leaves(root)
```

Algorithm

Here is the algorithm, as we described it above.

Java | Python3 | Copy

```python
class Solution:

    def sumOfLeftLeaves(self, root: TreeNode) -> int:

        # An empty root is one of the test cases!
        if root is None:
            return 0

        def process_subtree(subtree, is_left):

            # Base case: This is a leaf node.
            if subtree.left is None and subtree.right is None:
                return subtree.val if is_left else 0

            # Recursive case: We need to add and return the results of the
            # left and right subtrees.
            total = 0
            if subtree.left:
                total += process_subtree(subtree.left, True)
            if subtree.right:
                total += process_subtree(subtree.right, False)
            return total

        # Call the recursive function on the root node to start the process.
        # We need to be careful of the case that the root is empty.
        return process_subtree(root, False)
```

We can simplify the code a bit by defining an additional base case: if the subtree is empty (null), then `0` should be returned. This means we no longer need to do null-checks in three separate places. This is a pattern you will see a lot for recursive tree algorithms.

Java | Python | Copy

```python
class Solution:

    def sumOfLeftLeaves(self, root: TreeNode) -> int:

        def process_subtree(subtree, is_left):

            # Base case: If this subtree is empty, return 0
            if subtree is None:
                return 0

            # Base case: This is a leaf node.
            if subtree.left is None and subtree.right is None:
                return subtree.val if is_left else 0

            # Recursive case: return result of adding the left and right subtrees.
            return process_subtree(subtree.left, True) + process_subtree(subtree.right, False)

        return process_subtree(root, False)
```

Complexity Analysis

Let N be the number of nodes.

- Time complexity : $O(N)$.

  The code within the recursive function is all $O(1)$. The function is called exactly once for each of the N nodes. Therefore, the total time complexity of the algorithm is $O(N)$.

- Space complexity : $O(N)$.

  In the worst case, the tree consists of nodes that form a single deep strand. In this case, the runtime-stack will have N calls to `processSubtree(...)` on it at the same time, giving a worst-case space complexity of $O(N)$.

Approach 3: Morris Tree Traversal (Pre-order)

Intuition

Note that this approach is quite advanced. Feel free to skip it if you're just starting out!

All of the algorithms we've looked at so far had a time complexity of $O(N)$, and a space complexity of $O(N)$.

We know it is impossible to reduce the time complexity any further, as we need to visit each node to access all the nodes.

The space complexity might initially seem impossible to reduce, as when a node has two children, we need to explore one immediately, and keep track of the other for exploration afterward (often, we explore the left subtree first, and keep track of the right subtree for later). Going down the tree, we can end up with many of these child nodes awaiting exploration. However, there is a tree traversal algorithm that requires $O(N)$ time and only $O(1)$ space: Morris Tree Traversal.

This traversal algorithm works by *temporarily* modifying the input tree so that before we explore a left subtree, we find the subtree root's in-order predecessor (which will never have a right child), and make its right link point back up to the root. Then we explore the left subtree. When we're done exploring the left subtree, the link back up to the root will then allow us to explore the right subtree. When we follow the link back up, we also remove it so that the input tree is restored. In this way, we can no longer need an auxiliary data structure to keep track of the right subtrees.

Given that this algorithm modifies the input tree, will we still be able to identify which nodes are left-leaves? As it turns out we still can. Whenever we reach a node for the first time, we know we haven't yet looked at its left subtree, and so have not modified it. Therefore, we can simply check if the left child is a leaf node, in the same way we did before.

For more information on this algorithm, check out Approach 2 in the Preorder Traversal Solution Article.

Algorithm

These solutions are based on C code written by @kamanelf and the template from the Preorder Traversal Solution Article.

Java | Python | C | Copy

```python
class Solution:

    def sumOfLeftLeaves(self, root):
        total_sum = 0
        current_node = root
        while current_node is not None:
            # If there is no left child, we can simply explore the right subtree
            # without needing to worry about keeping track of currentNode's other
            # child.
            if current_node.left is None:
                current_node = current_node.right
            else:
                previous = current_node.left
                # Check if this left node is a leaf node.
                if previous.left is None and previous.right is None:
                    total_sum += previous.val
                # Find the inorder predecessor for currentNode.
                while previous.right is not None and previous.right is not current_node:
                    previous = previous.right
                # We've not yet visited the inorder predecessor. This means that we
                # still need to explore currentNode's left subtree. Before doing this,
                # we will put a link back so that we can get back to the right subtree
                # when we need to.
                if previous.right is None:
                    previous.right = current_node
                    current_node = current_node.left
                # We have already visited the inorder predecessor. This means that we
```

Complexity Analysis

- Time complexity : $O(N)$.

  Each node is visited at least once; with some nodes visited twice to remove the added links and move back up to the subtree root. However, no node is visited more than twice, so our time complexity is $O(N)$.

- Space complexity : $O(1)$.

  We are only using constant extra space.

Note that while the input is modified, it is restored after the algorithm has finished running. The downside of this is that it is not thread-safe. Any other thread that needs to access the tree will have to wait until this algorithm has finished running. For applications that must support concurrent access, this is almost certainly not worth it given the availability of thread-safe alternatives.

Rate this article: ★★★★★

Previous Next

Comments: 6 Sort By

Type comment here... (Markdown is supported)

Preview Post

shuangpan ★25 June 22, 2020 12:00 PM

Java 0ms preorder

```
class Solution {
    private int sum = 0;
    public int sumOfLeftLeaves(TreeNode root) {
```

Read More

1 Share Reply

muthu90ec ★2 July 15, 2020 7:26 AM

Yet another DFS solution:

```
class Solution {
    int sum = 0;
```

Read More

0 Share Reply

vibhutiwari ★1 July 6, 2020 9:27 AM

Simple easy to understand recursive java solution:

class Solution {
int sum = 0;

Read More

0 Share Reply

vsharda1 ★44 July 5, 2020 12:11 PM

@Hai_dee Nice Solutions, here is my simple and easy to understand BFS Solution!!

```
    def sumOfLeftLeaves(self, root):
        if not root:
            return 0
```

Read More

0 Share Reply

iampolo ★28 June 15, 2020 6:48 AM

@Hai_dee where I can find a list of all of your articles?
The search doesn't work anymore.

0 Share Reply

jaithrik ★37 May 11, 2020 3:04 AM

I really like the last solution. Thanks @Hai_dee

0 Share Reply