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## Write a function to see if a binary tree is *"superbalanced"* (a new tree property we just made up).

A tree is "superbalanced" if the difference between the depths of any two leaf nodes is no greater than one.

Here's a sample binary tree node class:

```

@interface ICKBinaryTreeNode : NSObject
@property (nonatomic) NSInteger value;
@property (nonatomic) ICKBinaryTreeNode *left;
@property (nonatomic) ICKBinaryTreeNode *right;
- (instancetype)initWithValue:(NSInteger)value;
- (ICKBinaryTreeNode*)insertLeft:(NSInteger)leftValue;
- (ICKBinaryTreeNode*)insertRight:(NSInteger)rightValue;
@end

@implementation ICKBinaryTreeNode

- (instancetype)initWithValue:(NSInteger)value {
    if (self = [super init]) {
        self.value = value;
    }
    return self;
}

- (ICKBinaryTreeNode*)insertLeft:(NSInteger)leftValue {
    self.left = [[ICKBinaryTreeNode alloc] initWithValue:leftValue];
    return self.left;
}

- (ICKBinaryTreeNode*)insertRight:(NSInteger)rightValue {
    self.right = [[ICKBinaryTreeNode alloc] initWithValue:rightValue];
    return self.right;
}

@end

```

## Gotchas

Your first thought might be to write a recursive function, thinking, "the tree is balanced if the left subtree is balanced and the right subtree is balanced." This kind of approach works well for some other tree problems.

**But this isn't quite true.** Counterexample: suppose that from the root of our tree:

- The left subtree only has leaves at depths 10 and 11.
- The right subtree only has leaves at depths 11 and 12.

Both subtrees are balanced, but from the root we will have leaves at 3 different depths.

We could instead have our recursive function get the array of distinct leaf depths for each subtree. That could work fine. But let's come up with an iterative solution instead. It's usually better to use an iterative solution instead of a recursive one because it avoids stack overflow.

We can do this in  $O(n)$  time and  $O(n)$  space.

What about a tree with only one leaf node? Does your function handle that case properly?

## Breakdown

Sometimes it's good to start by rephrasing or "simplifying" the problem.

The requirement of "the difference between the depths of any two leaf nodes is no greater than 1" implies that we'll have to compare the depths of *all possible pairs* of leaves. That'd be expensive—if there are  $n$  leaves, there are  $O(n^2)$  possible pairs of leaves.

**But we can simplify this requirement to require less work.** For example, we could equivalently say:

- "The difference between the min leaf depth and the max leaf depth is 1 or less"
- "There are at most two distinct leaf depths, and they are at most 1 apart"

If you're having trouble with a recursive approach, try using an iterative one.

To get to our leaves and measure their depths, we'll have to traverse the tree somehow. **What methods do we know for traversing a tree?**

Depth-first and breadth-first are common ways to traverse a tree. Which one should we use here?

The worst-case time and space costs of both are the same—you could make a case for either.

But one characteristic of our algorithm is that it could **short-circuit** and return false as soon as it finds two leaves with depths more than 1 apart. So maybe we should **use a traversal that will hit leaves as quickly as possible...**

Depth-first traversal will generally hit leaves before breadth-first, so let's go with that. How could we write a depth-first walk that also keeps track of our depth?

## Solution

We do a depth-first walk through our tree, keeping track of the depth as we go. When we find a leaf, we add its depth to an array of depths *if* we haven't seen that depth already.

Each time we hit a leaf with a new depth, there are two ways that our tree might now be unbalanced:

1. There are more than 2 different leaf depths
2. There are exactly 2 leaf depths and they are more than 1 apart.

Why are we doing a depth-first walk and not a breadth-first one? You could make a case for either. We chose depth-first because it reaches leaves faster, which allows us to short-circuit earlier in some cases.

```

@interface ICKNodeDepthPair : NSObject
@property (nonatomic) ICKBinaryTreeNode *node;
@property (nonatomic) NSUInteger depth;
- (instancetype)initWithNode:(ICKBinaryTreeNode*)node depth:(NSUInteger)depth;
@end

@implementation ICKNodeDepthPair

- (instancetype)initWithNode:(ICKBinaryTreeNode*)node depth:(NSUInteger)depth {
    if (self = [super init]) {
        self.node = node;
        self.depth = depth;
    }
    return self;
}

@end

BOOL ICKIsBalanced(ICKBinaryTreeNode *treeRoot) {

    // a tree with no nodes is superbalanced, since there are no leaves!
    if (treeRoot == nil) {
        return YES;
    }

    // we short-circuit as soon as we find more than 2
    NSMutableArray<NSNumber *> *depths = [NSMutableArray new];

    // nodes will store pairs of a node and the node's depth
    NSMutableArray<ICKNodeDepthPair *> *nodes = [NSMutableArray new];
    [nodes addObject:[ICKNodeDepthPair alloc] initWithNode:treeRoot depth:0];

    while (nodes.count) {

        // pop a node and its depth from the top of our stack
        ICKNodeDepthPair *nodePair = [nodes lastObject];
        [nodes removeLastObject];
        ICKBinaryTreeNode *node = nodePair.node;
        NSUInteger depth = nodePair.depth;

```

```

// case: we found a leaf
if (!node.left && !node.right) {

    // we only care if it's a new depth
    if (![depths containsObject:@(depth)]) {
        [depths addObject:@(depth)];
    }

    // two ways we might now have an unbalanced tree:
    // 1) more than 2 different leaf depths
    // 2) 2 leaf depths that are more than 1 apart
    if (depths.count > 2 || (depths.count == 2 &&
        labs(((NSNumber *)depths[0]).integerValue -
            ((NSNumber *)depths[1]).integerValue) > 1)) {
        return NO;
    }

    // case: this isn't a leaf - keep stepping down
} else {
    if (node.left) {
        [nodes addObject:[[ICKNodeDepthPair alloc] initWithNode:node.left
                                                                depth:(depth + 1)]];
    }
    if (node.right) {
        [nodes addObject:[[ICKNodeDepthPair alloc] initWithNode:node.right
                                                                depth:(depth + 1)]];
    }
}

return YES;
}

```

## Complexity

$O(n)$  time and  $O(n)$  space.

For time, the worst case is the tree is balanced and we have to iterate over *all*  $n$  nodes to make sure.

For the space cost, we have two data structures to watch: depths and nodes.

depths will never hold more than three elements, so we can write that off as  $O(1)$ .

Because we're doing a depth first search, nodes will hold at most  $d$  nodes where  $d$  is the depth of the tree (the number of levels in the tree from the root node down to the lowest node). So we could say our space cost is  $O(d)$ .

But we can also relate  $d$  to  $n$ . In a balanced tree,  $d$  is  $O(\log_2(n))$  (/concept/binary-tree#property2). And the *more unbalanced* the tree gets, the closer  $d$  gets to  $n$ .

In the worst case, the tree is a straight line of right children from the root where every node in that line also has a left child. The traversal will walk down the line of right children, adding a new left child to nodes at each step. When the traversal hits the rightmost node, nodes will hold *half* of the  $n$  total nodes in the tree. Half  $n$  is  $O(n)$ , so our worst case space cost is  $O(n)$ .

## What We Learned

This is an intro to some tree basics. If this is new to you, don't worry—it can take a few questions for this stuff to come together. We have a few more coming up.

Particular things to note:

Focus on **depth-first vs breadth-first traversal**. You should be very comfortable with the differences between the two and the strengths and weaknesses of each.

You should also be very comfortable coding each of them up.

One tip: **Remember that breadth-first uses a queue and depth-first uses a stack** (could be the call stack or an actual stack object). That's not just a clue about implementation, it also helps with figuring out the differences in behavior. Those differences come from whether we visit nodes in the order we see them (first in, first out) or we visit the last-seen node first (last in, first out).

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Next up: Binary Search Tree Checker ➡ (/question/bst-checker?course=fc1&section=trees-graphs)

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