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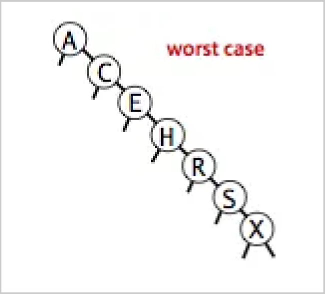
AVL Tree in C#

Karim Oumghar / September 16, 2014

Updated as of Nov 2016 **AVL Tree** is a self balancing binary tree data structure. It has a very efficient Insert, Delete, and Find times. In terms of the depth of an AVL tree on both sides, it differs at most by 1 level. At any other time where difference in height/depth is greater than 1 or less than -1, rebalancing occurs. In terms of space it has a O(n) complexity. With time complexity it has O(log n) for all cases (worst, average, best). Comparing this with the commonly known Red-Black Tree, the AVL Tree is more rigidly balanced than the RB Tree, thus while having fast retrieval times, the RB Tree is more efficient in insertion & deletion times. Nonetheless, both have a runtime of O(log n) and are self balancing. The name AVL comes from the creators of this algorithm (Adelson-Velskii and Landis).

Why the need to balance?

Consider a regular binary tree or a binary search tree. We know that in the worst case retrieval and insertion is O(n), when the tree looks like a linked list, and traversal is pretty much like that of a linked list. This is quite inefficient and costs time. To remedy and eliminate this problem, we introduce the idea of a self balancing tree; through height checking and rotations, maintains a more balanced structure; thus less time to lookup some data.



In the worst case, a regular BST or Binary Tree takes the shape resembling a linked list.

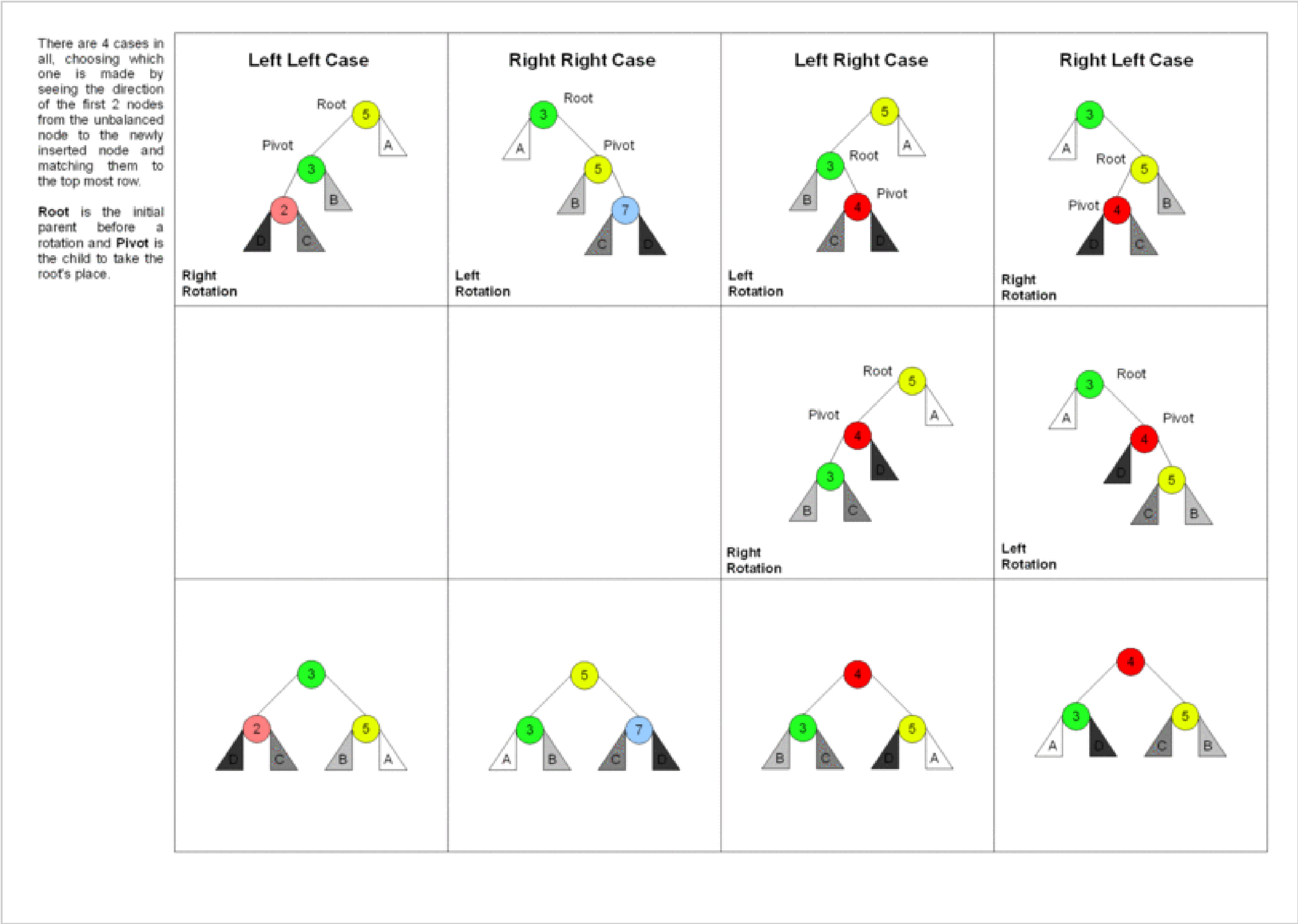
The algorithm of an AVL Tree is as follows:

- Get the height difference from both sides of the tree, using recursion and the difference in balance is the height of the left side minus height of the right side
- If the balance is greater 1 or less than -1, rotations must occur to balance the tree, if the balance is -1,0,or 1, then no rotations are needed.
- Nodes in the AVL Tree also store their height, for example, nodes at the top are higher than nodes at the bottom therefore the root would store the highest height while leaf nodes at the bottom would store a height of 1

In this kind of self balancing tree, we have what are called rotations. The data structure is as follows:

- There are 4 cases for rotations: right-right, right-left, left-left, and left-right
- Right-Right: All nodes are to the right of the root/parent, the pivot becomes the new parent/root and original parent/root node becomes a child of the pivot
- Right-Left: Pivot is the right child of the root/parent
- Left-Left: All nodes are to the left of the root
- Left-Right: Pivot is the left child of the root/parent
- To go even further with how rotations work:

- A generic rotation in pseudocode:
- Pivot = Parent.L
  Parent.L = Pivot.L
  Pivot.R = Parent
  return Pivot
- Illustrations:



Rotation Illustrations

Methods:

- Insert(): after inserting a new node using normal procedure (recursive or non recursive), its necessary to check each of the nodes ancestors for an unbalance in the tree, therefore calling the Balance() method, basically, insert and then a small fix.
  - To go into further detail, we have private and public Insert methods. The private method inserts recursively and it takes a new node object, and a node reference/pointer, and it is here where we call Balance_Tree(). In the public method, we call the private recursive insert method and we need to set our root pointer/reference equal to the method call because the private method returns type Node. Also because of the recursion, when we perform a rotation from calling the Balance_Tree() method, we need to recurse up one level and make the necessary re-connections of parent to pivot nodes. The best way to visualise this recursion is to draw a stack frame of calls in order to see the process better.
  - In short, our base case is that if our current node we use to traverse the tree to insert is null, current = new node and return current. That would go to our next statement which recurses up one level and sets current->left/right to the newly added node. Then we balance our tree by calling Balance_Tree. Once rotations have been done, we return our pivot node and re-check the balance factor once again to make sure we have no imbalances. Recurse up a level once more and reconnect the rotated nodes to the parent node.

- Search(): Searching is more optimized since things are more balanced, therefore normal implementation in this function is sufficient.
- Delete(): Just like Insert(), after Deletion occurs we have to call Balance() to check each of the nodes for any unbalance in the tree, we have a public Delete() and a private recursive Delete() that does the actual work
- RotateRR(), RotateLL(), RotateLR(), and RotateRL() all take in a node pointer/reference argument, and return a pivot node with the rotation
- GetHeight(): takes a node reference/pointer argument, and returns the height. More info here on why we add 1 to the height.
- Balance_Factor(): takes a Node reference as an argument, this will recursively get the heights for both sides and return an integer (left height – right height)
- Balance_Tree(): This method takes a node pointer/reference passed into it. When we balance the tree, the algorithm in goes something like this:
  - If balance factor is 2, we first check if we have a left-left case, if we do then we perform that rotation, else, we perform a left-right rotation
  - If balance factor is -2, we first check if we have a right-right case, if we do then we perform a right right rotation, else, we perform a right-left rotation

Implementation in C#

```
class Program
```

```
    {
        static void Main(string[] args)
        {
            AVL tree = new AVL();
            tree.Add(5);
            tree.Add(3);
            tree.Add(7);
            tree.Add(2);
            tree.Delete(7);
            tree.DisplayTree();
        }
    }
    class AVL
    {
        class Node
        {
            public int data;
            public Node left;
            public Node right;
            public Node(int data)
            {
                this.data = data;
            }
        }
        Node root;
        public AVL()
        {
        }
        public void Add(int data)
        {
            Node newItem = new Node(data);
            if (root == null)
            {
                root = newItem;
            }
            else
            {
                root = RecursiveInsert(root, newItem);
            }
        }
        private Node RecursiveInsert(Node current, Node n)
        {
            if (current == null)
            {
                current = n;
                return current;
            }
            else if (n.data < current.data)
            {
                current.left = RecursiveInsert(current.left, n);
                current = balance_tree(current);
            }
```

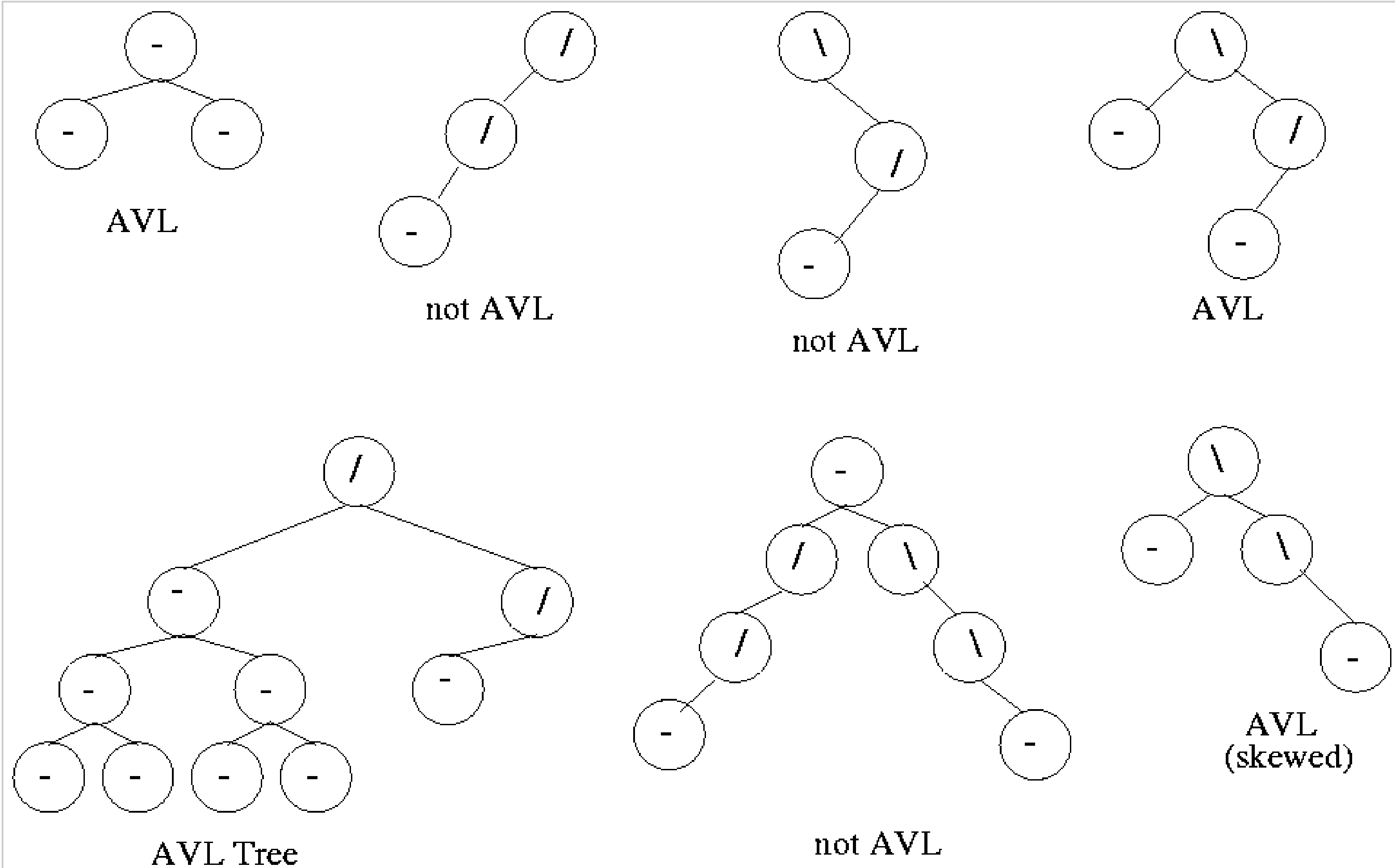
```
            else if (n.data > current.data)
            {
                current.right = RecursiveInsert(current.right, n);
                current = balance_tree(current);
            }
            return current;
        }
        private Node balance_tree(Node current)
        {
            int b_factor = balance_factor(current);
            if (b_factor > 1)
            {
                if (balance_factor(current.left) > 0)
                {
                    current = RotateLL(current);
                }
                else
                {
                    current = RotateLR(current);
                }
            }
            else if (b_factor < -1)
            {
                if (balance_factor(current.right) > 0)
                {
                    current = RotateRL(current);
                }
                else
                {
                    current = RotateRR(current);
                }
            }
            return current;
        }
        public void Delete(int target)
        {//and here
            root = Delete(root, target);
        }
        private Node Delete(Node current, int target)
        {
            Node parent;
            if (current == null)
            { return null; }
            else
            {
                //left subtree
                if (target < current.data)
                {
                    current.left = Delete(current.left, target);
                    if (balance_factor(current) == -2)//here
                    {
                        if (balance_factor(current.right) <= 0)
```

```
                {
                    current = RotateRR(current);
                }
                else
                {
                    current = RotateRL(current);
                }
            }
        }
        //right subtree
        else if (target > current.data)
        {
            current.right = Delete(current.right, target);
            if (balance_factor(current) == 2)
            {
                if (balance_factor(current.left) >= 0)
                {
                    current = RotateLL(current);
                }
                else
                {
                    current = RotateLR(current);
                }
            }
        }
        //if target is found
        else
        {
            if (current.right != null)
            {
                //delete its inorder successor
                parent = current.right;
                while (parent.left != null)
                {
                    parent = parent.left;
                }
                current.data = parent.data;
                current.right = Delete(current.right, parent.data);
                if (balance_factor(current) == 2)//rebalancing
                {
                    if (balance_factor(current.left) >= 0)
                    {
                        current = RotateLL(current);
                    }
                    else { current = RotateLR(current); }
                }
            }
            else
            {   //if current.left != null
                return current.left;
            }
        }
```

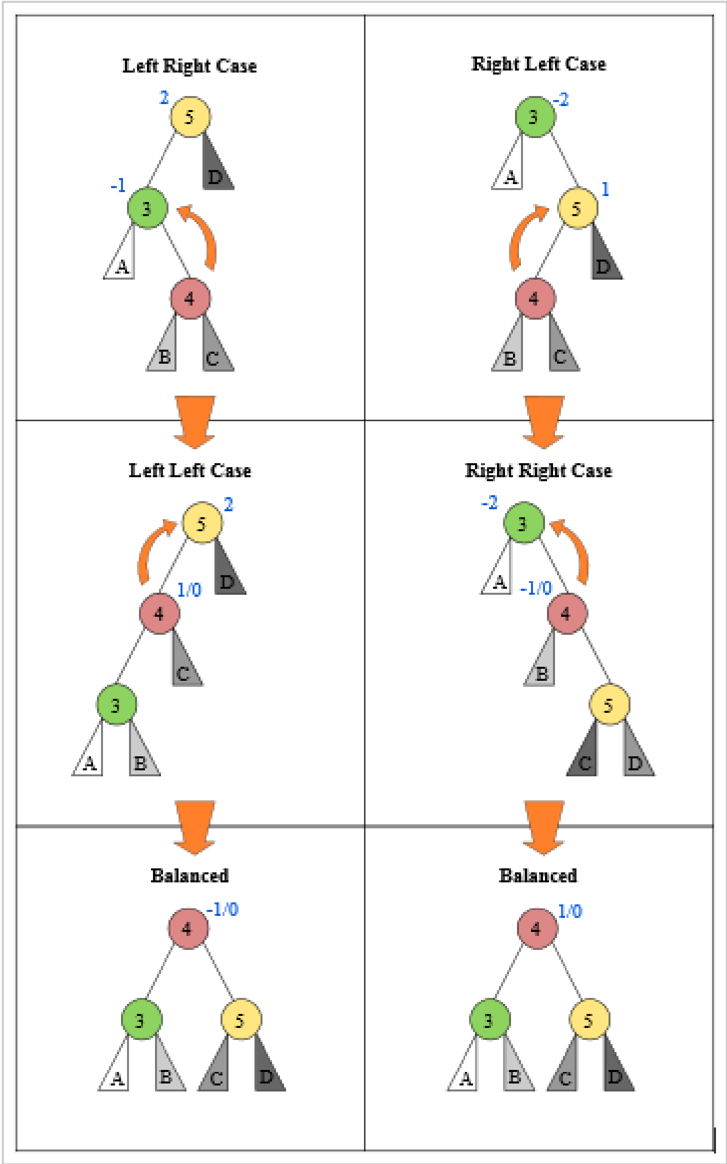
```
            }
            return current;
        }
        public void Find(int key)
        {
            if (Find(key, root).data == key)
            {
                Console.WriteLine("{0} was found!", key);
            }
            else
            {
                Console.WriteLine("Nothing found!");
            }
        }
        private Node Find(int target, Node current)
        {

                if (target < current.data)
                {
                    if (target == current.data)
                    {
                        return current;
                    }
                    else
                    return Find(target, current.left);
                }
                else
                {
                    if (target == current.data)
                    {
                        return current;
                    }
                    else
                    return Find(target, current.right);
                }

        }
        public void DisplayTree()
        {
            if (root == null)
            {
                Console.WriteLine("Tree is empty");
                return;
            }
            InOrderDisplayTree(root);
            Console.WriteLine();
        }
        private void InOrderDisplayTree(Node current)
        {
            if (current != null)
            {
                InOrderDisplayTree(current.left);
```

```
                Console.Write("({0}) ", current.data);
                InOrderDisplayTree(current.right);
            }
        }
        private int max(int l, int r)
        {
            return l > r ? l : r;
        }
        private int getHeight(Node current)
        {
            int height = 0;
            if (current != null)
            {
                int l = getHeight(current.left);
                int r = getHeight(current.right);
                int m = max(l, r);
                height = m + 1;
            }
            return height;
        }
        private int balance_factor(Node current)
        {
            int l = getHeight(current.left);
            int r = getHeight(current.right);
            int b_factor = l - r;
            return b_factor;
        }
        private Node RotateRR(Node parent)
        {
            Node pivot = parent.right;
            parent.right = pivot.left;
            pivot.left = parent;
            return pivot;
        }
        private Node RotateLL(Node parent)
        {
            Node pivot = parent.left;
            parent.left = pivot.right;
            pivot.right = parent;
            return pivot;
        }
        private Node RotateLR(Node parent)
        {
            Node pivot = parent.left;
            parent.left = RotateRR(pivot);
            return RotateLL(parent);
        }
        private Node RotateRL(Node parent)
        {
            Node pivot = parent.right;
            parent.right = RotateLL(pivot);
            return RotateRR(parent);
```

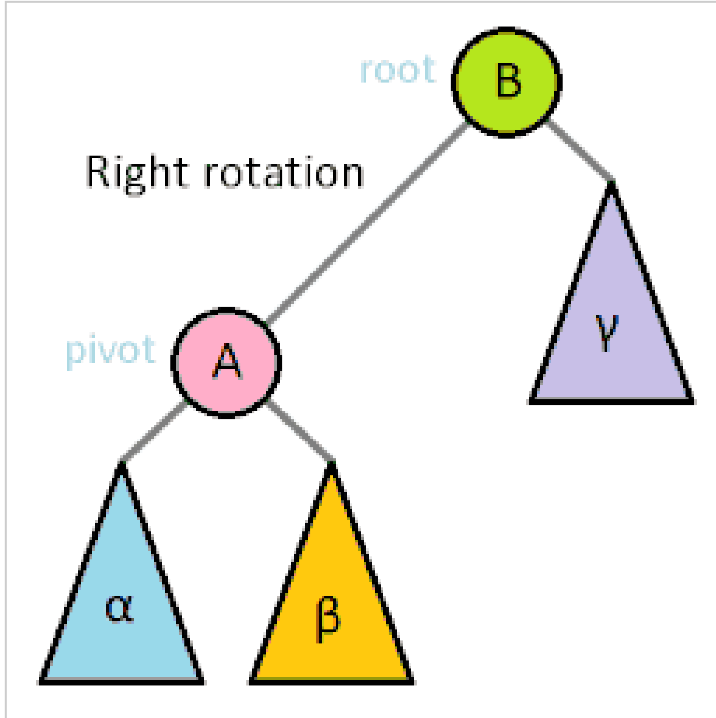
```
        }
    }
```



AVL Tree depictions



AVL Tree (unbalanced and balanced tree process)



Tree rotation animation

[Interactive AVL Tree Applet demo.]

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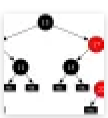
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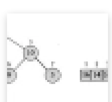
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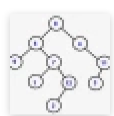
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16 thoughts on "AVL Tree in C#"

Pingback: Red-Black Tree in C# | Bits and Pieces of Code

GoodNPlenty333 (@GoodNPlenty333) July 3, 2015 at 3:44 pm

You are recalculating the height of each node recursively, which is very costly. You can gain significant performance improvements by storing the height in each node.

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Reply

Karim Oumghar July 7, 2015 at 5:39 pm

I am aware of this. At the moment I am busy with other things however I have kept a note of this and will update this tutorial soon. Thanks for your feedback.

★ Like

Reply

---

aljensen September 22, 2015 at 5:12 pm

Reblogged this on .Net Programming with Al Jensen.

★ Like

Reply

kalitr March 16, 2016 at 11:30 am

Thanks bro

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Reply

ashley beshir May 1, 2016 at 6:03 pm

AVL tree = new AVL();
tree.Add(5);
tree.Add(3);
tree.Add(7);
tree.Add(8);
tree.Delete(3);
tree.DisplayTree();

this causes a null error ? the code is just copy paste of yours ?

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Reply

Karim Oumghar May 1, 2016 at 9:31 pm

I have resolved this bug as of now. I have tested with various scenarios and it works as it should. Thanks for your feedback and for detecting this issue.

★ Like

Reply

---

ashley beshir May 4, 2016 at 7:45 am

Hello , i think i found another bug

```
AVL tree = new AVL();
tree.Add(5);
tree.Add(3);
tree.Add(7);
tree.Add(2);
tree.Delete(7);
tree.DisplayTree();
```

when i try this , i get a 'System.NullReferenceException' error and visual studio shows this line
parent.right = pivot.left;

Regards Ashley

★ Like

Reply

Karim Oumghar May 4, 2016 at 10:41 am

I don’t get this error. I recently updated this code yesterday again so try the new source code. After deletion I get 2 3 5.

★ Like

Reply

---

ashley beshir May 4, 2016 at 5:08 pm

i tried the new source . if i write the code like this

AVL tree = new AVL();
tree.Add(5);
tree.Add(3);
tree.Add(2);
tree.Add(7);
tree.Delete(7);
tree.DisplayTree();

i wont get a error
but if i write it like this

AVL tree = new AVL();
tree.Add(5);
tree.Add(3);
tree.Add(7);
tree.Add(2);
tree.Delete(7);
tree.DisplayTree();

i still get the error

★ Liked by 1 person

Karim Oumghar May 4, 2016 at 5:25 pm

Are you sure you're using the new source code? Btw I just updated it right now. I tried your code and I have no errors at all. The result after the deletion of 7 is 2, 3, and 5. Please email me if you have more questions.

★ Liked by 1 person

Greg Mulvihill November 20, 2016 at 12:15 pm

Ashley Beshir's example posted May 4, 2016 at 5:08 pm still produces a NullReferenceException at parent.right = pivot.left; in RotateRR when executing tree.Delete(7);

FYI, In my search for an AVL tree, I came across a non-recursive example that seems pretty stable. https://bitlush.com/blog/efficient-avl-tree-in-c-sharp

★ Like

Suresh September 20, 2016 at 7:31 am

Very detailed explanation. Found many web sites for AVL trees, but finally stick with yours. Looking forward to see the solution without recalculating the height of each node every time. Thanks!

★ Like

Reply

Lurtzel October 27, 2016 at 11:46 pm

Small Question, can you add the expected outcome.

★ Like

Reply

yovel April 25, 2018 at 11:55 am

"(2) (3) (5)" is the expected outcome.

★ Like

Reply

Saurabh February 1, 2020 at 5:51 am

else if (b_factor 0)
{
current = RotateRL(current);
}
else
{
current = RotateRR(current);
}

}
return current;

RotateRR should be in first condition and then RotateRL because if content is in the extreme right then we should call RotateRR.

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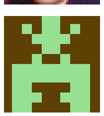 Saurabh on AVL Tree in C#

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