IMPLEMENTING A PHONE DIRECTORY USING RED-BLACK TREES

PROJECT REPORT for DATA STRUCTURES AND ALGORITHMS (IT-353A)

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2021

ACKNOWLEDGEMENT

This project has in due course helped us learn many important concepts surrounding the subject of Data Structures. We feel grateful to do this as our Data structures and Algorithms (IT-353A) minor-project and Prof. Ruchi Holkar as our project guide. We are thankful to her for her help and guidance. She has always been willing to encourage us and clear our doubts. Finally, we would like to thank our family and friends who stood by us all the time and cooperated in the best way they could. There is a profound sense of satisfaction in completing this project.

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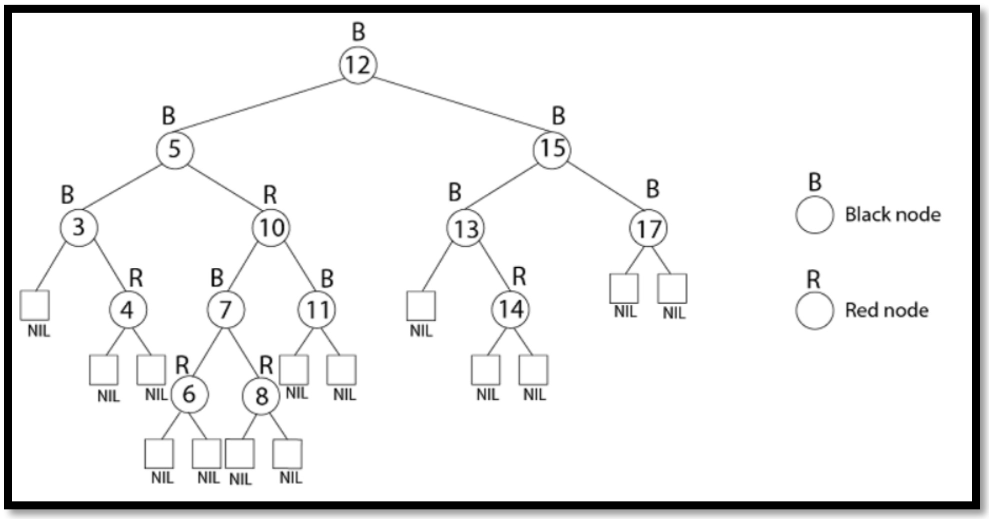
INTRODUCTION TO RB TREES

Red black trees or RB trees are a type of self-balancing binary search trees (BST). Self-balancing BSTs rearrange their node in way that the left and right subtrees have near to equal height. Red black trees are not strictly balancing like AVL trees. But unlike AVL trees, rearranging of nodes to achieve minimum balance requires considerably smaller number of rotations for restructuring. The nodes of a red black tree (RBNode) have an additional **property of color**, which can be either red or black.

By checking the node colors on any simple path from the root to a leaf, red-black trees secure that no such path is higher than twice as long as any other, so that the tree is generally balanced.



CHARACTERISTICS OF RED-BLACK TREES

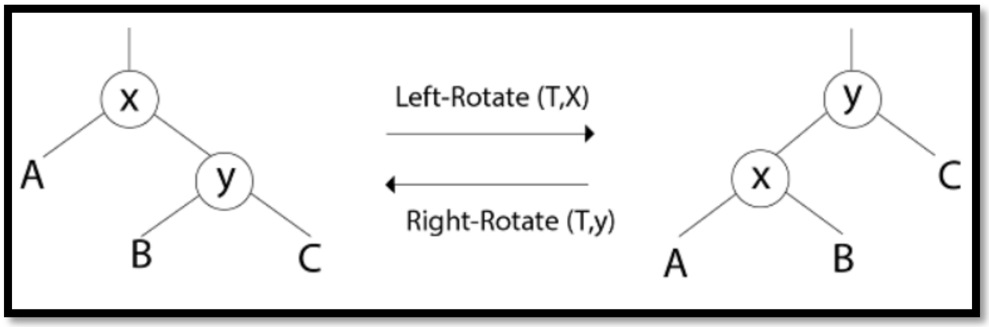
PROPERTIES

1. Every node is colored either red or black.
2. Root of the tree is black.
3. All leaves are black.
4. Both children of a red node are black i.e., there can't be consecutive red nodes.
5. All the simple paths from a node to descendant leaves contain the same number of black nodes.

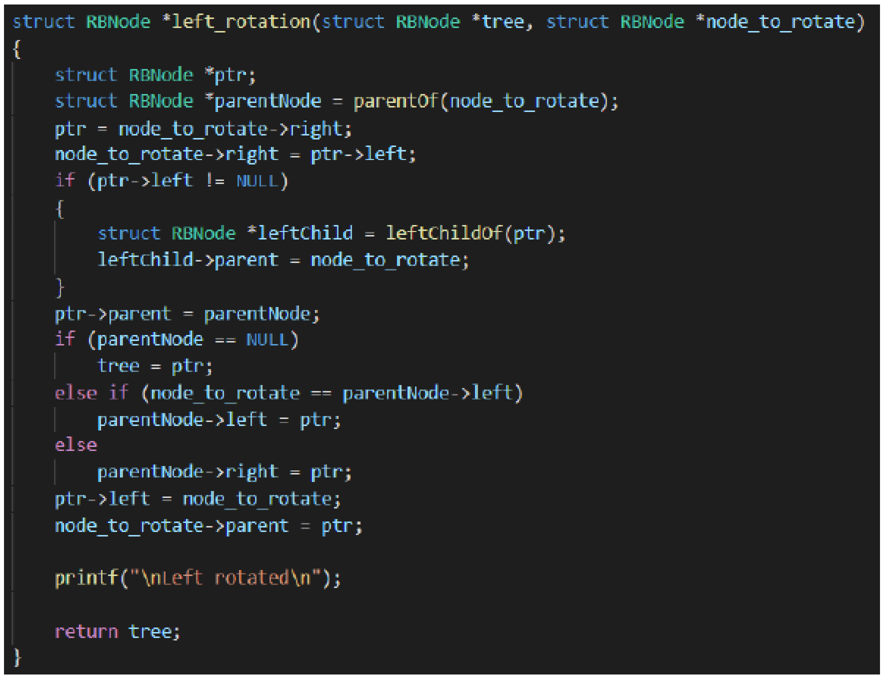
ROTATIONS

There are two kinds of rotations in an RB tree.

- Left rotation
- Right rotation

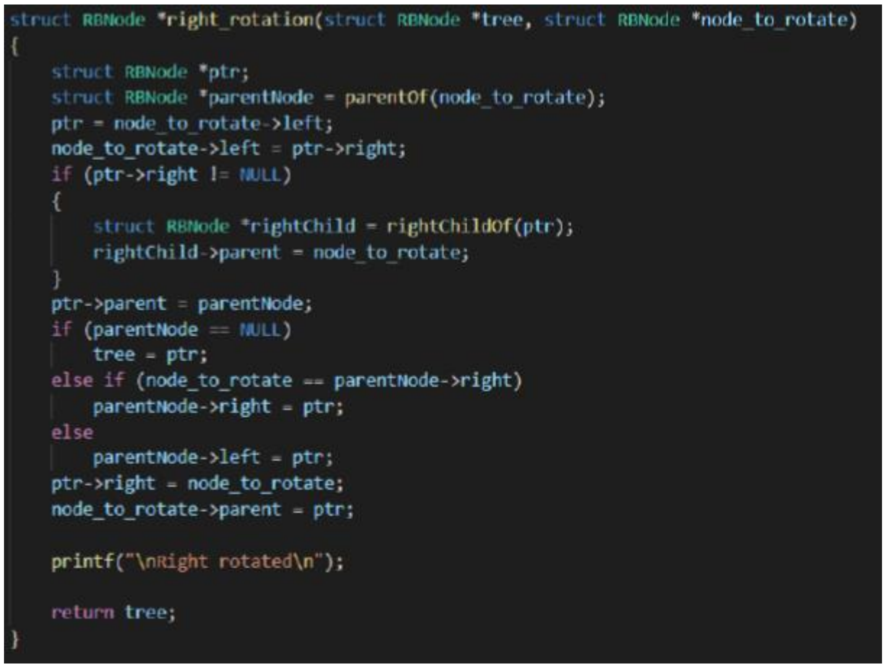


LEFT-ROTATE



```c
struct RBNode *left_rotation(struct RBNode *tree, struct RBNode *node_to_rotate)
{
    struct RBNode *ptr;
    struct RBNode *parentNode = parentOf(node_to_rotate);
    ptr = node_to_rotate->right;
    node_to_rotate->right = ptr->left;
    if (ptr->left != NULL)
    {
        struct RBNode *leftChild = leftChildOf(ptr);
        leftChild->parent = node_to_rotate;
    }
    ptr->parent = parentNode;
    if (parentNode == NULL)
        tree = ptr;
    else if (node_to_rotate == parentNode->left)
        parentNode->left = ptr;
    else
        parentNode->right = ptr;
    ptr->left = node_to_rotate;
    node_to_rotate->parent = ptr;

    printf("\nLeft rotated\n");

    return tree;
}
```

RIGHT-ROTATE



```c
struct RBNode *right_rotation(struct RBNode *tree, struct RBNode *node_to_rotate)
{
    struct RBNode *ptr;
    struct RBNode *parentNode = parentOf(node_to_rotate);
    ptr = node_to_rotate->left;
    node_to_rotate->left = ptr->right;
    if (ptr->right != NULL)
    {
        struct RBNode *rightChild = rightChildOf(ptr);
        rightChild->parent = node_to_rotate;
    }
    ptr->parent = parentNode;
    if (parentNode == NULL)
        tree = ptr;
    else if (node_to_rotate == parentNode->right)
        parentNode->right = ptr;
    else
        parentNode->left = ptr;
    ptr->right = node_to_rotate;
    node_to_rotate->parent = ptr;

    printf("\nRight rotated\n");

    return tree;
}
```

TIME COMPLEXITIES

RB tree, being a self-balancing BST, arranges its nodes in a manner that the height is nearly equal to $\log_2 n$. Thus, it significantly reduces the time complexity of various query operations, in comparison to a linked list or a standard BST.

1. Insertion: O (In n)
2. Searching: O (In n)
3. Deletion: O (In n)

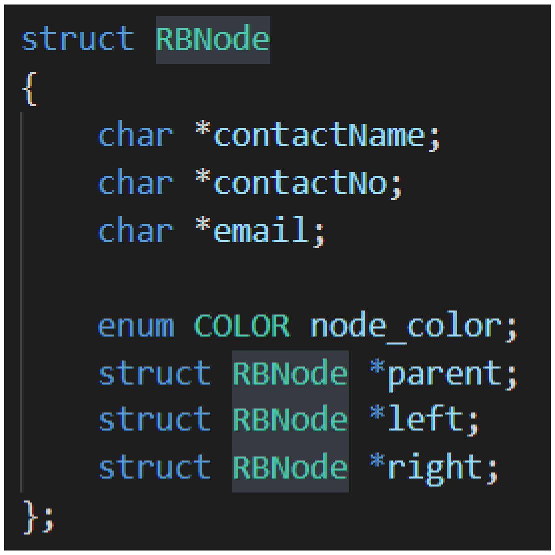
SPACE COMPLEXITIES

A Red black tree takes the amount of memory, given by the sum of the memory allocated to its nodes, which is: **O (n).**

IMPLEMENTATION OF OUR PROJECT

STRUCTURE OF A NODE IN OUR TREE

The node in the tree used in our project stores the properties {“ContactName”, “ContactNo”, “Email” and enum node_color}. It also contains pointers to its parent, left child and right child node.



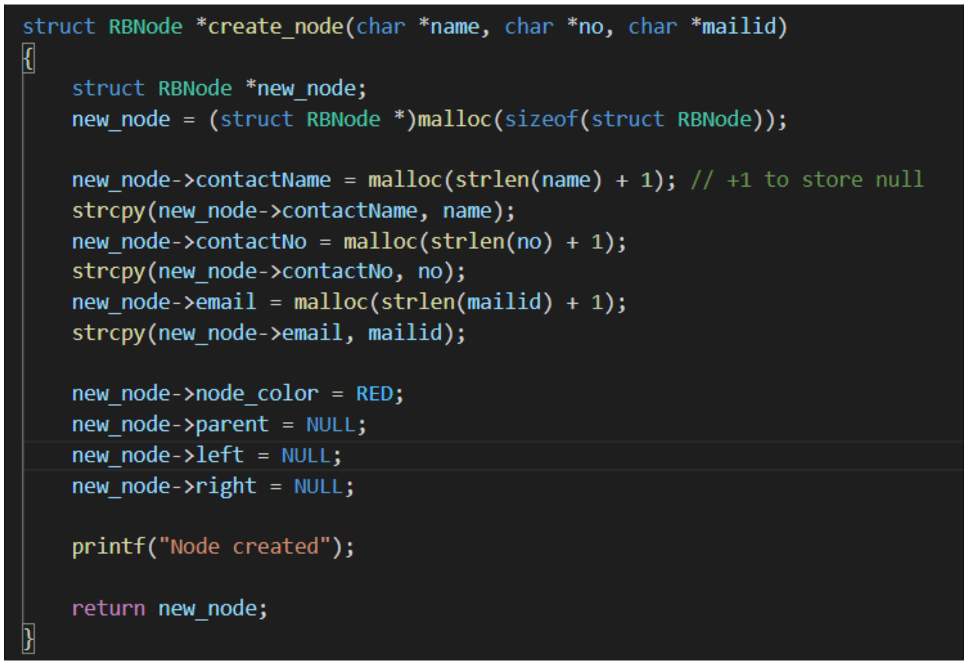
```
struct RBNode
{
    char *contactName;
    char *contactNo;
    char *email;

    enum COLOR node_color;
    struct RBNode *parent;
    struct RBNode *left;
    struct RBNode *right;
};
```

OPERATIONS PERFORMED

1. RB Tree creation (New directory)
2. Creating a new contact
3. Searching a new contact
4. Deleting a contact
5. Displaying the full directory

CREATING A CONTACT

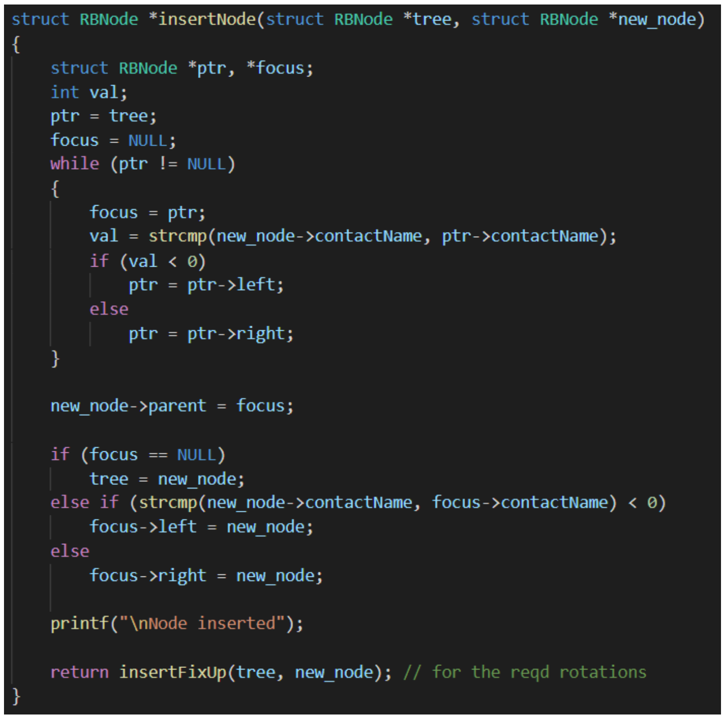
This function creates a new node and inserts it into the RB tree.



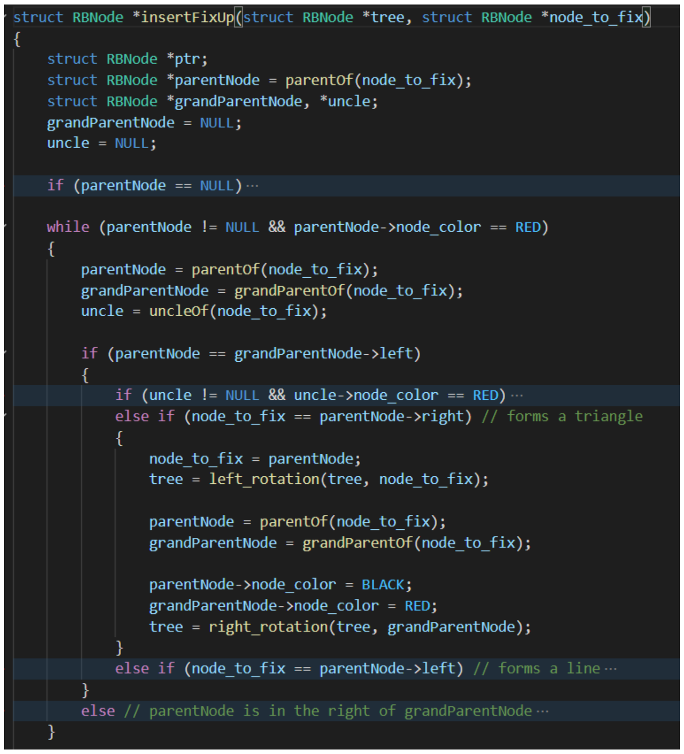
```c
struct RBNode *create_node(char *name, char *no, char *mailid)
{
    struct RBNode *new_node;
    new_node = (struct RBNode *)malloc(sizeof(struct RBNode));

    new_node->contactName = malloc(strlen(name) + 1); // +1 to store null
    strcpy(new_node->contactName, name);
    new_node->contactNo = malloc(strlen(no) + 1);
    strcpy(new_node->contactNo, no);
    new_node->email = malloc(strlen(mailid) + 1);
    strcpy(new_node->email, mailid);

    new_node->node_color = RED;
    new_node->parent = NULL;
    new_node->left = NULL;
    new_node->right = NULL;

    printf("Node created");

    return new_node;
}
```

INSERT TO THE DIRECTORY

1. The tree algorithm finds the appropriate place of the newly created node, following the rules of a BST.
2. After inserting the new_node into the directory tree, it checks for any Red-Red conflict.
3. If found, the tree goes through some rotations to regain its ‘lost’ balance.
4. The insertFixUp() method returns a balanced RB tree after completing these rotations.
5. The insertNode() function takes O (log n) time and the insertFixUp() function also takes O (log n) time.
6. Thus, the combined time complexity of this operation is O (log n)



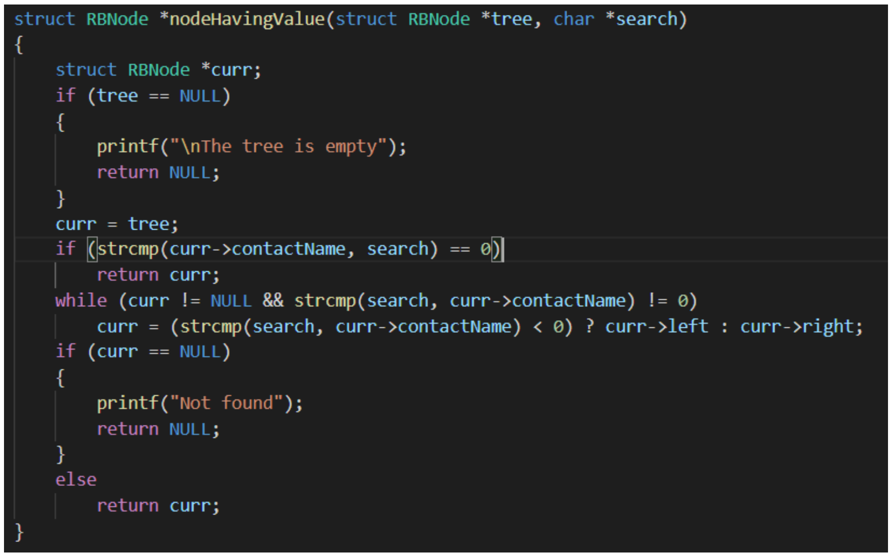
```c
struct RBNode *insertNode(struct RBNode *tree, struct RBNode *new_node)
{
    struct RBNode *ptr, *focus;
    int val;
    ptr = tree;
    focus = NULL;
    while (ptr != NULL)
    {
        focus = ptr;
        val = strcmp(new_node->contactName, ptr->contactName);
        if (val < 0)
            ptr = ptr->left;
        else
            ptr = ptr->right;
    }

    new_node->parent = focus;

    if (focus == NULL)
        tree = new_node;
    else if (strcmp(new_node->contactName, focus->contactName) < 0)
        focus->left = new_node;
    else
        focus->right = new_node;

    printf("\nNode inserted");

    return insertFixUp(tree, new_node); // for the reqd rotations
}
```



```
struct RBNode *insertFixUp(struct RBNode *tree, struct RBNode *node_to_fix)
{
    struct RBNode *ptr;
    struct RBNode *parentNode = parentOf(node_to_fix);
    struct RBNode *grandParentNode, *uncle;
    grandParentNode = NULL;
    uncle = NULL;

    if (parentNode == NULL)···

    while (parentNode != NULL && parentNode->node_color == RED)
    {
        parentNode = parentOf(node_to_fix);
        grandParentNode = grandParentOf(node_to_fix);
        uncle = uncleOf(node_to_fix);

        if (parentNode == grandParentNode->left)
        {
            if (uncle != NULL && uncle->node_color == RED)···
            else if (node_to_fix == parentNode->right) // forms a triangle
            {
                node_to_fix = parentNode;
                tree = left_rotation(tree, node_to_fix);

                parentNode = parentOf(node_to_fix);
                grandParentNode = grandParentOf(node_to_fix);

                parentNode->node_color = BLACK;
                grandParentNode->node_color = RED;
                tree = right_rotation(tree, grandParentNode);
            }
            else if (node_to_fix == parentNode->left) // forms a line···
        }
        else // parentNode is in the right of grandParentNode···
    }
```

SEARCHING FOR A CONTACT

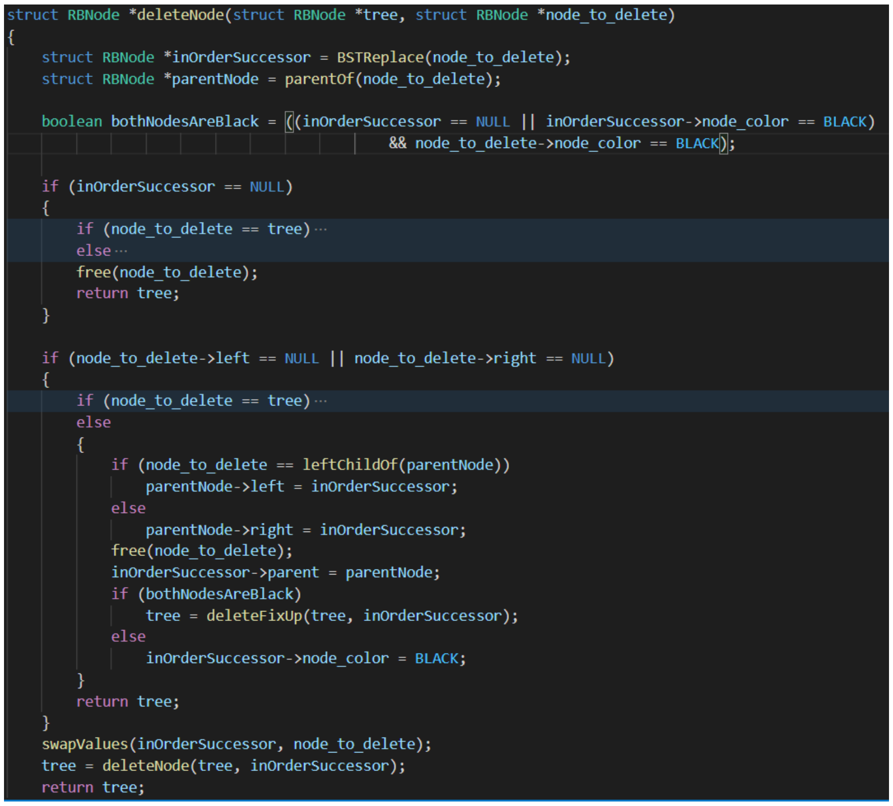
- This function takes in an input from the user (Contact name to be searched)
- The nodeHavingValue() does a BST search to find the node which has the property value same as the value being searched.
- It takes O (log n) time.



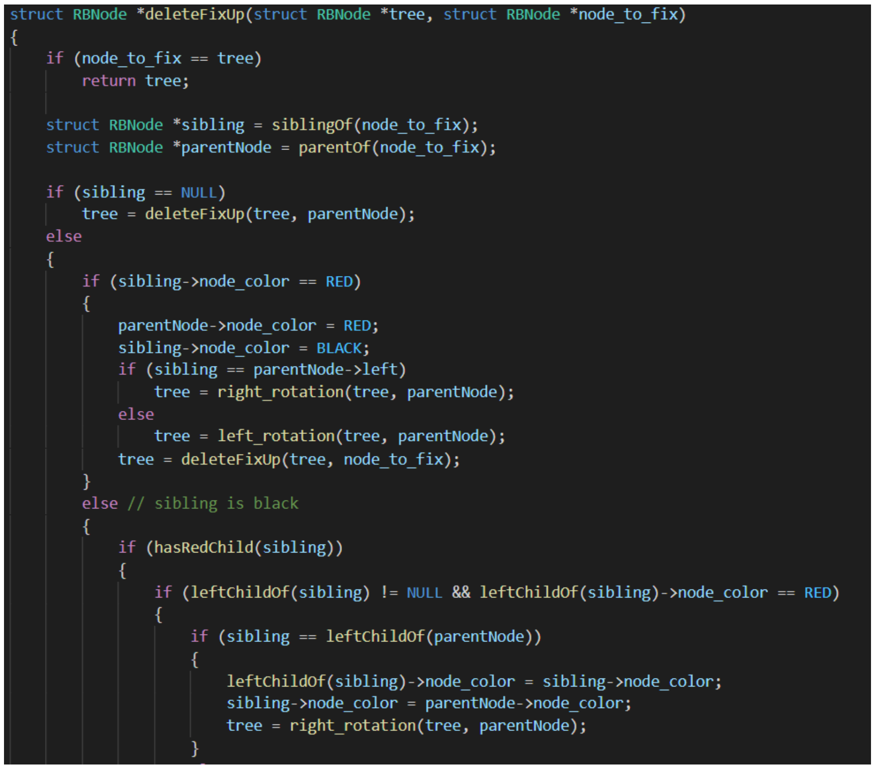
```c
struct RBNode *nodeHavingValue(struct RBNode *tree, char *search)
{
    struct RBNode *curr;
    if (tree == NULL)
    {
        printf("\nThe tree is empty");
        return NULL;
    }
    curr = tree;
    if (strcmp(curr->contactName, search) == 0)
        return curr;
    while (curr != NULL && strcmp(search, curr->contactName) != 0)
        curr = (strcmp(search, curr->contactName) < 0) ? curr->left : curr->right;
    if (curr == NULL)
    {
        printf("Not found");
        return NULL;
    }
    else
        return curr;
}
```

DELETING A CONTACT

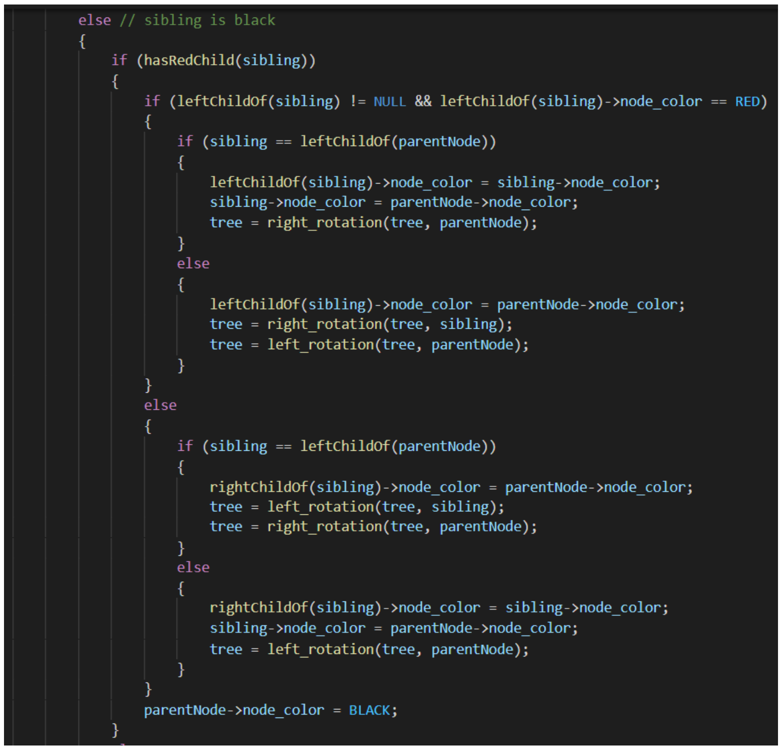
- This function first searches for the contact using nodeHavingValue() and then deletes it.
- It goes through all the different cases and performs a suitable algorithm.



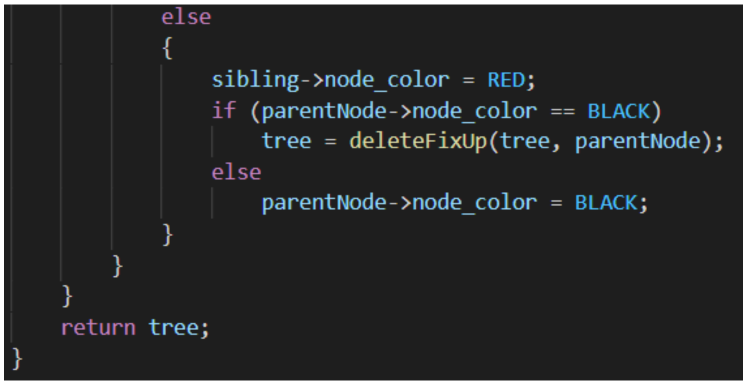
```
struct RBNode *deleteNode(struct RBNode *tree, struct RBNode *node_to_delete)
{
    struct RBNode *inOrderSuccessor = BSTReplace(node_to_delete);
    struct RBNode *parentNode = parentOf(node_to_delete);

    boolean bothNodesAreBlack = ((inOrderSuccessor == NULL || inOrderSuccessor->node_color == BLACK)
                                        && node_to_delete->node_color == BLACK);

    if (inOrderSuccessor == NULL)
    {
        if (node_to_delete == tree)···
        else···
        free(node_to_delete);
        return tree;
    }

    if (node_to_delete->left == NULL || node_to_delete->right == NULL)
    {
        if (node_to_delete == tree)···
        else
        {
            if (node_to_delete == leftChildOf(parentNode))
                parentNode->left = inOrderSuccessor;
            else
                parentNode->right = inOrderSuccessor;
            free(node_to_delete);
            inOrderSuccessor->parent = parentNode;
            if (bothNodesAreBlack)
                tree = deleteFixUp(tree, inOrderSuccessor);
            else
                inOrderSuccessor->node_color = BLACK;
        }
        return tree;
    }
    swapValues(inOrderSuccessor, node_to_delete);
    tree = deleteNode(tree, inOrderSuccessor);
    return tree;
```



```
struct RBNode *deleteFixUp(struct RBNode *tree, struct RBNode *node_to_fix)
{
    if (node_to_fix == tree)
        return tree;

    struct RBNode *sibling = siblingOf(node_to_fix);
    struct RBNode *parentNode = parentOf(node_to_fix);

    if (sibling == NULL)
        tree = deleteFixUp(tree, parentNode);
    else
    {
        if (sibling->node_color == RED)
        {
            parentNode->node_color = RED;
            sibling->node_color = BLACK;
            if (sibling == parentNode->left)
                tree = right_rotation(tree, parentNode);
            else
                tree = left_rotation(tree, parentNode);
            tree = deleteFixUp(tree, node_to_fix);
        }
        else // sibling is black
        {
            if (hasRedChild(sibling))
            {
                if (leftChildOf(sibling) != NULL && leftChildOf(sibling)->node_color == RED)
                {
                    if (sibling == leftChildOf(parentNode))
                    {
                        leftChildOf(sibling)->node_color = sibling->node_color;
                        sibling->node_color = parentNode->node_color;
                        tree = right_rotation(tree, parentNode);
                    }
```



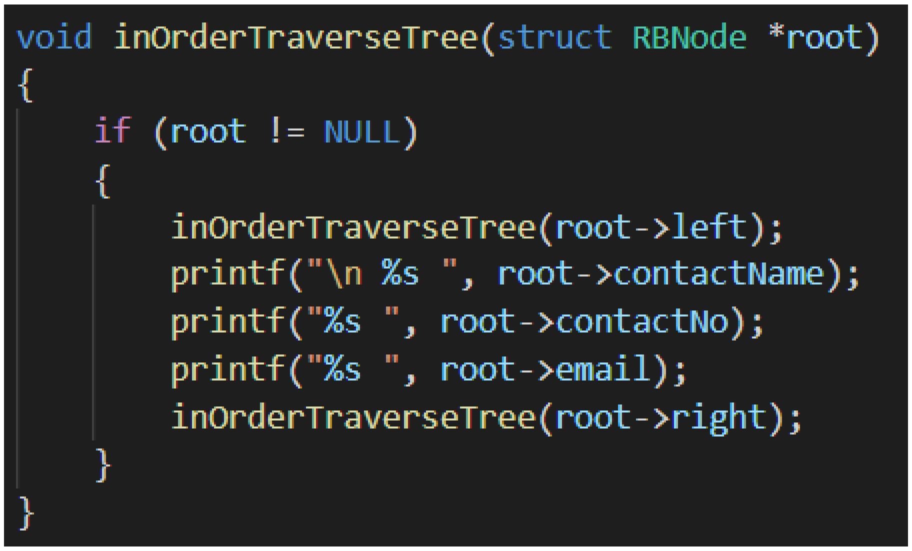
```
        else // sibling is black
        {
            if (hasRedChild(sibling))
            {
                if (leftChildOf(sibling) != NULL && leftChildOf(sibling)->node_color == RED)
                {
                    if (sibling == leftChildOf(parentNode))
                    {
                        leftChildOf(sibling)->node_color = sibling->node_color;
                        sibling->node_color = parentNode->node_color;
                        tree = right_rotation(tree, parentNode);
                    }
                    else
                    {
                        leftChildOf(sibling)->node_color = parentNode->node_color;
                        tree = right_rotation(tree, sibling);
                        tree = left_rotation(tree, parentNode);
                    }
                }
                else
                {
                    if (sibling == leftChildOf(parentNode))
                    {
                        rightChildOf(sibling)->node_color = parentNode->node_color;
                        tree = left_rotation(tree, sibling);
                        tree = right_rotation(tree, parentNode);
                    }
                    else
                    {
                        rightChildOf(sibling)->node_color = sibling->node_color;
                        sibling->node_color = parentNode->node_color;
                        tree = left_rotation(tree, parentNode);
                    }
                }
                parentNode->node_color = BLACK;
            }
```



```
            else
            {
                sibling->node_color = RED;
                if (parentNode->node_color == BLACK)
                    tree = deleteFixUp(tree, parentNode);
                else
                    parentNode->node_color = BLACK;
            }
        }
    }
    return tree;
}
```

DISPLAYING THE PHONE DIRECTORY

Here, we have used the **inorder traversal of a BST** to print the complete directory in a sorted (ascending) order, as we know that the inorder traversal of a BST gives the elements of the tree as (Left Root Right).



```
void inOrderTraverseTree(struct RBNode *root)
{
    if (root != NULL)
    {
        inOrderTraverseTree(root->left);
        printf("\n %s ", root->contactName);
        printf("%s ", root->contactNo);
        printf("%s ", root->email);
        inOrderTraverseTree(root->right);
    }
}
```

LINK TO THE GIT REPOSITORY

Phone directory Implementation using Red-Black Trees

REFERENCES

- javatpoint.com
- geeksforgeeks.com
- wikipedia.org
- https://www.javatpoint.com/daa-red-black-tree

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