AMRITA VISHWA VIDYAPEETHAM
DEEMED TO BE UNIVERSITY UNDER SECTION 3 OF UGC ACT, 1956
SCHOOL OF COMPUTING

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CH.SC.U4CSE24150

Week – 4

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Design and Analysis of Algorithm(23CSE211)

1. BST Balancing using Rotation Method

Code:

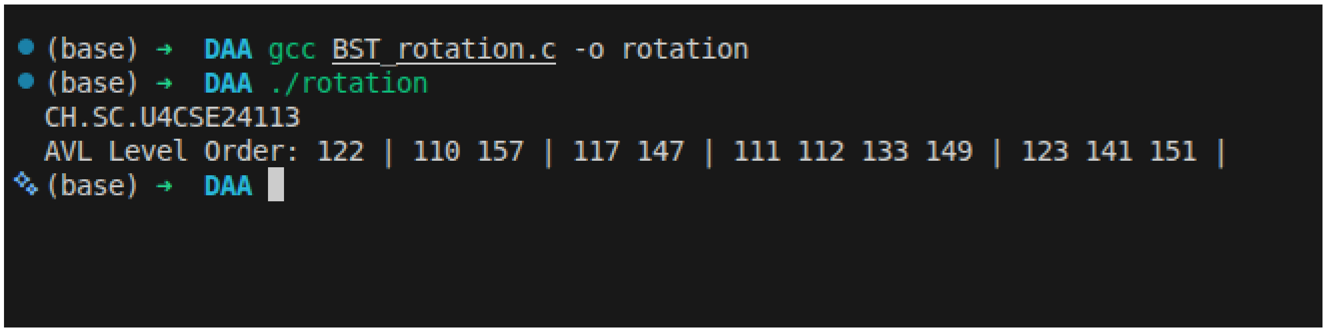
```c
#include <stdio.h>
#include <stdlib.h>
struct Node {
    int key;
    struct Node *left, *right;
    int height;
};
int max(int a, int b) { return (a > b) ? a : b; }
int getHeight(struct Node *n) { return (n == NULL) ? 0 : n->height; }
struct Node* newNode(int key) {
    struct Node* node = (struct Node*)malloc(sizeof(struct Node));
    node->key = key;
    node->left = node->right = NULL;
    node->height = 1;
    return node;
}

struct Node *rightRotate(struct Node *y) {
    struct Node *x = y->left;
    struct Node *T2 = x->right;
    x->right = y;
    y->left = T2;
    y->height = max(getHeight(y->left), getHeight(y->right)) + 1;
    x->height = max(getHeight(x->left), getHeight(x->right)) + 1;
    return x;
}

struct Node *leftRotate(struct Node *x) {
    struct Node *y = x->right;
    struct Node *T2 = y->left;
    y->left = x;
    x->right = T2;
    x->height = max(getHeight(x->left), getHeight(x->right)) + 1;
    y->height = max(getHeight(y->left), getHeight(y->right)) + 1;
    return y;
}

struct Node* balanceTree(struct Node* node) {
    if (node == NULL) return NULL;
    node->left = balanceTree(node->left);
    node->right = balanceTree(node->right);
    node->height = 1 + max(getHeight(node->left), getHeight(node->right));
    int balance = getHeight(node->left) - getHeight(node->right);
    if (balance > 1 && getHeight(node->left->left) >= getHeight(node->left-
>right)) return rightRotate(node);
    if (balance > 1 && getHeight(node->left->left) < getHeight(node->left-
>right)) {
        node->left = leftRotate(node->left);
        return rightRotate(node);
    }
    if (balance < -1 && getHeight(node->right->right) >= getHeight(node->right-
>left)) return leftRotate(node);
    if (balance < -1 && getHeight(node->right->right) < getHeight(node->right-
>left)) {
        node->right = rightRotate(node->right);
        return leftRotate(node);
    }
    return node;
}
void printGivenLevel(struct Node* root, int level) {
    if (root == NULL) return;
    if (level == 1) printf("%d ", root->key);
    else if (level > 1) {
        printGivenLevel(root->left, level - 1);
        printGivenLevel(root->right, level - 1);
    }
}
void printLevelOrder(struct Node* root) {
    int h = getHeight(root);
    for (int i = 1; i <= h; i++) {
        printGivenLevel(root, i);
        printf("| ");
    }
}
int main() {
    printf("CH.SC.U4CSE24113\n");
    struct Node *root = newNode(157);
    root->left = newNode(110);
    root->left->right = newNode(147);
    root->left->right->left = newNode(122);
    root->left->right->right = newNode(149);
    root->left->right->right->right = newNode(151);
    root->left->right->left->left = newNode(111);
    root->left->right->left->right = newNode(141);
    root->left->right->left->left->right = newNode(112);
    root->left->right->left->right->left  = newNode(123);
    root->left->right->left->right->left->right = newNode(133);
    root->left->right->left->left->right->left = newNode(117);
    root = balanceTree(root);
    printf("AVL Level Order: ");
    printLevelOrder(root);
    printf("\n");
    return 0;
}
```

Output:



```
● (base) → DAA gcc BST_rotation.c -o rotation
● (base) → DAA ./rotation
  CH.SC.U4CSE24113
  AVL Level Order: 122 | 110 157 | 117 147 | 111 112 133 149 | 123 141 151 |
  (base) → DAA
```

Time Complexity: O(n)
Justification: The balanceTree function is called once on the root, but it recursively visits every node in the tree exactly once to calculate heights and perform rotations. Since the code manually builds a tree with n nodes and then runs a single post-order traversal to balance it, the time taken is proportional to the number of nodes.

Note: While standard AVL insertions are O(log n), your specific implementation balances an existing unbalanced tree in a single pass, making it linear for the total number of nodes.

Space Complexity: O(log n)
Justification: The space complexity is determined by the maximum depth of the function call stack during recursion. Since an AVL tree is strictly balanced, its height h is guaranteed to be O(log n). Even though you start with an unbalanced tree, the recursive depth of balanceTree or printLevelOrder will not exceed the initial height of the tree. No significant auxiliary data structures (like arrays or queues) are used, only the memory for the nodes themselves and the recursion stack.

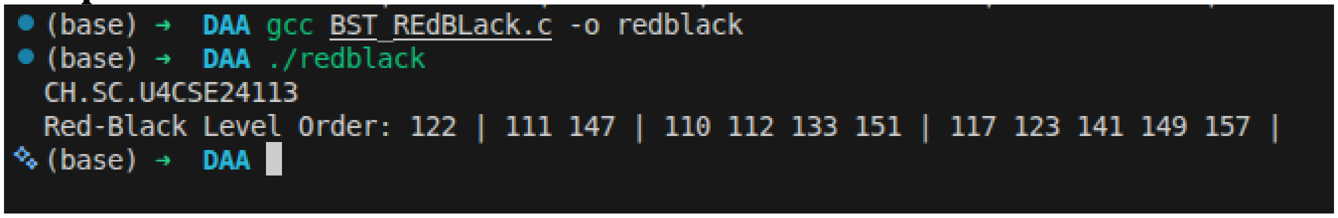
2. BST Balancing using Red-Black Method

Code:

```
#include <stdio.h>
#include <stdlib.h>
enum Color { RED, BLACK };
struct Node {
    int data;
    enum Color color;
    struct Node *left, *right, *parent;
};
struct Node* newNode(int data) {
    struct Node* temp = (struct Node*)malloc(sizeof(struct Node));
    temp->data = data;
    temp->left = temp->right = temp->parent = NULL;
    temp->color = RED;
    return temp;
}
void rotateLeft(struct Node** root, struct Node* x) {
    struct Node* y = x->right;
    x->right = y->left;
    if (y->left != NULL) y->left->parent = x;
    y->parent = x->parent;
    if (x->parent == NULL) *root = y;
    else if (x == x->parent->left) x->parent->left = y;
    else x->parent->right = y;
    y->left = x;
    x->parent = y;
}
void rotateRight(struct Node** root, struct Node* y) {
    struct Node* x = y->left;
    y->left = x->right;
    if (x->right != NULL) x->right->parent = y;
    x->parent = y->parent;
    if (y->parent == NULL) *root = x;
    else if (y == y->parent->left) y->parent->left = x;
    else y->parent->right = x;
    x->right = y;
    y->parent = x;
}
void fixViolation(struct Node** root, struct Node* z) {
    while (z != *root && z->parent->color == RED) {
        if (z->parent == z->parent->parent->left) {
            struct Node* y = z->parent->parent->right;
            if (y != NULL && y->color == RED) {
                z->parent->color = BLACK;
                y->color = BLACK;
                z->parent->parent->color = RED;
                z = z->parent->parent;
            } else {
                if (z == z->parent->right) {
                    z = z->parent;
                    rotateLeft(root, z);
                }
                z->parent->color = BLACK;
                z->parent->parent->color = RED;
                rotateRight(root, z->parent->parent);
            }
        } else {
            struct Node* y = z->parent->parent->left;
            if (y != NULL && y->color == RED) {
                z->parent->color = BLACK;
                y->color = BLACK;
                z->parent->parent->color = RED;
                z = z->parent->parent;
            } else {
                if (z == z->parent->left) {
                    z = z->parent;
                    rotateRight(root, z);
                }
                z->parent->color = BLACK;
                z->parent->parent->color = RED;
                rotateLeft(root, z->parent->parent);
            }
        }
    }
    (*root)->color = BLACK;
}
int height(struct Node* node) {
    if (node == NULL) return 0;
    int l = height(node->left);
    int r = height(node->right);
    return (l > r ? l : r) + 1;
}
void printGivenLevel(struct Node* root, int level) {
    if (root == NULL) return;
    if (level == 1) printf("%d ", root->data);
    else if (level > 1) {
        printGivenLevel(root->left, level - 1);
        printGivenLevel(root->right, level - 1);
    }
}
void printLevelOrder(struct Node* root) {
    int h = height(root);
    for (int i = 1; i <= h; i++) {
        printGivenLevel(root, i);
        printf("| ");
    }
}
```

```
int main() {
    printf("CH.SC.U4CSE24113\n");
    struct Node* root = newNode(157); root->color = BLACK;
    struct Node* n110 = newNode(110); root->left = n110; n110->parent = root;
    struct Node* n147 = newNode(147); n110->right = n147; n147->parent = n110;
    struct Node* n122 = newNode(122); n147->left = n122; n122->parent = n147;
    struct Node* n149 = newNode(149); n147->right = n149; n149->parent = n147;
    struct Node* n111 = newNode(111); n122->left = n111; n111->parent = n122;
    struct Node* n141 = newNode(141); n122->right = n141; n141->parent = n122;
    struct Node* n151 = newNode(151); n149->right = n151; n151->parent = n149;
    struct Node* n112 = newNode(112); n111->right = n112; n112->parent = n111;
    struct Node* n123 = newNode(123); n141->left = n123; n123->parent = n141;
    struct Node* n117 = newNode(117); n112->left = n117; n117->parent = n112;
    struct Node* n133 = newNode(133); n123->right = n133; n133->parent = n123;
    fixViolation(&root, n147);
    fixViolation(&root, n111);
    fixViolation(&root, n141);
    fixViolation(&root, n151);
    fixViolation(&root, n117);
    fixViolation(&root, n133);
    printf("Red-Black Level Order: ");
    printLevelOrder(root);
    printf("\n");
    return 0;
}
```

Output:



```
● (base) → DAA gcc BST_REdBLack.c -o redblack
● (base) → DAA ./redblack
  CH.SC.U4CSE24113
  Red-Black Level Order: 122 | 111 147 | 110 112 133 151 | 117 123 141 149 157 |
  (base) → DAA
```

Time Complexity: O(n log n)
Justification: While a single insertion and balance (fixViolation) in a Red-Black Tree takes O(log n) time, this code manually links nodes and then calls fixViolation multiple times in a sequence.

- **Balancing:** Each call to fixViolation takes O(log n) as it may traverse up to the root.
- **Printing:** The printLevelOrder function uses a nested loop and recursion that visits nodes level-by-level. For a balanced tree, this specific level-order implementation (without a queue) takes O(n) time.
- **Overall:** For n elements, if you were inserting them normally, it would be O(n log n).

Space Complexity: O(n)
Justification: The program requires memory to store each element as a struct Node, which includes pointers for left, right, parent, and the color attribute. This auxiliary memory is directly proportional to the number of nodes n in the tree. Furthermore, the recursive functions for height and level-printing use the function call stack, which requires O(log n) space for a balanced Red-Black Tree.