Search Trees in C

Course: Introduction to Programming and Data Structures

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- Analysis of Recursive Approaches

Binary Search Trees

What is a Tree?

- A Tree is a data structure consisting of nodes.
- Each node contains a value or data, and links to child nodes.
- The topmost node is called the **root**.
- A node without children is called a **leaf**.

Tree Terminology

- Root: The topmost node in the tree.
- Leaf: A node with no children.
- Parent: A node that has children.
- Subtree: A tree consisting of a node and its descendants.
- Binary Tree: A tree where each node has at most two children.

Types of Trees

- **Binary Tree**: Each node has at most two children.
- **Binary Search Tree (BST)**: A binary tree with ordered nodes.
- **AVL Tree**: A self-balancing binary search tree.
- m-**ary Tree**: Each node has at most m children.
- **Heap**: A tree where the parent node is greater (or smaller) than its children.

Binary Search Tree

- **left** subtree contains **lesser** values, by convention
- **right** subtree contains **higher** values, by convention

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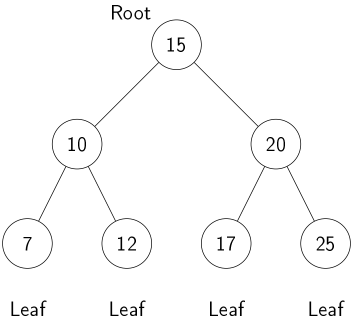
Binary Search Tree (BST) Example



- **Root**: The topmost node (15).
- **Leaf**: Nodes without children (7, 12, 17, 25).
- **Parent and Child**: Relationships between nodes (e.g., 10 is parent, 7 and 12 are children).
- **Subtree**: A smaller part of the tree, e.g., (10, 7, 12).

Binary Search Tree (BST) Implementation in C

Node structure

```c
struct Node {
    int data;
    struct Node* left;
    struct Node* right;
};

// Function to create a new node
struct Node* createNode(int value) {
    struct Node* newNode = (struct Node*)malloc(sizeof(struct Node
    ));
    newNode->data = value;
    newNode->left = NULL;
    newNode->right = NULL;
    return newNode;
}
```

Insert Function in C

```c
struct Node* insert(struct Node* node, int data) {
    if (node == NULL) {
        struct Node* temp = createNode(data);
        return temp;
    }
    if (data < node->data)
        node->left = insert(node->left, data);
    else if (data > node->data)
        node->right = insert(node->right, data);
    return node;
}

```

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Searching in a BST

```
struct Node* search(struct Node* root, int key)
{

    // Base Cases: root is null or key is present at root
    if (root == NULL || root->key == key)
        return root;

    // Key is greater than root's key
    if (root->key < key)
        return search(root->right, key);

    // Key is smaller than root's key
    return search(root->left, key);
}

```

Tree Traversal Algorithms in C

- **Inorder Traversal** (Left, Root, Right):
  - Traverse the left subtree.
  - Visit the root.
  - Traverse the right subtree.
- **Preorder Traversal** (Root, Left, Right):
  - Visit the root.
  - Traverse the left subtree.
  - Traverse the right subtree.
- **Postorder Traversal** (Left, Right, Root):
  - Traverse the left subtree.
  - Traverse the right subtree.
  - Visit the root.

Tree Traversal Examples

Sample Tree:

```
      1
     / \
    2   3
   / \
  4   5
```

- **Inorder Traversal**: 4, 2, 5, 1, 3
- **Preorder Traversal**: 1, 2, 4, 5, 3
- **Postorder Traversal**: 4, 5, 2, 3, 1

Inorder Traversal in C

```c
void inorder(struct Node* root) {
    if (root != NULL) {
        inorder(root->left);
        printf("%d ->", root->data);
        inorder(root->right);
    }
}
```

Preorder Traversal in C

```c
void preorder(struct Node* root) {
    if (root != NULL) {
        printf("%d ->", root->data);
        preorder(root->left);
        preorder(root->right);
    }
}

```

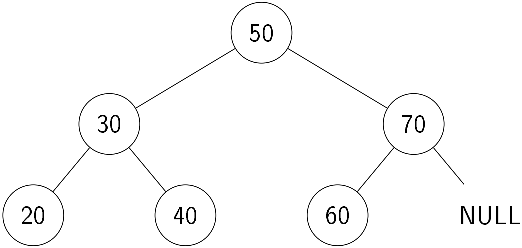
Postorder Traversal in C

```
void postorder(struct Node* root) {
    if (root != NULL) {
        postorder(root->left);
        postorder(root->right);
        printf("%d ->", root->data);
    }
}
```

Deletion in a Binary Search Tree

- **Case 1:** Deleting a leaf node (no children).
- **Case 2:** Deleting a node with one child.
- **Case 3:** Deleting a node with two children (find in-order successor or predecessor).

Example: Deletion in a BST



- **Case 1**: Deleting a Leaf Node, Delete 20
- **Case 2**: Deleting a Node with One Child, Delete 70
- **Case 3**: Deleting a Node with Two Children, Delete 50

Detailed Explanation of Deletion Cases

- **Case 1: Deleting a Leaf Node**
  Example: Delete node 20. Since it has no children, simply remove the node.
- **Case 2: Deleting a Node with One Child**
  Example: Delete node 70. Replace the node with its only child (80).
- **Case 3: Deleting a Node with Two Children**
  Example: Delete node 50. Replace the node with its in-order successor (60), and adjust the tree.

Deletion in Binary Search Tree

```
struct Node* deleteNode(struct Node* root, int key) {
    if (root == NULL) return root;

    if (key < root->data)
        root->left = deleteNode(root->left, key);
    else if (key > root->data)
        root->right = deleteNode(root->right, key);
    else {
        if (root->left == NULL) {
            struct Node* temp = root->right;
            free(root);
            return temp;
        } else if (root->right == NULL) {
            struct Node* temp = root->left;
            free(root);   return temp;
        }
        struct Node* temp = minValueNode(root->right);
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
    }
    return root;
}
```

minValueNode() Function in C

```c
struct Node* minValueNode(struct Node* node) {
    struct Node* current = node;

    // Find the leftmost leaf
    while (current && current->left != NULL)
        current = current->left;

    return current;
}
```

Iterative Algorithms
in
Binary Search Trees

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Iterative Inorder Traversal

- Inorder Traversal: Left subtree, Root, Right subtree.
- Use an explicit stack to simulate the recursive behavior.

```
void iterativeInorder(struct Node* root) {
    struct Node* current = root;
    struct Stack* stack = createStack(MAX_HEIGHT);

    while (!isEmpty(stack) || current != NULL) {
        if (current != NULL) {
            push(stack, current);
            current = current->left;
        } else {
            current = pop(stack);
            printf("%d ->", current->data);
            current = current->right;
        }
    }
}

```

Iterative Preorder Traversal

- Preorder Traversal: Root, Left subtree, Right subtree.
- Use an explicit stack to simulate recursive preorder traversal.

```
void iterativePreorder(struct Node* root) {
    if (root == NULL) return;
    struct Stack* stack = createStack(MAX_HEIGHT);
    push(stack, root);

    while (!isEmpty(stack)) {
        struct Node* current = pop(stack);
        printf("%d -> ", current->data);

        if (current->right != NULL) push(stack, current->right);
        if (current->left != NULL) push(stack, current->left);
    }
}
```

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Iterative Postorder Traversal

- Postorder Traversal: Left subtree, Right subtree, Root.
- Use two stacks to simulate the recursive behavior.

```c
void iterativePostorder(struct Node* root) {
    if (root == NULL) return;
    struct Stack* s1 = createStack(MAX_HEIGHT);
    struct Stack* s2 = createStack(MAX_HEIGHT);

    push(s1, root);
    while (!isEmpty(s1)) {
        struct Node* current = pop(s1);
        push(s2, current);

        if (current->left != NULL) push(s1, current->left);
        if (current->right != NULL) push(s1, current->right);
    }

    while (!isEmpty(s2)) {
        struct Node* node = pop(s2);
        printf("%d ->", node->data);
    }
}
```

Iterative Search in BST

- Search for a key in the Binary Search Tree using a loop.
- Traverse left if the key is smaller than the current node.
- Traverse right if the key is larger.

```
struct Node* iterativeSearch(struct Node* root, int key) {
    while (root != NULL) {
        if (root->data == key)
            return root;
        else if (key < root->data)
            root = root->left;
        else
            root = root->right;
    }
    return NULL;
}
```

Iterative Deletion in BST

- Delete a node in a Binary Search Tree iteratively.
- Handle three cases: node to be deleted has no child, one child, or two children.

Iterative Deletion Algorithm in BST I

```c
struct Node* deleteNodeIterative(struct Node* root, int key) {
    struct Node* parent = NULL;
  struct Node* * current = root;

    while (current != NULL && current->data != key) {
        parent = current;
        if (key < current->data)
      current = current->left;
        else
      current = current->right;
    }
    if (current == NULL) return root;  // Node not found
    if (current->left == NULL || current->right == NULL) {
        struct Node* newCurr = (current->left) ? current->left : current->right;
        if (parent == NULL)
            return newCurr;
        if (current == parent->left)
            parent->left = newCurr;
        else
```

Iterative Deletion Algorithm in BST II

```
            parent->right = newCurr;
        free(current);
    } else {
        struct Node* successor = minValueNode(current->right);
        int successorData = successor->data;
        deleteNodeIterative(root, successorData);
        current->data = successorData;
    }
    return root;
}
```

minValueNode() Function in BST

- The ‘minValueNode()‘ function finds the smallest node in a subtree.
- This is useful when deleting a node with two children.

```c
struct Node* minValueNode(struct Node* node) {
    struct Node* current = node;
    while (current && current->left != NULL)
        current = current->left;
    return current;
}

```

Complexity Analysis
of
of BST algorithms

Complexities of Inorder, Preorder, and Postorder Traversals

- **Time Complexity**: $O(n)$
  - Each node is visited once.
- **Space Complexity**:
  - **Recursive Traversal**: $O(h)$, where h is the height of the tree.
  - **Iterative Traversal**: $O(h)$, as an explicit stack is used to simulate recursion.
- **Best Case**:
  - For a balanced BST, the height h is $O(\log n)$, making the space complexity $O(\log n)$.
- **Worst Case**:
  - In a skewed tree, the height h can be $O(n)$, leading to $O(n)$ space complexity.

Complexity of Search in a BST

- **Time Complexity**:
  - **Best Case**: $O(1)$, when the key is found at the root.
  - **Average Case**: $O(\log n)$, for a balanced tree.
  - **Worst Case**: $O(n)$, for a skewed tree.
- **Space Complexity**:
  - **Recursive Search**: $O(h)$, due to the call stack, where h is the height of the tree.
  - **Iterative Search**: $O(1)$, no extra space is required aside from the traversal.

Complexity of Deletion in a BST

- **Time Complexity**:
  - **Best Case**: $O(1)$, when deleting a node with no children.
  - **Average Case**: $O(\log n)$, for a balanced tree.
  - **Worst Case**: $O(n)$, for a skewed tree.
- **Space Complexity**:
  - **Recursive Deletion**: $O(h)$, due to the call stack, where h is the height of the tree.
  - **Iterative Deletion**: $O(1)$, as there is no need for recursion.

Advantages of Recursive Algorithms

Advantages:

- **Simplicity**:
  - Recursive code is more compact and easier to write for tree-based operations.
  - Natural fit for trees due to the recursive structure of trees (hierarchical data).
- **Clarity**:
  - Recursive code is often clearer and easier to understand, particularly for beginners.

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Drawbacks of Recursive Algorithms

Drawbacks:

- **Memory Overhead**:
  - Each recursive call adds a new frame to the call stack. For deep trees (e.g., skewed trees), this could lead to stack overflow.
- **Performance**:
  - Recursion may add some overhead due to function calls, and managing the call stack.
- **Stack Limitations**:
  - Recursive solutions can fail for very deep trees if the depth exceeds the stack size, leading to stack overflow errors.

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