AVL Tree

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A clear, compact guide covering essential data structures and algorithms, designed for easy understanding and quick learning.

An **AVL Tree** is a type of self-balancing binary search tree. It is named after its inventors, **Adelson-Velsky and Landis**, who introduced it in 1962.

The height of a binary tree determines the time complexity of its operations. A completely balanced tree has a height of O(log n), where n is the number of nodes.

In an AVL tree, the balance of the tree is maintained by ensuring that the **height difference** (or **balance factor**) between the left and right subtrees of every node is at most 1. Additionally, each subtree of an AVL tree is itself an AVL tree.

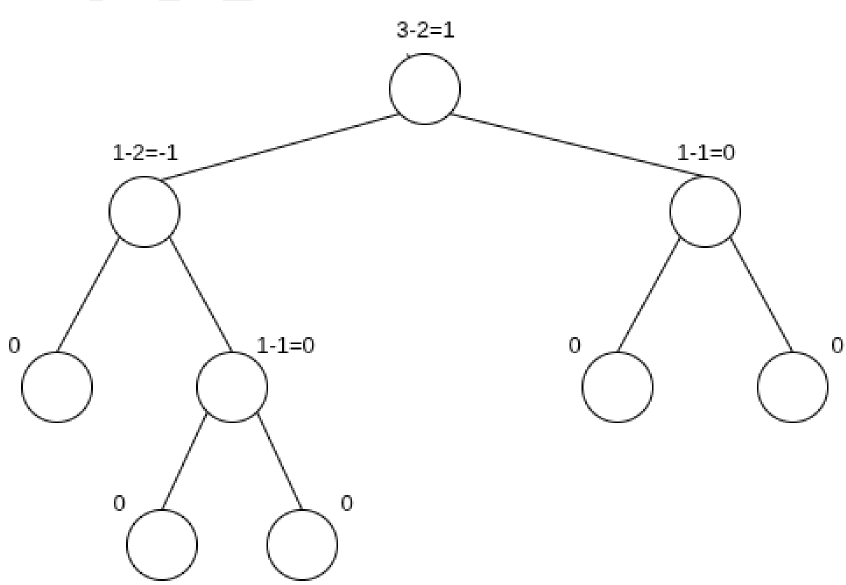
If the height difference between subtrees (the balance factor) is allowed to grow beyond 1, the tree can become **skewed**, resembling a linked list in the worst case. This would degrade the time complexity of operations to O(n).

Maintaining a strict balance factor means that search, insertion, and deletion always take O(log n) time because the height of the tree never exceeds log(n) for n nodes.

Characteristics of an AVL Tree:

- **Binary Search Tree Property:**
  All the nodes in the left subtree < Parent
  All the nodes in the right subtree > Parent

- **Balance Factor:**
  For each node in the tree:
  Balance Factor = Height of Left Subtree – Height of Right Subtree
  Balance factor must be **1, -1 or 0** for the tree to remain balanced.

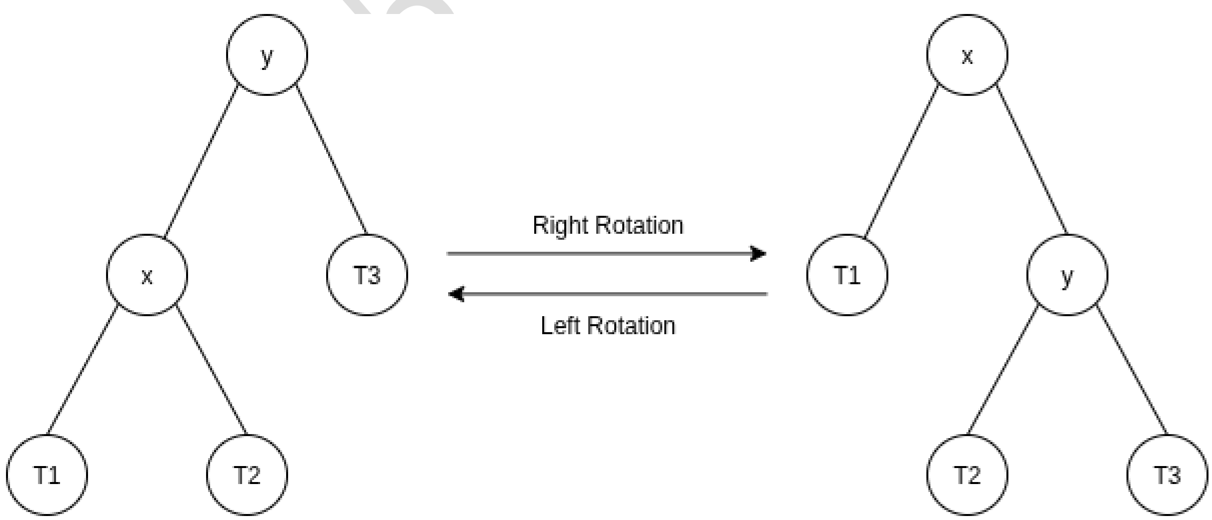


- **Rotations:**

  To maintain balance, the tree performs **rotations** when a node becomes unbalanced.

  1. **Right Rotation:**
     By performing a right rotation on a node:
     - The left child of the node will become the new root of the subtree.
     - The original root will become the right child of the new root.
     - Existing right subtree of the node -that has become the new root- (if exists), will become the left subtree of the previous root (which is now the right child of the root).

  2. **Left Rotation:**
     By performing a left rotation on a node:
     - The right child of the node will become the new root of the subtree.
     - The original root will become the left child of the new root.
     - Existing left subtree of the node -that has become the new root- (if exists), will become the right subtree of the previous root (which is now the left child of the root).



- **Imbalances**

  There are 4 types of imbalances in an AVL Tree:

  1. **Left-Left Case (LL Case):**
     This occurs when a node becomes unbalanced due to an insertion in the left subtree of the left child. Or a deletion in the right subtree of the left child.

     - **Fix:** Perform a single **right rotation**.

  2. **Right-Right Case (RR Case):**
     This occurs when a node becomes unbalanced due to an insertion in the right subtree of the right child. Or a deletion in the left subtree of the right child.

     - **Fix:** Perform a single **left rotation**.

  3. **Left-Right Rotation (LR):**
     This occurs when a node becomes unbalanced due to an insertion in the right subtree of the left child. Or a deletion in the left subtree of the left child.

     - **Fix:** Perform a left rotation on the left child, then a right rotation on the node.

  4. **Right-Left Rotation (RL):**
     This occurs when a node becomes unbalanced due to an insertion in the left subtree of the right child. Or a deletion in the right subtree of the right child.

     - **Fix:** Perform a right rotation on the right child, then a left rotation on the node.

AVL Tree Applications:

- **Database indexing:** AVL trees are commonly used in database indexing to speed up search queries by providing a fast access path to data.
- **Compiler Design:** AVL trees are used in compiler design to build and optimize syntax trees for efficient code generation.
- **Network Routing:** AVL trees are used in network routing algorithms to quickly find the shortest path between two nodes.

Advantages & Disadvantages of AVL Trees

Advantages:

- AVL trees provide efficient searching, insertion, and deletion operations.
- AVL trees ensure that the height of the tree remains logarithmic, making them suitable for applications that require optimal performance.

Disadvantages:

- AVL trees require more rotations than other self-balancing trees, making them less efficient.
- AVL trees are more complex to implement than other binary search trees.

Compared to Red-Black Tree:

- AVL trees are more balanced than red-black trees, but they require more rotations to maintain the balance property.
- AVL trees are better suited for applications that require frequent search operations.
- AVL trees have a more rigid balance requirement than red-black trees, meaning they may be less flexible in certain situations.

Ultimately, the choice between AVL trees and red-black trees will depend on the specific application and the performance requirements.