YZM2031

Data Structures and Algorithms

Week 7: Balanced Trees (AVL Trees)

Instructor: Ekrem Çetinkaya

Date: 26.11.2025

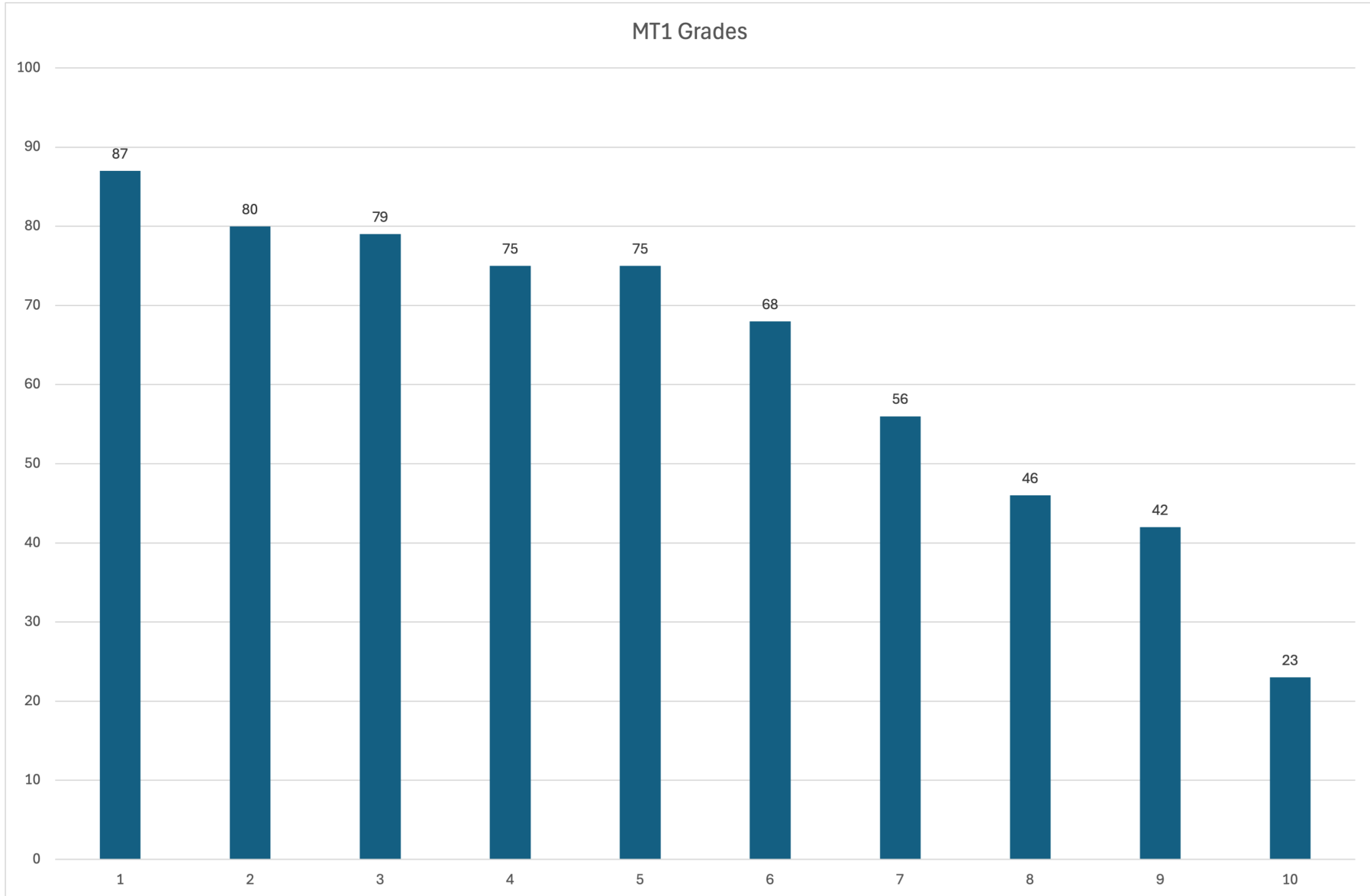
Midterm 1 Grades Are Out

Average: 63,1

Maximum: 87

Average Points per Question

- Q1: 4,3 / 10
- Q2: 3,8 / 5
- Q3: 7,4 / 10
- Q4: 3.6 / 10
- Q5: 8,5 / 15
- Q6: 13,5 / 15
- Q7: 8,7 / 15
- Q8: 13,3 / 20


MT1 Grades
100
90
80
70
60
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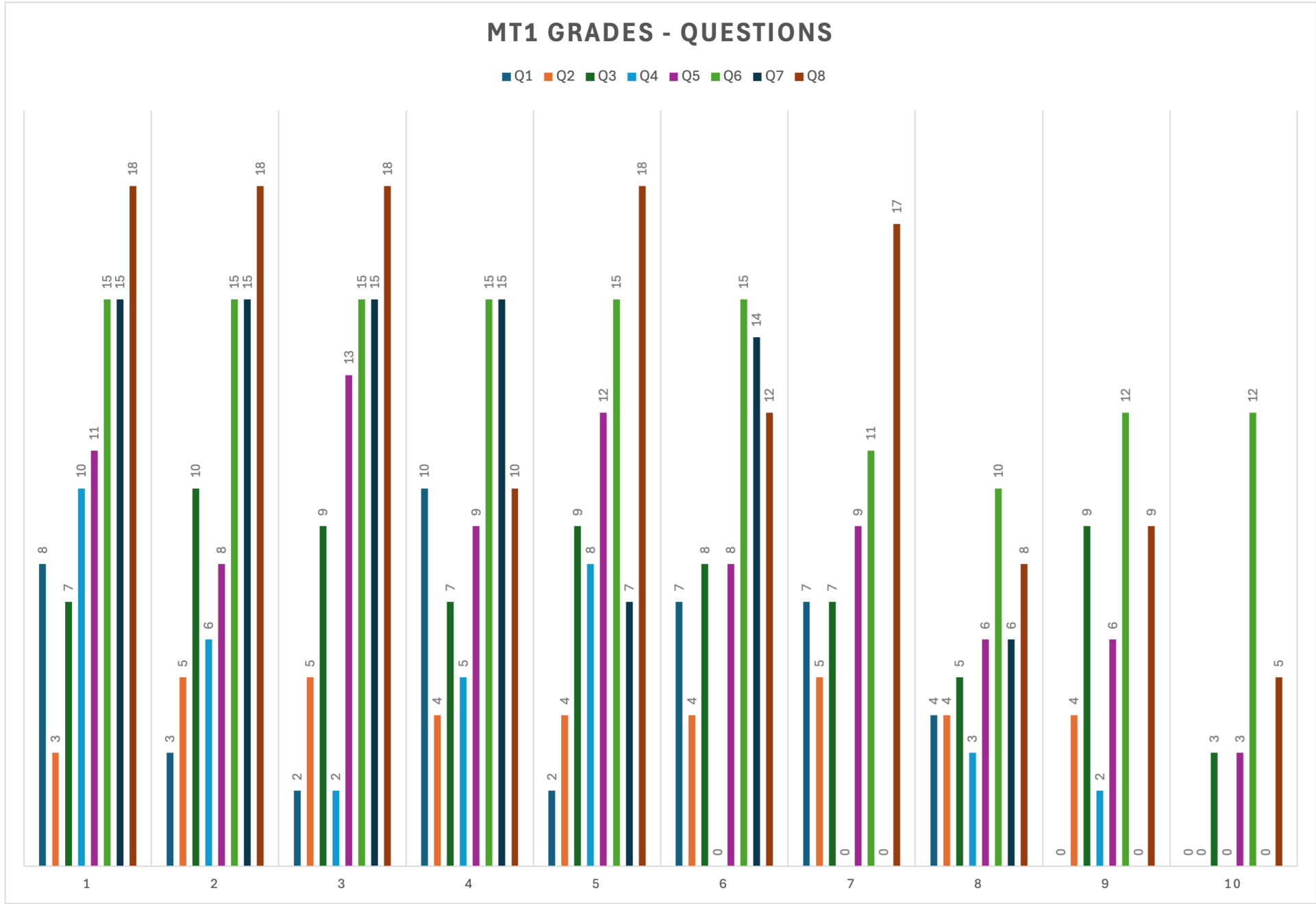
MT1 GRADES - QUESTIONS
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
1
2
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Recap - Week 6

Binary Search Trees

- **Property:** Left Subtree < Root < Right Subtree
- **Operations:** Search, Insert, Delete
- **Traversal:** In-order traversal yields sorted data

The Problem

- **Best Case (Balanced):** Height ≈ log n → O(log n)
- **Worst Case (Skewed):** Height ≈ n → O(n)

Challenge: As we insert/delete, how do we prevent the tree from becoming a line?

The Problem: Skewed BST

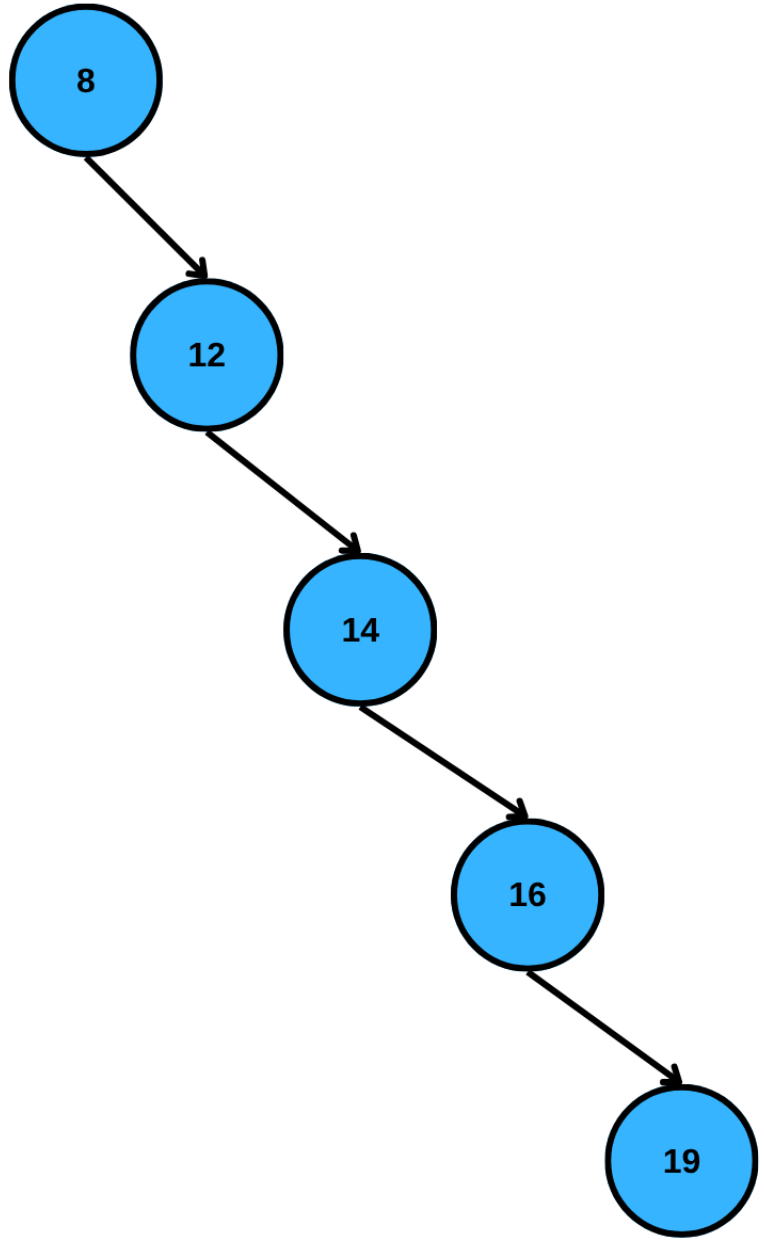
When BST Becomes Inefficient

```
Insert Sequence: 8, 12, 14, 16, 19
```

Result:

- **Structure:** Looks like a linked list
- **Height:** n-1 (Max possible)
- **Performance:** O(n) for all operations

We lose the primary benefit of binary search



The Solution - Self-Balancing Trees

Automated Balancing

Key Idea:

- Detect when the tree becomes too onesided
- Perform local adjustments (*rotations*) to fix it
- Ensure height stays close to **log n**

Result: Guaranteed **O(log n)** for Search, Insert, and Delete

Introduction to AVL Trees

Adelson-Velsky and Landis (1962)

- The **first** self-balancing binary search tree invented.
- Strictly height-balanced.

Definition:

> An AVL tree is a BST where for **every node**, the height difference between its left and right subtrees is **at most 1**.

Balance Property:

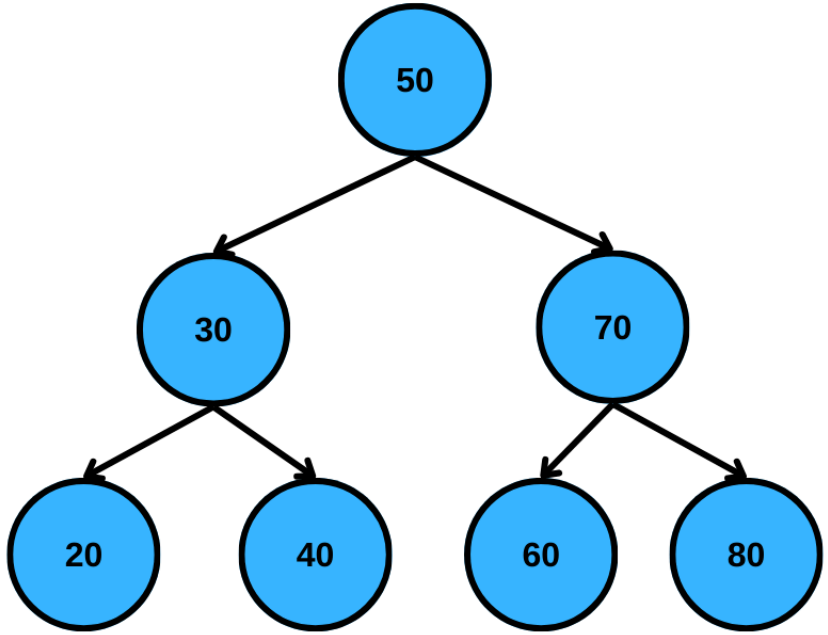
$$| \text{Height(Left)} - \text{Height(Right)} | \leq 1$$

AVL Tree Example

Checking the Property:

- **Leaves:** Height difference is 0.
- **Internal Nodes:**
  - 30: |1 - 1| = 0
  - 50: |2 - 2| = 0

Verdict: Valid AVL Tree.

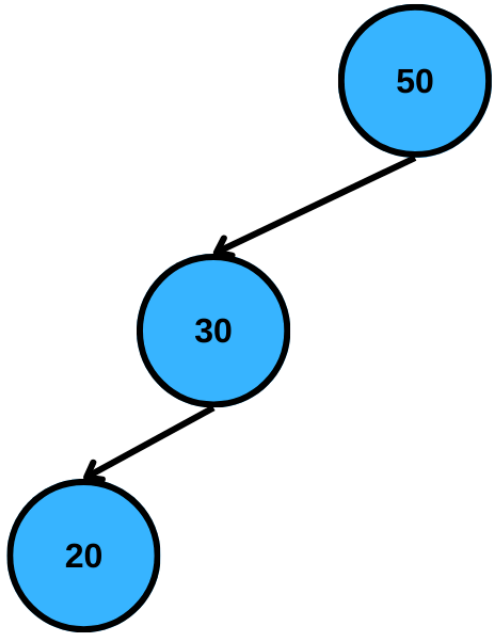


Not an AVL Tree

Checking the Property:

- **Node 20:** Balanced (0)
- **Node 30:** Balanced (1)
- **Node 50:** Left height = 2, Right height = 0.
  - Difference = 2 > 1

Verdict: Not an AVL Tree. Needs rebalancing



Balance Factor (BF)

The Metric for Balance

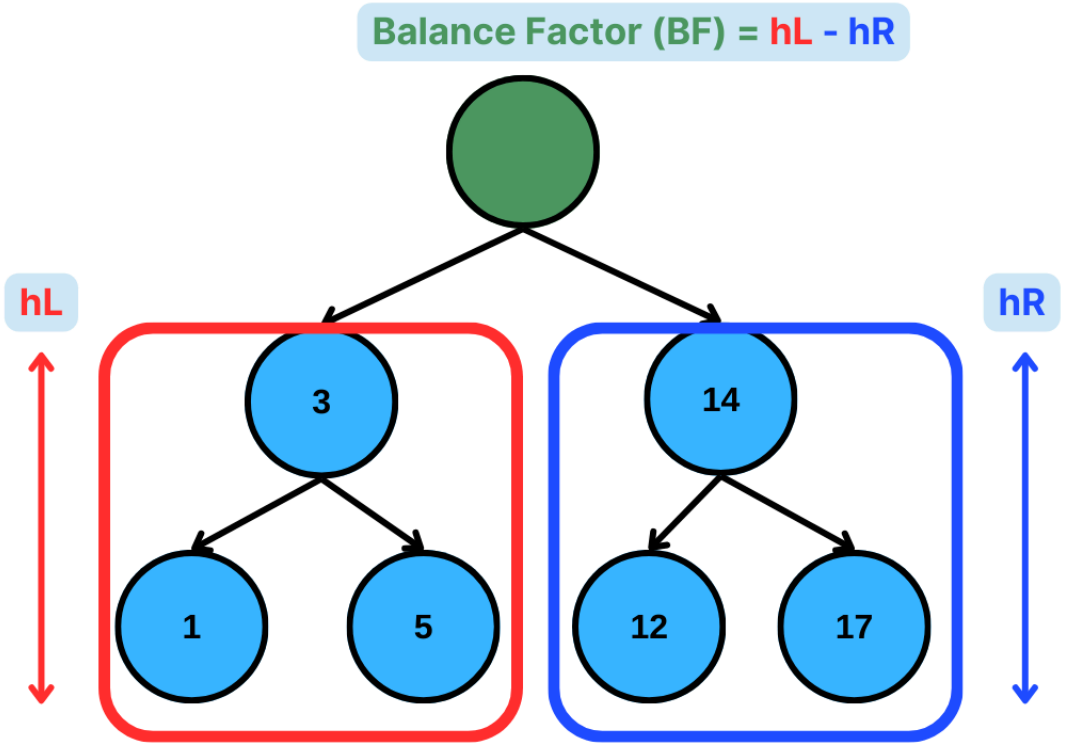
Balance Factor (BF) = Height(Left Subtree) - Height(Right Subtree)

Interpretation

- **BF = 0:** Perfectly balanced.
- **BF = +1:** Left-heavy (but allowed)
- **BF = -1:** Right-heavy (but allowed)

Violation

- **|BF| > 1:** The node is unbalanced



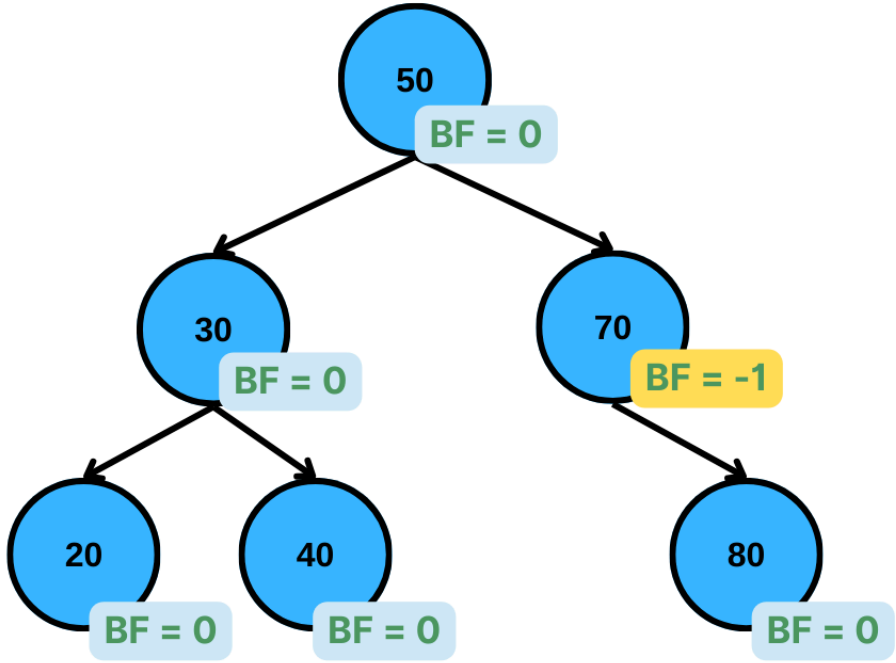
Calculating Height and Balance Factor

```
struct AVLNode {
    int data;
    AVLNode* left;
    AVLNode* right;
    int height;  // Cache height to avoid O(n) calculation

    AVLNode(int val) : data(val), left(nullptr),
                       right(nullptr), height(1) {}
};

// Utility to get height safely (handles nullptr)
int getHeight(AVLNode* node) {
    return (node == nullptr) ? 0 : node->height;
}

// Calculate Balance Factor
int getBalance(AVLNode* node) {
    if (node == nullptr) return 0;
    return getHeight(node->left) - getHeight(node->right);
}
```

Balance Factor Examples

- **50:** Left H=2, Right H=2 → 0
- **70:** Left H=0, Right H=1 → -1
- **20:** Left H=0, Right H=0 → 0

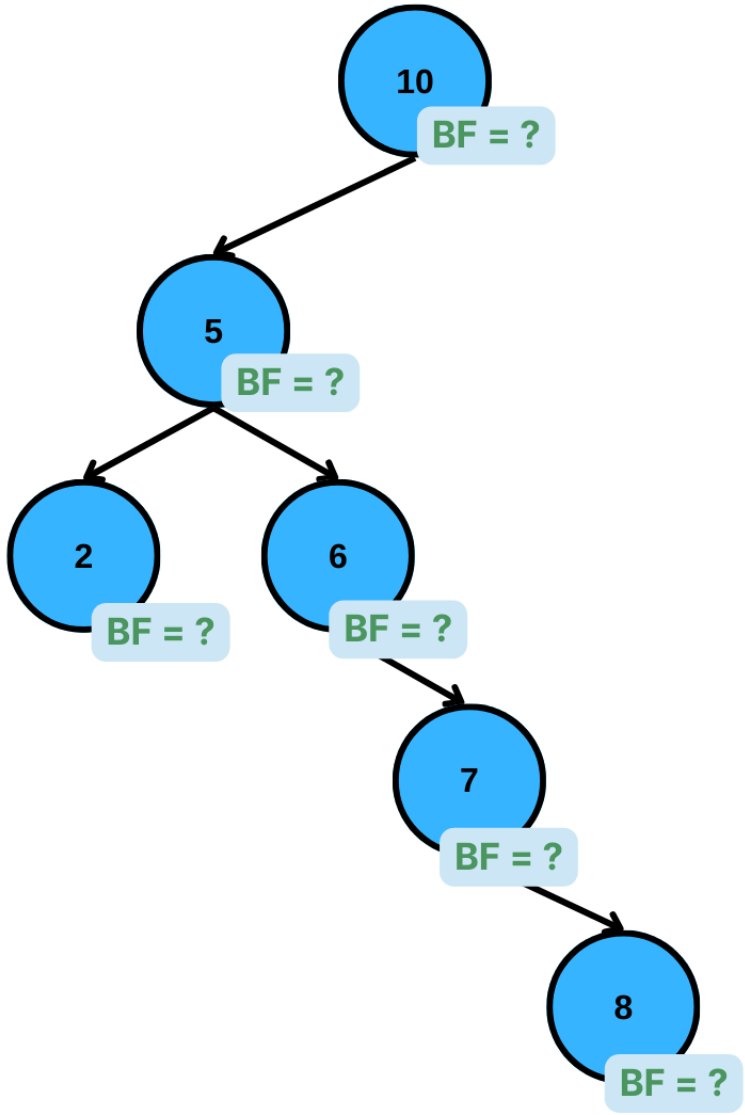
Note: Heights are 1-based (leaf height = 1) or 0-based (leaf height = 0). Just be consistent. We usually assume height(null) = 0.



Question - Balance Factors

Calculate the Balance Factor for each node

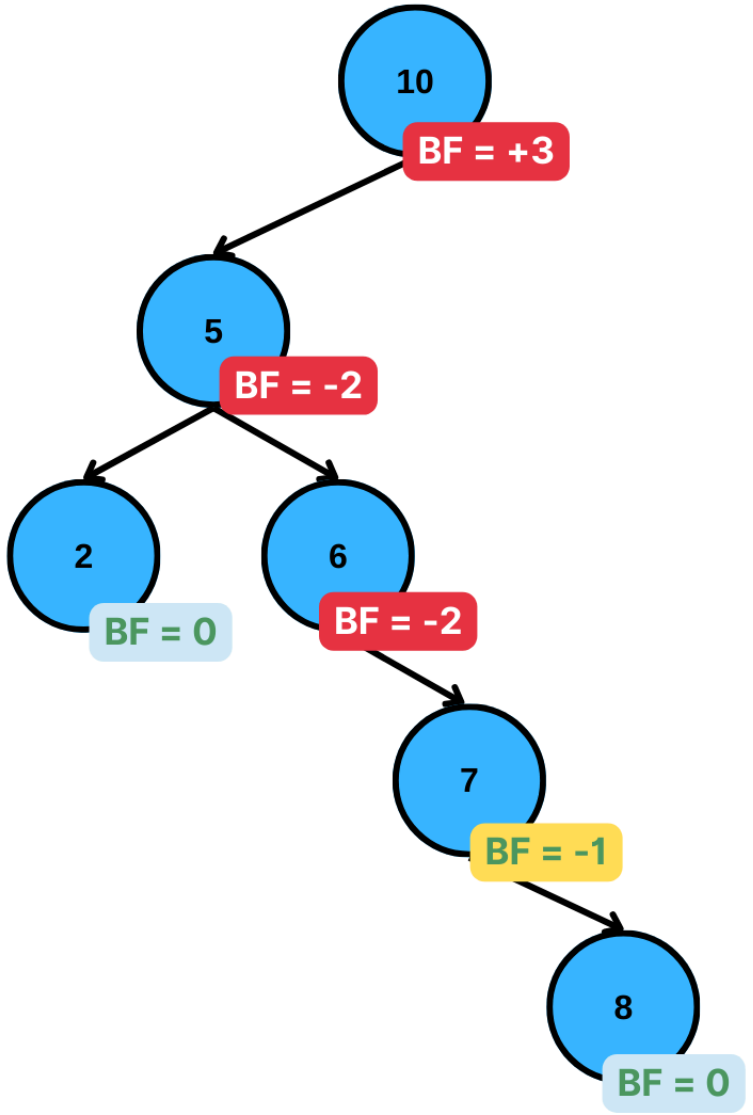
Is this an AVL tree?



Answer - Balance Factors

Calculate the Balance Factor for each node

Is this an AVL tree? No



Practice

Which of these insertion sequences result in a valid AVL tree (without rotations)?

Sequence A: 50, 25, 75, 10, 30, 60, 80

Sequence B: 50, 40, 30, 20, 10

Sequence C: 100, 50, 150, 25, 75, 125, 175, 12

Think about:

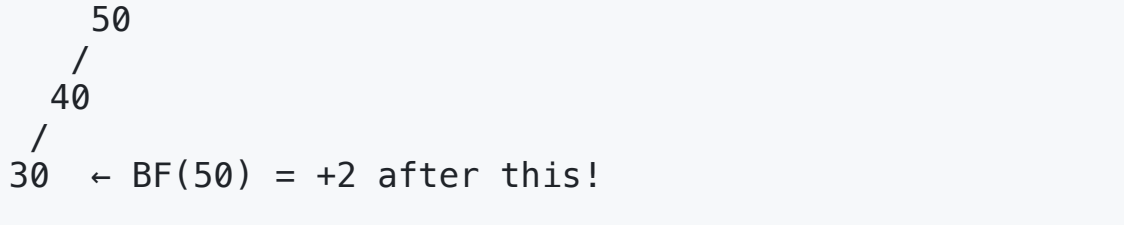
- What does the tree look like after each insert?
- What is the BF at the root after all inserts?
- Does any node violate $|BF| \leq 1$?

Practice - Answers

✅ Sequence A: 50, 25, 75, 10, 30, 60, 80

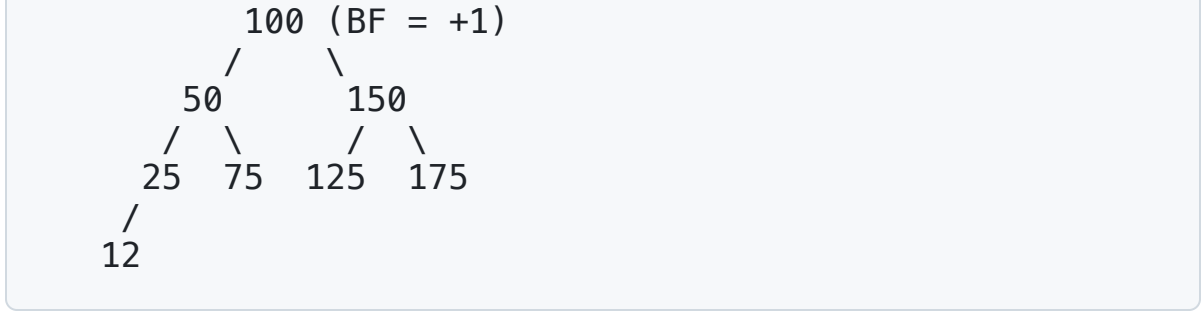
Perfect binary tree! All BFs = 0

❌ Sequence B: 50, 40, 30, 20, 10



Left-skewed: Violates AVL after 3rd insert

✅ Sequence C: 100, 50, 150, 25, 75, 125, 175, 12



- BF(25) = +1, BF(50) = +1, BF(100) = +1
- All valid! ✅

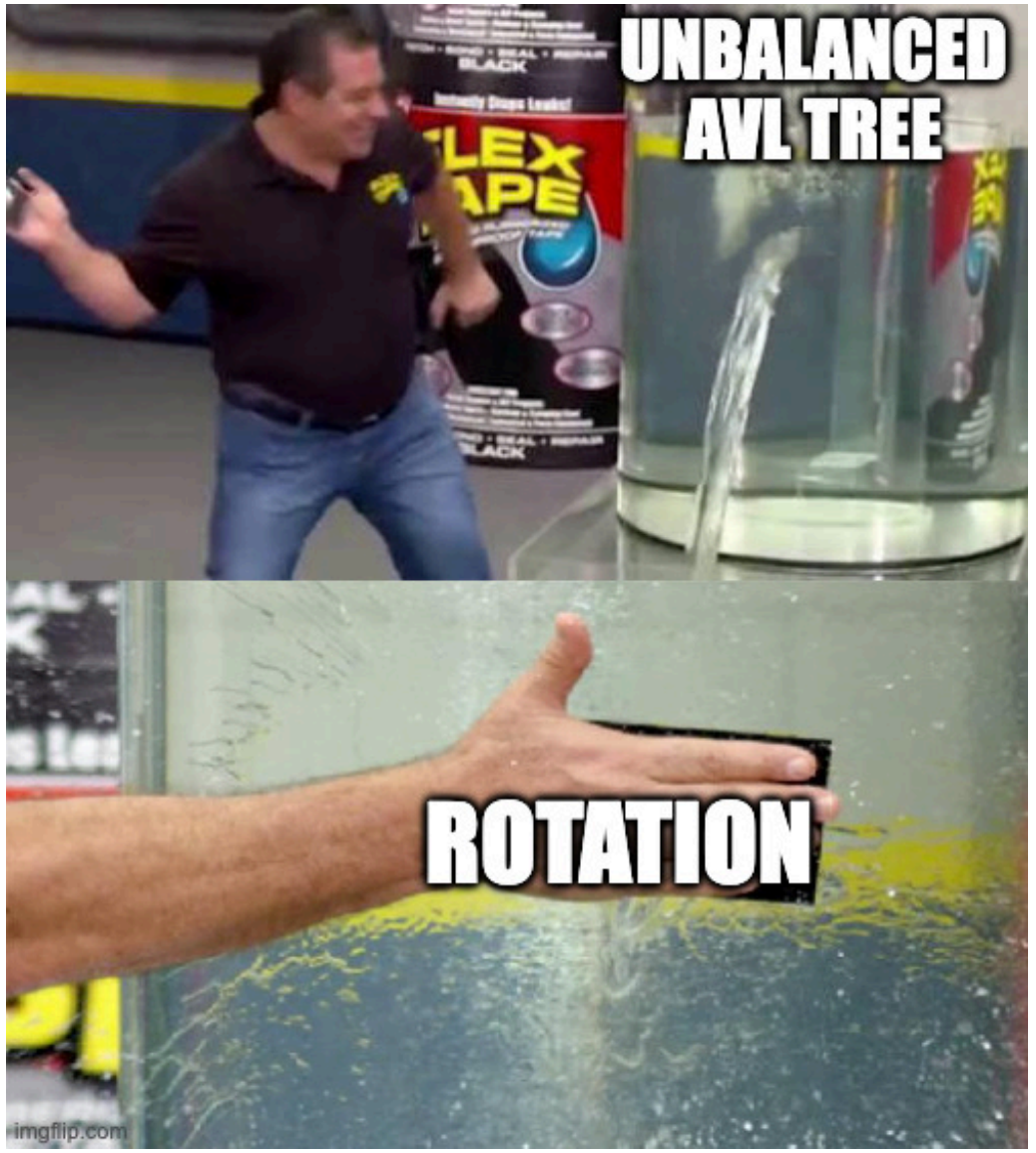
Automated Fixes

When an insertion or deletion creates a violation (|BF| > 1):

1. **Identify** the deepest node that is unbalanced.
2. **Determine** the type of imbalance (which subtrees are heavy?).
3. **Perform Rotation(s)** to fix it locally.

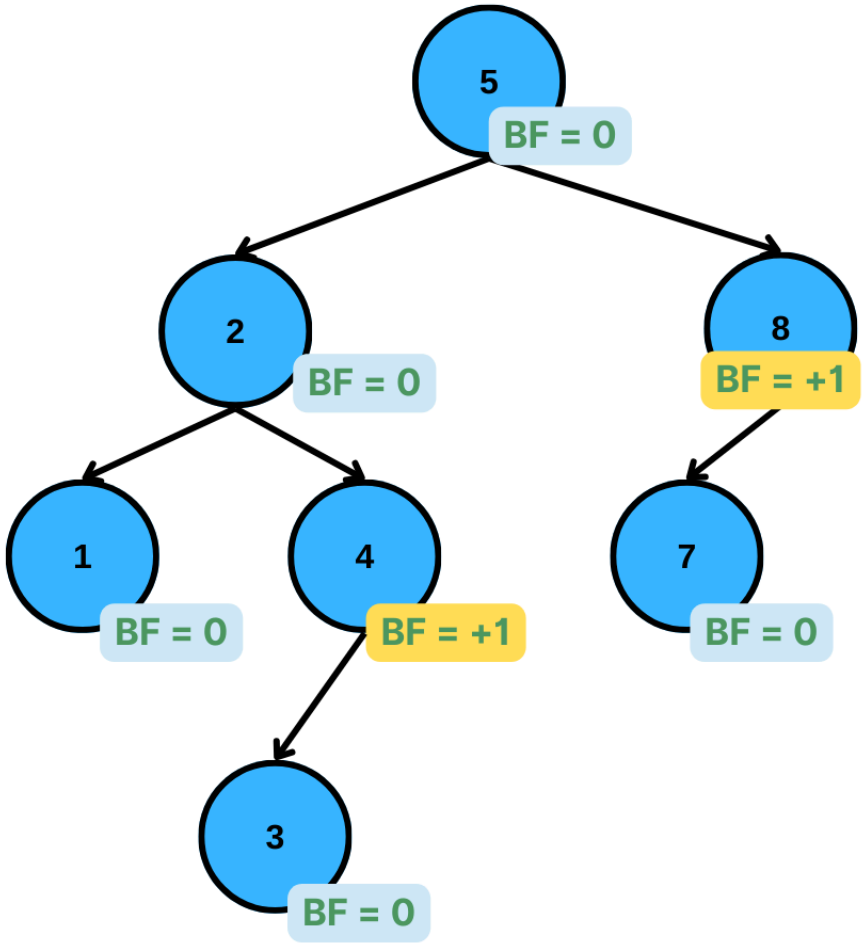
Goals

- Restore |BF| ≤ 1.
- **Crucial:** Preserve the BST ordering property (Left < Root < Right).
- Operations are O(1) pointer changes.



Rotation

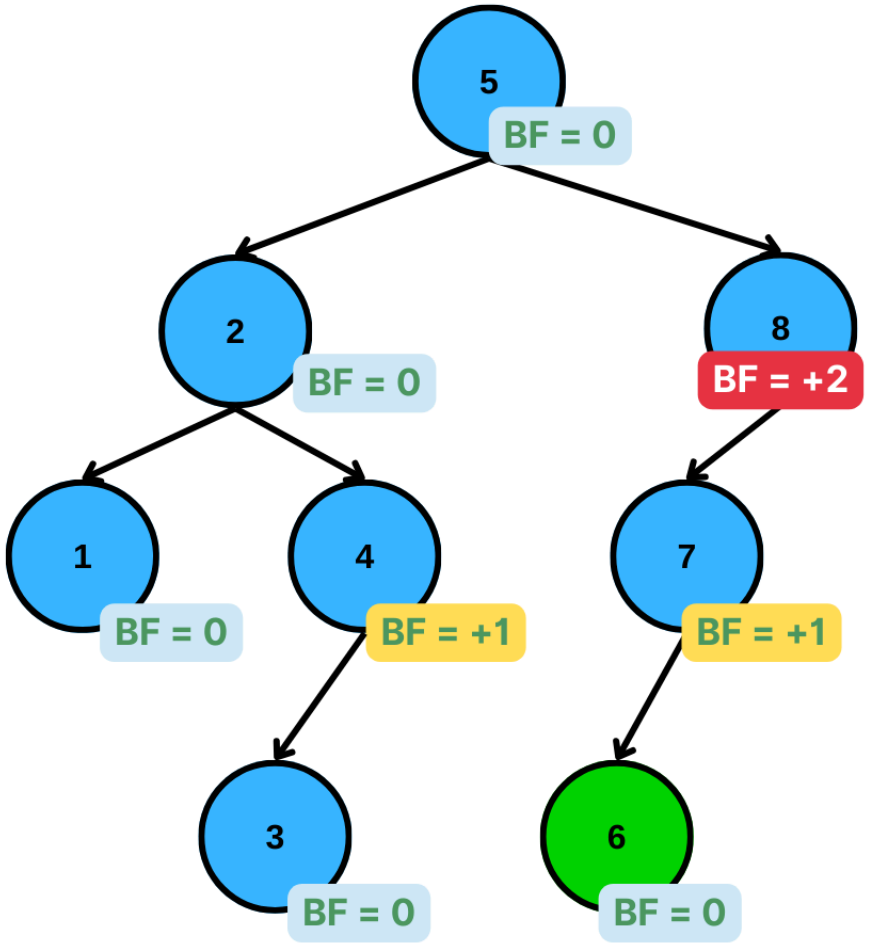
Suppose we have an AVL tree



Rotation

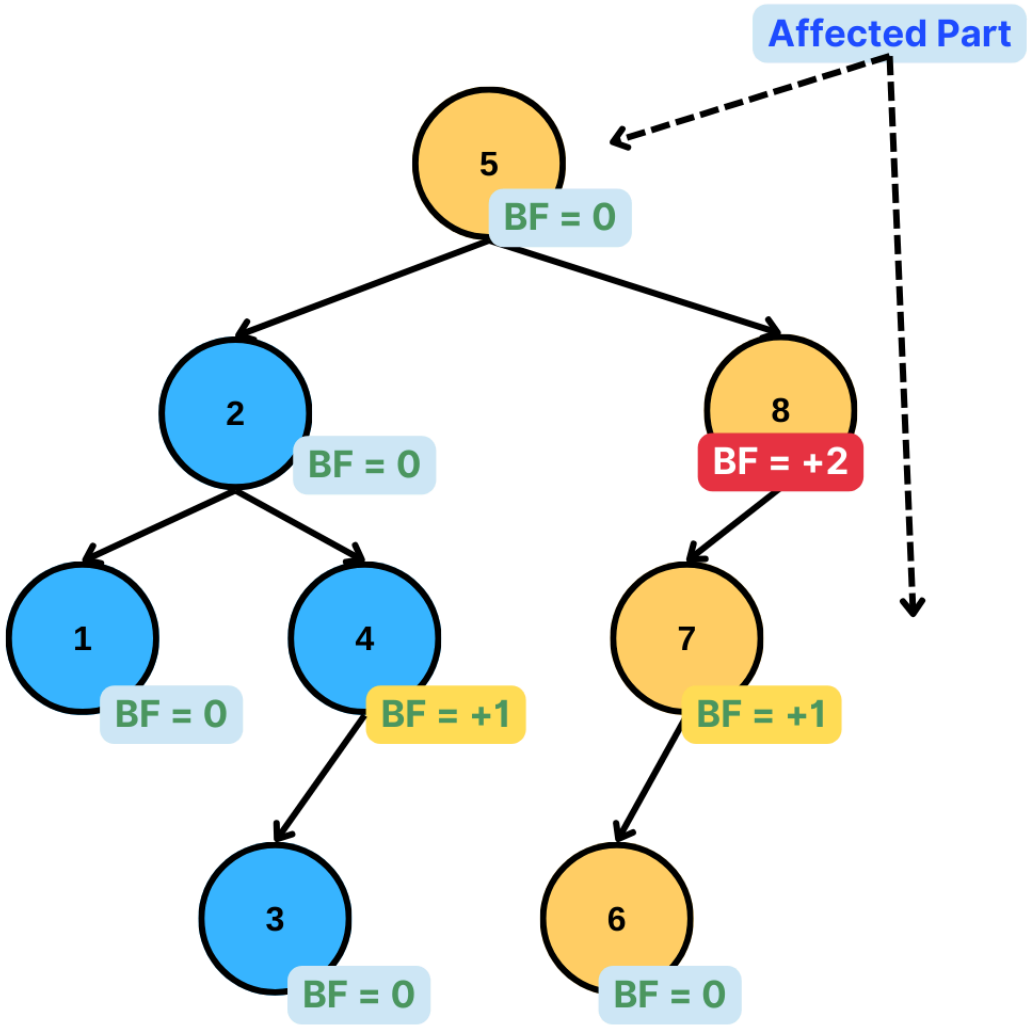
We insert 6 to the AVL tree

- Like a normal BST insert
- AVL tree no more



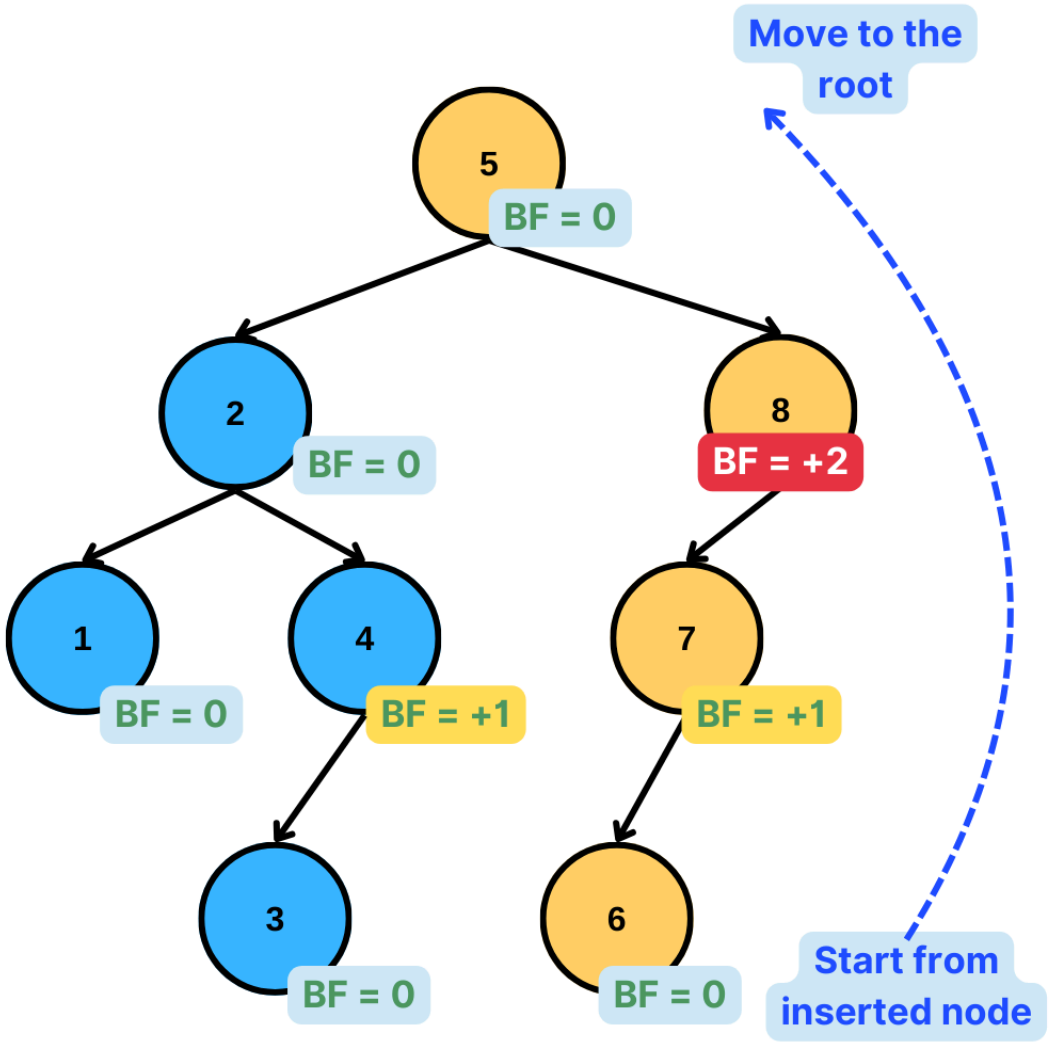
Rotation

Only nodes on the path from the inserted node to the root may have their subtrees altered



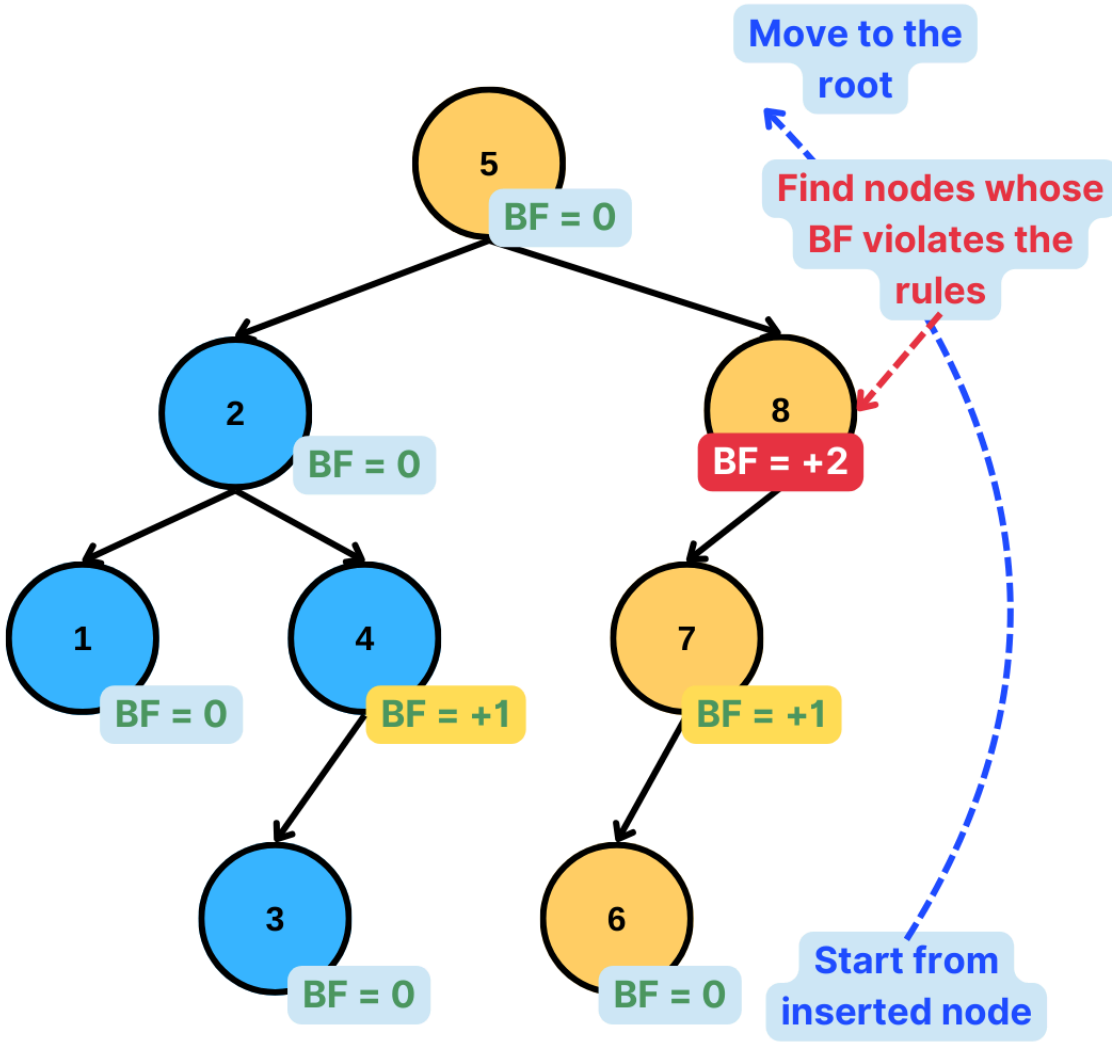
Rotation

To fix it, we need to follow from the inserted node up towards the root



Rotation

Find nodes whose new balance violates the AVL condition.
The tree must be re-organized to restore the balance.

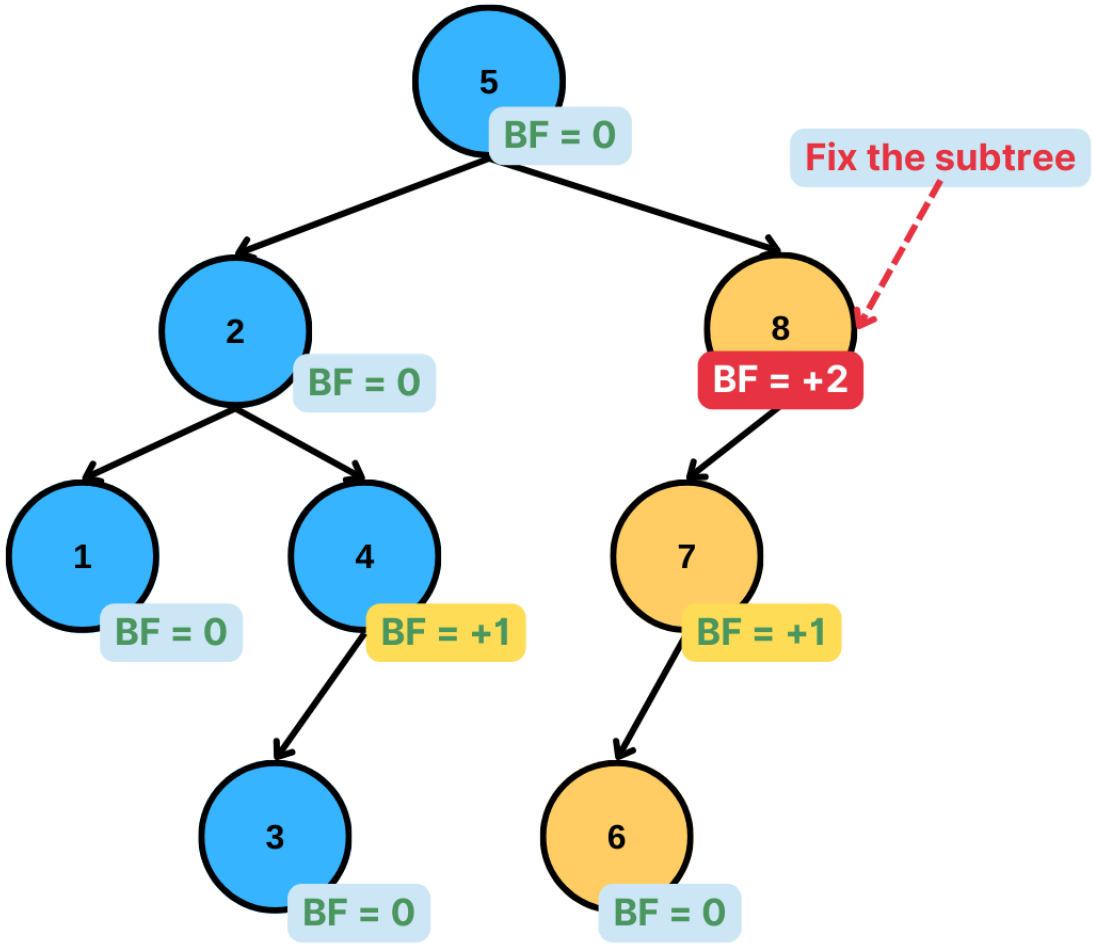


Rotation

Fixing the subtree rooted at the deepest such node guarantees that the whole tree has the AVL property.

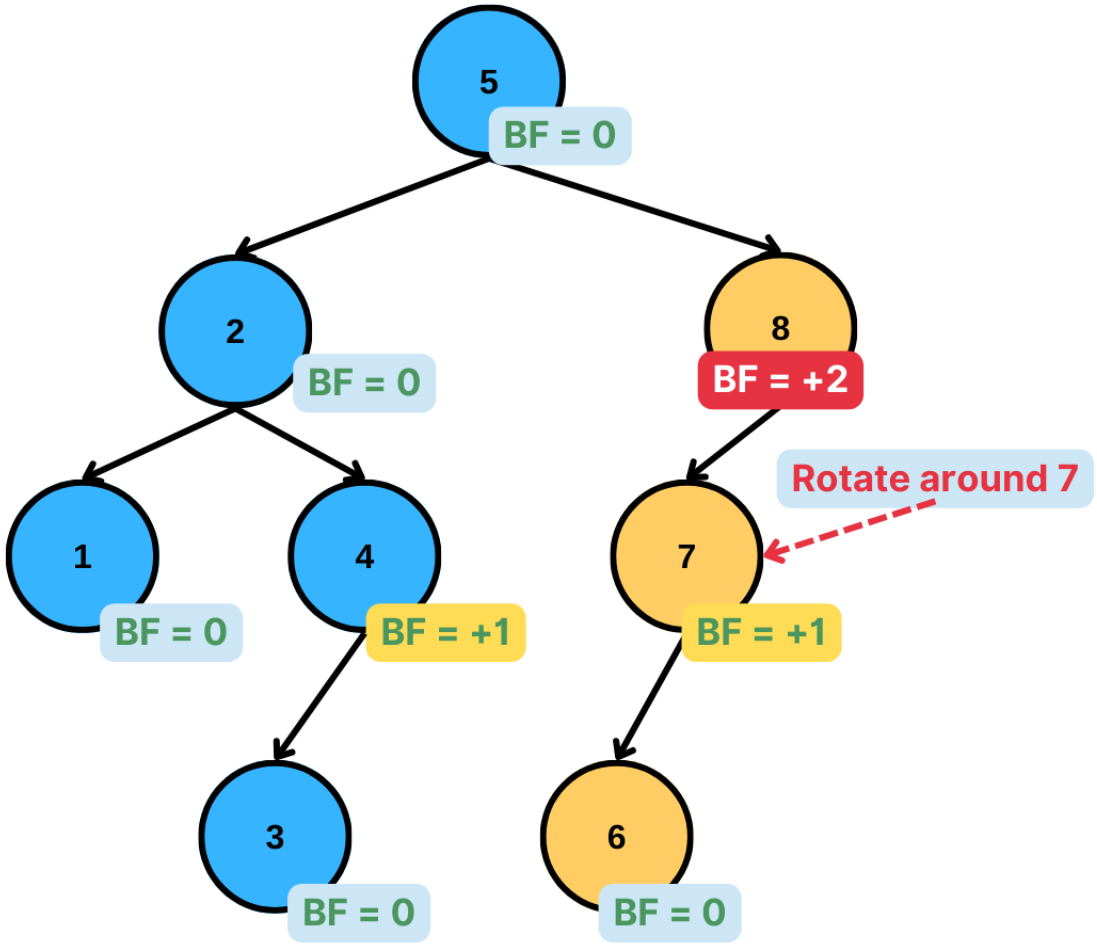
8 is the node whose balance is disrupted.

We should reorganize the tree rooted at 8.



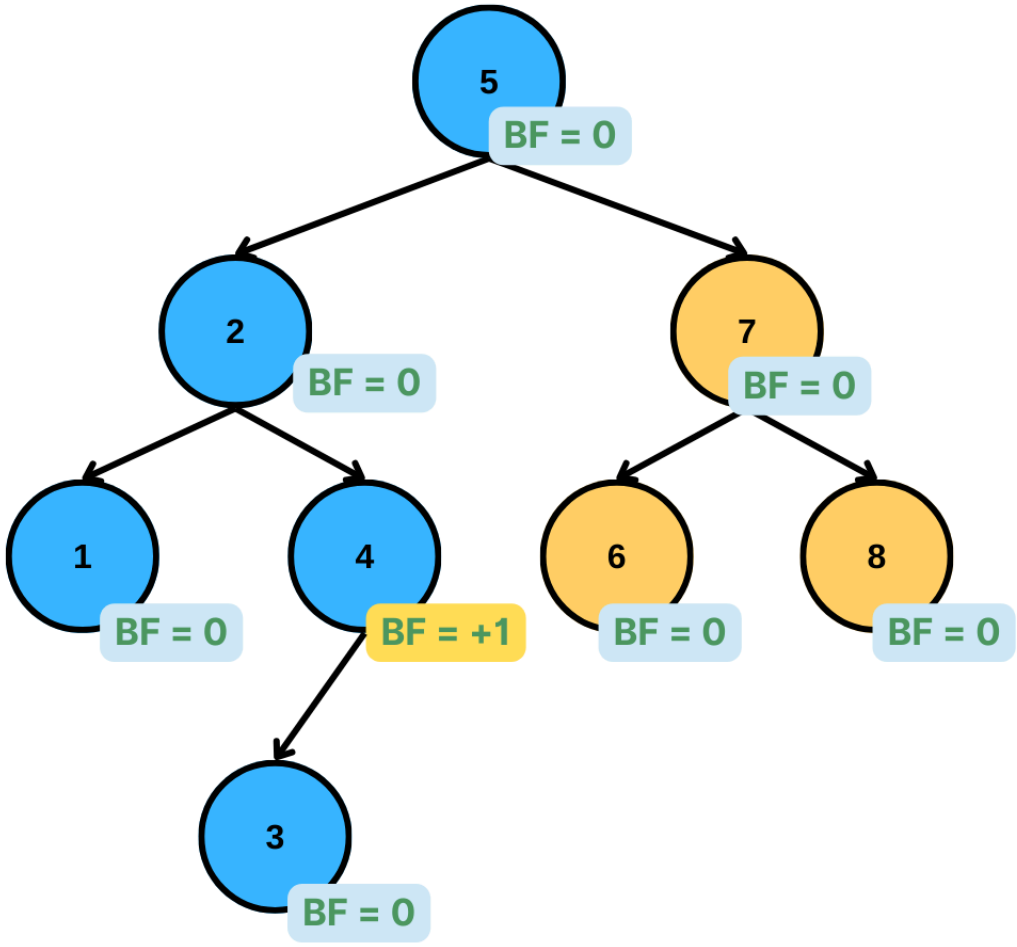
Rotation

Rotate around 7



Rotation

Now the tree is balanced 😎



Insertion

Since any node A has at most two children and a height imbalance requires that A's two subtrees' heights differ by two, there are four cases to consider:

1. **LL Case:** Left child, Left subtree.
2. **RR Case:** Right child, Right subtree.
3. **LR Case:** Left child, Right subtree.
4. **RL Case:** Right child, Left subtree.

Four Types of Rotations

1. Single Rotations (Outer Cases)

- **LL Case:** Left child, Left subtree.
- **RR Case:** Right child, Right subtree.

2. Double Rotations (Inner Cases)

- **LR Case:** Left child, Right subtree.
- **RL Case:** Right child, Left subtree.

The name tells you the path from the unbalanced node to the inserted node

1. Left-Left (LL) Case → Right Rotation

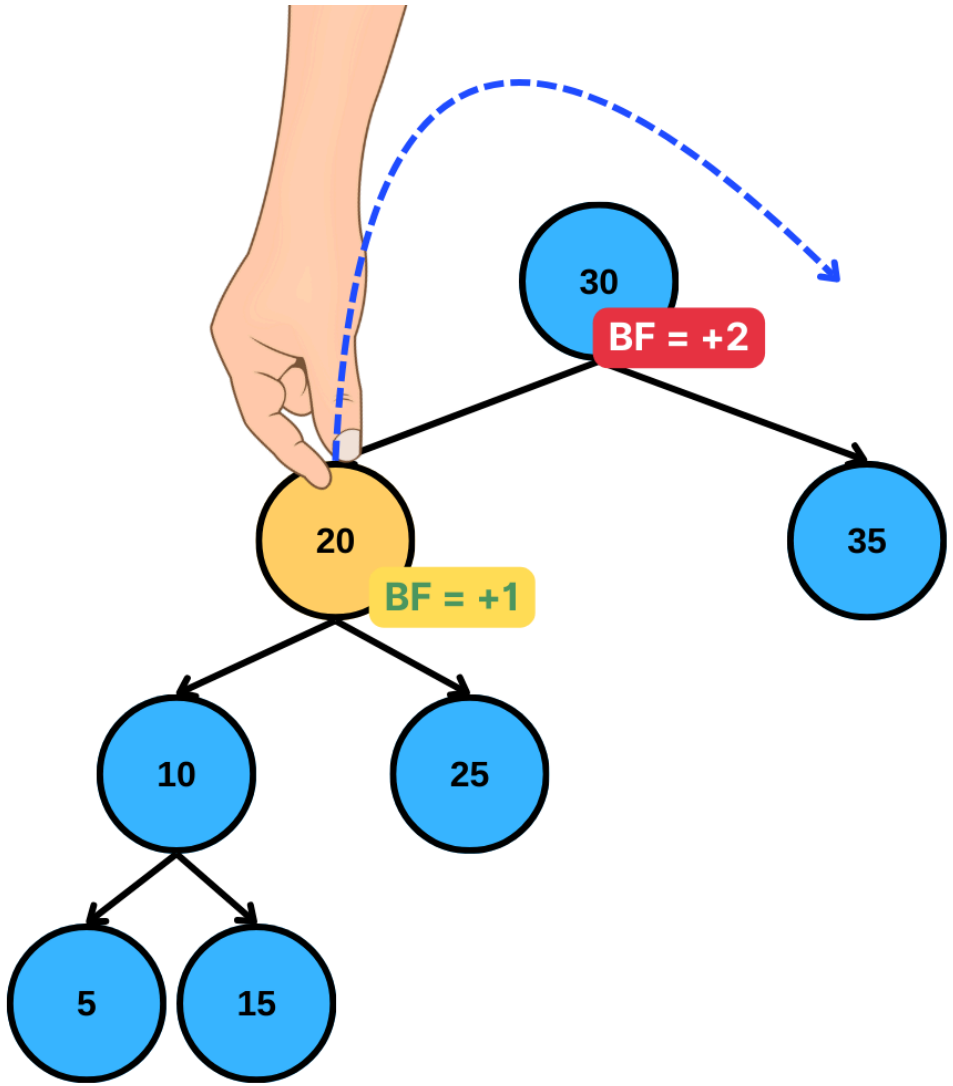
When to Use?

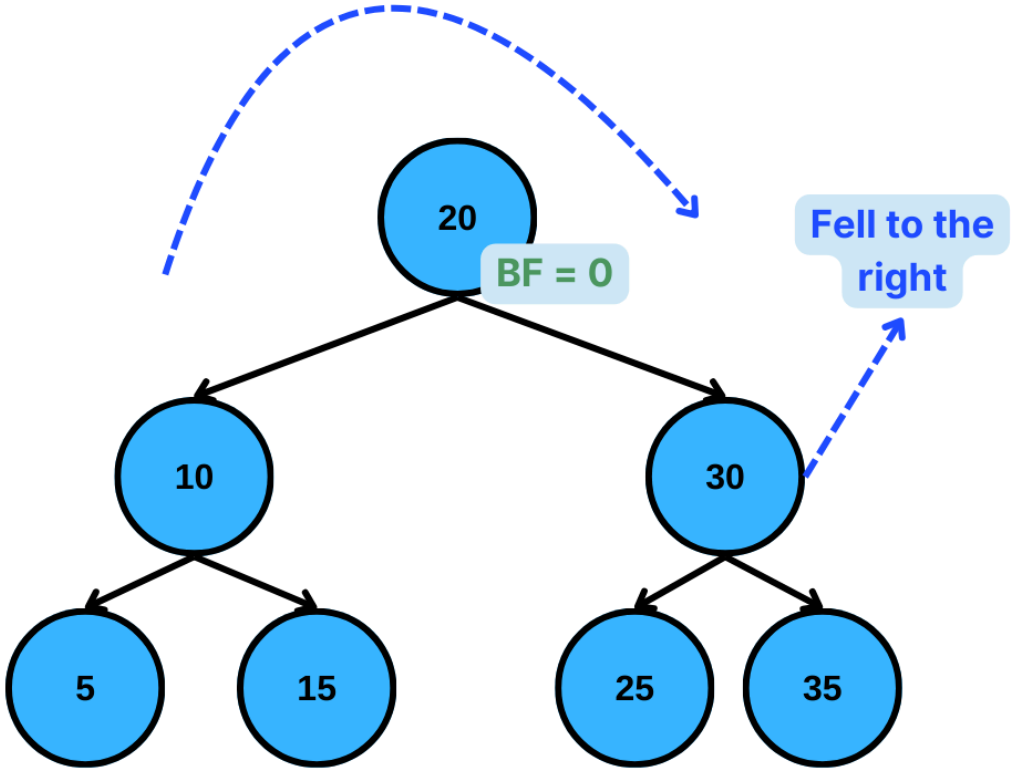
- Imbalance is at **X** (BF = +2).
- Left child **Y** is left-heavy (BF = +1 or 0).

Right Rotation

- Visualize grabbing **Y** and pulling it up.
- **X** falls down to the right.

Right Rotation - Example





Right Rotation - Code

```
AVLNode* rightRotate(AVLNode* x) {
    AVLNode* y = x->left;      // y is the new root
    AVLNode* T2 = y->right;    // T2 is the subtree moving across

    // Perform rotation
    y->right = x;
    x->left = T2;

    // Update heights (x first, then y)
    x->height = 1 + max(getHeight(x->left), getHeight(x->right));
    y->height = 1 + max(getHeight(y->left), getHeight(y->right));

    return y;  // Return new root
}
```

Time Complexity: O(1)

2. Right-Right (RR) Case → Left Rotation

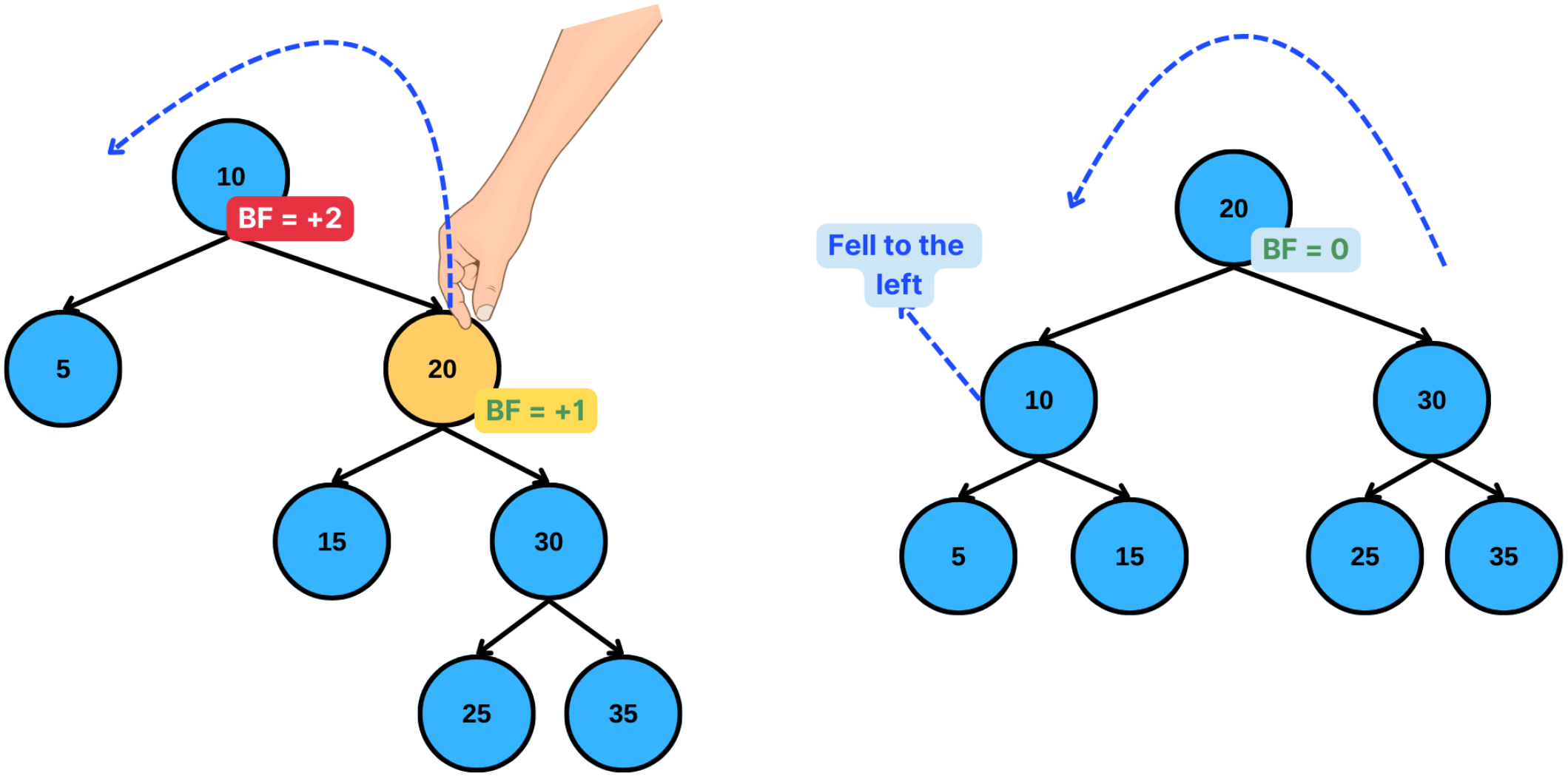
When to Use?

- Imbalance is at **X** (BF = -2).
- Right child **Y** is right-heavy (BF = -1 or 0).

The Fix: Left Rotation

- Visualize grabbing **Y** and pulling it up.
- **X** falls down to the left.

Left Rotation - Example



Left Rotation - Code

```
AVLNode* leftRotate(AVLNode* x) {
    AVLNode* y = x->right;     // y is the new root
    AVLNode* T2 = y->left;     // T2 is the subtree moving across

    // Perform rotation
    y->left = x;
    x->right = T2;

    // Update heights
    x->height = 1 + max(getHeight(x->left), getHeight(x->right));
    y->height = 1 + max(getHeight(y->left), getHeight(y->right));

    return y;  // Return new root
}
```

Time Complexity: O(1)

3. Left-Right (LR) Case - Double Rotation

When to Use?

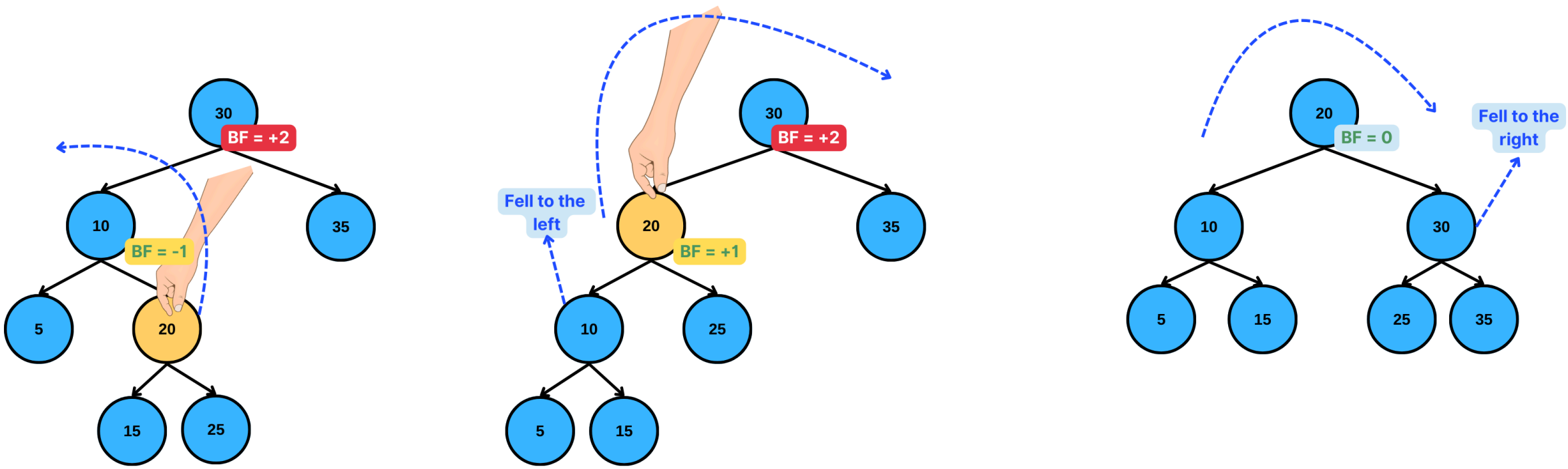
- Imbalance at **X** (BF = +2).
- Left child **Y** is **right-heavy** (BF = -1).
- "Zig-Zag" shape.

Single rotation does not solve the problem

The Fix - Left-Right Rotation

1. **Left Rotate Y** to convert it into LL case.
2. **Right Rotate X** to balance the tree.

Left-Right Rotation - Example



Logic: *We simply lift the "grandchild"* ***20*** *all the way up to become the new root*

Left-Right Rotation - Code

```
AVLNode* leftRightRotate(AVLNode* node) {
    // 1. Transform LR into LL
    node->left = leftRotate(node->left);

    // 2. Fix LL
    return rightRotate(node);
}
```

4. Right-Left (RL) Case - Double Rotation

When to Use?

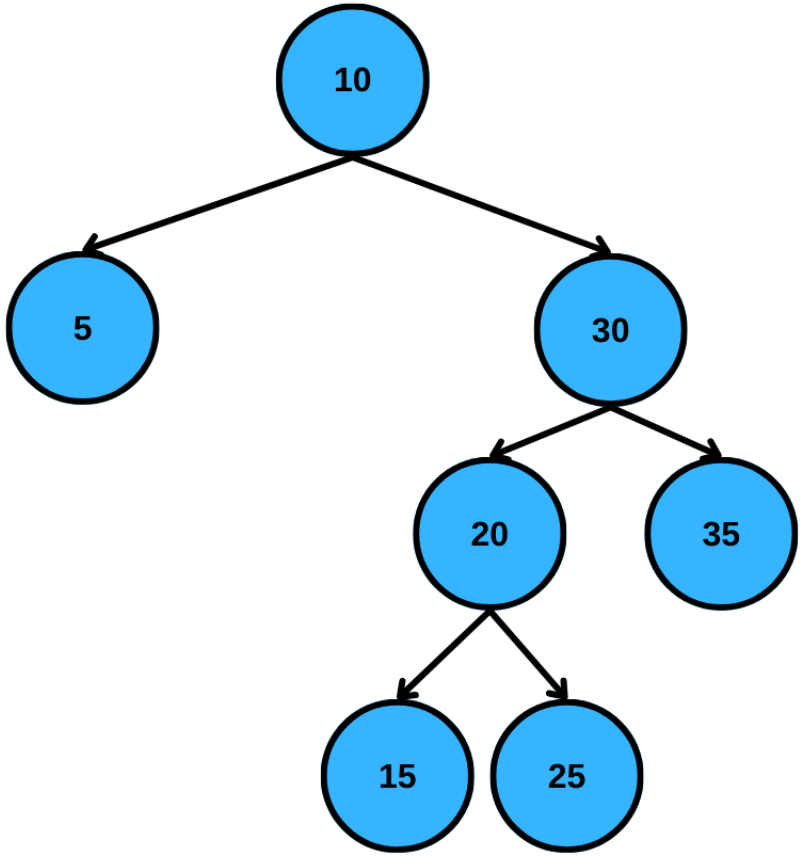
- Imbalance at **X** (BF = -2).
- Right child **Y** is **left-heavy** (BF = +1).
- "Zag-Zig" shape.

The Fix: Right-Left Rotation

1. **Right Rotate Y** to convert it into RR case.
2. **Left Rotate X** to balance the tree.

Right-Left Rotation - Practice

Let's do it together



Right-Left Rotation - Code

```
AVLNode* rightLeftRotate(AVLNode* node) {
    // 1. Transform RL into RR
    node->right = rightRotate(node->right);

    // 2. Fix RR
    return leftRotate(node);
}
```

Summary:

- Outer cases (LL, RR) → 1 Rotation.
- Inner cases (LR, RL) → 2 Rotations.

Rotation Decision Table

Balance Factor (Root)	Child's Balance Factor	Case	Rotation(s)
+2 (Left Heavy)	**≥ 0** (Left Heavy)	**LL**	Right(Root)
+2 (Left Heavy)	**< 0** (Right Heavy)	**LR**	Left(Child) → Right(Root)
-2 (Right Heavy)	**≤ 0** (Right Heavy)	**RR**	Left(Root)
-2 (Right Heavy)	**> 0** (Left Heavy)	**RL**	Right(Child) → Left(Root)

Key: Always check the node where violation happens + its heavy child.

Practice - Identify the Case

For each scenario, identify: LL, RR, LR, or RL?

Scenario 1:

- Root BF = +2
- Left Child BF = +1

Scenario 2:

- Root BF = -2
- Right Child BF = +1

Scenario 3:

- Root BF = +2
- Left Child BF = -1

Scenario 4:

- Root BF = -2
- Right Child BF = -1

Scenario 5:

- Root BF = -2
- Right Child BF = 0

Scenario 6:

- Root BF = +2
- Left Child BF = 0

Practice - Identify the Case - Answers

Scenario	Root BF	Child BF	Case	Rotation(s)
1	+2	+1	**LL**	Right(Root)
2	-2	+1	**RL**	Right → Left
3	+2	-1	**LR**	Left → Right
4	-2	-1	**RR**	Left(Root)
5	-2	0	**RR**	Left(Root)
6	+2	0	**LL**	Right(Root)

Tip: The case name tells you the path from unbalanced node to the heavy subtree!

AVL Insertion Logic

A Recursive Process

1. **Standard BST Insert:** Go down, insert leaf.
2. **Unwind Recursion:** Move back up to root.
3. **Update Height:** For current node.
4. **Check Balance:** Calculate BF.
5. **Rebalance:** If |BF| > 1, perform rotation.
6. **Return:** The (potentially new) root of this subtree.

Why is this efficient?

Rotations are local. Height is O(log n), so we do at most O(log n) checks.

AVL Insert - Implementation

```
AVLNode* insert(AVLNode* node, int val) {
    // 1. Standard BST Insert
    if (node == nullptr) return new AVLNode(val);

    if (val < node->data)
        node->left = insert(node->left, val);
    else if (val > node->data)
        node->right = insert(node->right, val);
    else
        return node; // No duplicates

    // 2. Update Height
    node->height = 1 + max(getHeight(node->left), getHeight(node->right));

    // 3. Get Balance Factor
    int balance = getBalance(node);

    // 4. Check & Fix Imbalance (Next Slide) ->
    return rebalance(node, balance, val);
}
```

Handling the 4 Cases

```
AVLNode* rebalance(AVLNode* node, int balance, int val) {
    // LL Case
    if (balance > 1 && val < node->left->data)
        return rightRotate(node);

    // RR Case
    if (balance < -1 && val > node->right->data)
        return leftRotate(node);

    // LR Case
    if (balance > 1 && val > node->left->data) {
        node->left = leftRotate(node->left);
        return rightRotate(node);
    }

    // RL Case
    if (balance < -1 && val < node->right->data) {
        node->right = rightRotate(node->right);
        return leftRotate(node);
    }

    return node; // Balanced
}
```

AVL Insertion Trace - Example 1

Sequence: 10, 20, 30

What happens?

AVL Insertion Trace - Example 1

1. Insert 10.
2. Insert 20. Tree is skewing right.
3. Insert 30.
    - Node 10 has BF = -2.
    - Child 20 has BF = -1.
    - **Case:** RR.
    - **Action:** Left Rotate(10).

Result: 20 becomes root, 10 left, 30 right. Perfectly balanced.

AVL Insertion Trace - Example 2

Sequence: 30, 20, 25

What happens?

AVL Insertion Trace - Example 2

1. Insert 30.
2. Insert 20 (Left of 30).
3. Insert 25 (Right of 20).
    - Node 30 has BF = +2.
    - Child 20 has BF = -1.
    - **Case:** LR.
    - **Action:** Left Rotate(20), then Right Rotate(30).

Result: 25 becomes root, 20 left, 30 right.

Practice - Complete AVL Build

Build an AVL tree by inserting: 50, 30, 70, 20, 40, 60, 80, 10, 25, 35, 45, 5

For each step:

1. Draw the tree after standard BST insert
2. Check if any node is unbalanced
3. If unbalanced, identify the case and perform rotation
4. Draw the final balanced tree

Work through this (3 minutes)

Practice - Complete AVL Build - Solution (Part 1)

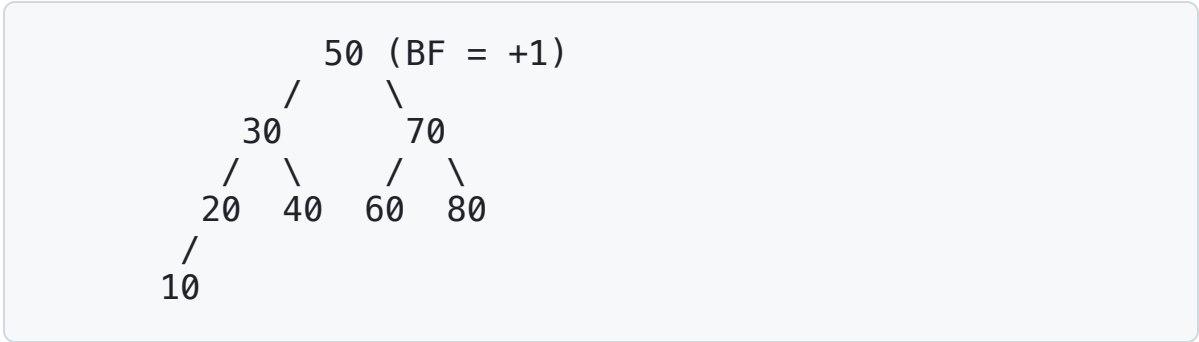
Insert 50, 30, 70, 20, 40, 60, 80:

```
            50 (BF = 0)
          /     \
        30       70
       /  \     /  \
      20  40   60  80
```

All nodes balanced! ✅ This is a perfect binary tree.

Practice - Complete AVL Build - Solution (Part 2)

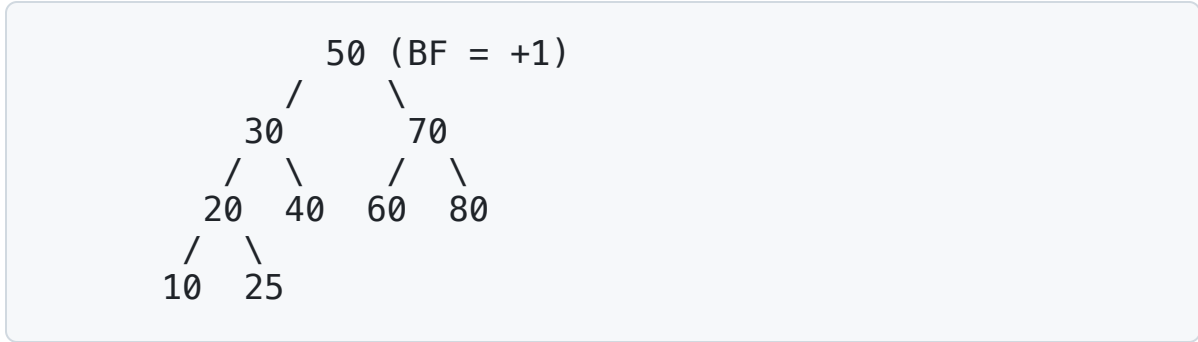
Insert 10:



- BF(20) = +1 ✅
- BF(30) = +1 ✅
- BF(50) = +1 ✅

Still balanced!

Insert 25:



- BF(20) = 0 ✅
- All other BFs unchanged

Still balanced!

Practice - Complete AVL Build - Solution (Part 3)

Insert 35:

- BF(40) = +1 ✅
- BF(30) = 0 ✅

Still balanced!

Insert 45:

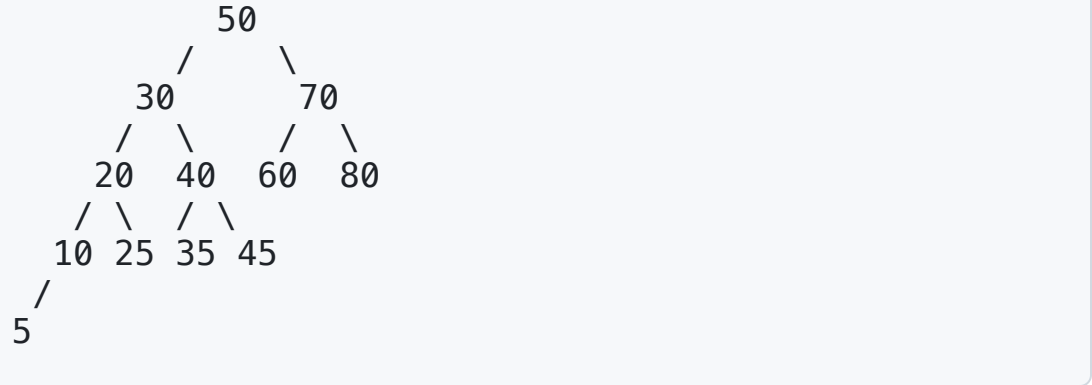
- BF(40) = 0 ✅
- All nodes balanced!

Still balanced!

Practice - Complete AVL Build - Solution (Part 4)

Insert 5:

After BST Insert:



Check Balance:

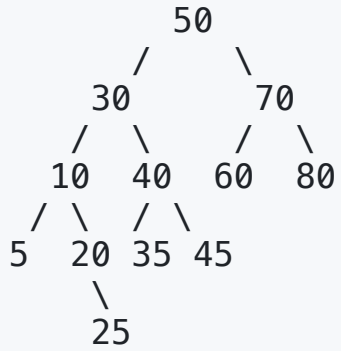
- BF(10) = +1 ✅
- BF(20) = +2 ❌ **UNBALANCED!**

Child BF(10) = +1 → LL Case!

Action: Right Rotate(20)

Practice - Complete AVL Build - Final Result

After Right Rotate(20):



- BF(10) = 0 ✅
- BF(30) = +1 ✅
- BF(50) = +1 ✅

Final tree is balanced!

Practice

Insert sequence: 3, 2, 1, 4, 5, 6, 7, 16, 15, 14, 13, 12, 11, 10, 8, 9

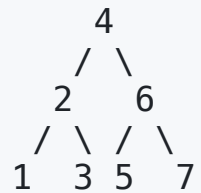
Task: Build the AVL tree step by step, noting each rotation

Hint: You'll need MANY rotations throughout the process

Practice - Challenge Problem - Answer (Part 1)

Step	Insert	Action	Tree State
1	3	Insert	Root = 3
2	2	Insert	2 left of 3
3	1	LL → Right Rotate(3)	Root = 2
4	4	Insert	4 right of 3
5	5	RR → Left Rotate(3)	4 becomes right child
6	6	RR → Left Rotate(4)	4 → 5 subtree
7	7	RR → Left Rotate(2)	Root = 4

After inserting 1-7:



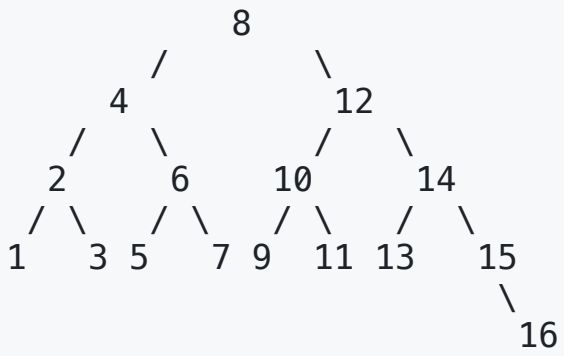
Practice - Challenge Problem - Answer (Part 2)

Step	Insert	Action	Rotation At
8	16	Insert	No rotation
9	15	RL → Right(16), Left(7)	Node 7
10	14	LL → Right Rotate(15)	Node 15
11	13	LL → Right Rotate(14)	Node 14
12	12	LL → Right Rotate(4)	Root changes!
13	11	LL → Right Rotate(13)	Node 13
14	10	LL → Right Rotate(12)	Node 12
15	8	Insert	No rotation
16	9	LR → Left(8), Right(10)	Node 10

Total Rotations: 11 (vs 0 in regular BST which would have height 16)

Practice - Challenge Problem - Final Tree

Final AVL Tree (16 nodes, height = 4):



Comparison:

- Regular BST height: **15**
- AVL Tree height: **4**
- Worst-case search: **4 comparisons** instead of 15

This is the power of self-balancing trees

AVL Deletion Algorithm

1. **Standard BST Delete:**
    - Leaf, One Child, or Two Children (successor).
2. **Unwind Recursion:** Move back up
3. **Update Height & Balance:** Same as insert
4. **Rebalance:**
    - **Critical Diff:** Deletion may require rotations at **multiple levels**
    - We must continue checking all the way to the root

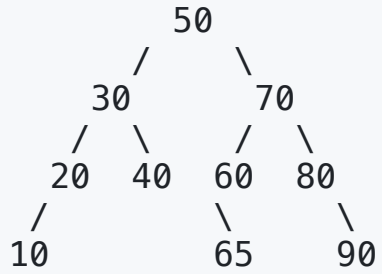
AVL Deletion - Code Snippet

```
AVLNode* deleteNode(AVLNode* root, int val) {
    // 1. Standard BST Delete (Recursive)
    if (!root) return root;
    if (val < root->data) root->left = deleteNode(root->left, val);
    else if (val > root->data) root->right = deleteNode(root->right, val);
    else {
        // Node Found: Handle 3 cases
        if (!root->left || !root->right) {
            AVLNode* temp = root->left ? root->left : root->right;
            if (!temp) { temp = root; root = nullptr; }
            else *root = *temp; // Copy child
            delete temp;
        } else {
            // 2 Children: Get successor
            AVLNode* temp = findMin(root->right);
            root->data = temp->data;
            root->right = deleteNode(root->right, temp->data);
        }
    }
    if (!root) return root;

    // 2. Update Height
    root->height = 1 + max(getHeight(root->left), getHeight(root->right));
```

AVL Deletion - Code Snippet

```
    // 3. Rebalance (Check Child's BF for case)
    int balance = getBalance(root);

    // Left Heavy
    if (balance > 1) {
        if (getBalance(root->left) >= 0) return rightRotate(root); // LL
        else { root->left = leftRotate(root->left); return rightRotate(root); } // LR
    }
    // Right Heavy
    if (balance < -1) {
        if (getBalance(root->right) <= 0) return leftRotate(root); // RR
        else { root->right = rightRotate(root->right); return leftRotate(root); } // RL
    }
    return root;
}
```

Practice - AVL Deletion



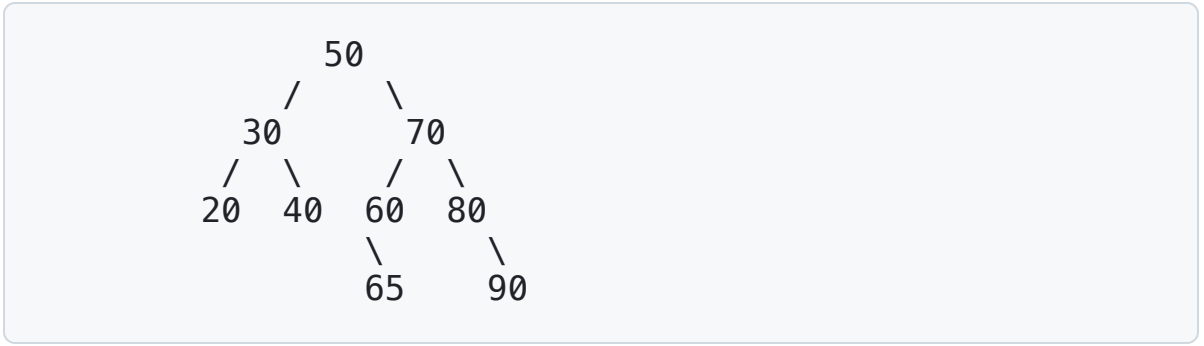
Delete nodes in this order: 10, 20, 30

For each deletion, show the tree and any rotations needed.

Practice - AVL Deletion - Step 1

Delete 10 (leaf node):

After deleting 10:



Check Balance:

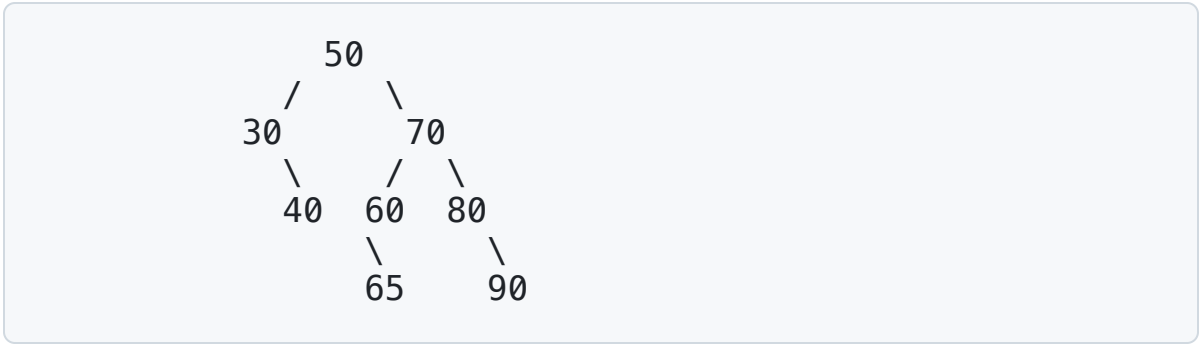
- BF(20) = 0
- BF(30) = 0
- BF(50) = 0

No rotation needed!

Practice - AVL Deletion - Step 2

Delete 20 (leaf node):

After deleting 20:



Check Balance:

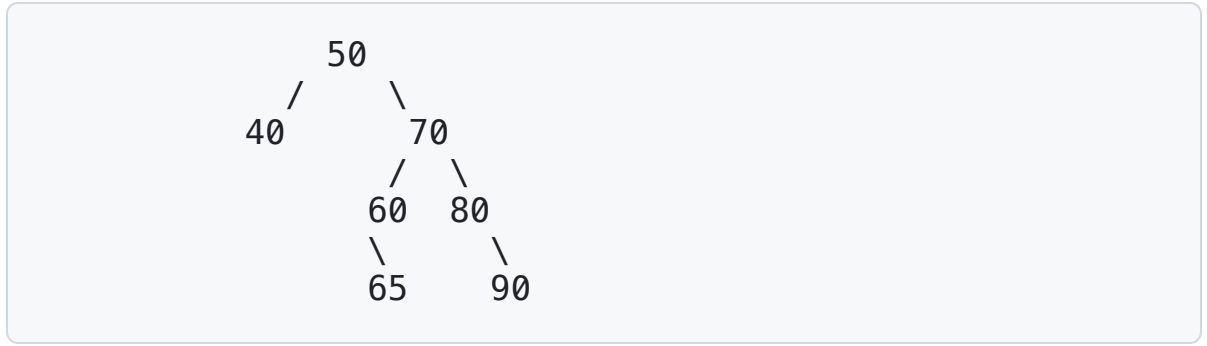
- BF(30) = -1
- BF(50) = 0

Still balanced!

Practice - AVL Deletion - Step 3

Delete 30 (node with one child):

After BST delete (replace with 40):



Check Balance:

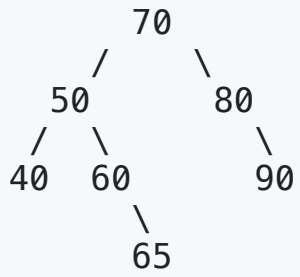
- BF(40) = 0
- BF(50) = -2 **UNBALANCED!**

Right child BF(70) = 0 → RR Case!

Action: Left Rotate(50)

Practice - AVL Deletion - Final Result

After Left Rotate(50):



Verify Balance:

- BF(40) = 0, BF(60) = -1, BF(50) = 0, BF(80) = -1, BF(70) = +1

All balanced

Comparison: AVL vs Regular BST

Feature	Regular BST	AVL Tree
Worst Search	O(n)	O(log n)
Worst Insert	O(n)	O(log n)
Worst Delete	O(n)	O(log n)
Structure	Can be skewed	Always balanced
Overhead	None	Store height/BF
Complexity	Simple	Complex (Rotations)

Verdict: AVL gives strict guarantees at the cost of implementation complexity.

Space Overhead

```
struct BSTNode {
    int data;        // 4 bytes
    BSTNode* left;   // 8 bytes
    BSTNode* right;  // 8 bytes
}; // Total: 20 bytes
```

```
struct AVLNode {
    int data;        // 4 bytes
    AVLNode* left;   // 8 bytes
    AVLNode* right;  // 8 bytes
    int height;      // 4 bytes <-- Overhead
}; // Total: 24 bytes
```

Trade-off: We pay ~20% more memory per node to gain exponential speedup in worst-case scenarios.

Why is Height O(log n)?

The worst-case AVL tree (minimum nodes for height h) occurs when every node has subtrees differing by exactly 1 in height.

$$N_h = N_{h-1} + N_{h-2} + 1$$

This recurrence relation is very close to the **Fibonacci sequence**.

- **Growth:** The number of nodes grows exponentially with height.
- **Inverse:** Therefore, height grows logarithmically with the number of nodes.
- **Exact Bound:** $Height < 1.44 \log_2(n+2)$

Example:
For 1 million nodes, a regular BST could have height 1,000,000. An AVL tree has height at most ~28.

Other Self-Balancing Trees

AVL is not the only self-balancing BST. Other popular ones include:

- **Red-Black Trees** (1972) - Used in `std::map`, `TreeMap`
- **B-Trees** (1970) - Used in databases and file systems
- **Splay Trees** (1985) - Self-adjusting, no extra storage
- **Treaps** (1989) - Randomized BST with heap property

We'll briefly look at **Red-Black Trees** since they're widely used in standard libraries.

Red-Black Trees - Introduction

What is it?

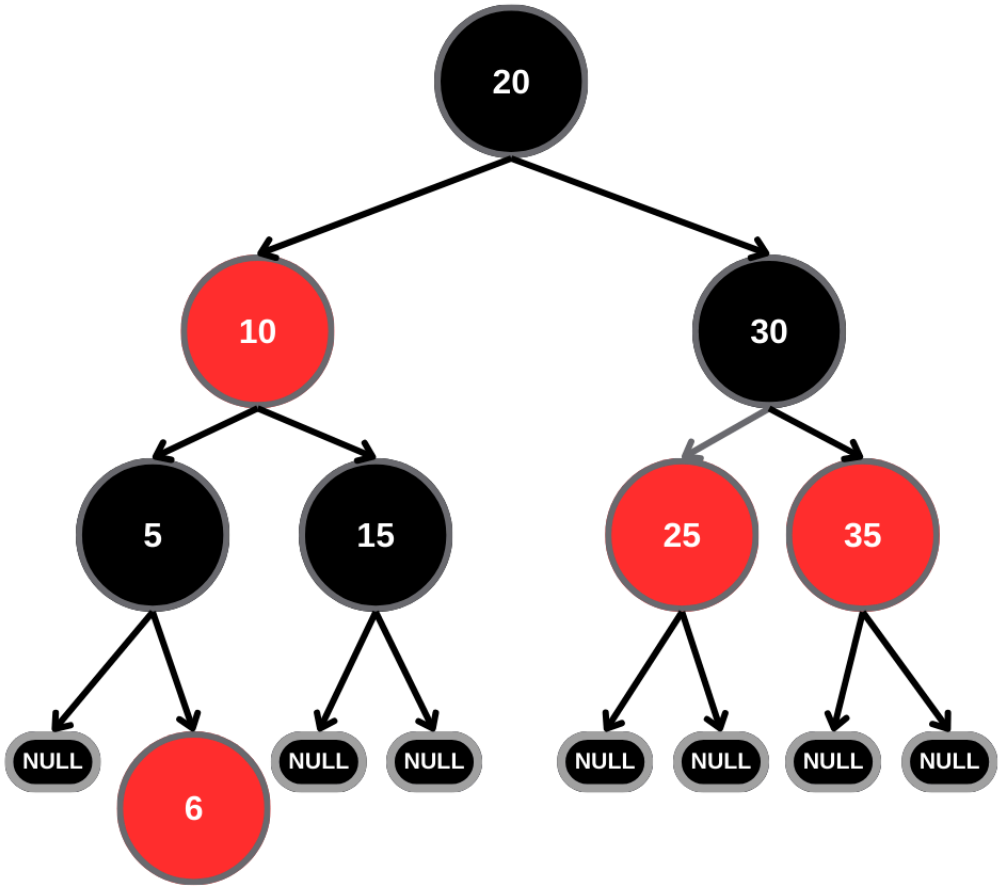
A BST where each node has a **color** (Red or black) and must follow specific rules to stay balanced.

Key Idea

Instead of tracking height like AVL, we use **color constraints** to ensure the tree remains approximately balanced.

- Maintain a slightly looser height invariant than AVL trees. * Because the height of the red-black tree is slightly larger, lookup will be slower in a red-black tree.
- However, the looser height invariant makes insertion and deletion faster.

Guarantee: Longest path is at most **2x** the shortest path.

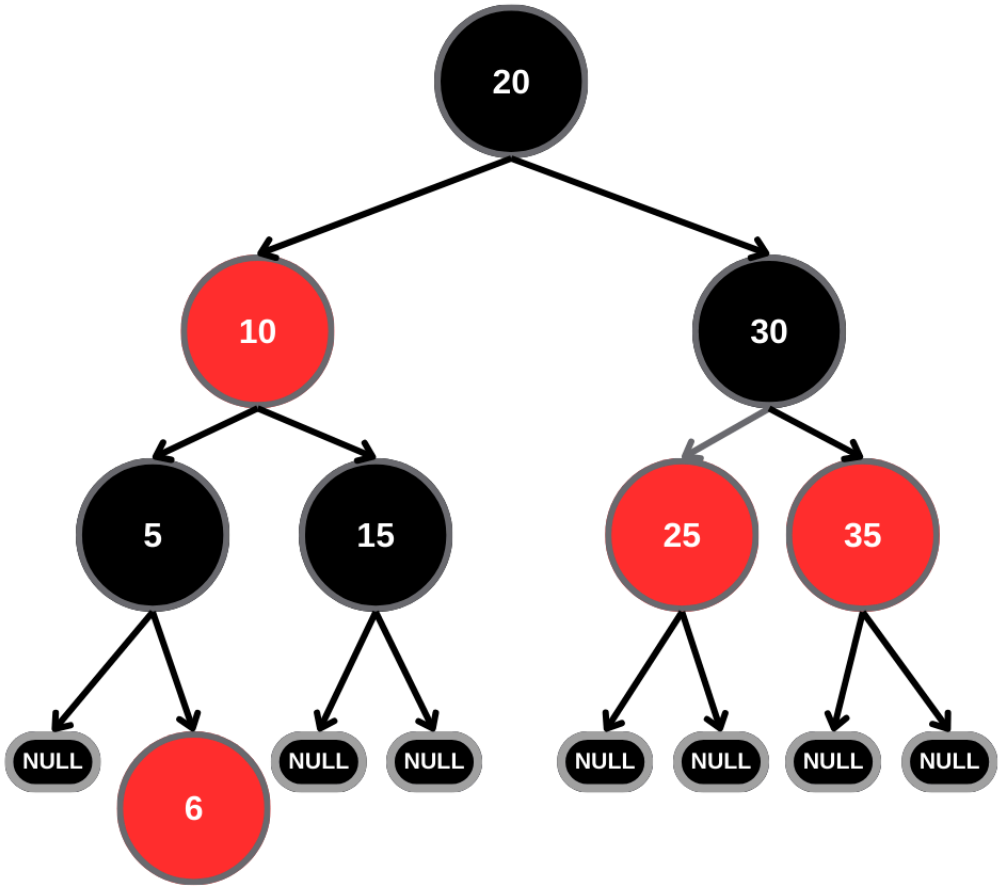


Red-Black Tree Properties

Every Red-Black tree must satisfy these 5 rules:

1. Every node is either **Red** or **Black**
2. The **root** is always **Black**
3. All **NULL leaves** are considered **Black**
4. **Red nodes** cannot have **Red children** (no two reds in a row)
5. Every path from a node to its NULL descendants has the **same number of Black nodes**
6. New nodes are inserted as **red** node

These rules guarantee the tree height is at most **2 × log(n+1)**



AVL vs Red-Black Trees

Both are self-balancing O(log n) trees, but they have different trade-offs:

1. **Strictness:**
   - **AVL:** Very strict ($|BF| \leq 1$). Tree is more compressed.
   - **Red-Black:** Looser balance. Tree can be slightly taller.
2. **Performance:**
   - **AVL:** Faster **Lookups** (shorter height).
   - **Red-Black:** Faster **Insert/Delete** (fewer rotations needed).
3. **Adoption:**
   - **AVL:** Read-heavy systems (Databases).
   - **Red-Black:** General purpose libraries (C++ `std::map`, Java `TreeMap`).

When to Use AVL Trees?

Ideal

- **Read-Heavy Workloads:**
  - You search much more often than you insert/delete.
  - AVL trees are more strictly balanced than Red-Black trees, making lookups slightly faster.
- **Databases:** Indexing records where fast retrieval is critical.
- **Dictionaries:** Spell checkers, symbol tables.

Less Ideal

- **Write-Heavy Workloads:**
  - Frequent insertions/deletions trigger many rotations.
  - Red-Black trees might be preferred here (fewer rotations).

Practice - Real World Scenario

You're designing a phone contact list with these requirements:

- ~1000 contacts
- Search by name
- Add new contacts
- Delete contacts

Questions:

1. Would you use a regular BST or AVL tree? Why?
2. What's the worst-case search time with each?
3. What's the trade-off you're making?

Answer

Recommendation: AVL Tree

Why?

- Read-heavy workload (searches >> writes)
- Need guaranteed fast lookups
- Small overhead for ~1000 nodes

Comparison:

Metric	BST (Worst)	AVL
Search	O(1000)	O(10)
Insert	O(1000)	O(10)
Memory/node	20 bytes	24 bytes
Total memory	20 KB	24 KB

4 KB extra memory for 100x faster worst-case!

Summary - Key Takeaways

1. **Self-Balancing:** AVL trees automatically keep height at O(log n).
2. **Balance Factor:** `Height(L) - Height(R)` must be {-1, 0, 1}.
3. **Rotations:** The mechanism to fix imbalance.
    - Single (LL, RR)
    - Double (LR, RL)
4. **Performance:** Guaranteed O(log n) for all basic operations.

Thank You!

Contact Information

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- **Office Hours:** Tuesday 14:00-16:00 - Room F-B21
- **Course Repo:** GitHub Link

Next Class

- **Topic:** Heap Data Structure (Priority Queues)
- **Reading:** Weiss Ch.6