

# COMP20007 Workshop Week 9

## Preparation:

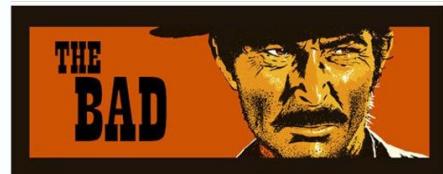
- have *draft papers and pen ready*
- open `wokshop9.pdf` (from LMS), and

- 1 Why BST, AVL, 2-3 Tree?
  - 2 BST: Rotation, Balance factor: Problems 1, 2
  - 3 AVL Tree: Concepts, Insertion (Problem 3)
  - 4 2-3 Tree: Concepts, Insertion (Problem 4)
  - 5 B-tree?
- LAB BST: insertion & level traversal (optional)  
2-3-4 Tree: insertion & level traversal (optional)  
Questions for previous week materials

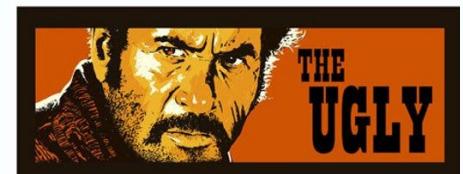
# BST efficiency depends on the order of input data



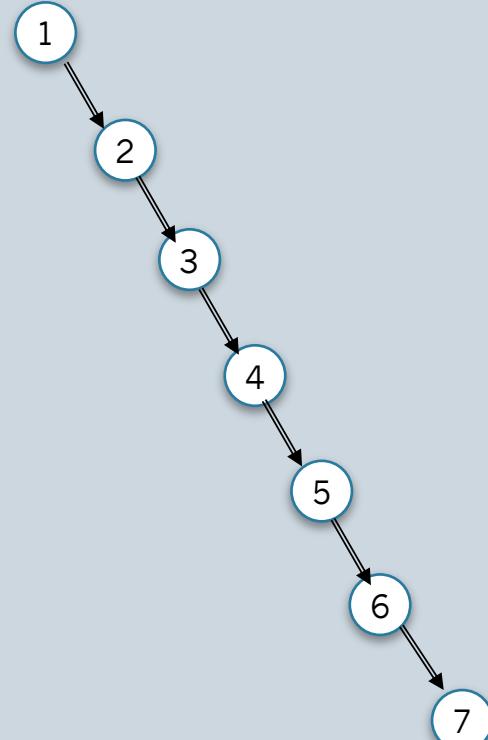
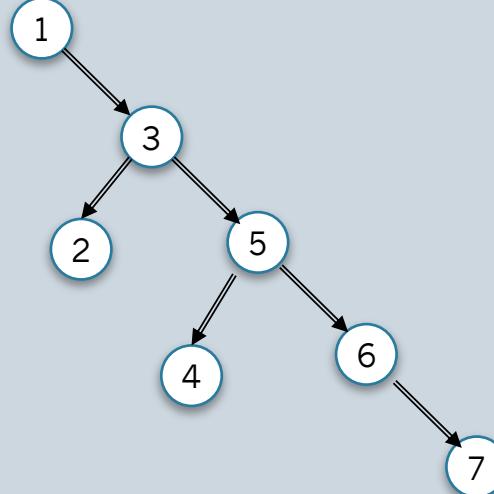
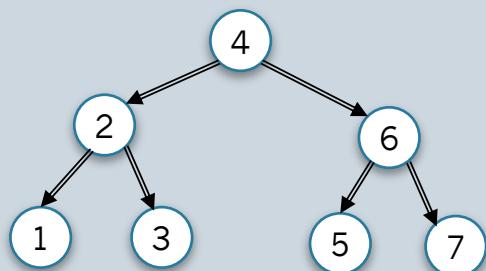
4 6 2 1 3 7 5



1 3 5 2 4 6 7



1 2 3 4 5 6 7



Want *The Good*, no matter what's the data input order? Use AVL or 2-3 Trees

Good-Bad-Ugly Picture Source: <https://www.pinterest.com.au/pin/170573904624610413/> Anh Vo 7 May 2021

## BST → AVL Tree, 2-3 Tree

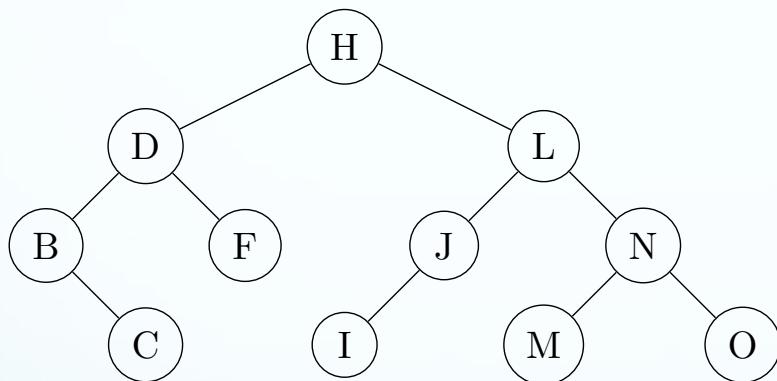
- AVL=? – just a balanced BST
- How: re-balance BST when it becomes unbalanced
- As opposed to 2-3 Trees:
  - 2-3 Tree is a search tree, but not a binary tree
  - 2-3 Tree is self-balancing tree [no re-balancing needed]

# Using Rotations to rebalance AVL

- *At the start:* an empty BST is an AVL
- *Problem:* After a insertion/deletion, the resulted tree might become unbalanced
- *Approach:* use Rotations to rebalance.
- To rotate:  
When? What? How?

# AVL: How to re-balance an un-balanced BST? use *rotation*

**Problem 2:** A node's '*balance factor*' is defined as the height of its right subtree minus the height of its left subtree. Calculate the balance factor of each node in the following binary search tree.



Note on balance factor (BF) definition

- Popular (as in lectures):  
 $BF = \text{height}(T.\text{left}) - \text{height}(T.\text{right})$
- Option 2:  
 $\text{height}(T.\text{right}) - \text{height}(T.\text{left})$
- Option 3:  
absolute value of the height difference

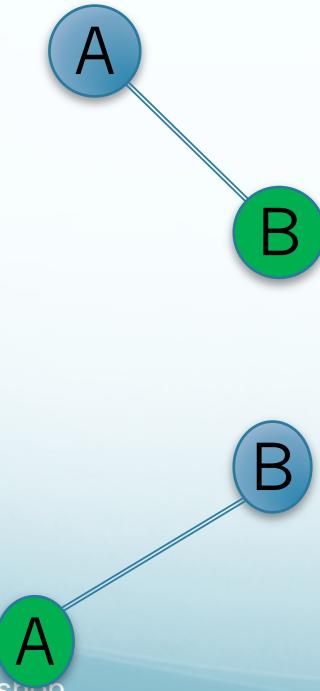
Any of them is OK, but needs **consistency!**

*Balanced tree* = when the balance factor of each node is 0, -1, or +1

= for each node, the difference of subtree heights is at most 1

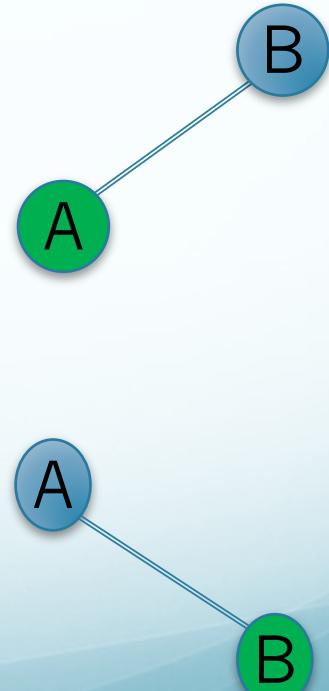
# BST: what's a rotation

- For each simple tree A **rotation** reverses the parent-child relationship of 2 connected nodes
- left rotation**: rotate **parent** to the left (to become the **left child**)
- right rotation**: rotate **parent** to the right (to become the **right child**)



Rotate A to the left

*can rotate(A, right)?  
why?*



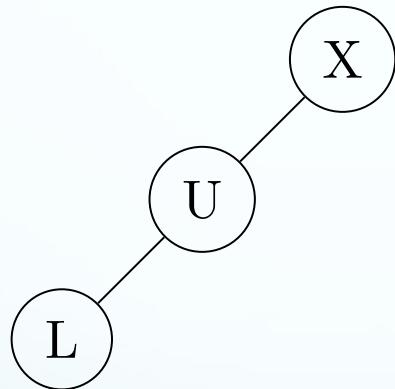
Rotate B to the right

*can rotate(B, left)?  
why?*

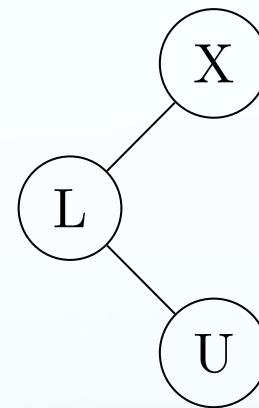
# Problem 1 [class]: Rotation

In the following binary trees, rotate the 'X' node to the right (that is, rotate it and its left child). Do these rotations improve the overall balance of the tree?

(c)



(b)

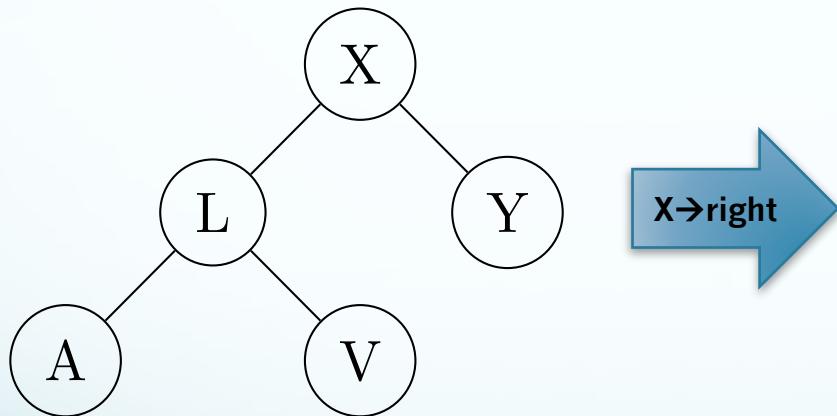


Recall: Only 2 types of rotations: *Right Rotation* (a node and its left child), and *Left Rotation* ( a node and its right child)

# Problem 1 [class]: Rotation

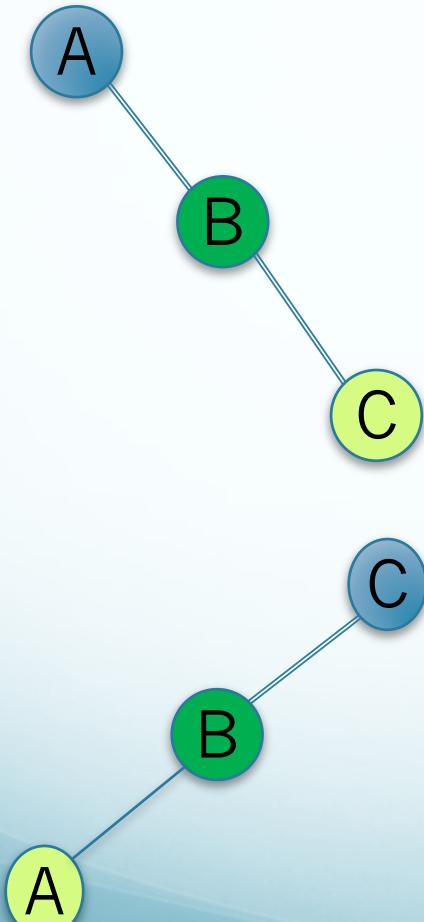
In the following binary trees, rotate the 'X' node to the right (that is, rotate it and its left child). Do these rotations improve the overall balance of the tree?

(a)



## AVL: Two Basic Rotations: 1) Single Rotation

Applied when an AVL (subtree) is a "stick":



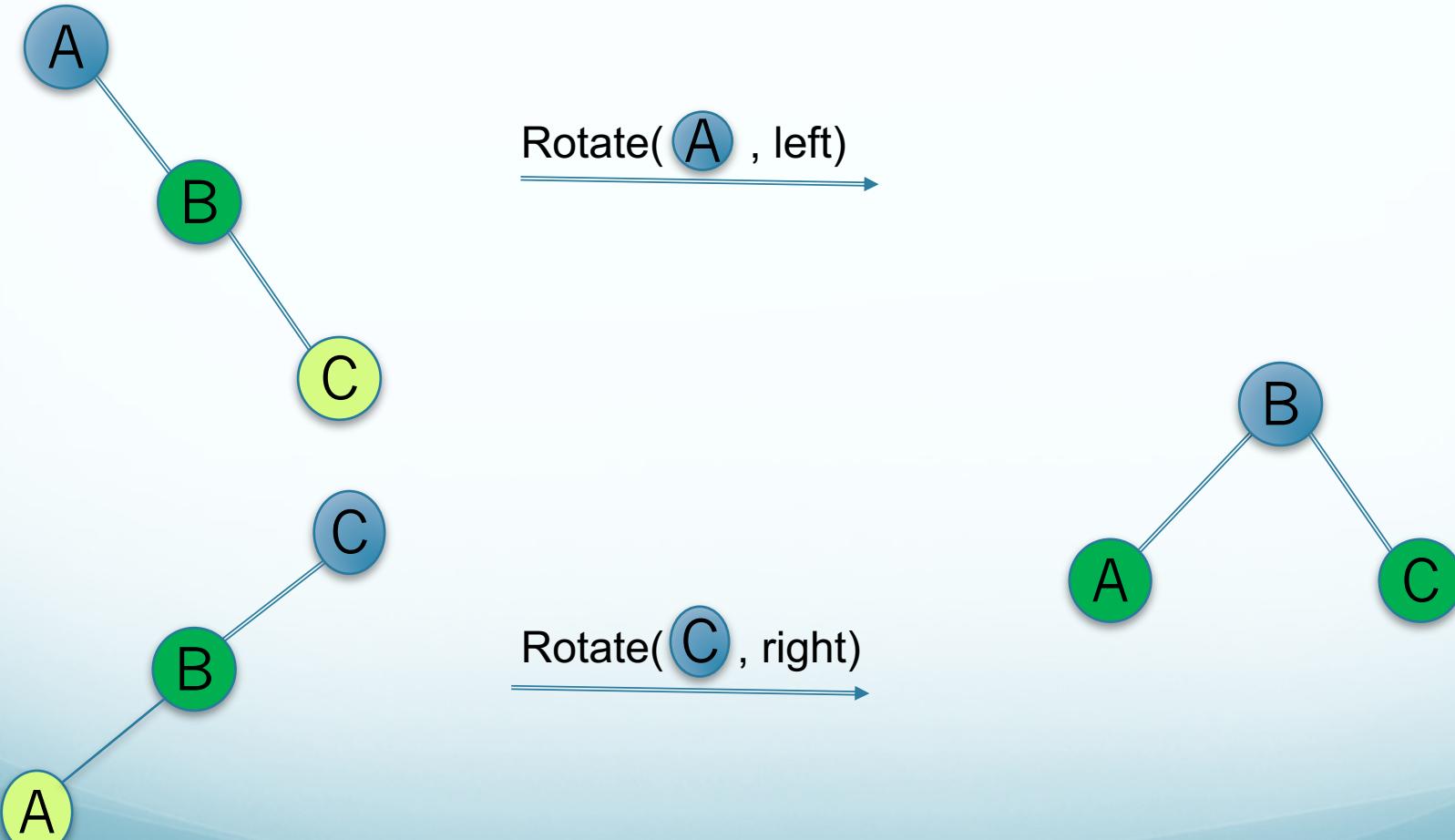
*Questions we  
should ask  
ourselves:*

- Which node (or subtree) is unbalanced?
- Which rotation can be done?

HERE:  
→ Rotate the root  
and hence  
balance the stick

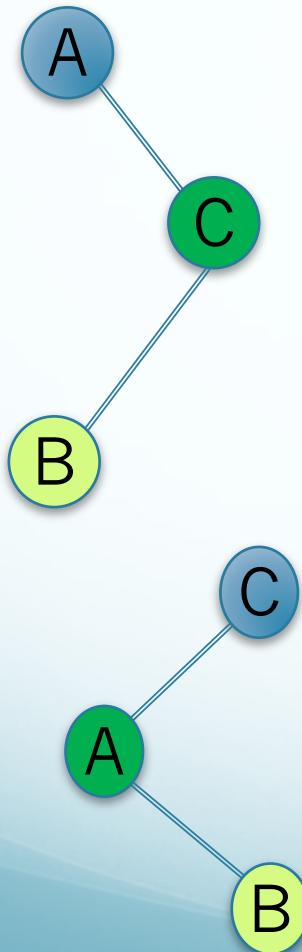
## AVL: Two Basic Rotations: 1) Single Rotation

Applied when an AVL (subtree) is a "stick":



## AVL: Two Basic Rotations: 2) Double Rotation

Applied when an AVL (subtree) is not a “stick”:



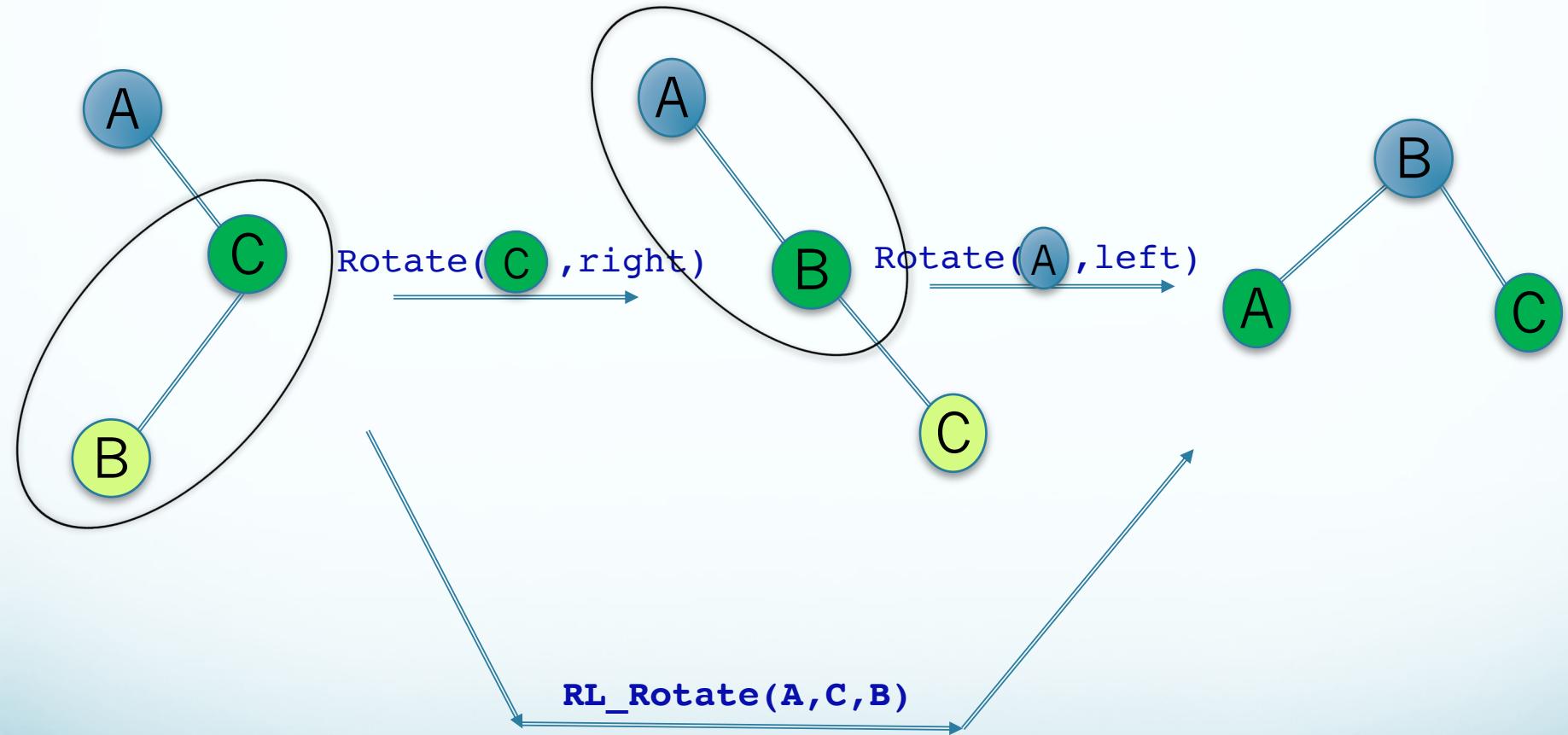
*Rotation1:*

- Rotate the **child** of the **unbalanced root** and turn the tree to a stick

*Rotation2:*

- Rotate the **root** of the stick.

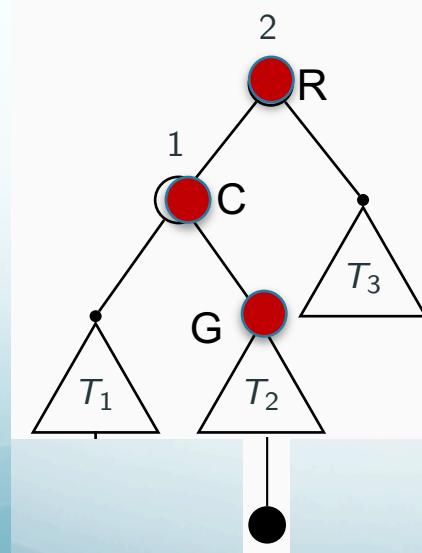
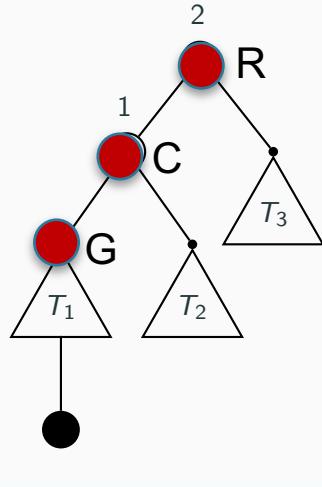
## 2) Double Rotation Example: RL rotation



Do it Yourself: Perform `LR_Rotate(C, A, B)` for the other case of the previous page

# AVL: Using Rotations to rebalance AVL

- Problem: When inserting/deleting node, AVL might become unbalanced
- Approach: Rotations (Rotate WHAT?, and HOW?)
- Rotate WHAT?
  - Walk up, find the *lowest* subtree R which is unbalanced
- HOW
  - Consider *the first 3 nodes* R→C→G in the path from root R to the just-inserted node
  - Apply a single rotations if that path is a stick, double rotation otherwise



# AVL Tree Insertion

Insert the following keys into an initially-empty AVL Tree.

*Class example:*

20 10 5 15 30 17 8 2 12 4

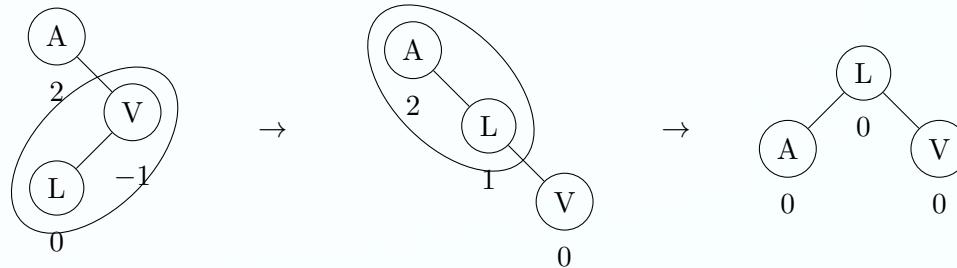
**Problem 3 [group/individual]:**

A V L T R E X M P

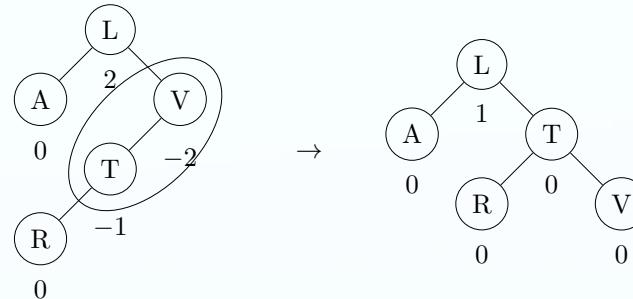
# Problem 3: Check your solution

Insert the following letters into an initially-empty AVL Tree: A V L T R E X M P

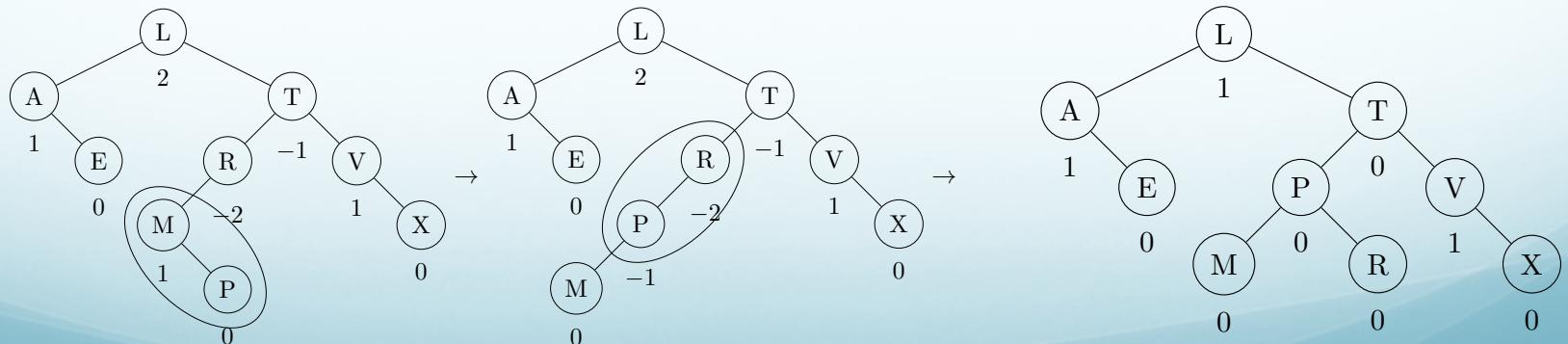
after A V L:



after T R:

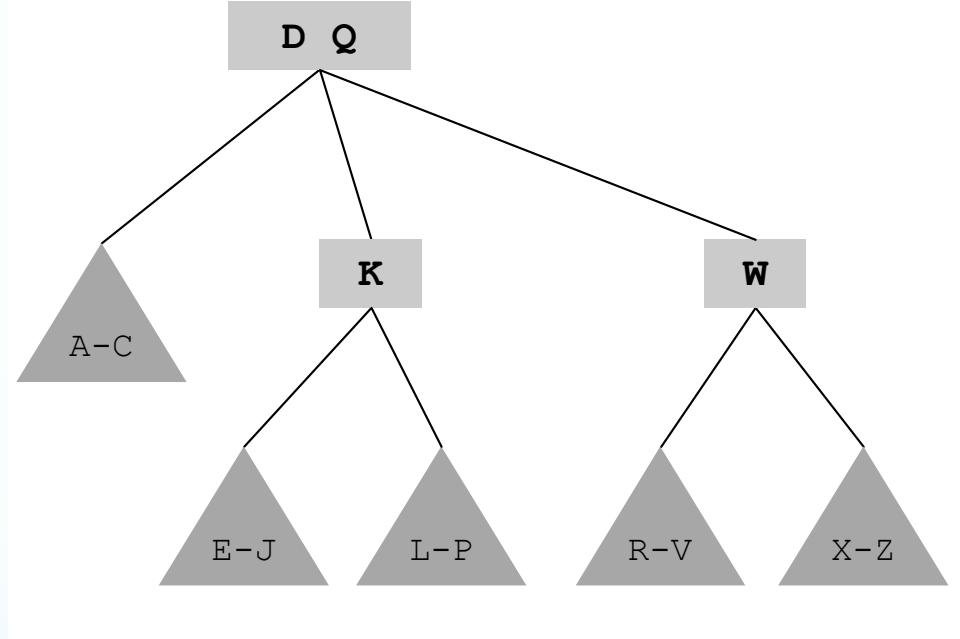


after R E X M P



# 2-3 Trees: What? What Special?

- *What?* It's a search tree, but not a binary! Each node might have 1 or 2 data, and hence 2 or 3 children.



- Always insert to a leaf node!

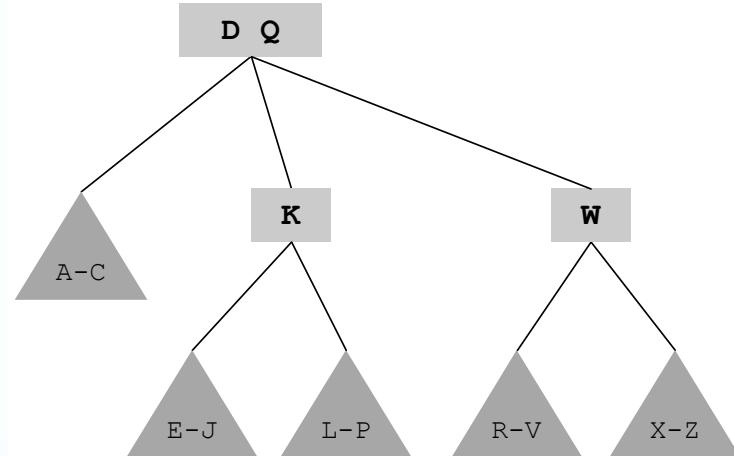
Image Source:

COMP20007.Worshop

Anh Vo 7 May 2021

# 2-3 Trees

- *What?* It's a search tree, but not a binary! Each node might have 1 or 2 data, and hence 2 or 3 children.



- How to insert:
  - start from root, go down and **insert to a leaf**
  - if the new leaf has  $\leq 2$  data, it's ok
  - if the new leaf has 3 data: promote the median data to the parent (the promoting might continue upward)

Image Source:

## 2-3 Tree Insertion

Insert the following keys into an initially-empty 2-3 Tree.

*Class example:*

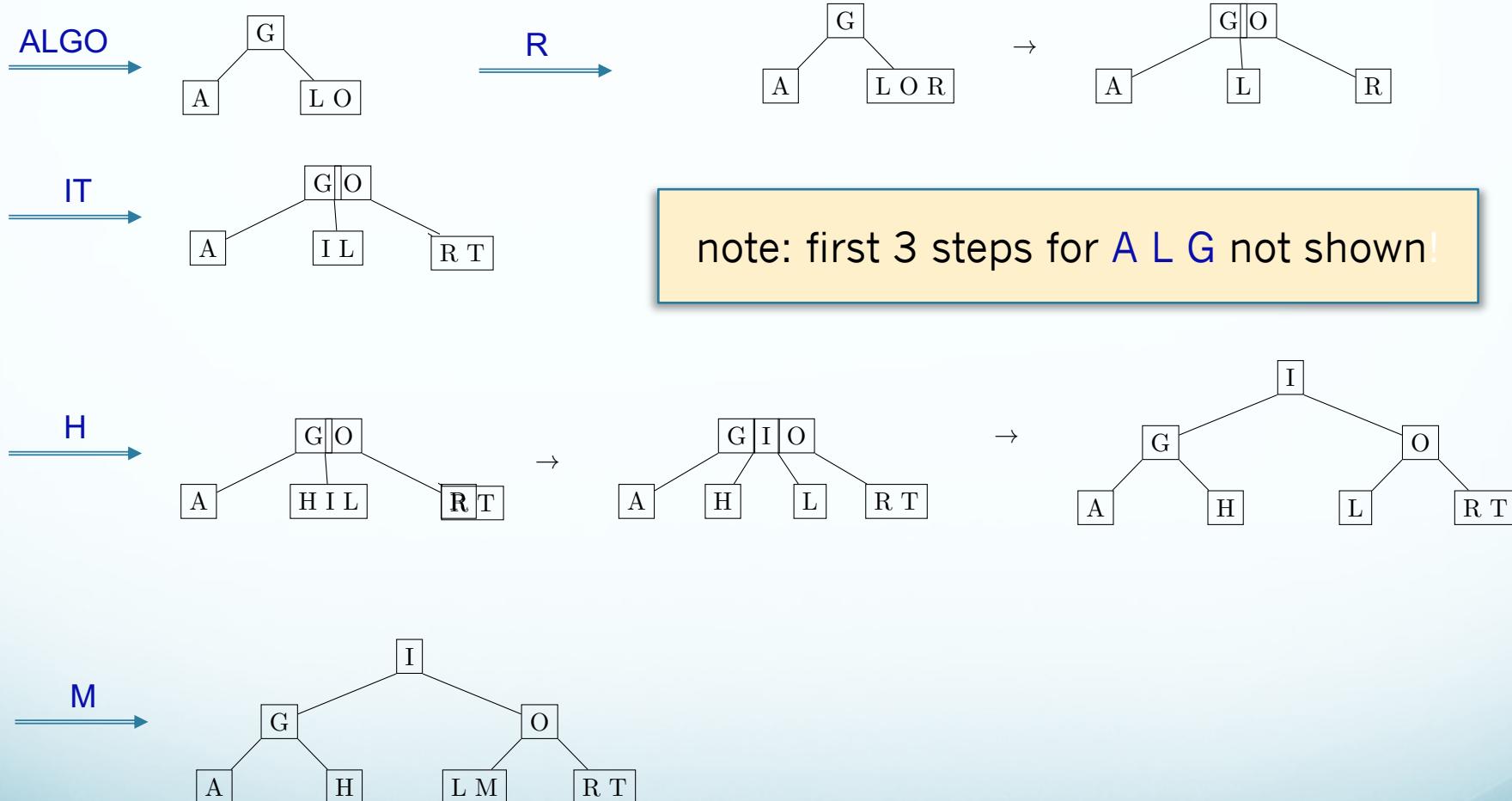
20 10 5 15 30 17 8 2 12 4

**Problem 4:**

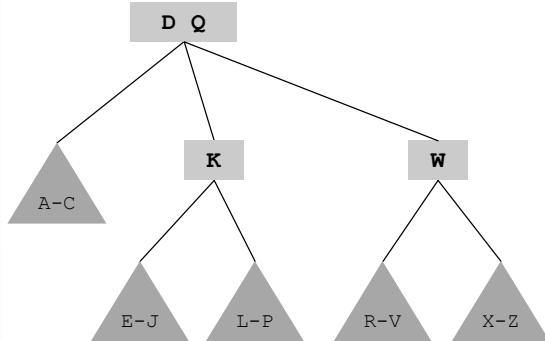
A L G O R I T H M

## Problem 4: Check your solution

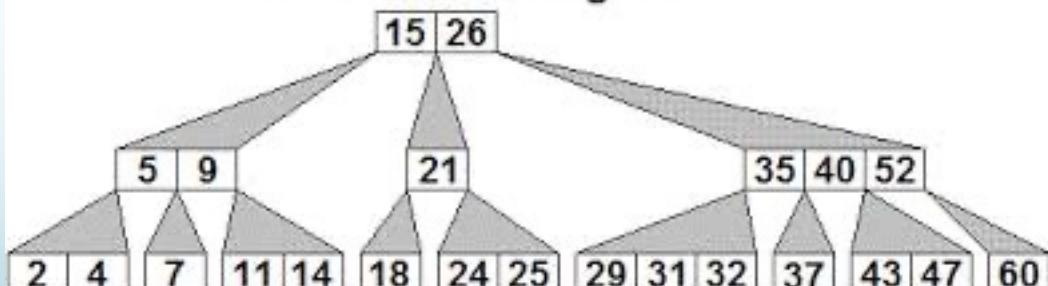
Insert the following keys into an initially-empty 2-3 Tree: A L G O R I T H M



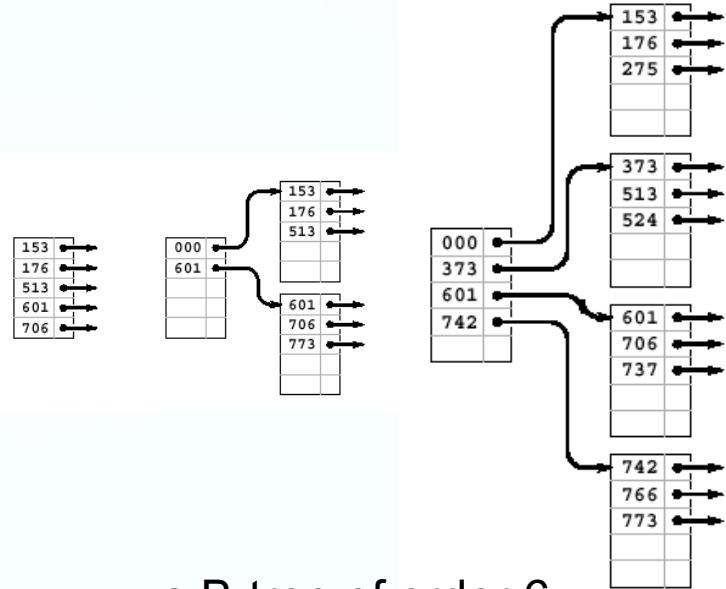
## 2-3 Trees, 2-3-4 Trees, B-Tree



2-3 trees= B-trees of order 3  
(order= max number of children)



2-3-4 trees= B-trees of order 4



a B-tree of order 6

### B-tree principles

- Always insert at leaves
- When a node full: promote the median data to the node's parent [and walk up further if needed]

Image sources: ?? and <http://anh.cs.luc.edu/363/notes/06DynamicDataStructures.html>

# Lab

- Q&A on previous week materials, and/or
- [Optional] Implement BST: insert, build tree from data, printing the tree. Note:
  - Build your program from scratch
  - But you can use last week list and queue modules
- And/or: [Optional] Implement 2-3-4 Tree with the above operations
- For easy printing of trees, first build a complete tree using data:

50 30 80 20 40 60 90 15 25 35 45 55 65

## Simple defs for binary trees

```
typedef struct treenode *tree_t;
struct treenode {
    int key;
    tree_t left, right;
} ;
tree_t insert(tree_t t, int key);
//OR
void insert(tree_t *t, int key);
```

## Example of creating a tree

```
tree_t t= NULL;
// equivalent to: insert 50 to empty tree t
t= malloc(sizeof(*t));
assert(t);
t->left= t->right= NULL;
t->data= 50;

// insert 10 to tree t
t= insert(t, 10); //OR
insert(&t, 10);
// depending on insert header
```