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COMP90038 Algorithms and Complexity

Lecture 12: Mo https://eduassistpro.github.io/ quer Algorithms

(with thanks to Hara ergaard)

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DMD 8.17 (Level 8, Doug McDonell Bldg)

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Divide and Conquer

- In the last lecture we studied the archetypal divide-and-conquer sorting algorithms: mergesort and quicksort.

- We also introduced the powerful **master theorem**, providing solution of recurrence relations, for free.

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  - allows us to quickly determine the complexity of these divide-and-conquer algorithms

- Now we shall look at tree traversal, and then a final example of divide-and-conquer, giving a better solution to the closest-pair problem.

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Binary Trees

- An example of a **binary tree**, with empty subtrees marked as □

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- This tree has **height** 4, the empty tree having height -1

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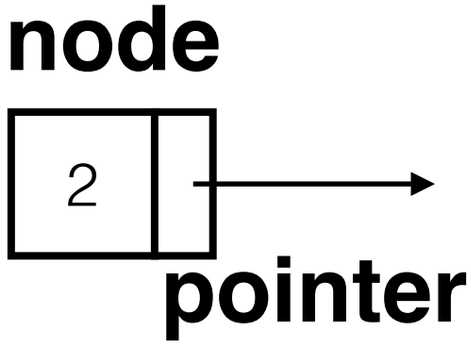
Review of Linked List Terminology



(in Java: “reference”)

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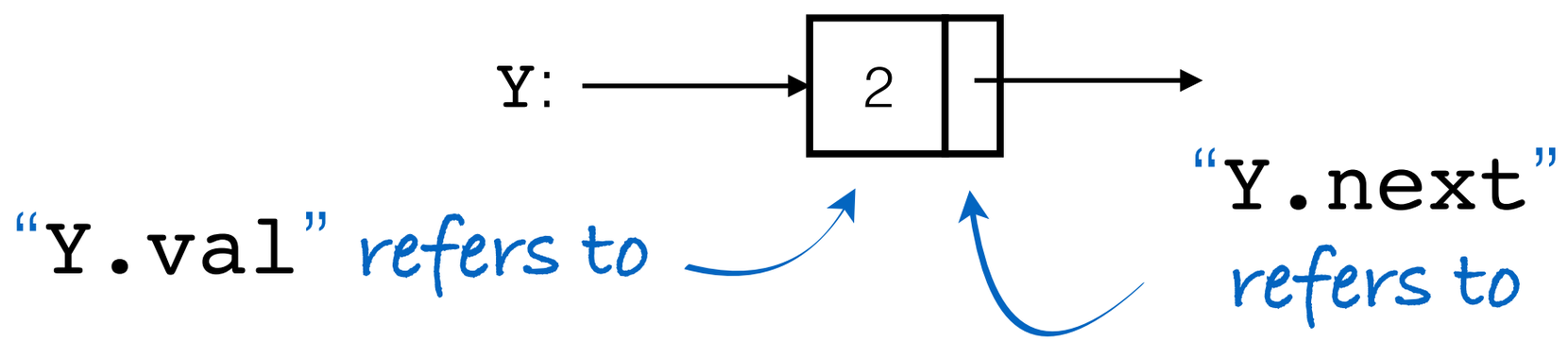
`x` is (a pointer to) the **head node** of the list



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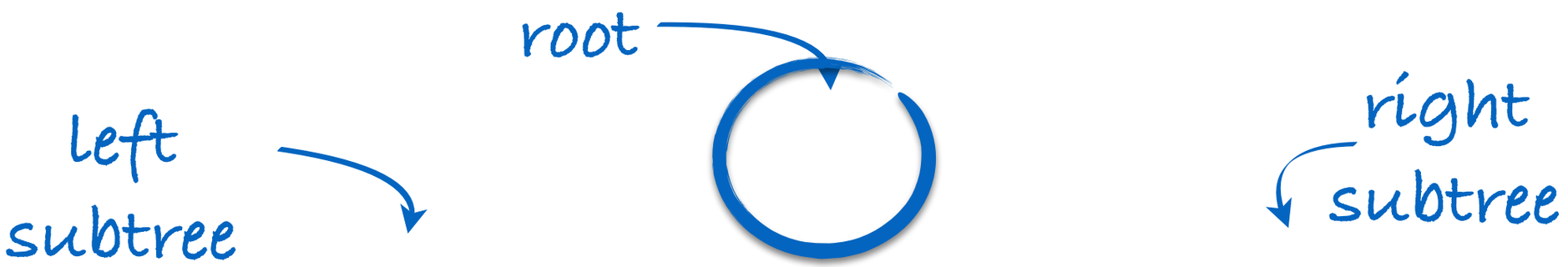
Tree Terminology



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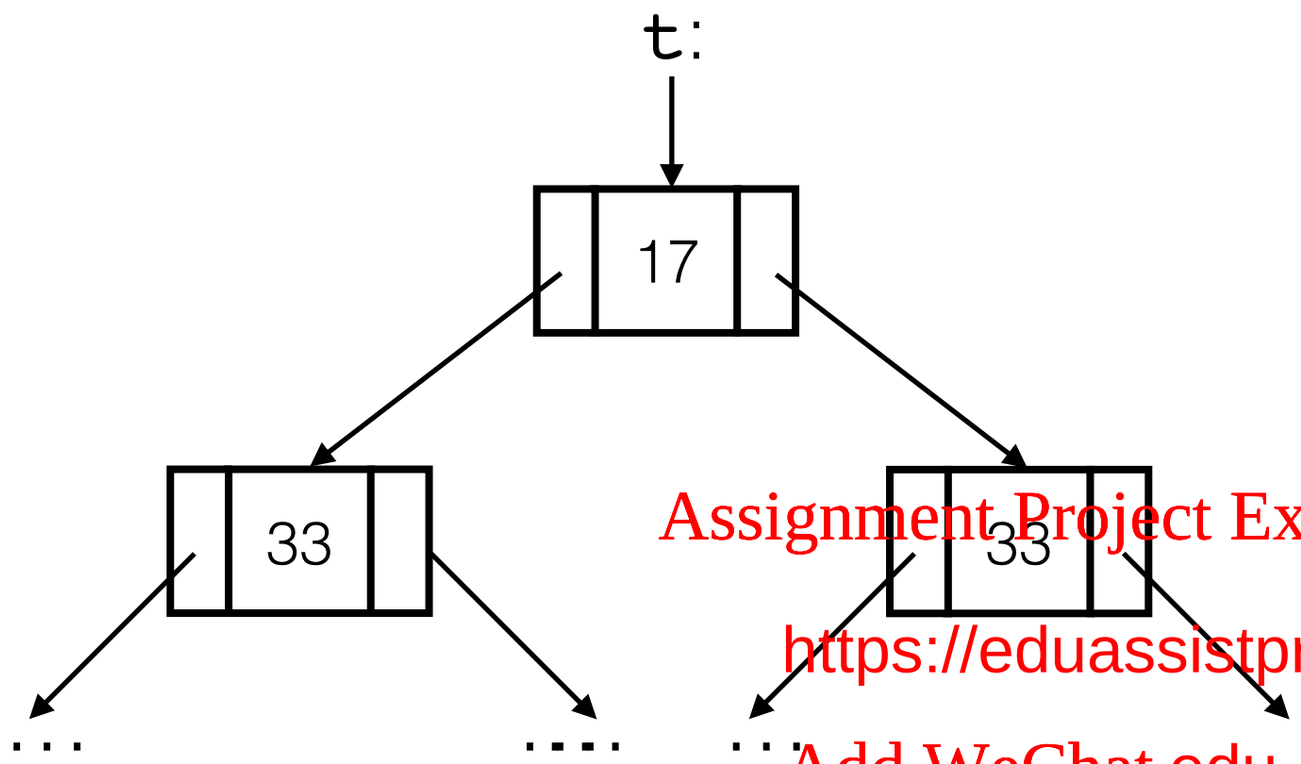
Tree Terminology



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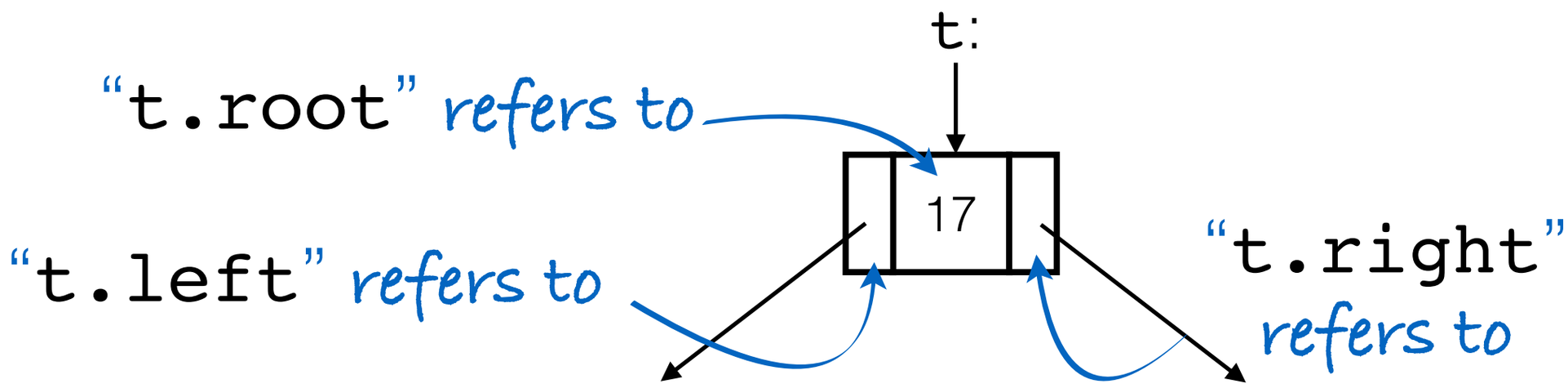
`t` is (a pointer to) the **root node** of the tree



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Binary Trees

- An example of a **binary tree**, with empty subtrees marked as □

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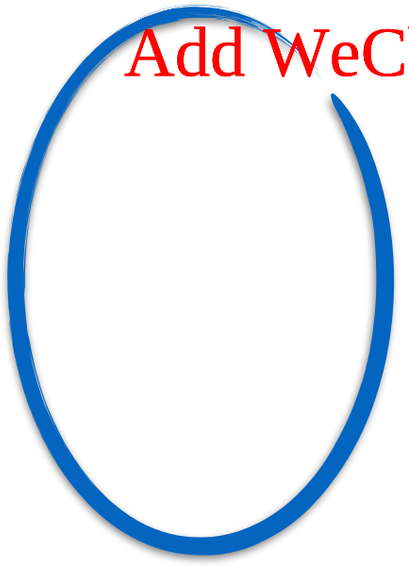

- This tree has **height** 4, the empty tree having height -1

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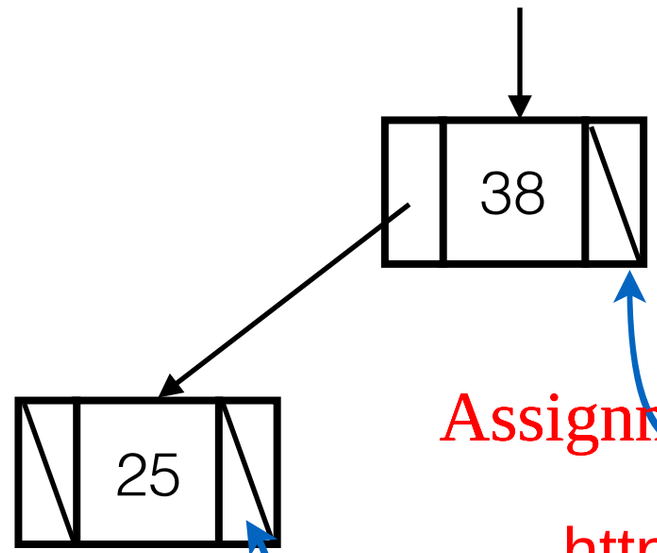
Empty Nodes



empty trees are just null pointers

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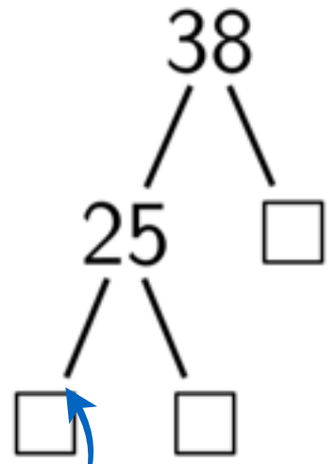

null pointer

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Levels and Height

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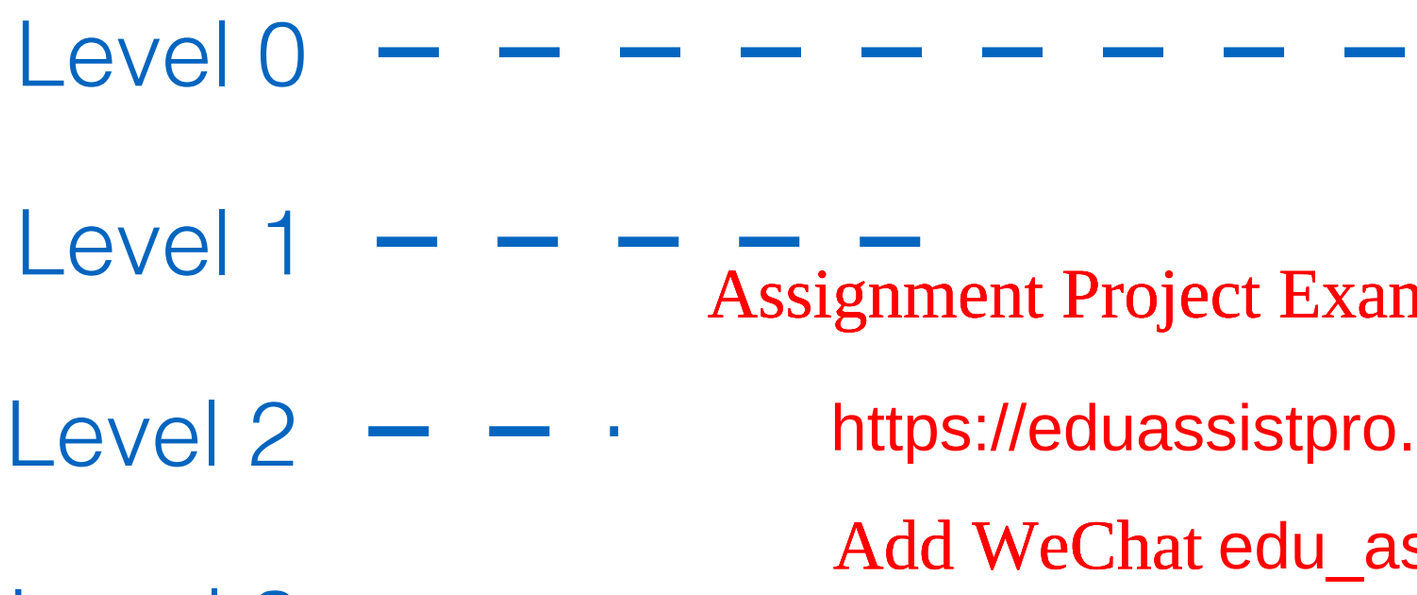

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So the tree has **height** 4 (its **maximum level**)

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Binary Tree Concepts

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- Special trees have their **external nodes** □ only at level *h* and *h*+1 for some *h*:

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A **full** binary tree:
Each node has 0 or 2 (non-empty) children.

A **complete** tree: Each level filled left to right.
(Every level except perhaps the last is completely filled.)

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Calculating the Height

- Recursion is the natural way of calculating the **height**:

T:
↓

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Height Complexity

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- Input size: number *n* of (internal) nodes (e.g. for T *n* is 13)
- Number of external nodes **always** *n*+1 (e.g. for T *x* is 14)
- The function HEIGHT makes one tree comparison (is T null/ empty?) per node (internal and external), so altogether 2n + 1 comparisons.

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Binary Tree Traversal

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- **Preorder** traversal visits the root, then the left subtree, and finally the right subtree.

- **Inorder** traversal visits the left subtree, then the root, and finally t

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- **Postorder** traversal visits t ubtree, the right subtree, and finally the root.

- **Level-order** traversal visits the nodes, level by level, starting from the root.

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Preorder Traversal

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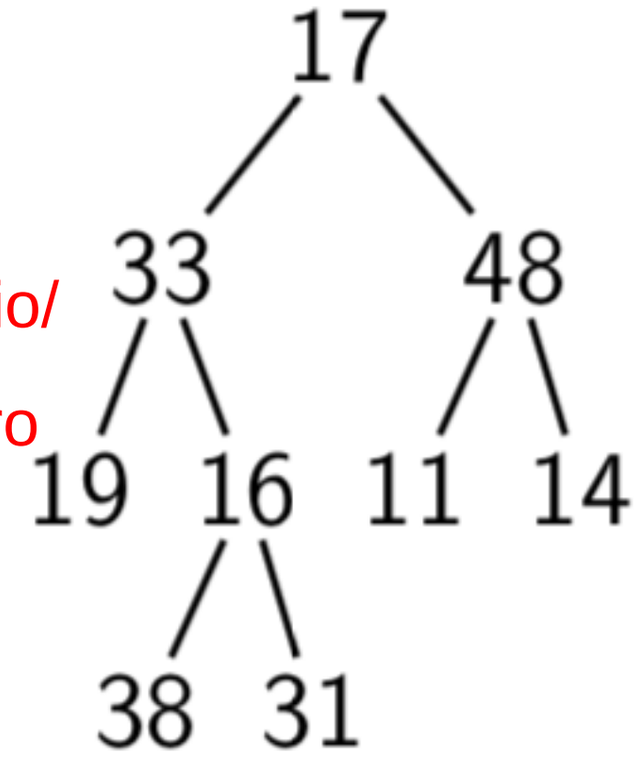

PREORDERTRAVERSE(17)

Call Stack

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Preorder Traversal

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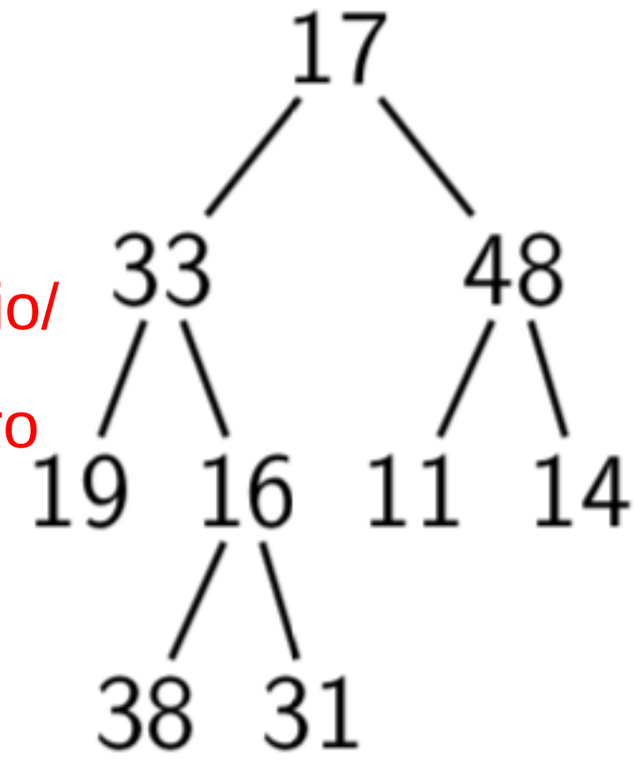

PREORDERTRAVERSE(17)

Call Stack

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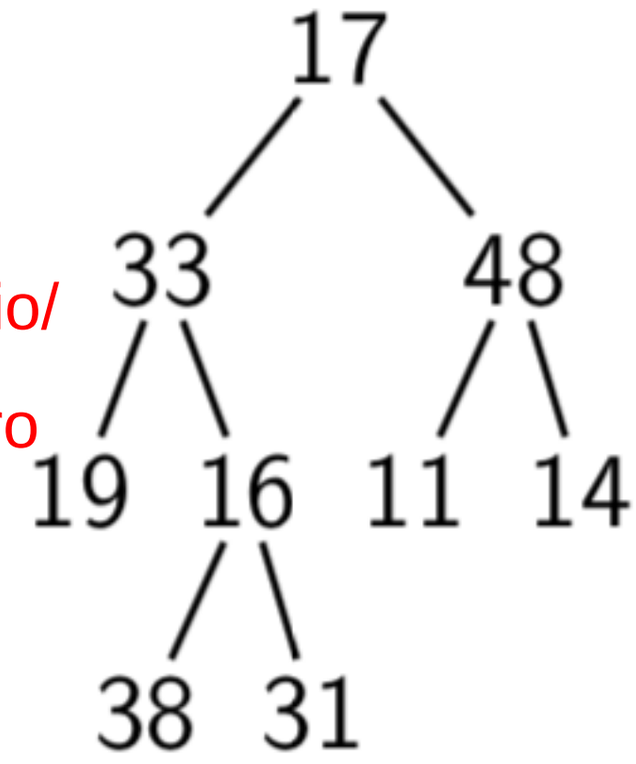

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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Preorder Traversal

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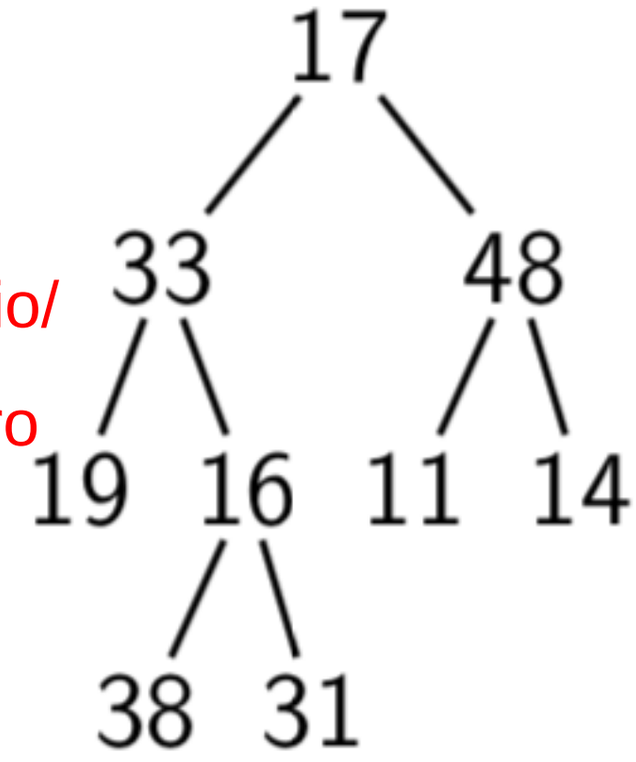

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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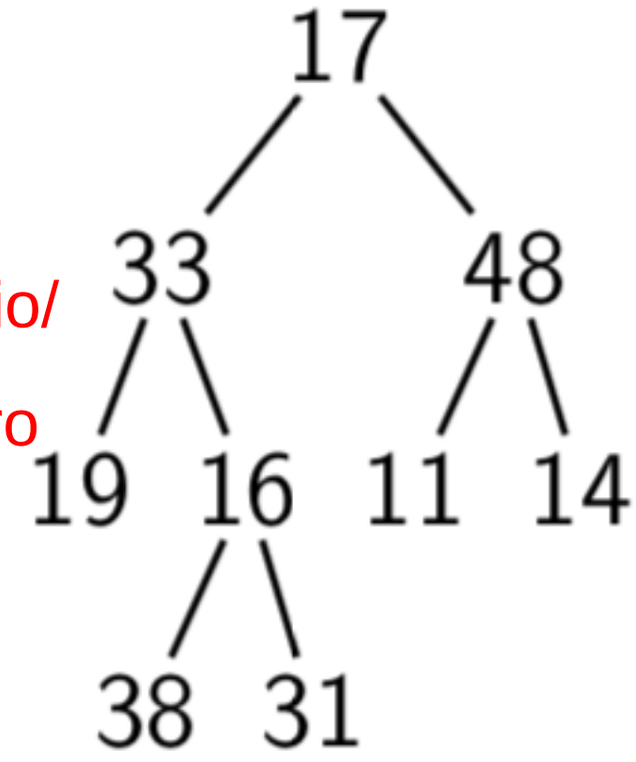

PREORDERTRAVERSE(19)
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PREORDERTRAVERSE(17)

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Preorder Traversal

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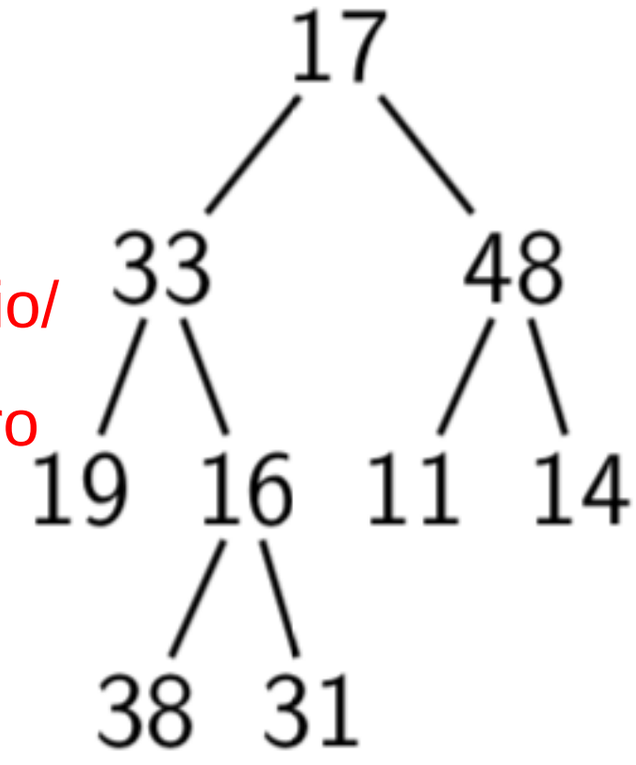

PREORDERTRAVERSE(19)
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PREORDERTRAVERSE(17)

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Preorder Traversal

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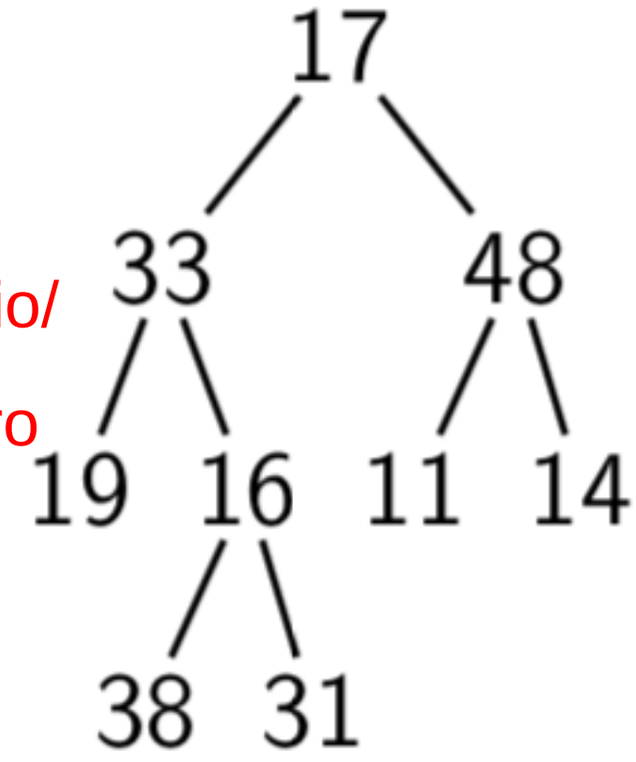

PREORDERTRAVERSE(null)

PREORDERTRAVERSE(19)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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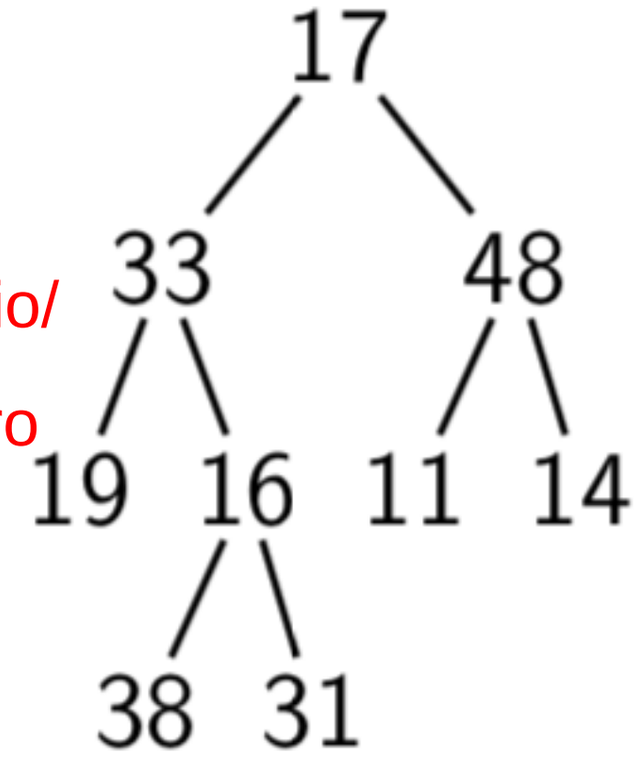

PREORDERTRAVERSE(19)
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Call Stack

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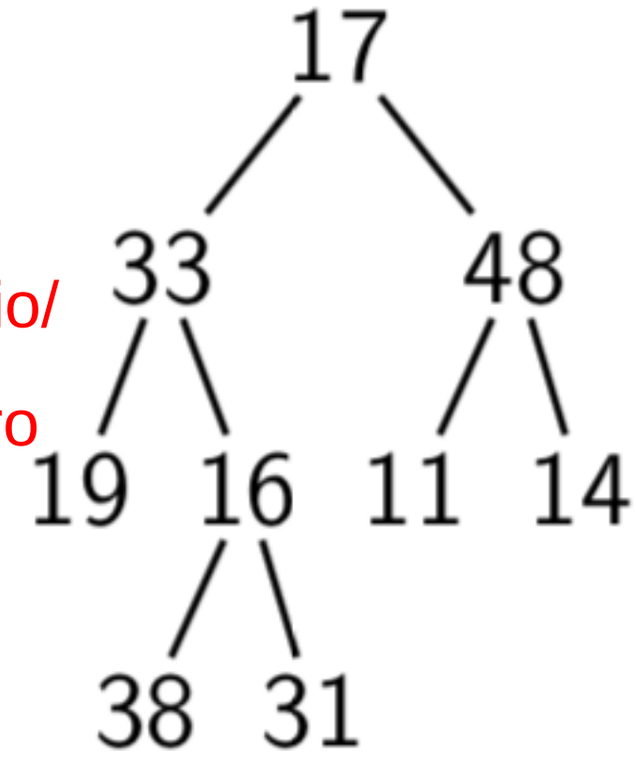

PREORDERTRAVERSE(null)

PREORDERTRAVERSE(19)

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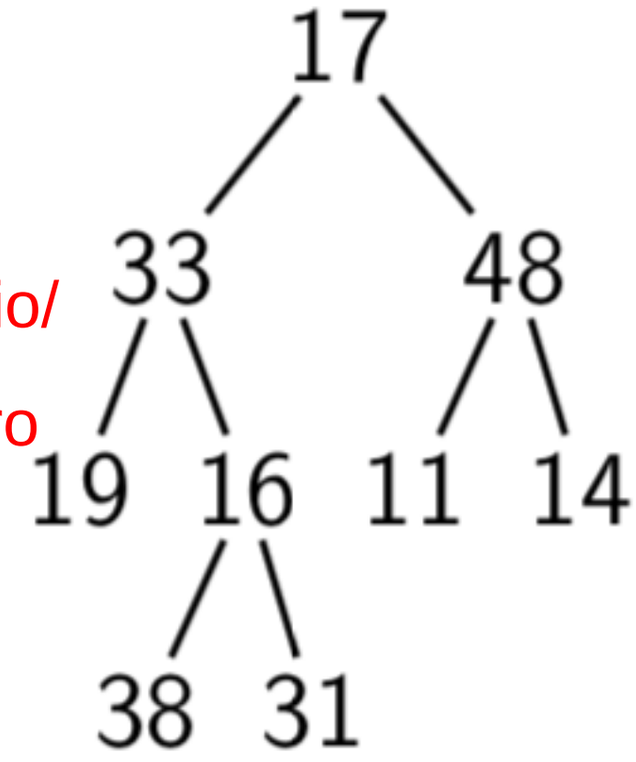

PREORDERTRAVERSE(19)
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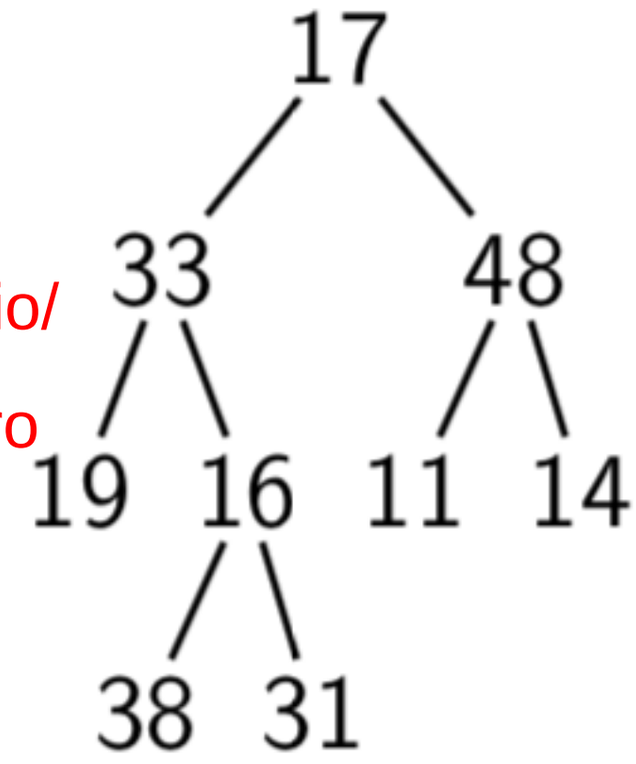

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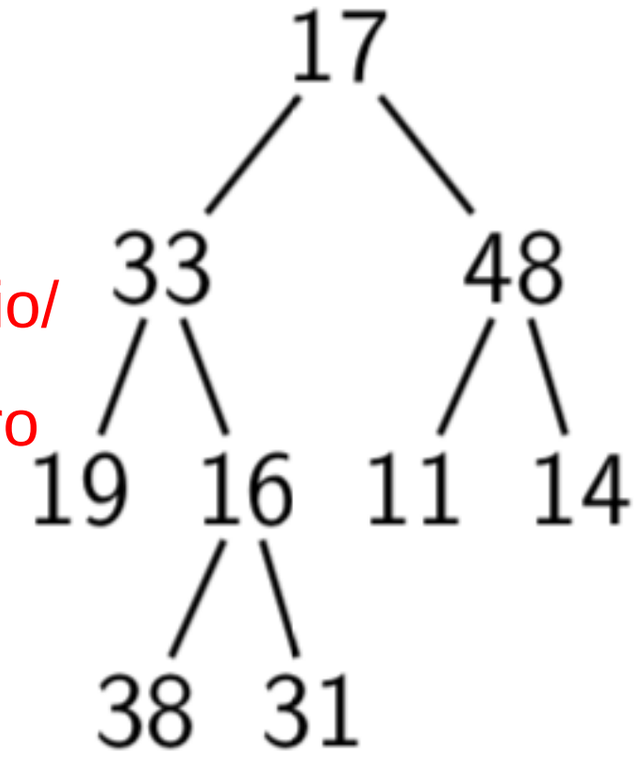

PREORDERTRAVERSE(16)

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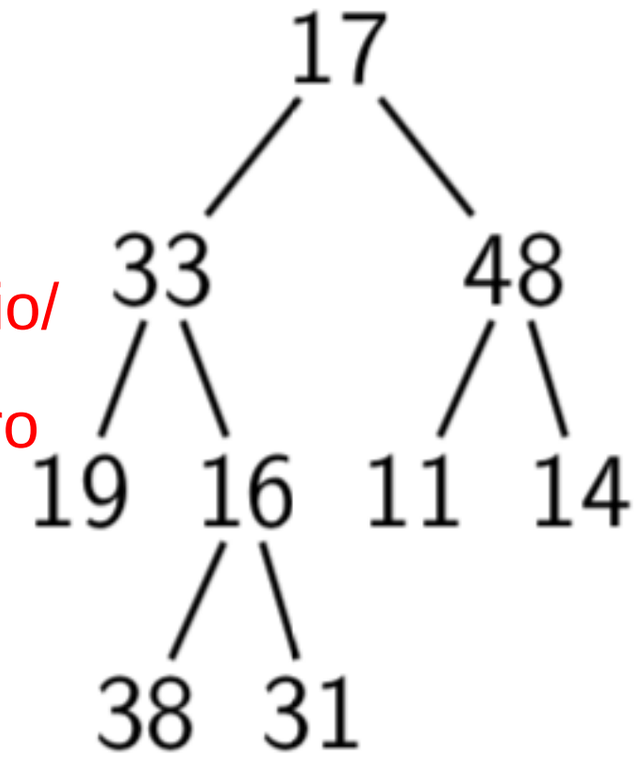

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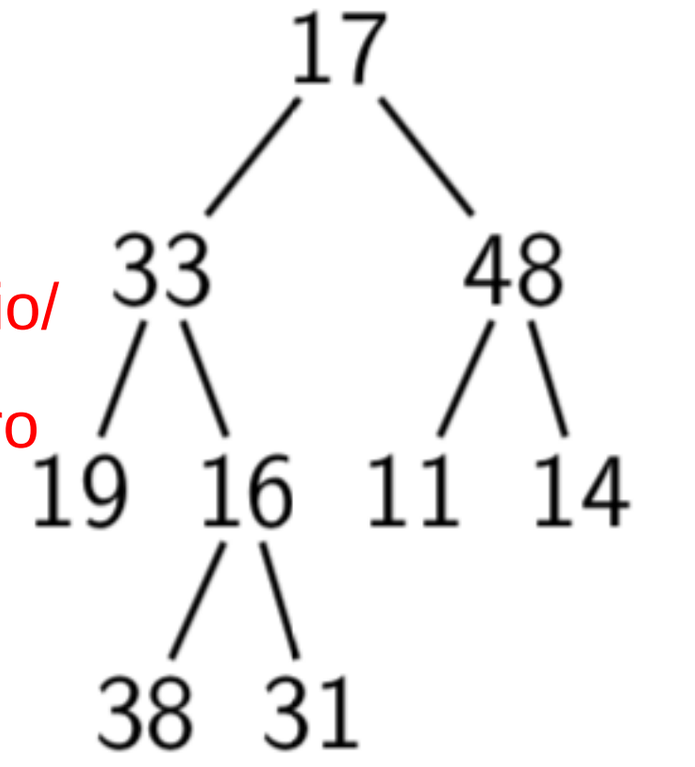

PREORDERTRAVERSE(38)

PREORDERTRAVERSE(16)

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PREORDERTRAVERSE(17)

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Preorder Traversal

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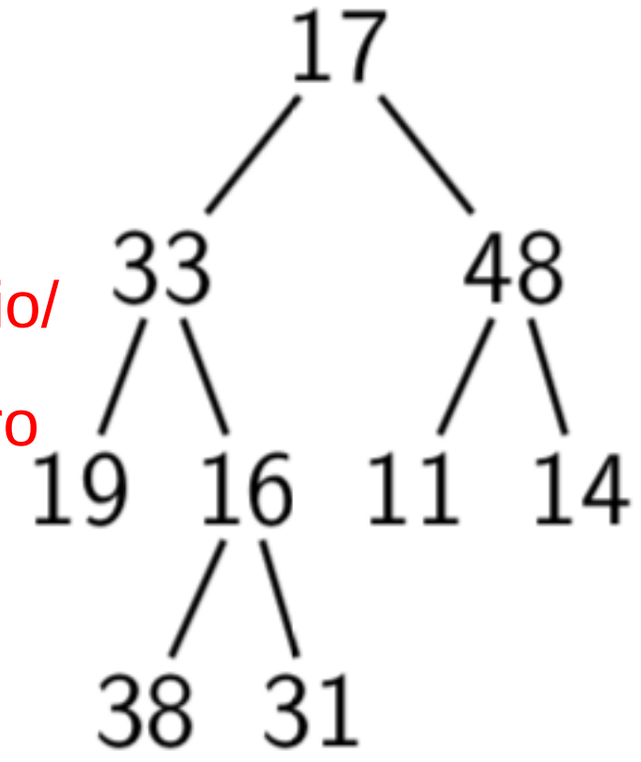

PREORDERTRAVERSE(38)

PREORDERTRAVERSE(16)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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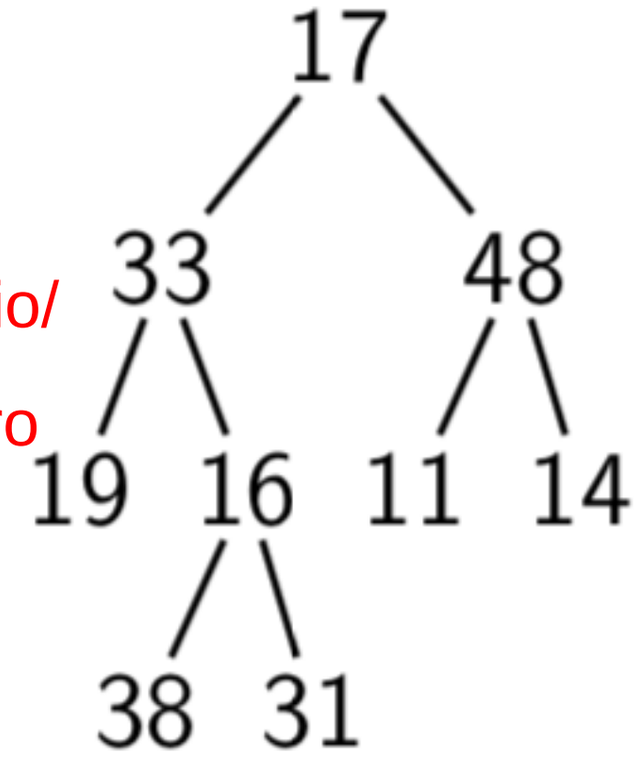

PREORDERTRAVERSE(38)

PREORDERTRAVERSE(16)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

(…skipping the calls to PREORDERTRAVERSE(null)…)

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Preorder Traversal

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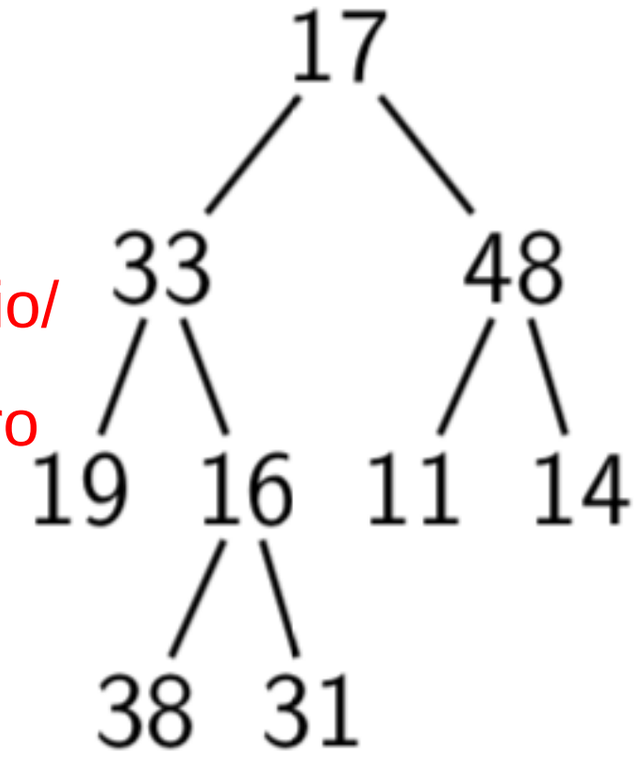

PREORDERTRAVERSE(16)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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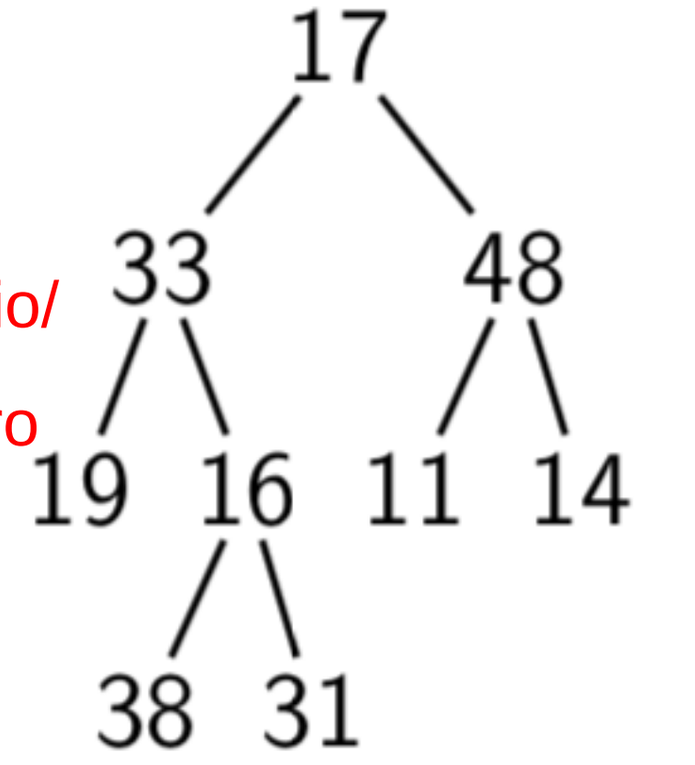

PREORDERTRAVERSE(31)

PREORDERTRAVERSE(16)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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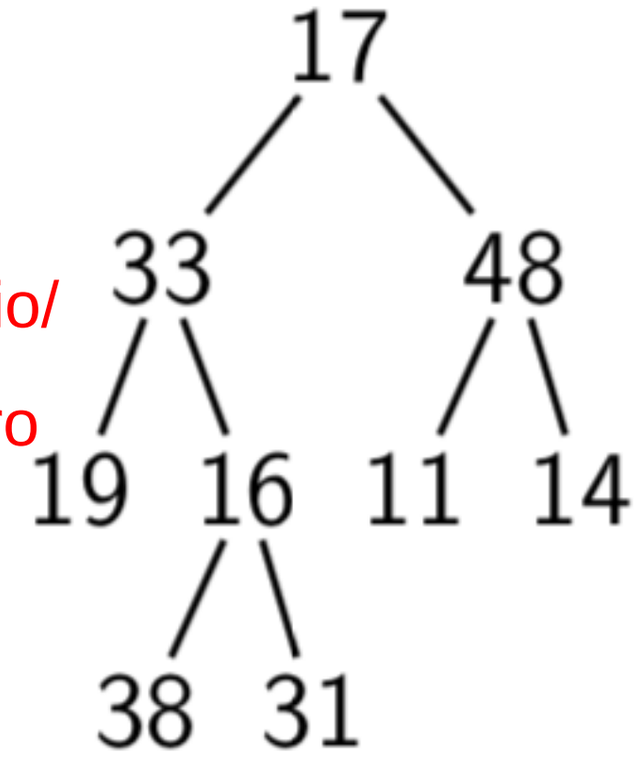

PREORDERTRAVERSE(31)

PREORDERTRAVERSE(16)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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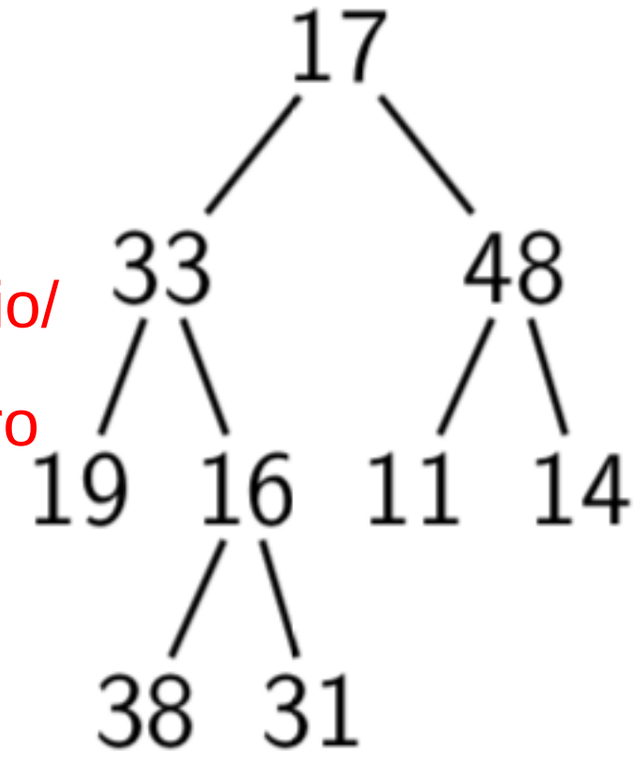

PREORDERTRAVERSE(31)

PREORDERTRAVERSE(16)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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Preorder Traversal

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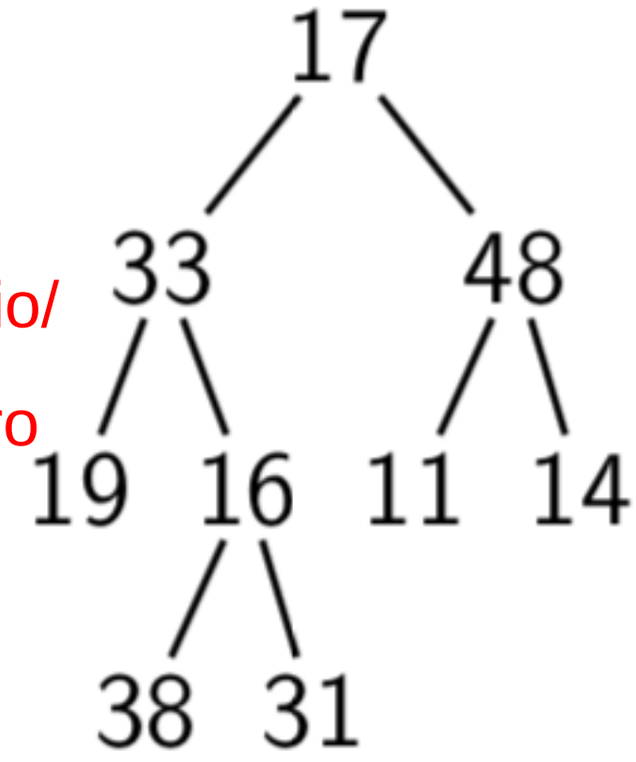

PREORDERTRAVERSE(16)

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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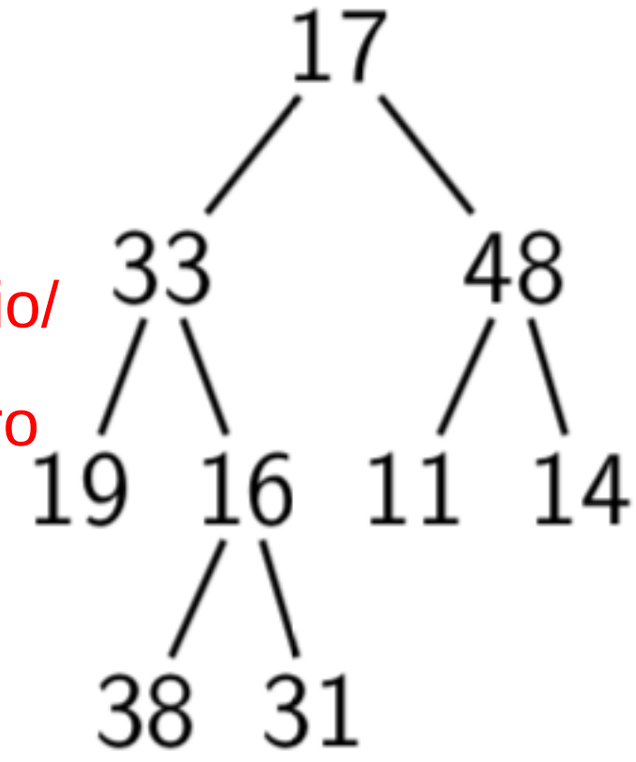

PREORDERTRAVERSE(33)

PREORDERTRAVERSE(17)

Call Stack

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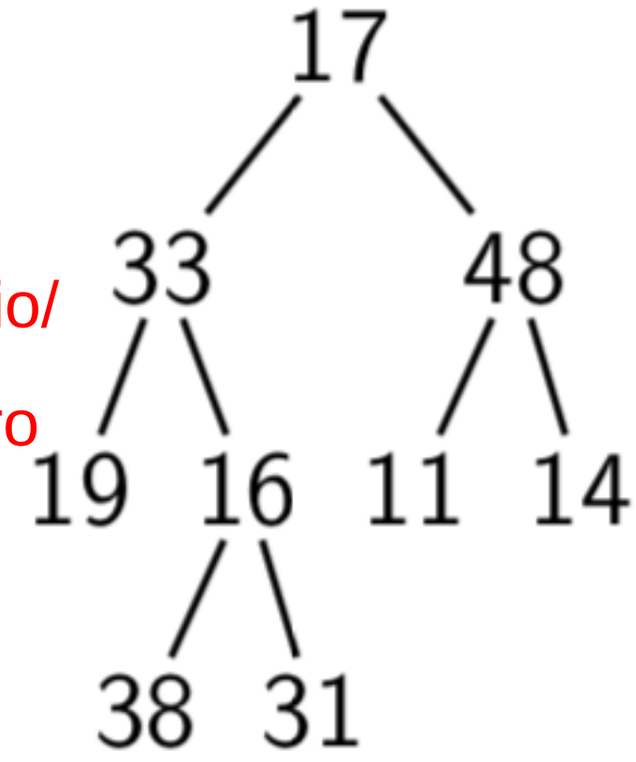

PREORDERTRAVERSE(17)

Call Stack

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Preorder Traversal

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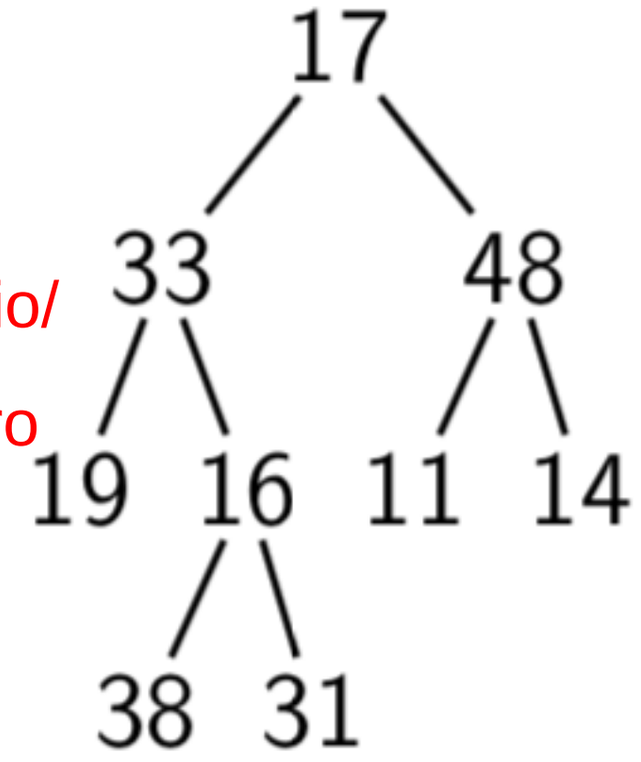

PREORDERTRAVERSE(48)
PREORDERTRAVERSE(17)

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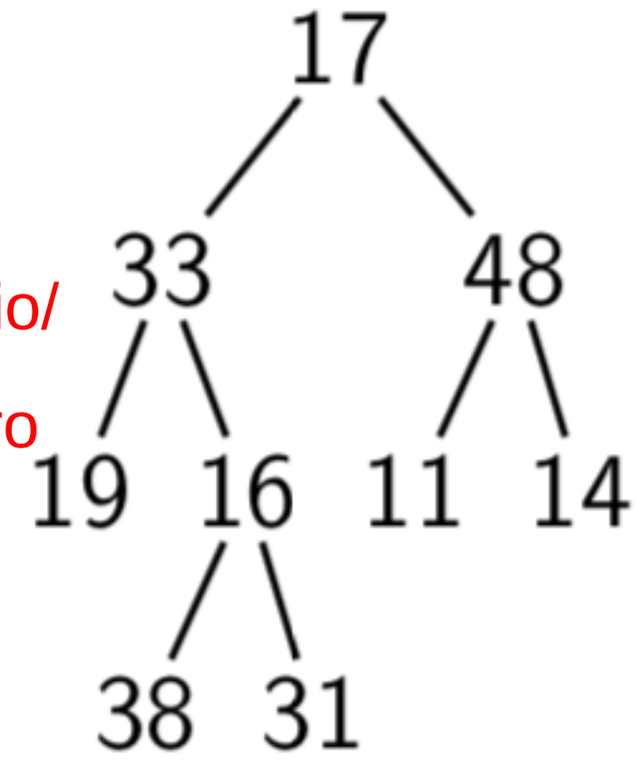

PREORDERTRAVERSE(48)

PREORDERTRAVERSE(17)

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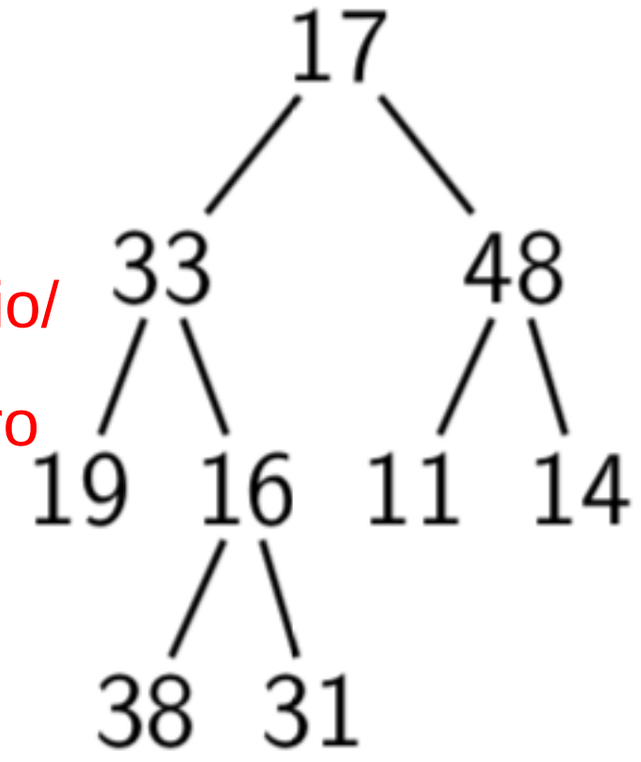

PREORDERTRAVERSE(11)
PREORDERTRAVERSE(48)
PREORDERTRAVERSE(17)

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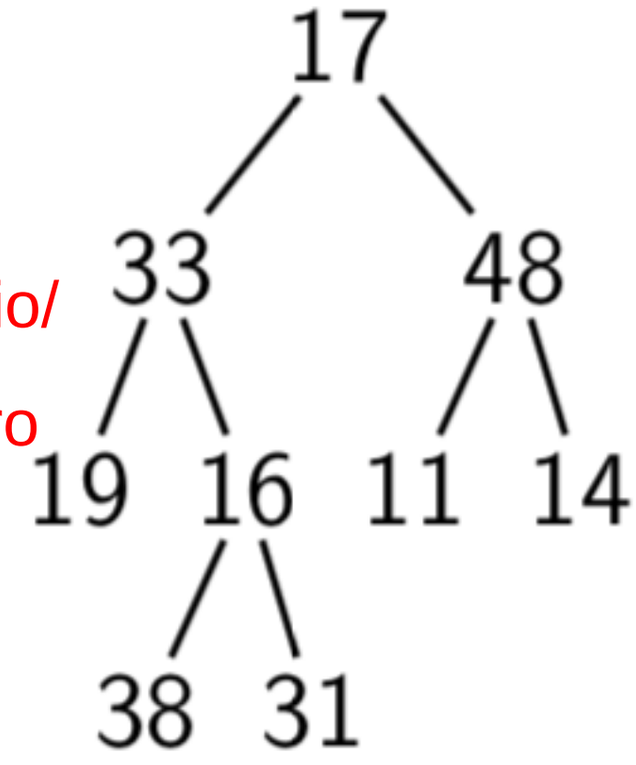

PREORDERTRAVERSE(11)
PREORDERTRAVERSE(48)
PREORDERTRAVERSE(17)

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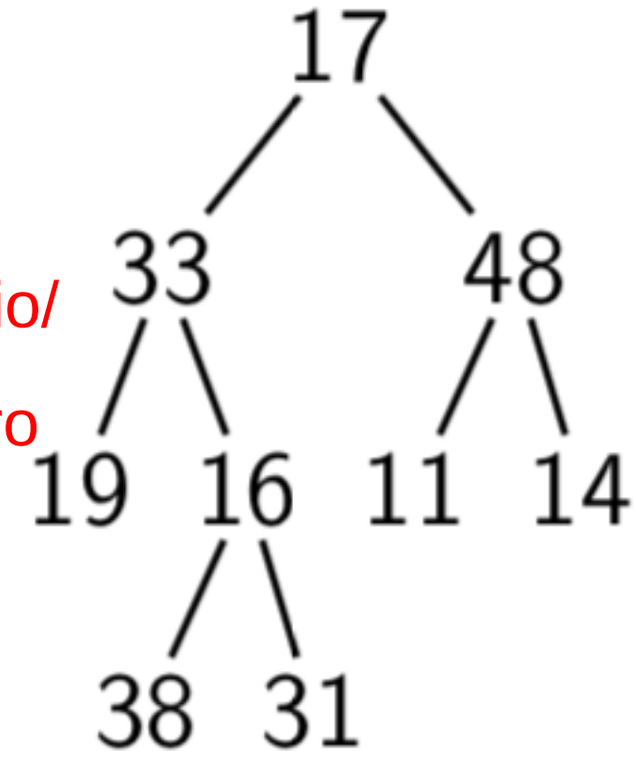

PREORDERTRAVERSE(11)
PREORDERTRAVERSE(48)
PREORDERTRAVERSE(17)

Call Stack

(…skipping the calls to PREORDERTRAVERSE(null)…)

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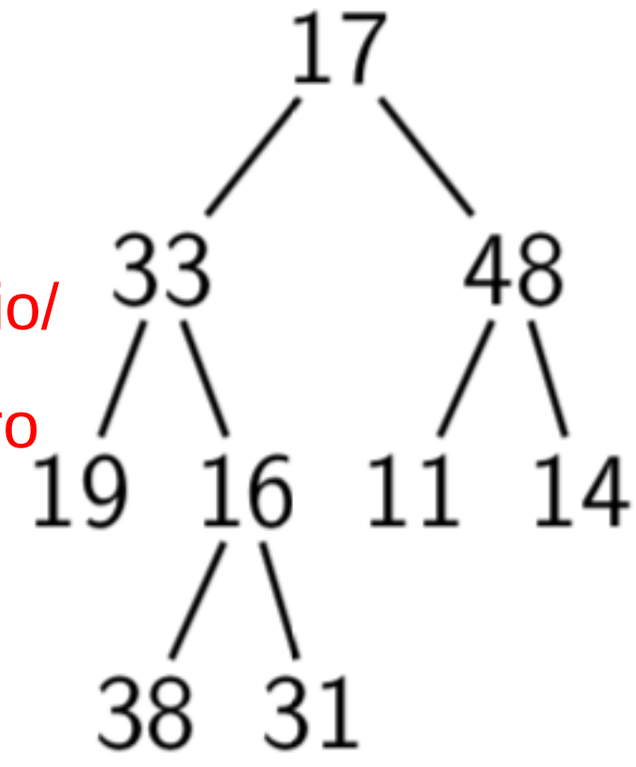

PREORDERTRAVERSE(48)

PREORDERTRAVERSE(17)

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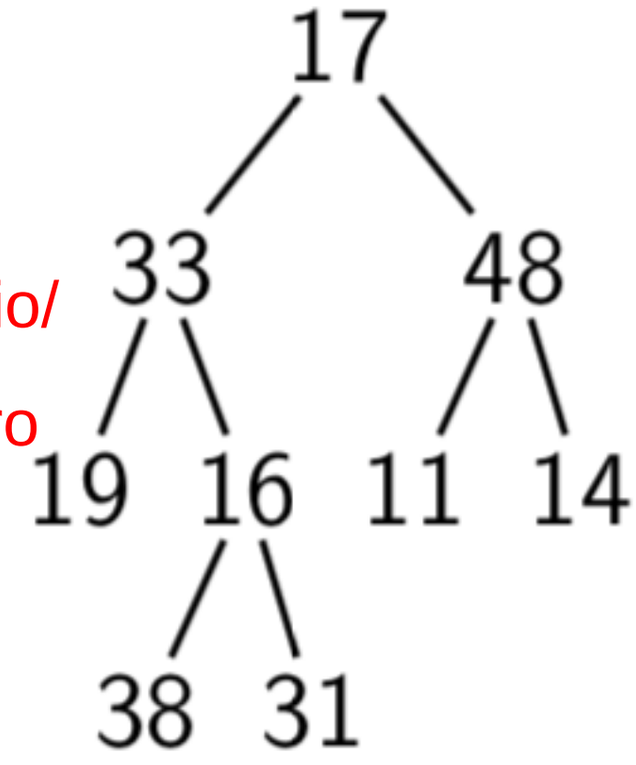

PREORDERTRAVERSE(14)
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PREORDERTRAVERSE(17)

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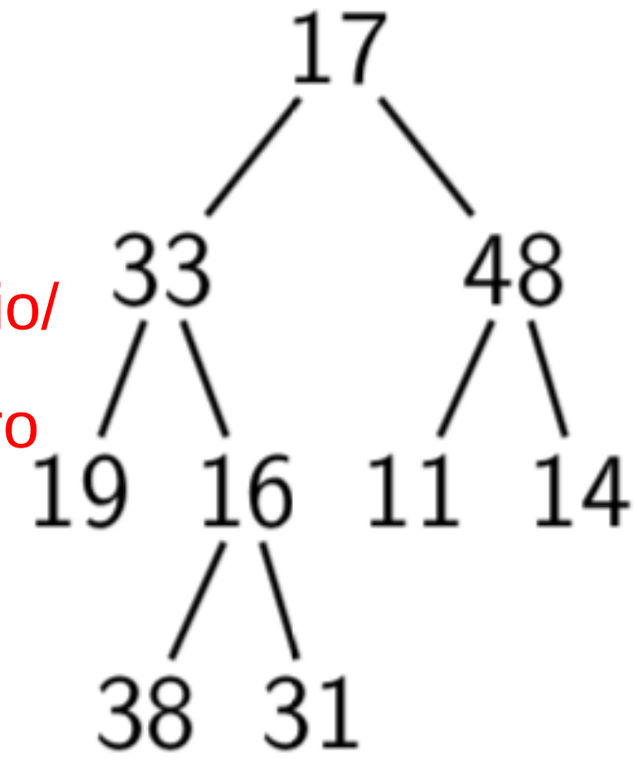

PREORDERTRAVERSE(14)
PREORDERTRAVERSE(48)
PREORDERTRAVERSE(17)

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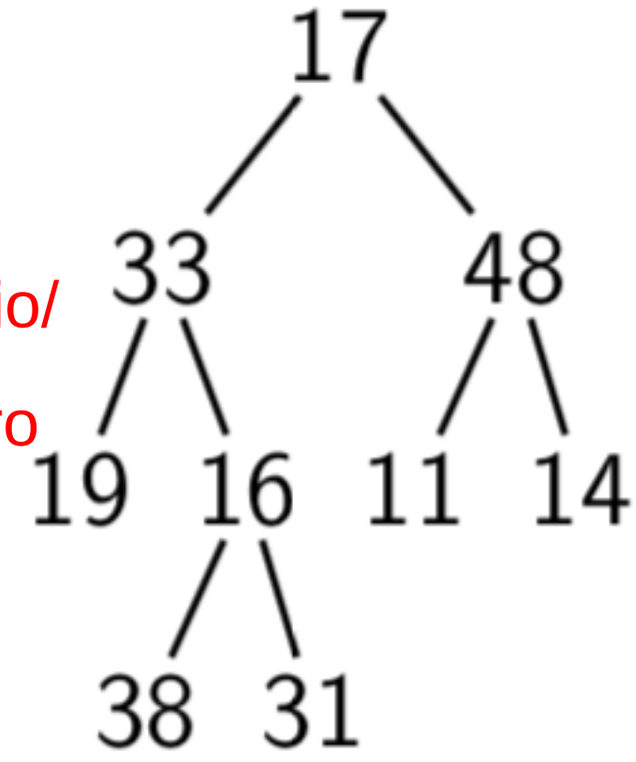

PREORDERTRAVERSE(14)
PREORDERTRAVERSE(48)
PREORDERTRAVERSE(17)

Call Stack

(…skipping the calls to PREORDERTRAVERSE(null)…)

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Preorder Traversal

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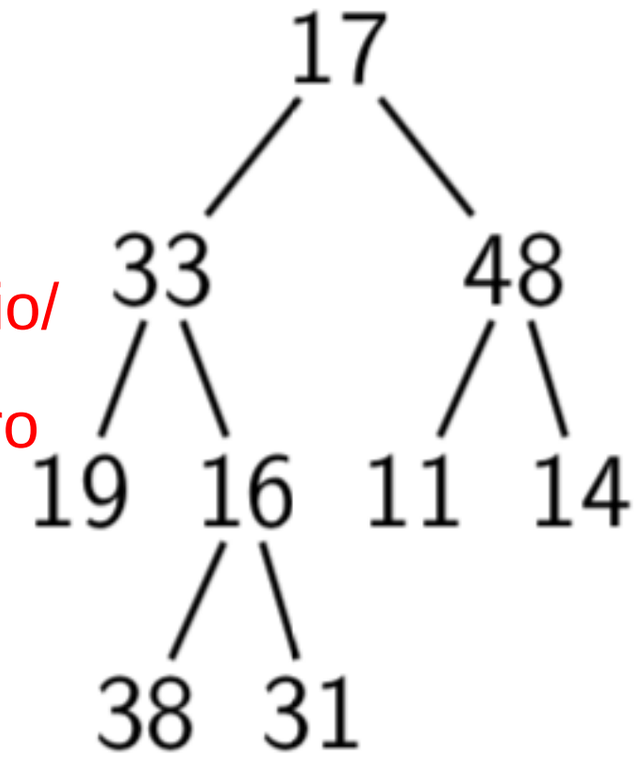

PREORDERTRAVERSE(48)

PREORDERTRAVERSE(17)

Call Stack

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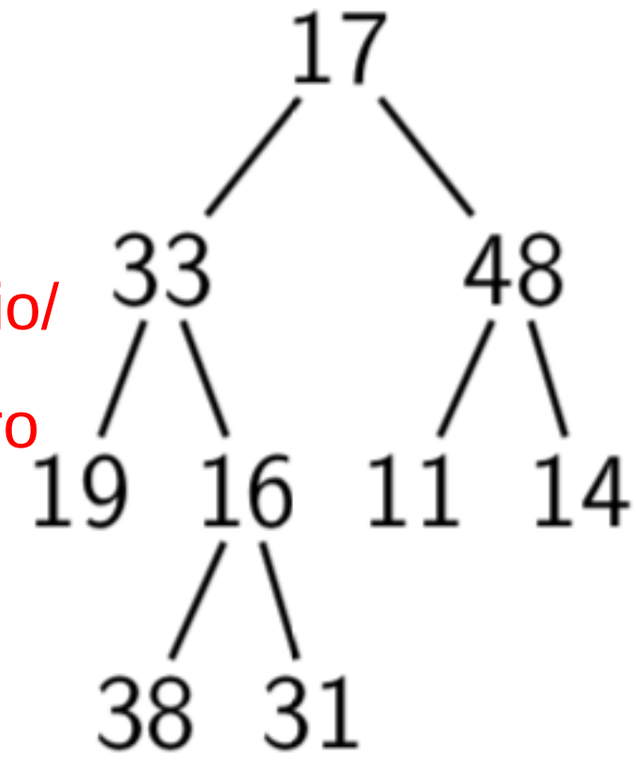

PREORDERTRAVERSE(17)

Call Stack

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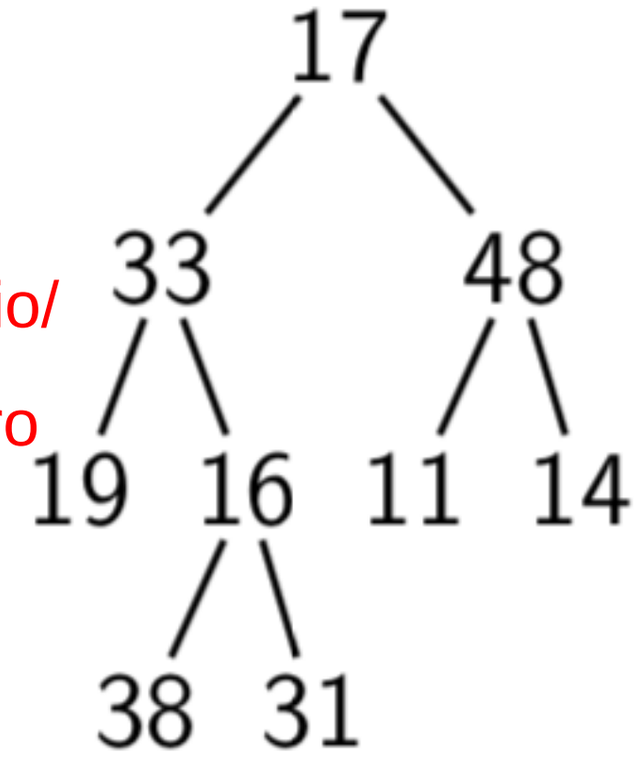

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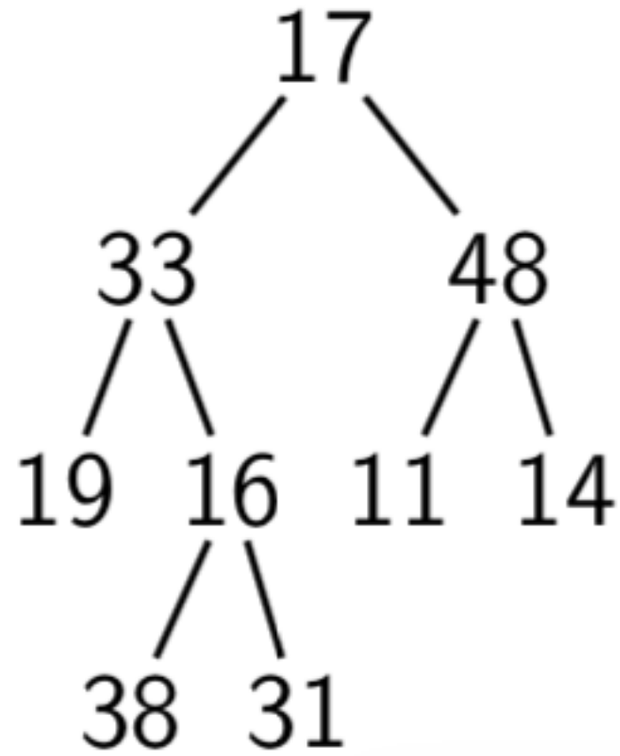

INORDERTRAVERSE(17)

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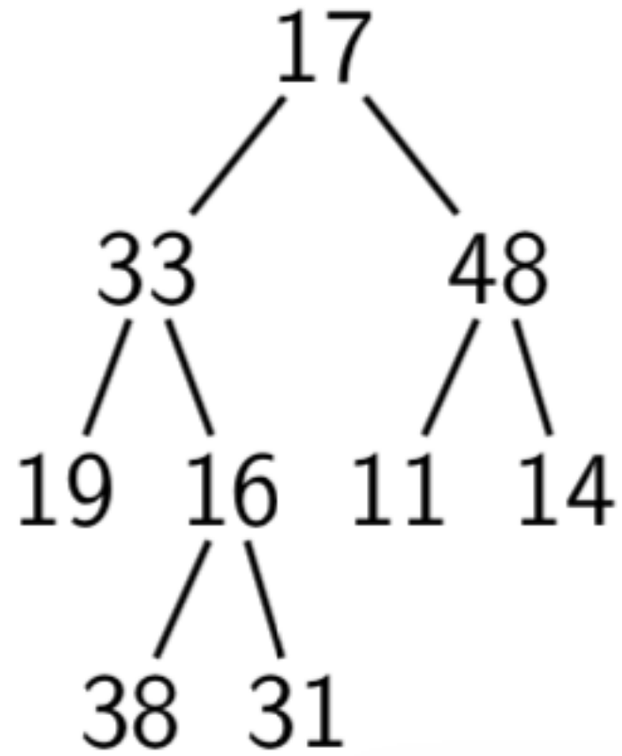

INORDERTRAVERSE(33)
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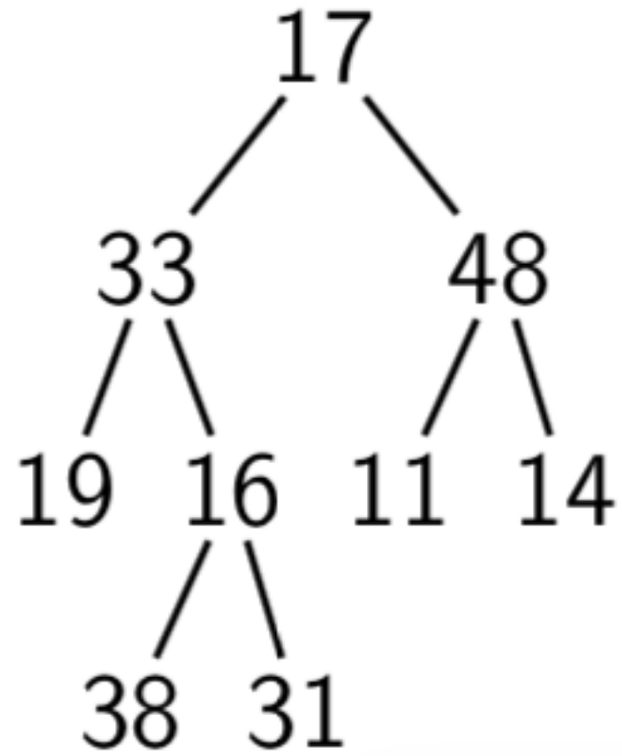

INORDERTRAVERSE(19)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

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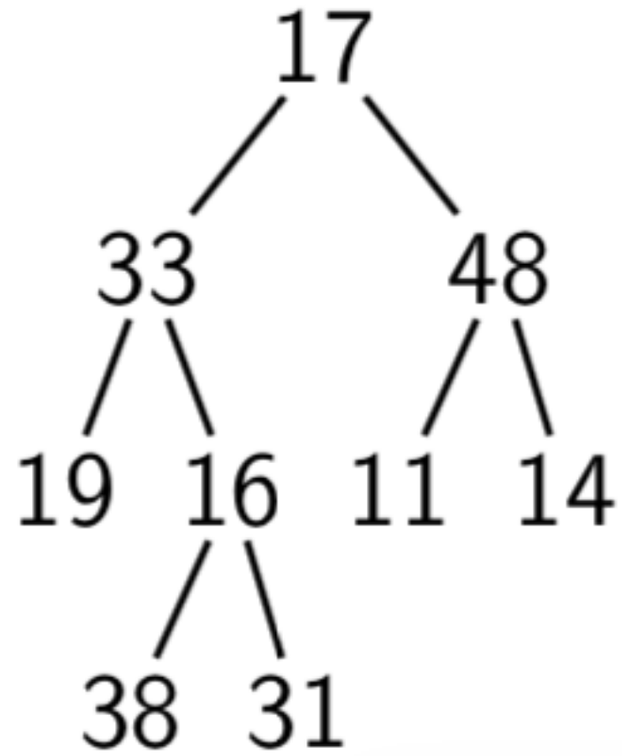

INORDERTRAVERSE(null)

INORDERTRAVERSE(19)

INORDERTRAVERSE(33)

INORDERTRAVERSE(17)

Call Stack

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Inorder Traversal

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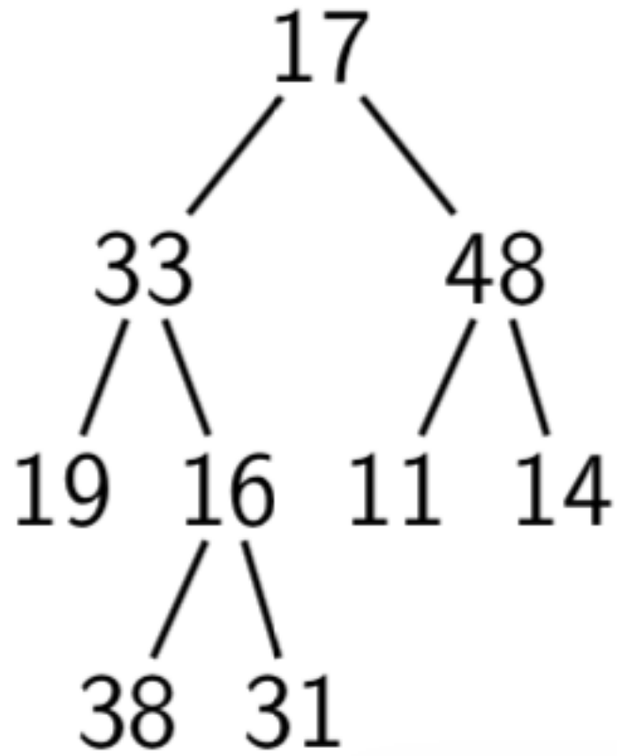

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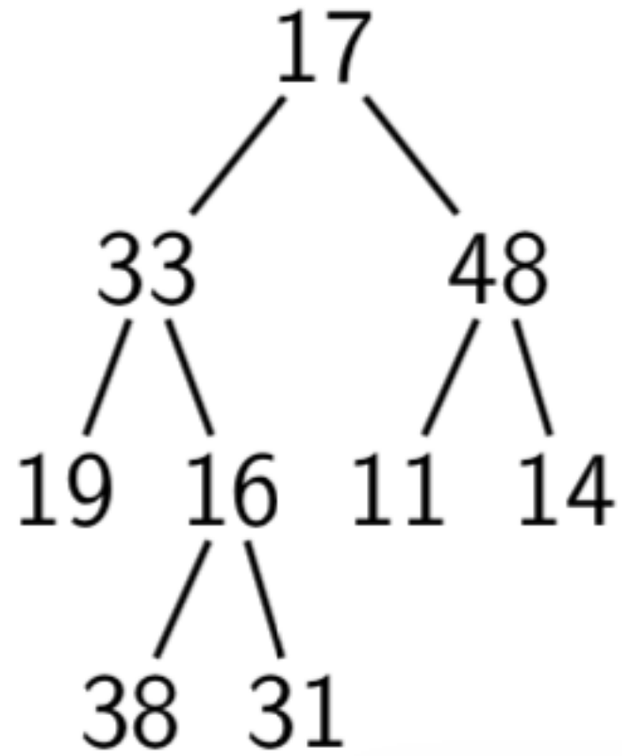

INORDERTRAVERSE(19)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

Call Stack

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Inorder Traversal

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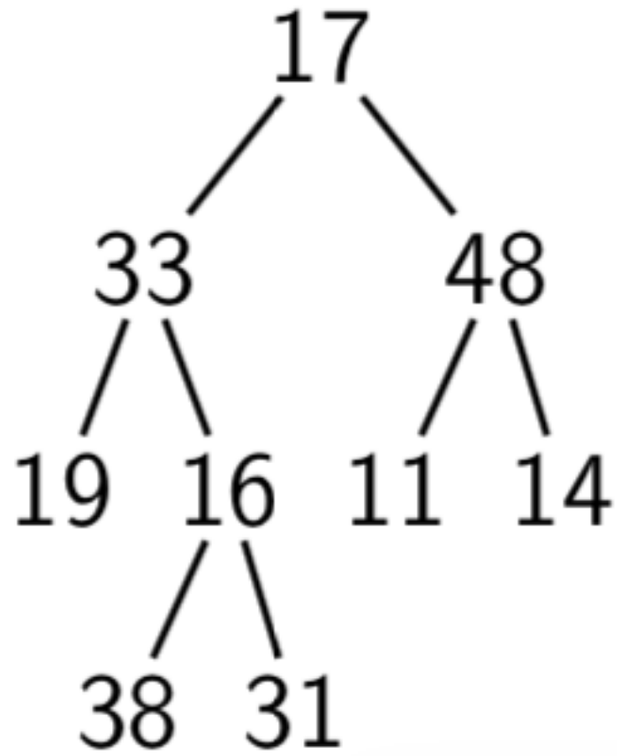

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INORDERTRAVERSE(17)

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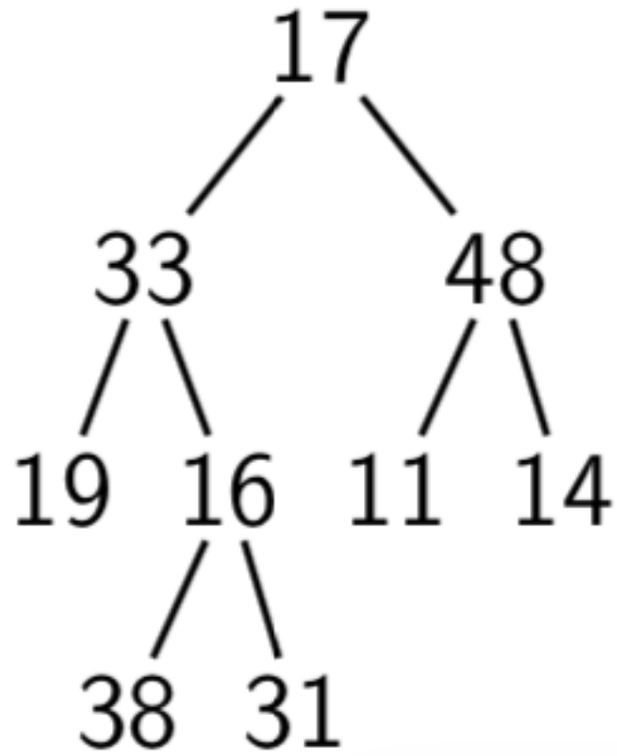

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INORDERTRAVERSE(17)

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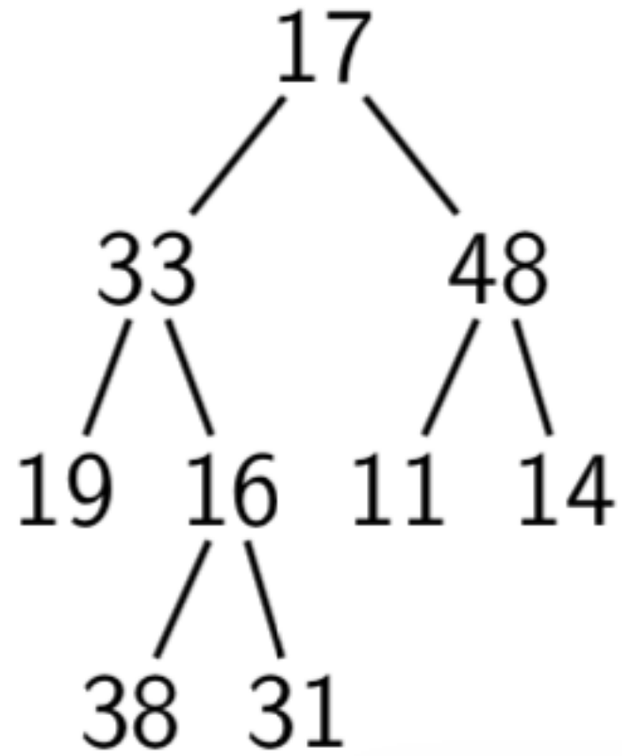

INORDERTRAVERSE(33)
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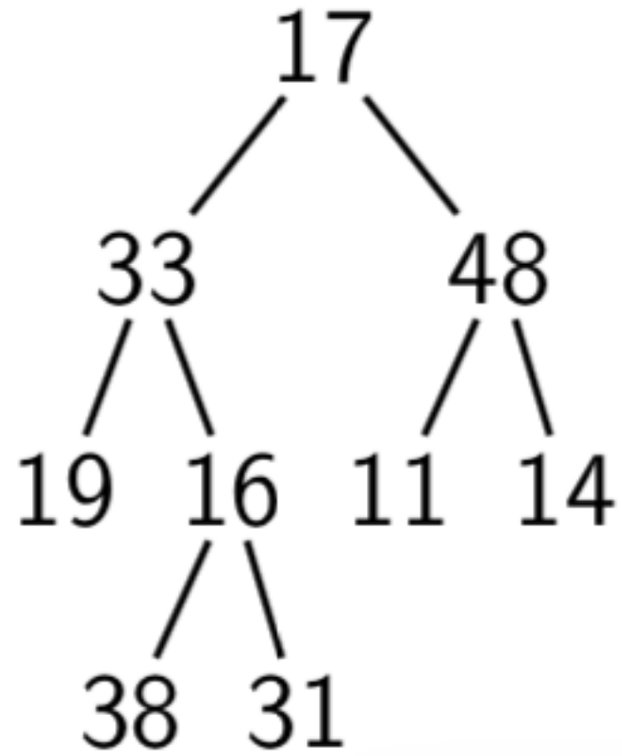

INORDERTRAVERSE(33)
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Inorder Traversal

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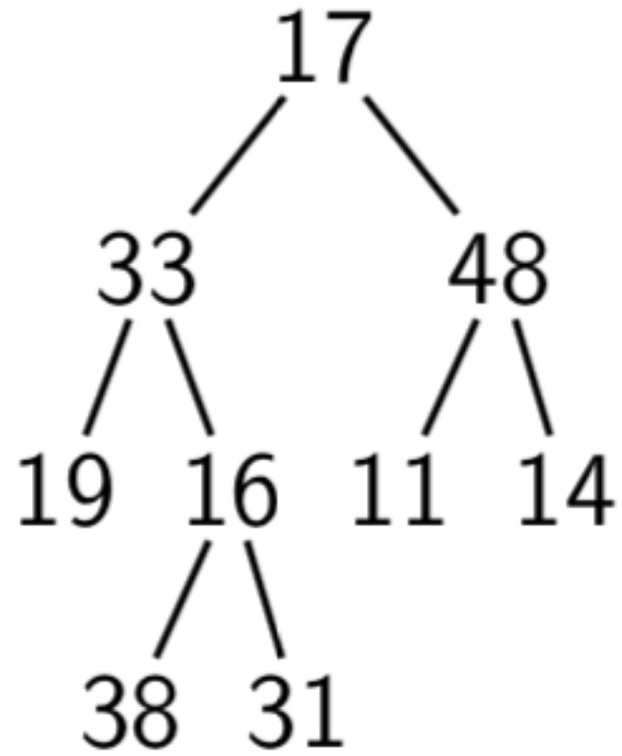

INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

Call Stack

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Inorder Traversal

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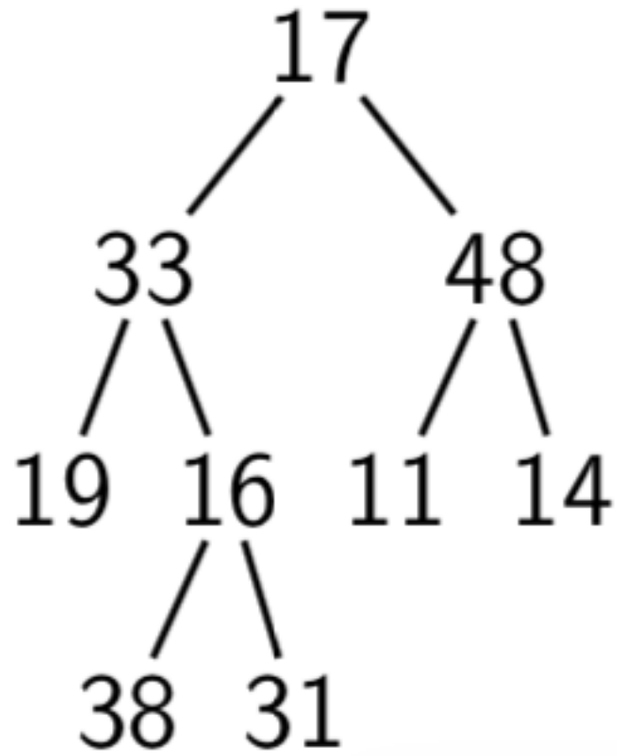

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INORDERTRAVERSE(38)
INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

Call Stack

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Inorder Traversal

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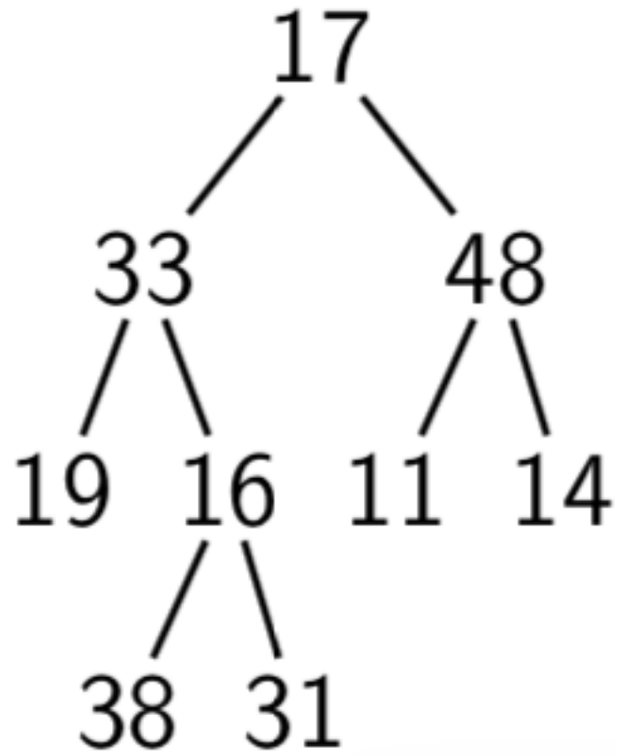

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INORDERTRAVERSE(38)

INORDERTRAVERSE(16)

INORDERTRAVERSE(33)

INORDERTRAVERSE(17)

Call Stack

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Inorder Traversal

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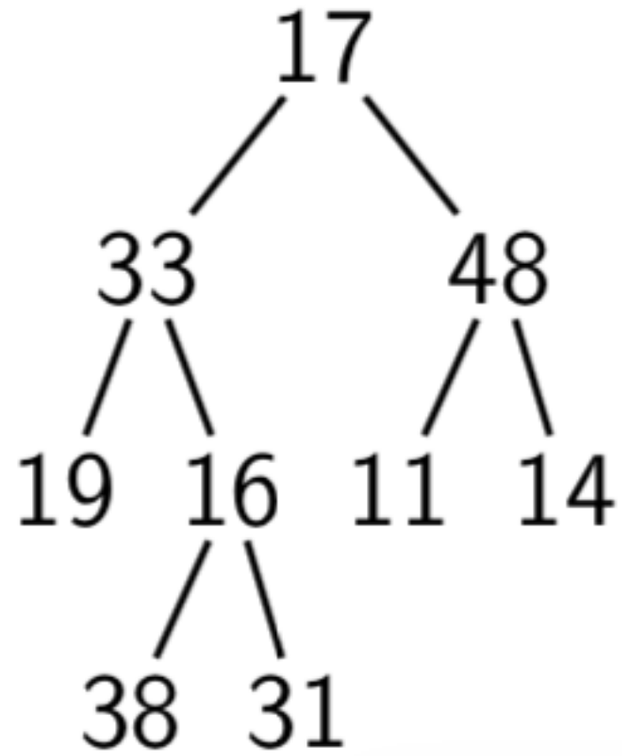

INORDERTRAVERSE(38)

INORDERTRAVERSE(16)

INORDERTRAVERSE(33)

INORDERTRAVERSE(17)

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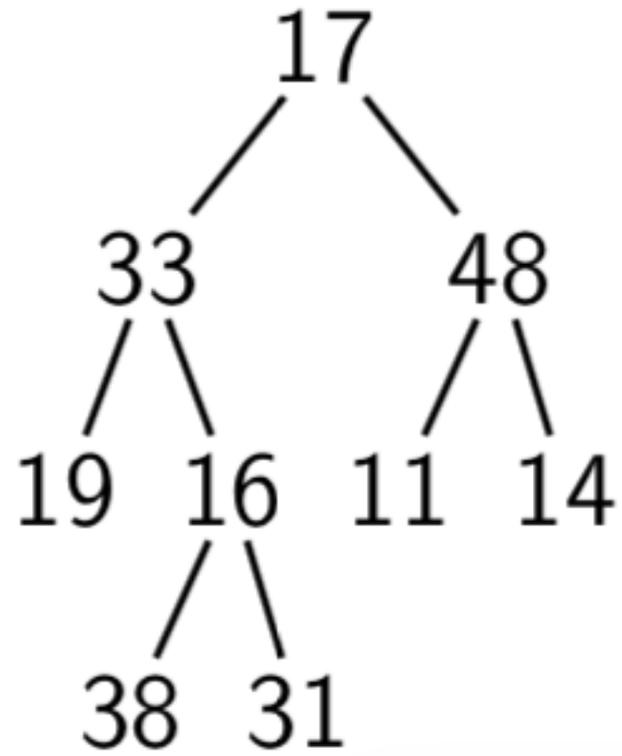

INORDERTRAVERSE(38)

INORDERTRAVERSE(16)

INORDERTRAVERSE(33)

INORDERTRAVERSE(17)

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Inorder Traversal

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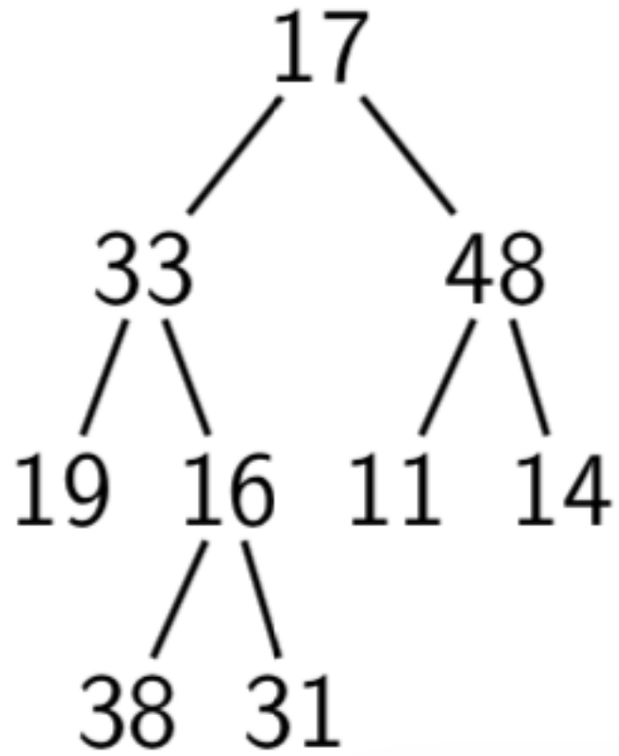

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INORDERTRAVERSE(null)
INORDERTRAVERSE(38)
INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

Call Stack

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Inorder Traversal

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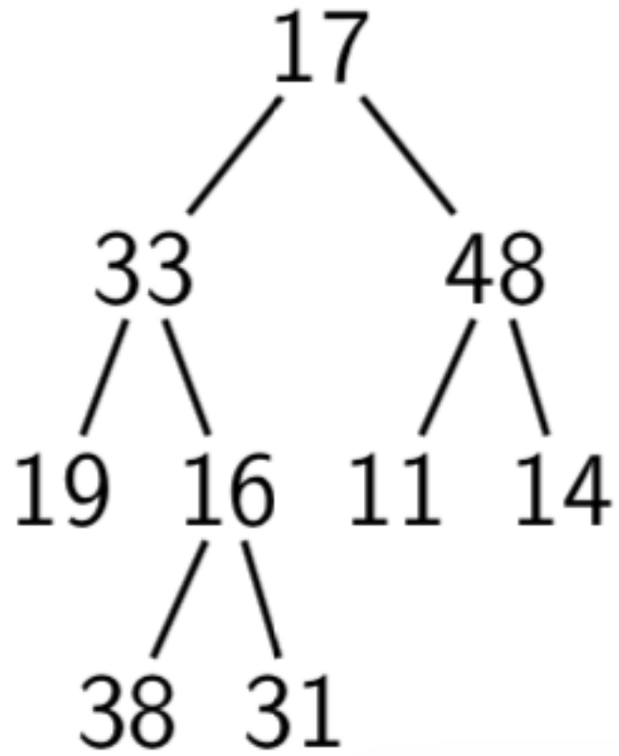

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INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

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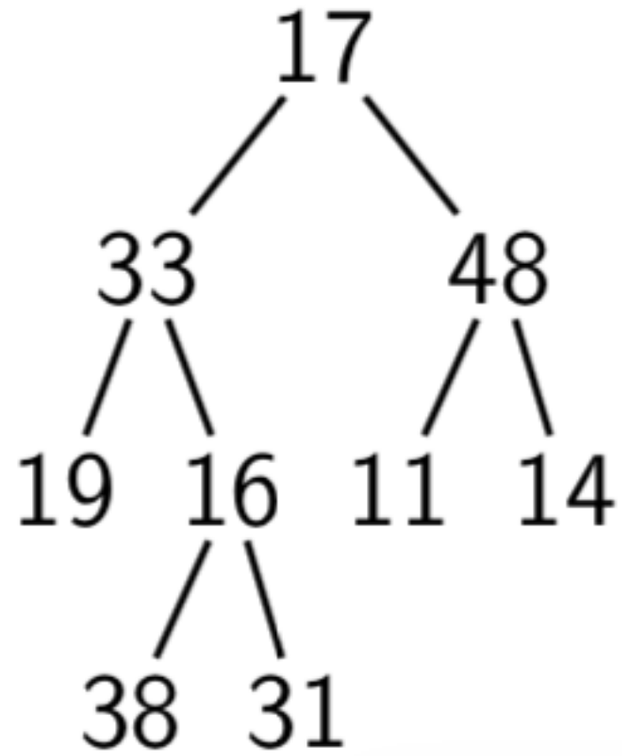

INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

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Inorder Traversal

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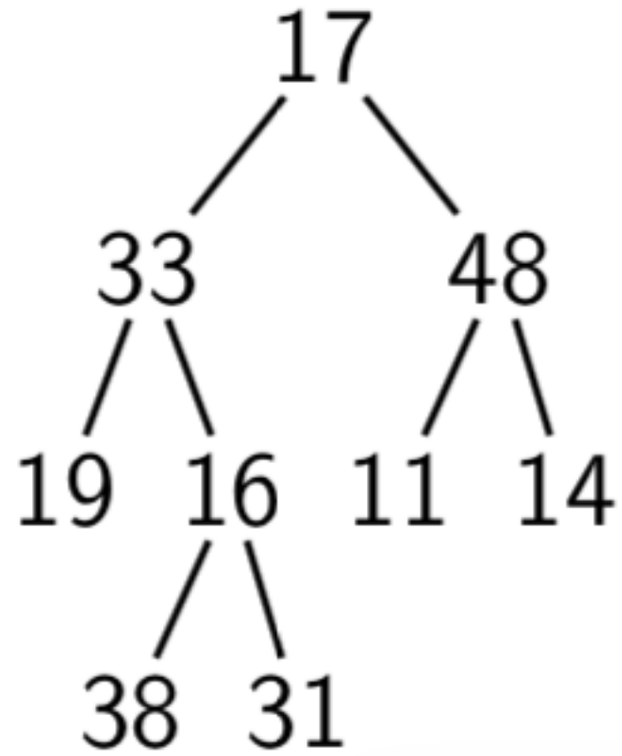

INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
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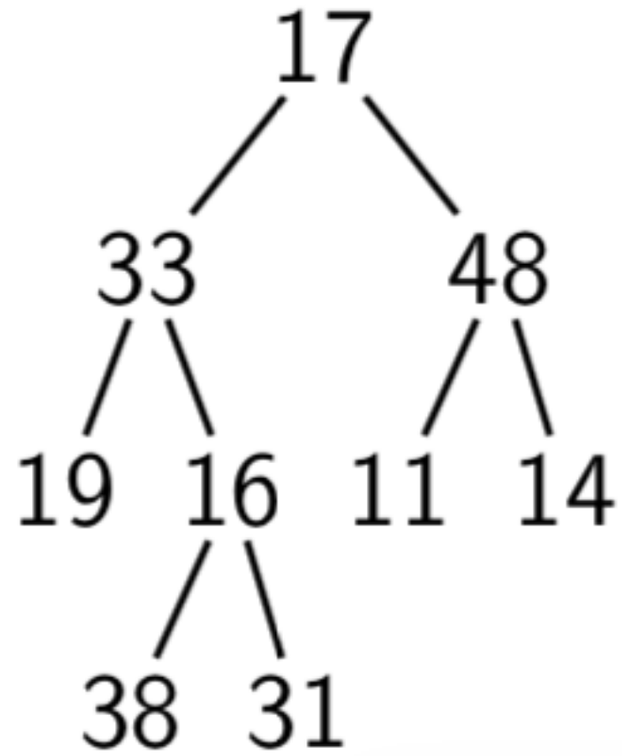

INORDERTRAVERSE(31)
INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
INORDERTRAVERSE(17)

Call Stack

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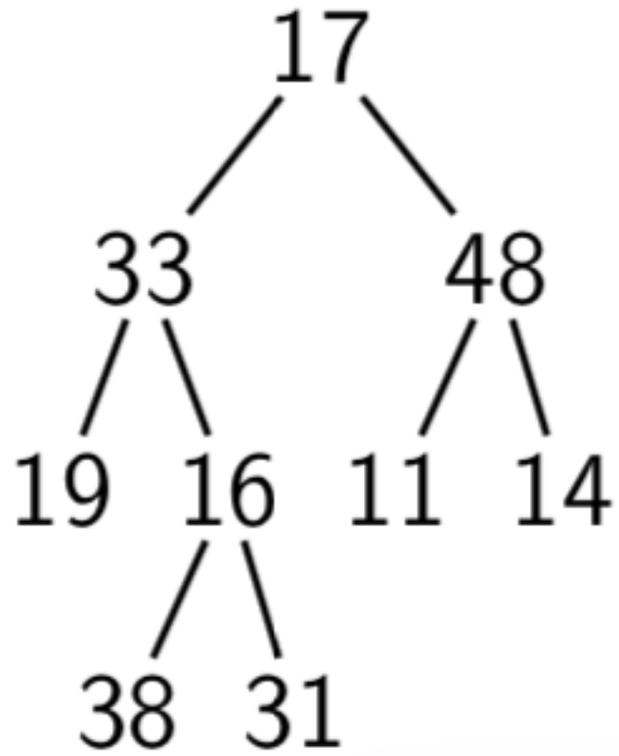

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INORDERTRAVERSE(31)
INORDERTRAVERSE(16)
INORDERTRAVERSE(33)
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Inorder Traversal

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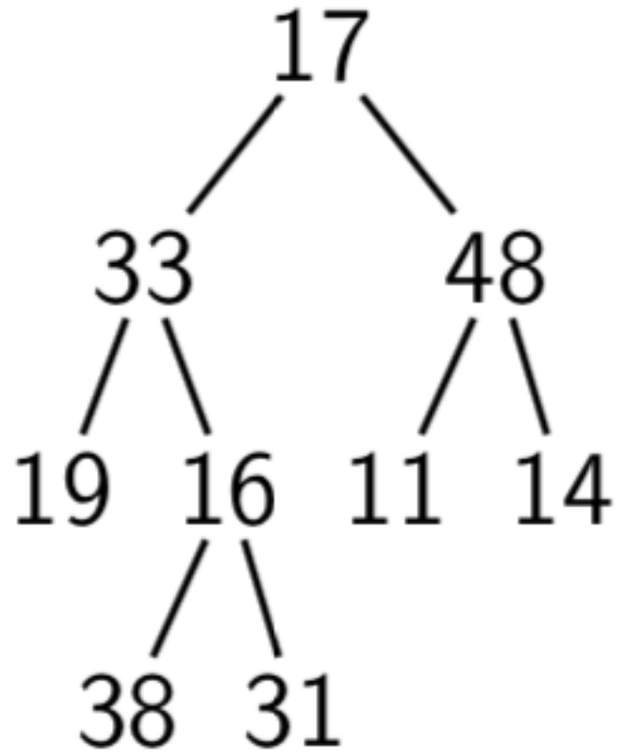

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Inorder Traversal

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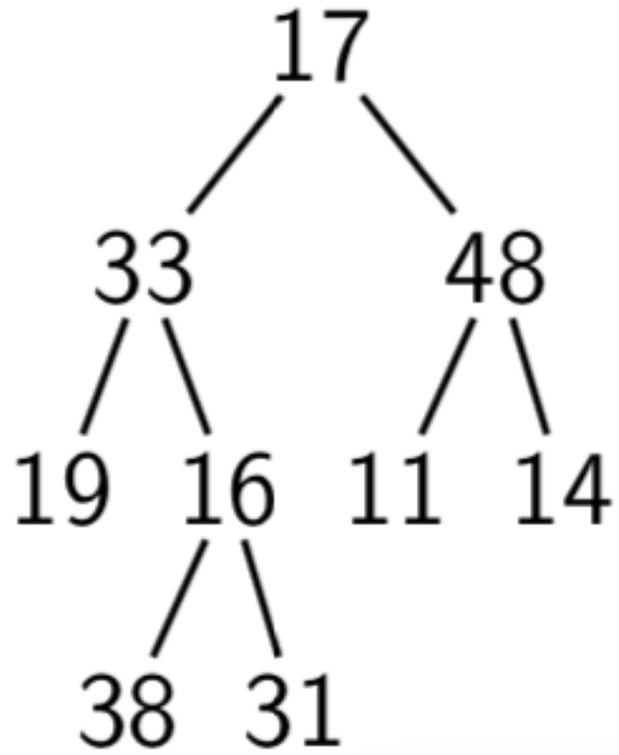

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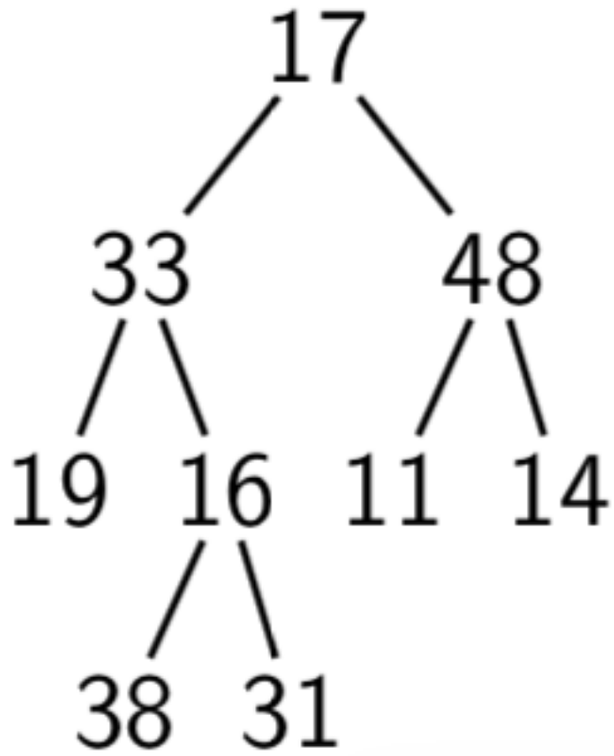

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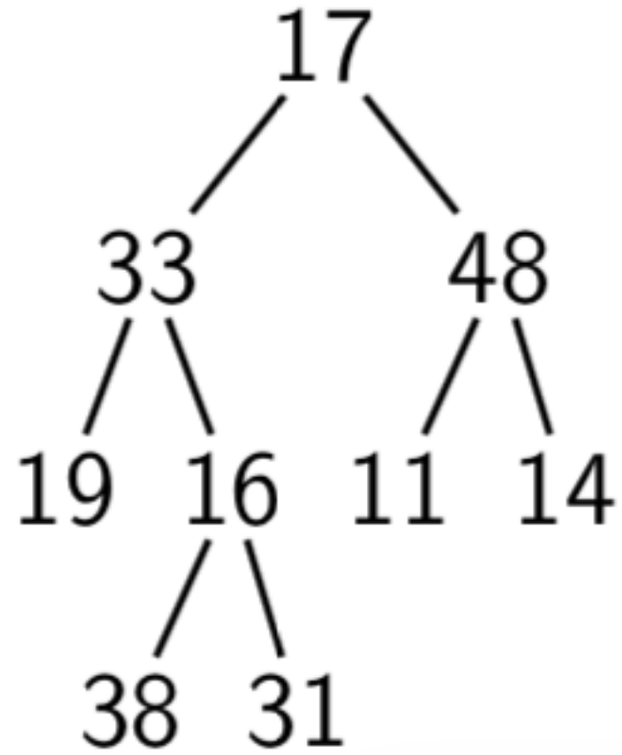

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INORDERTRAVERSE(16)
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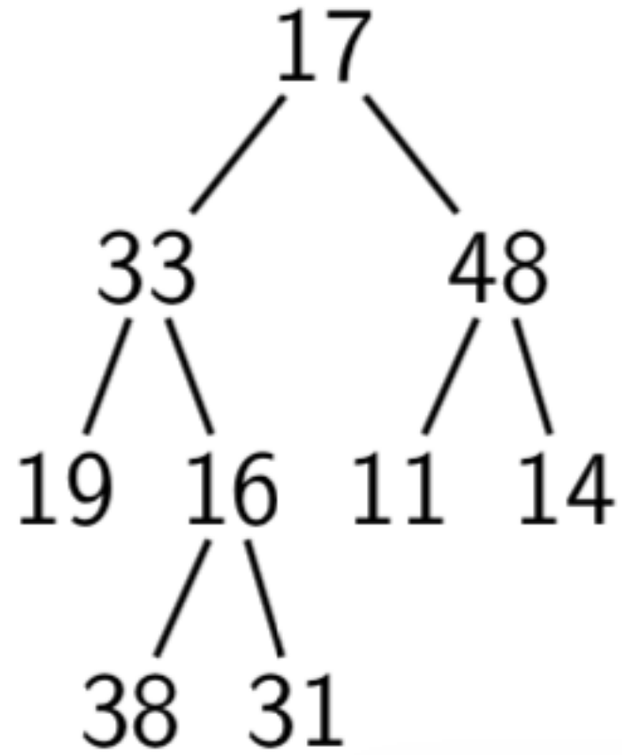

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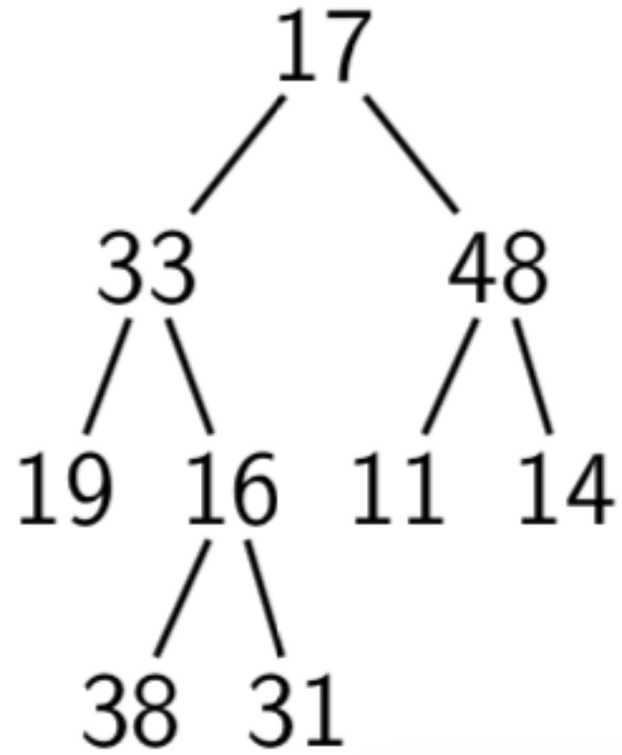

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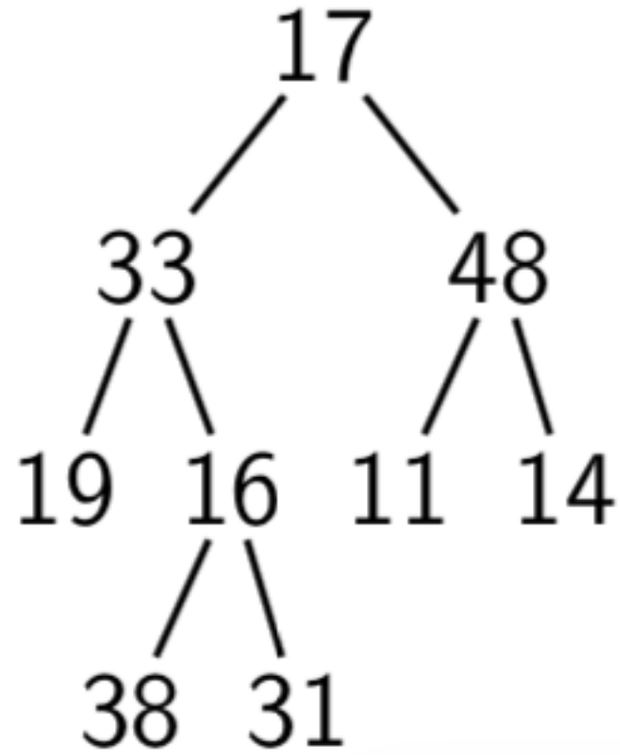

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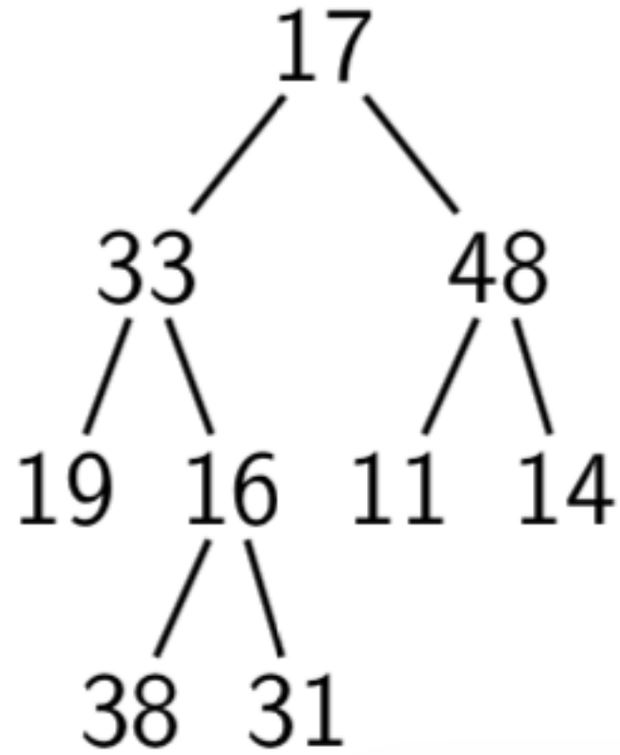

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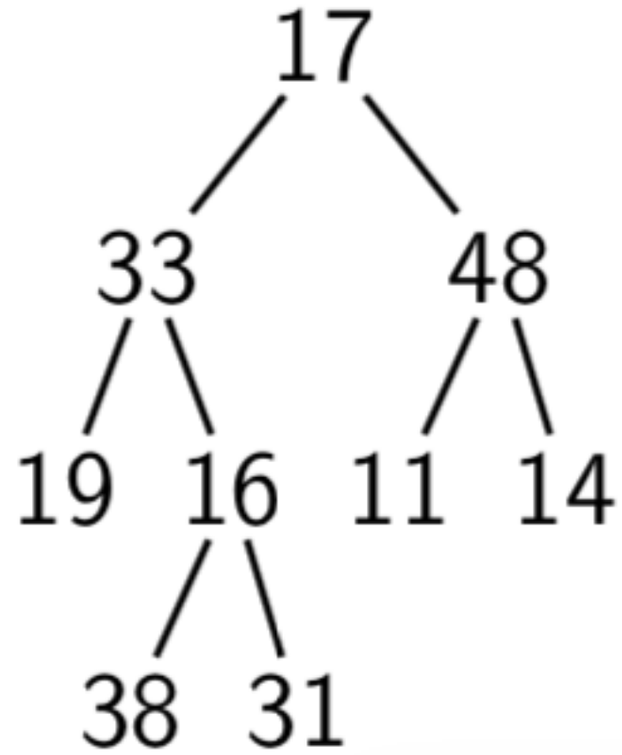

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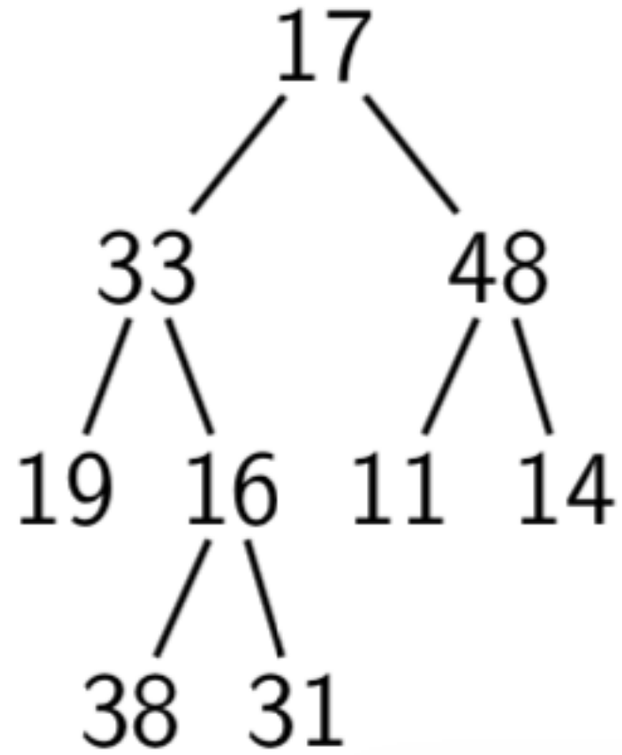

INORDERTRAVERSE(11)
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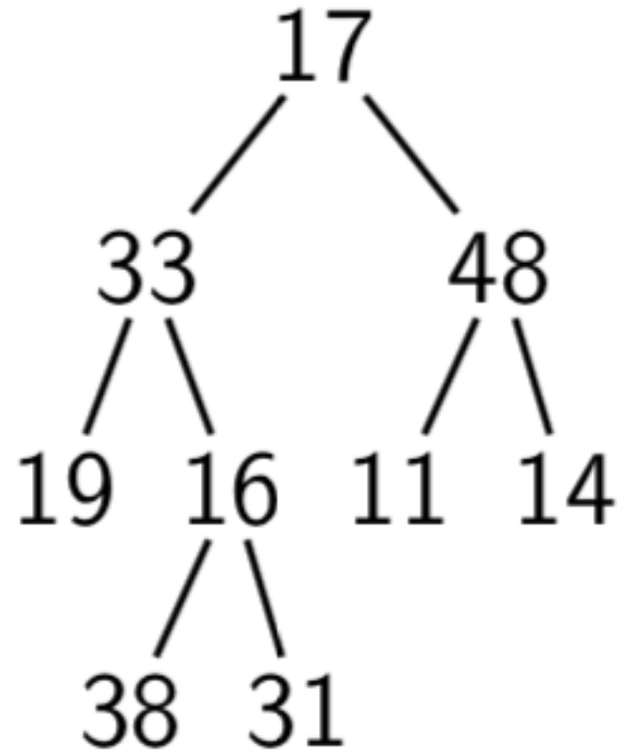

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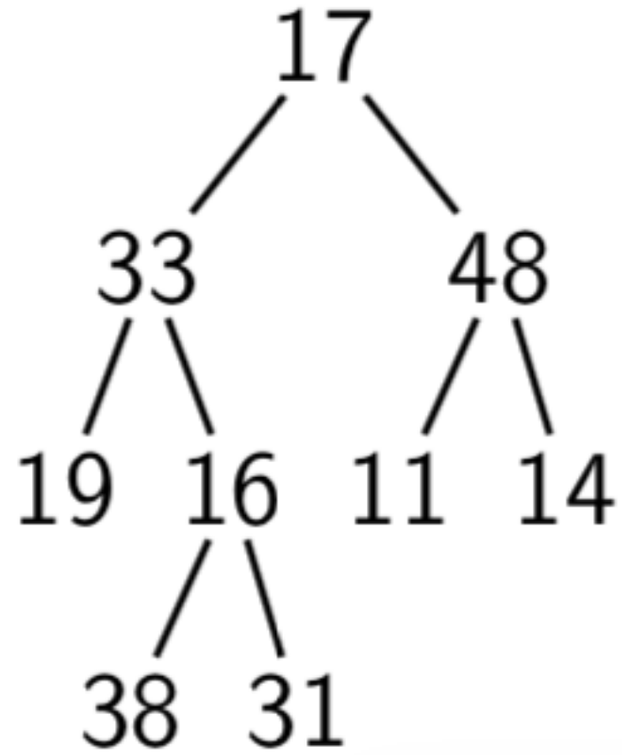

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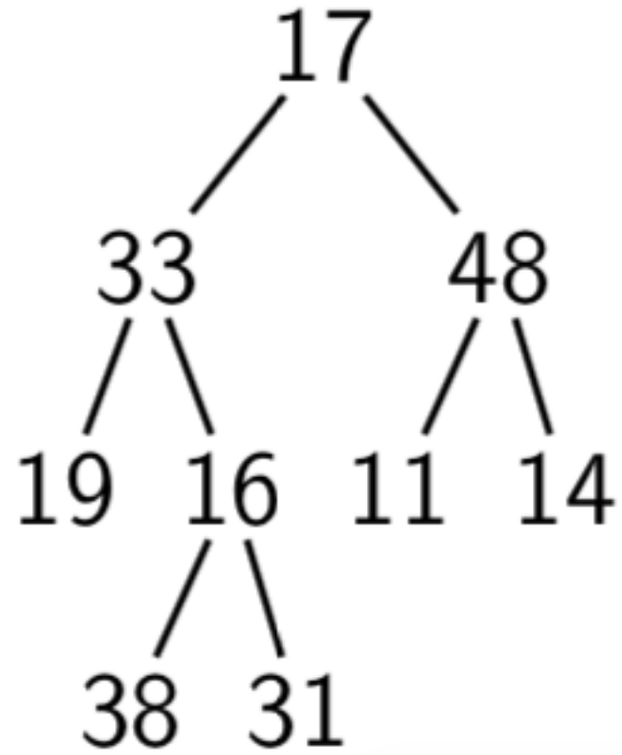

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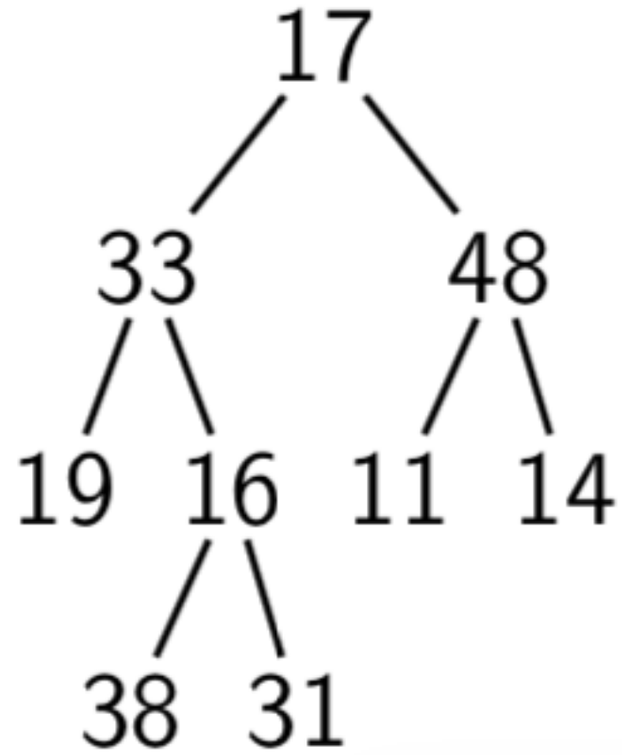

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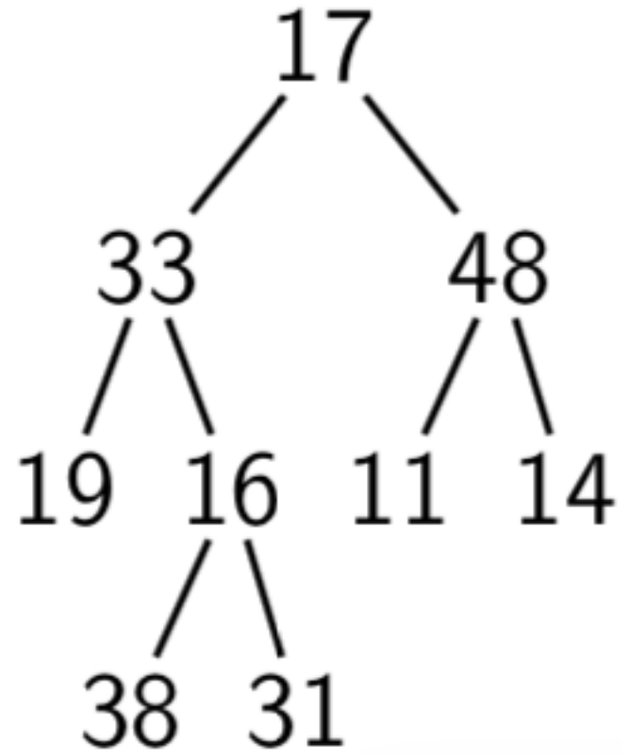

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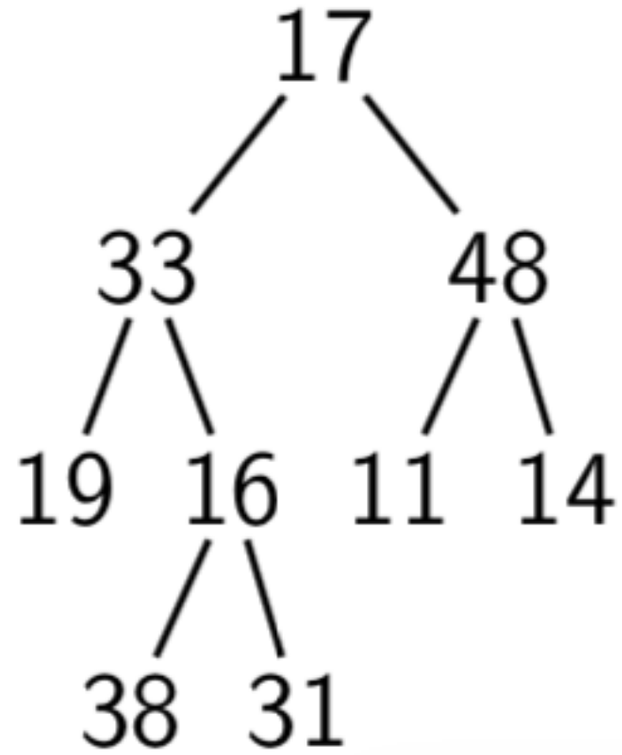

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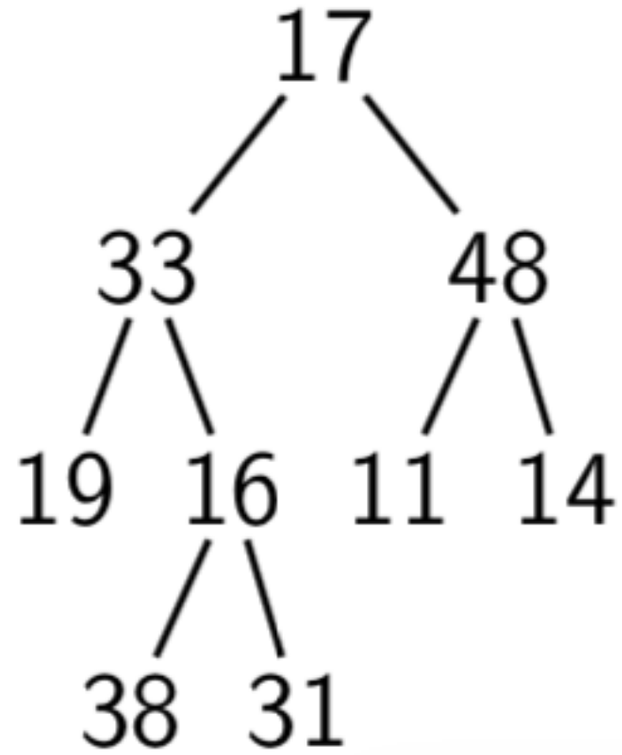

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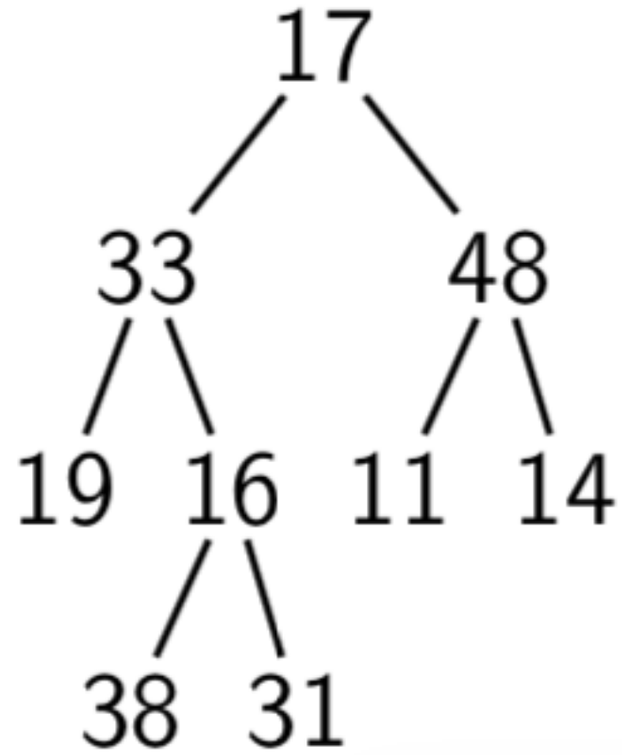

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INORDERTRAVERSE(17)

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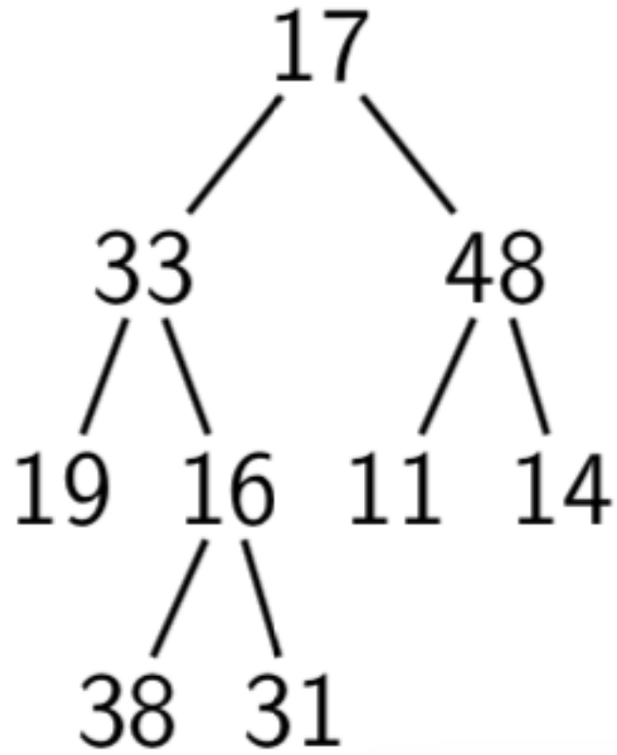

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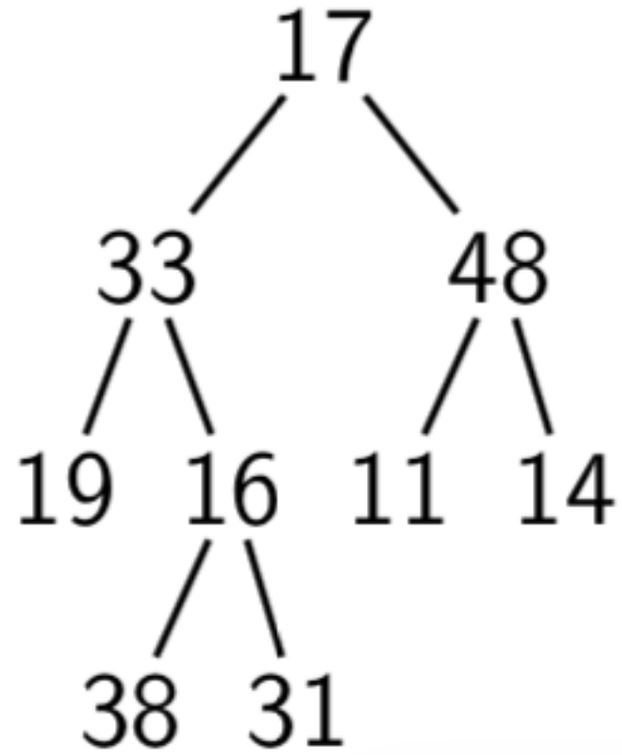

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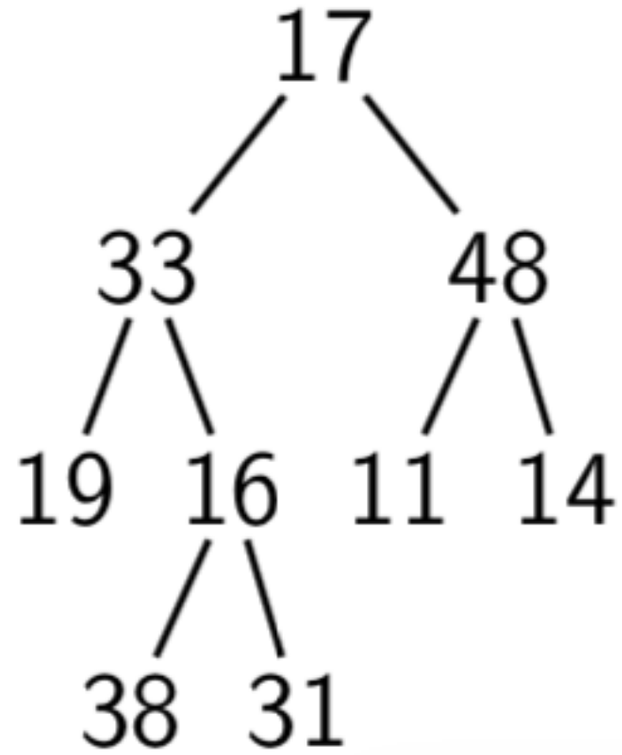

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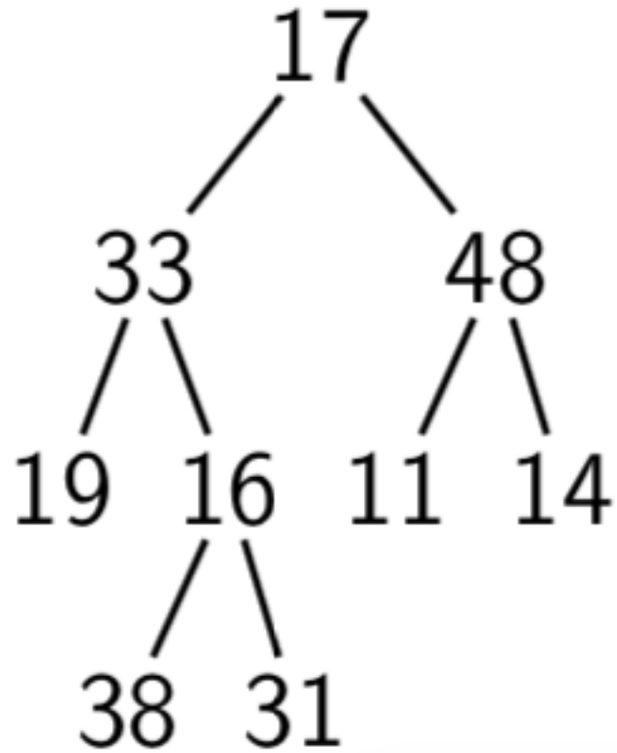

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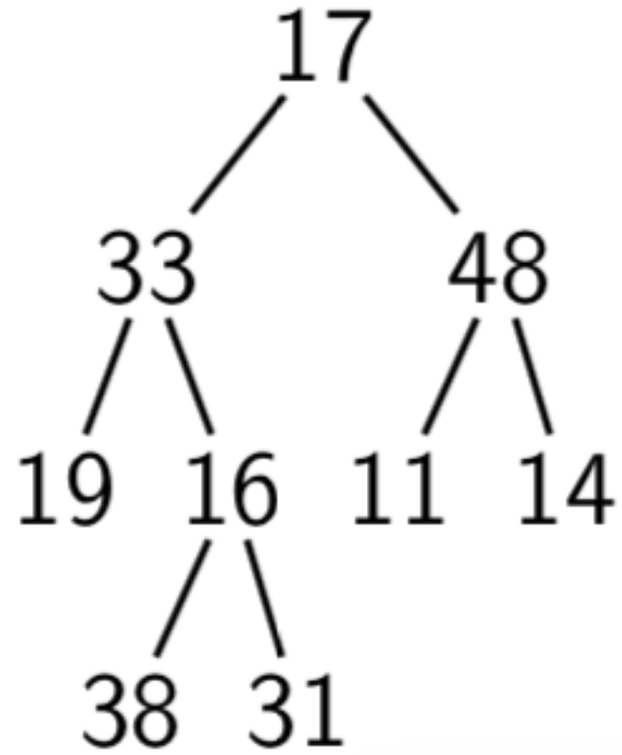

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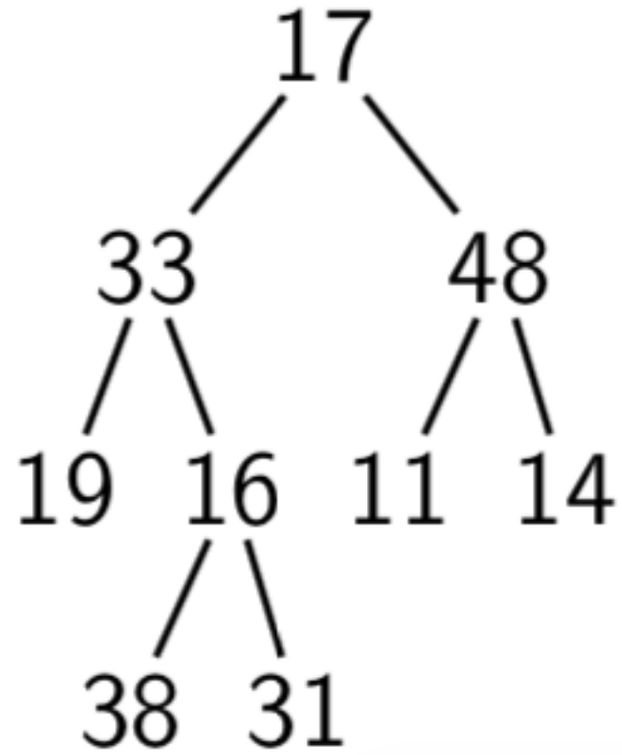

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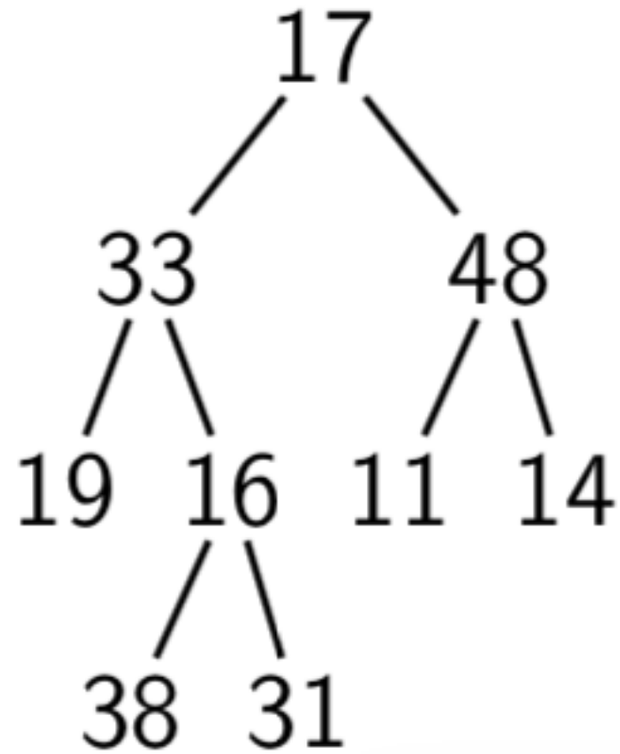

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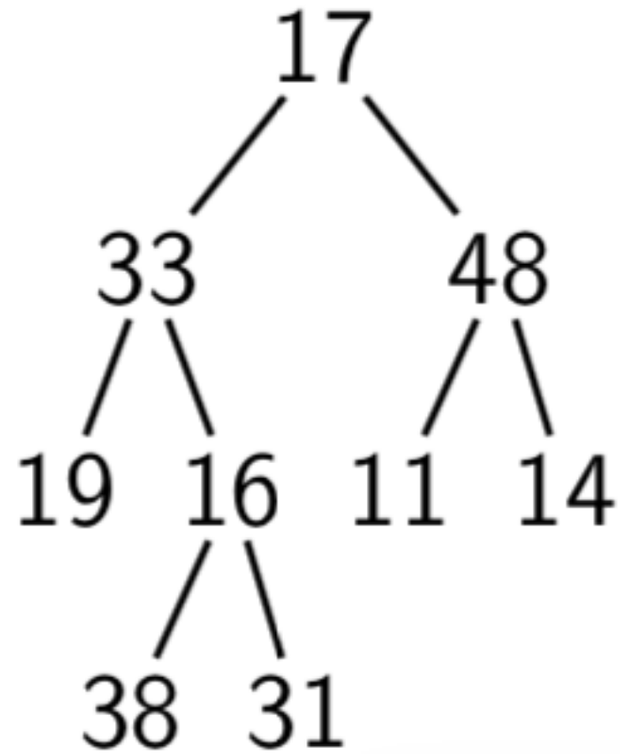

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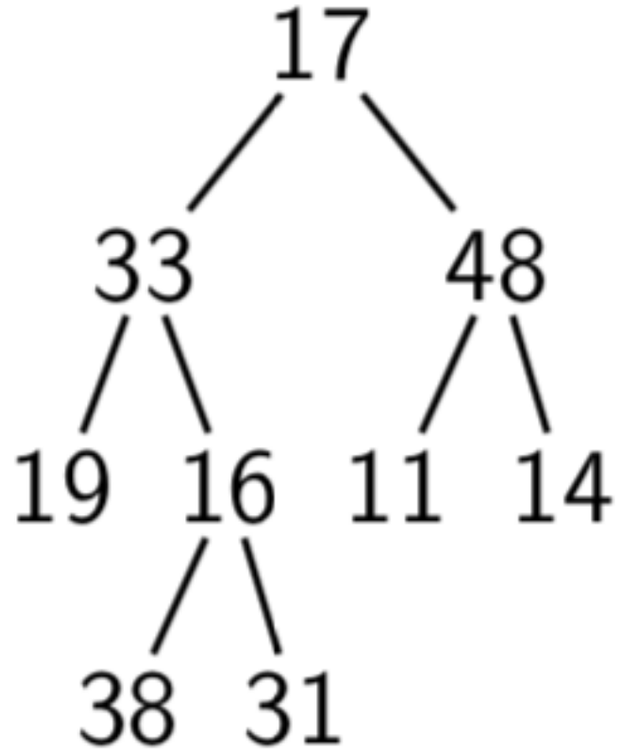

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PostorderTraverse(17)

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Postorder Traversal

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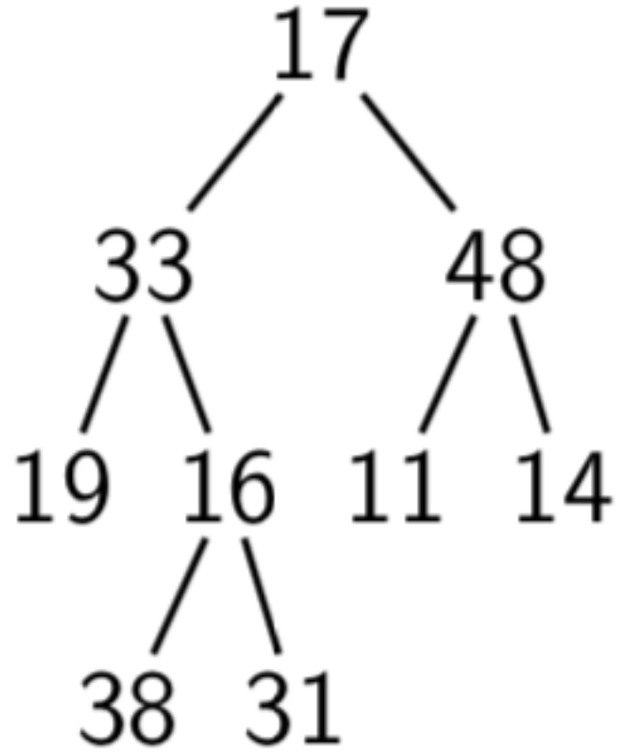

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PostorderTraverse(33)
PostorderTraverse(17)

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Postorder Traversal

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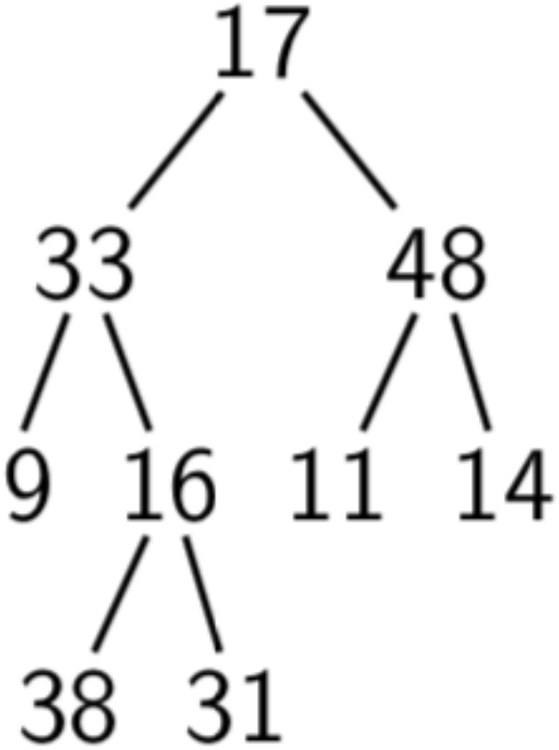

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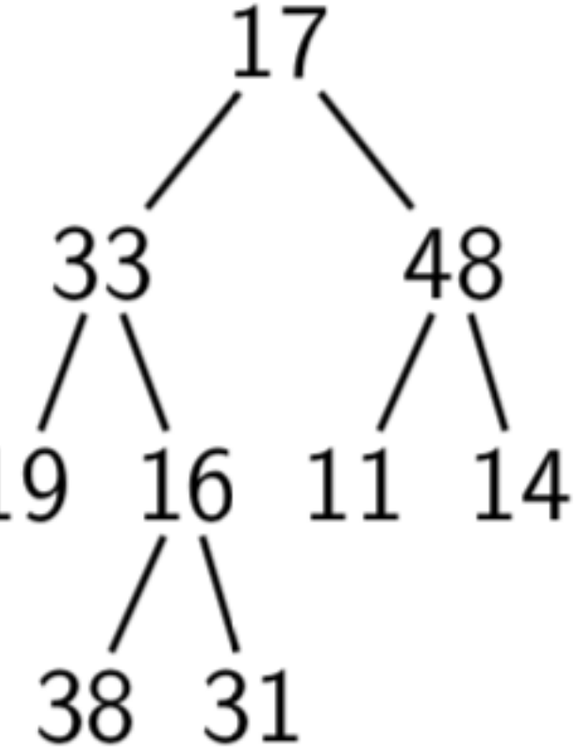

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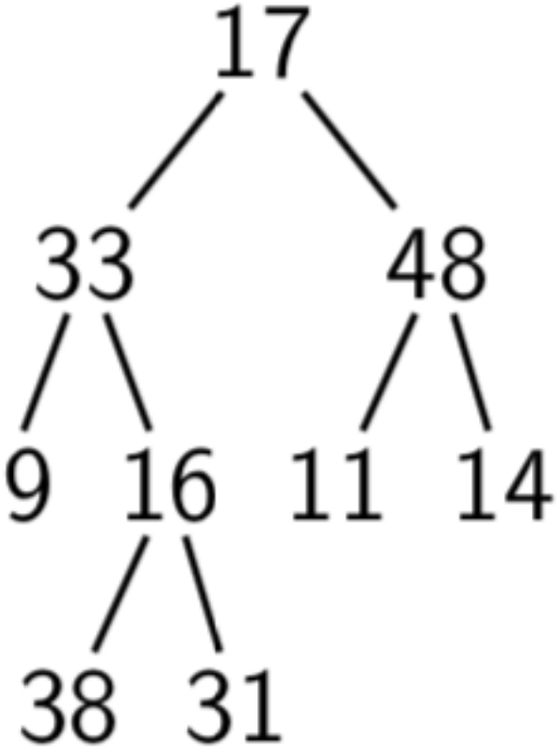

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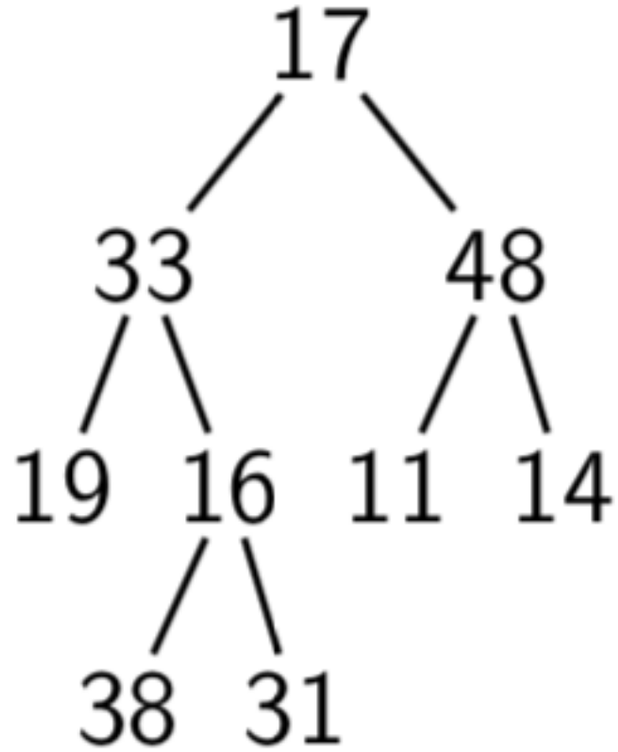

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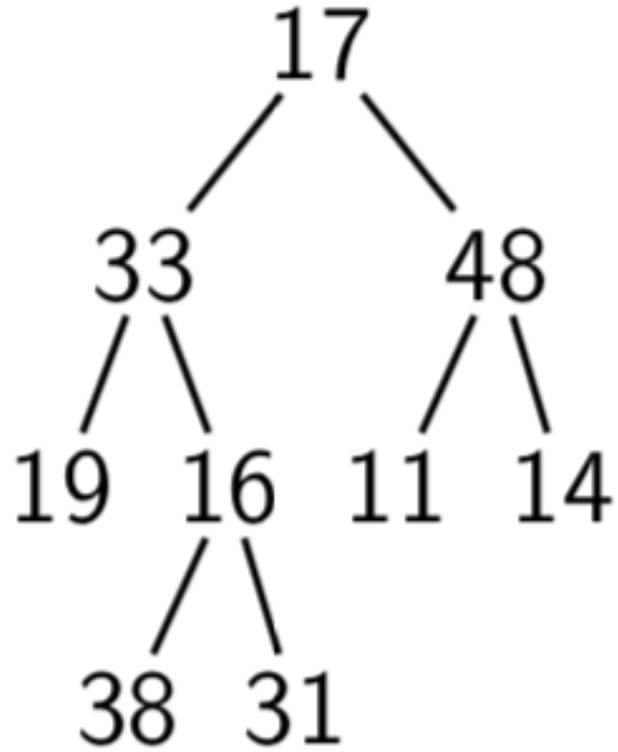

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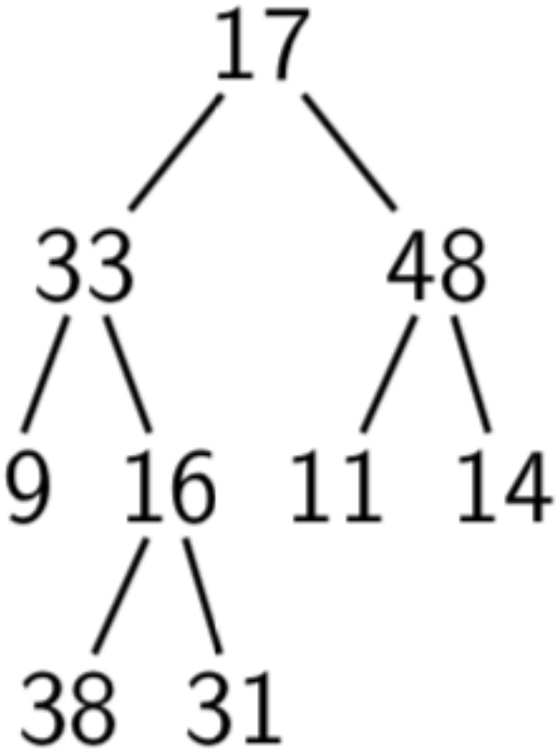

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PostorderTraverse(19)
PostorderTraverse(33)
PostorderTraverse(17)

Call Stack

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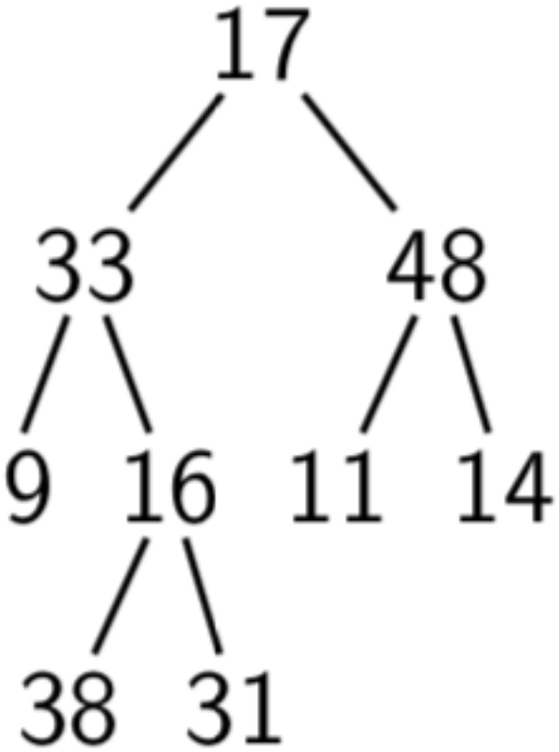
Postorder Traversal

Visit order: 19



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Postorder Traversal

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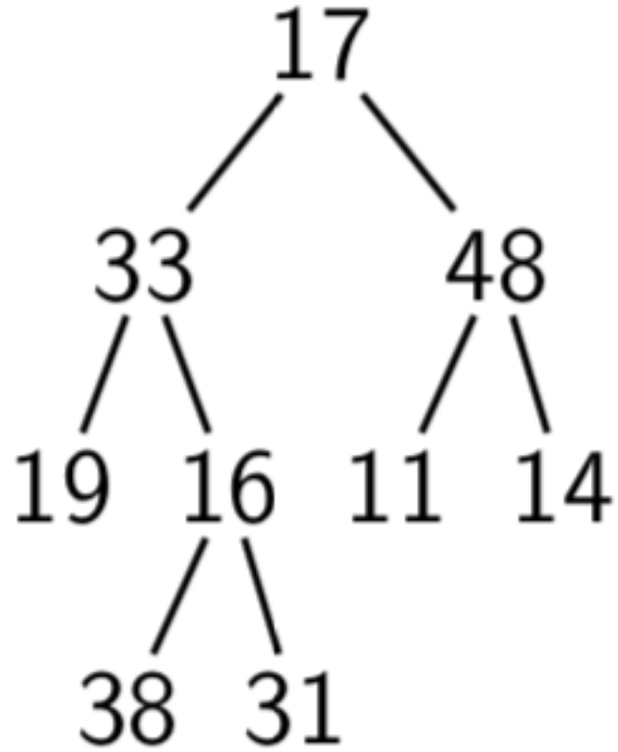

PostorderTraverse(16)
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Call Stack

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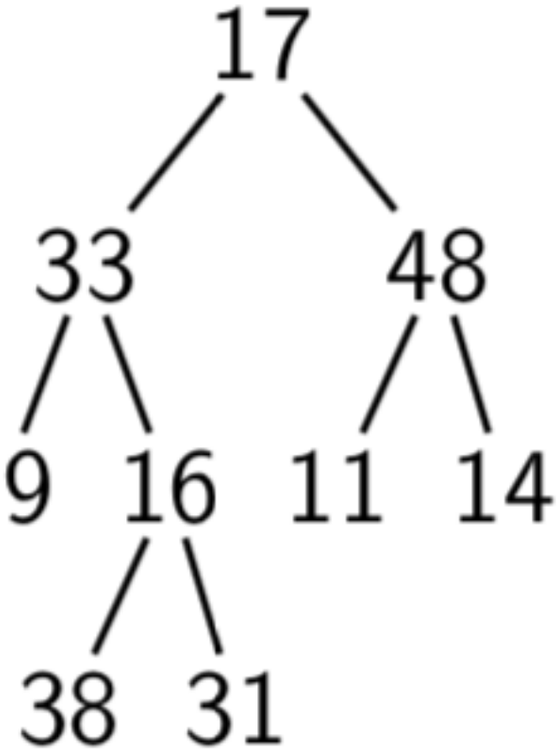
Postorder Traversal

Visit order: 19



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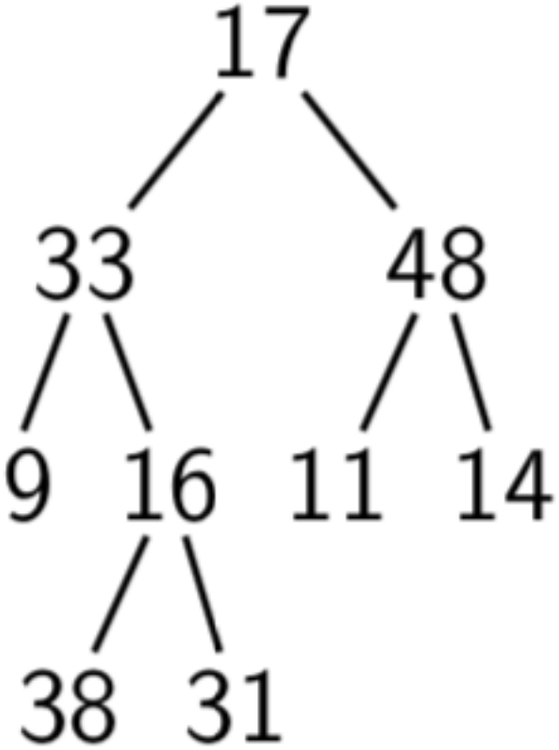
Postorder Traversal

Visit order: 19



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PostorderTraverse(null)
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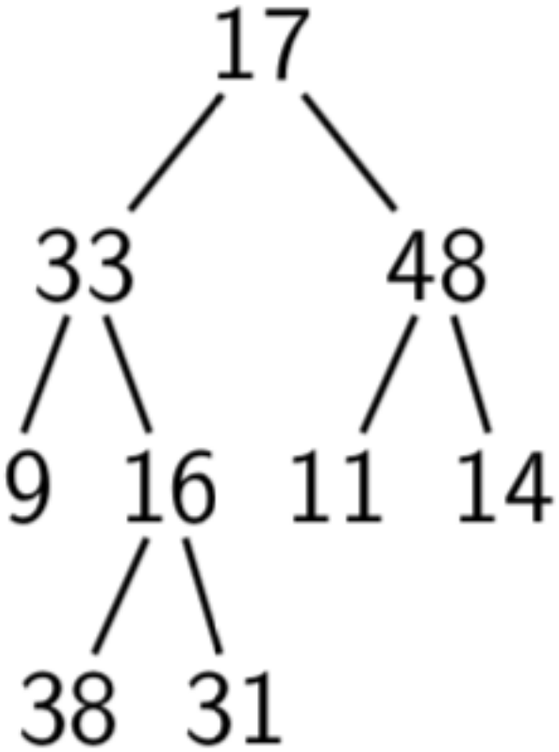

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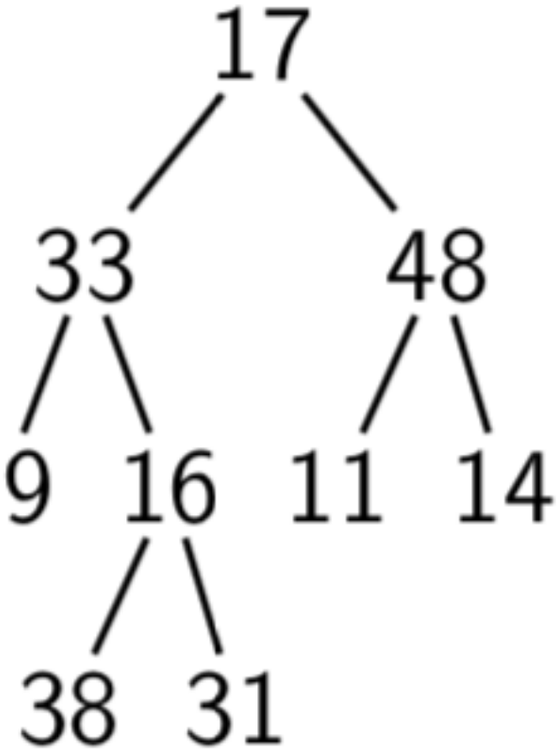

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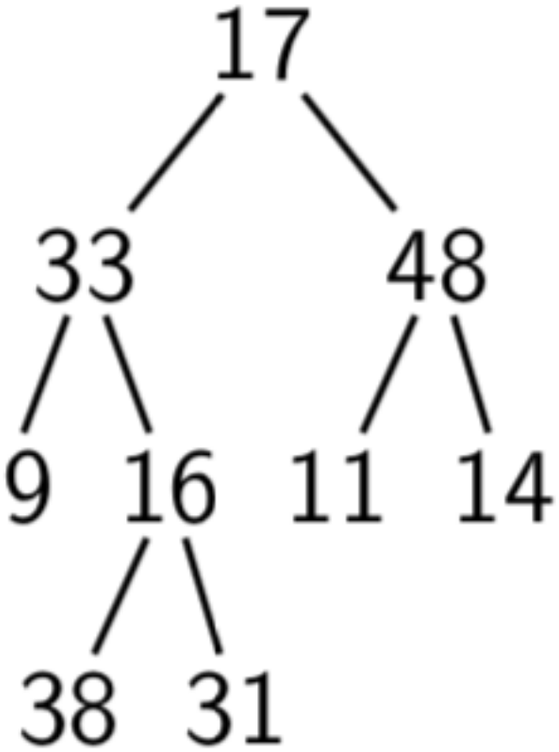

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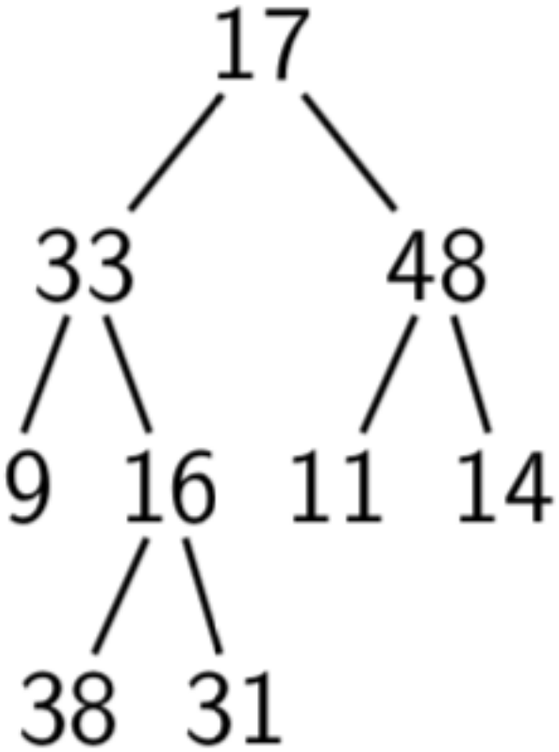
Postorder Traversal

Visit order: 19 38



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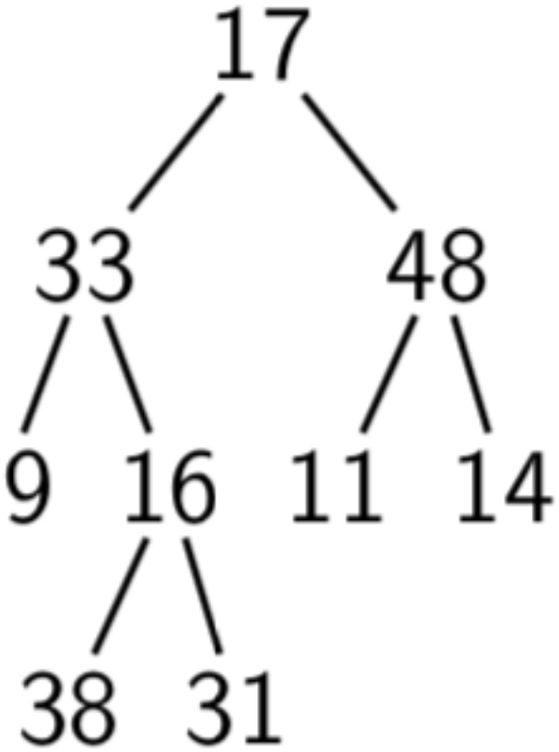

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Postorder Traversal

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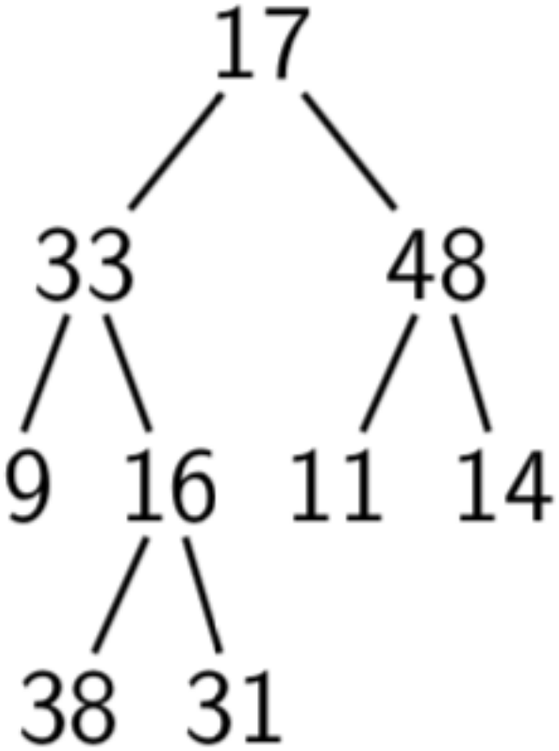

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Postorder Traversal

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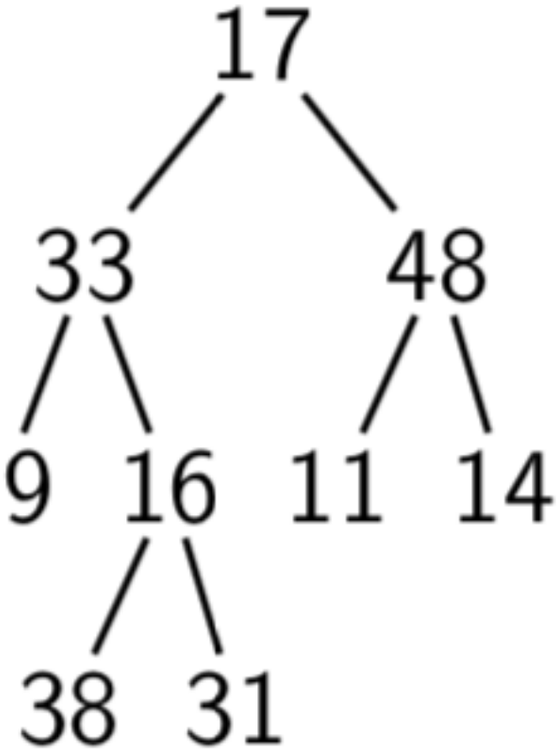

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PostorderTraverse(31)
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PostorderTraverse(33)
PostorderTraverse(17)

Call Stack

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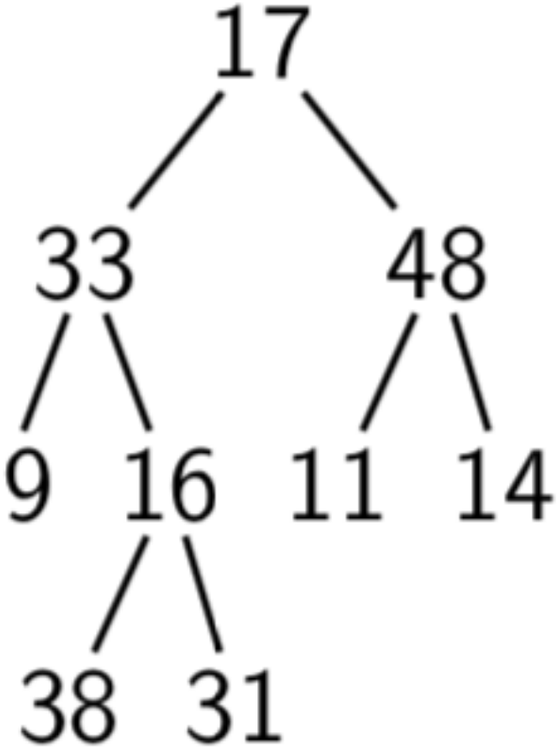
Postorder Traversal

Visit order: 19 38 31



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PostorderTraverse(17)

Call Stack

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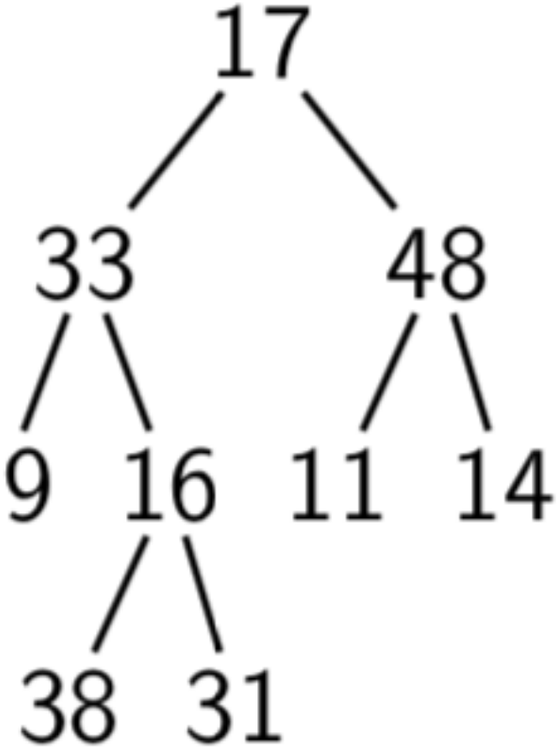
Postorder Traversal

Visit order: 19 38 31



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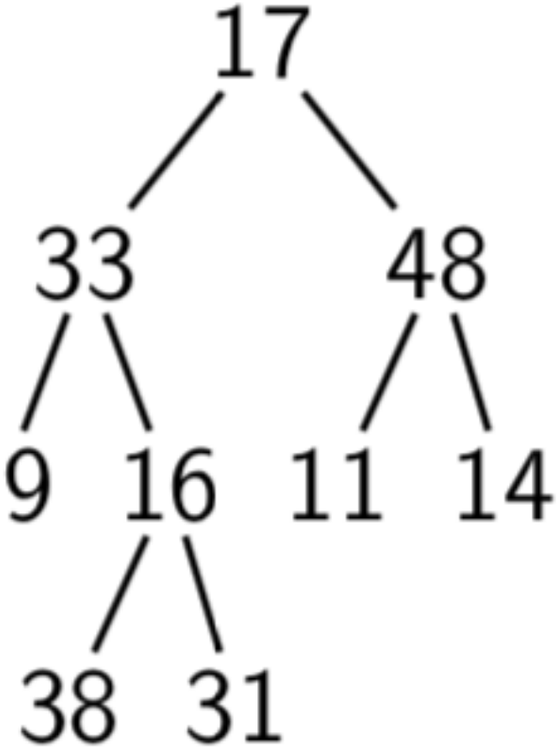
Postorder Traversal

Visit order: 19 38 31 16



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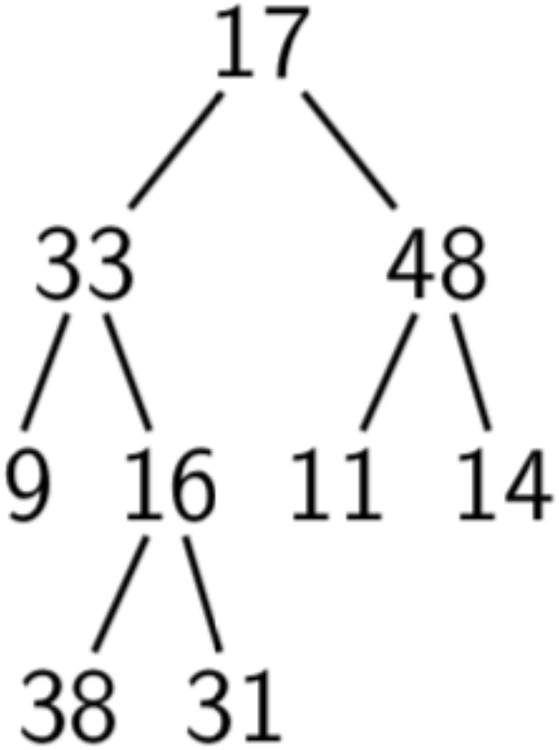

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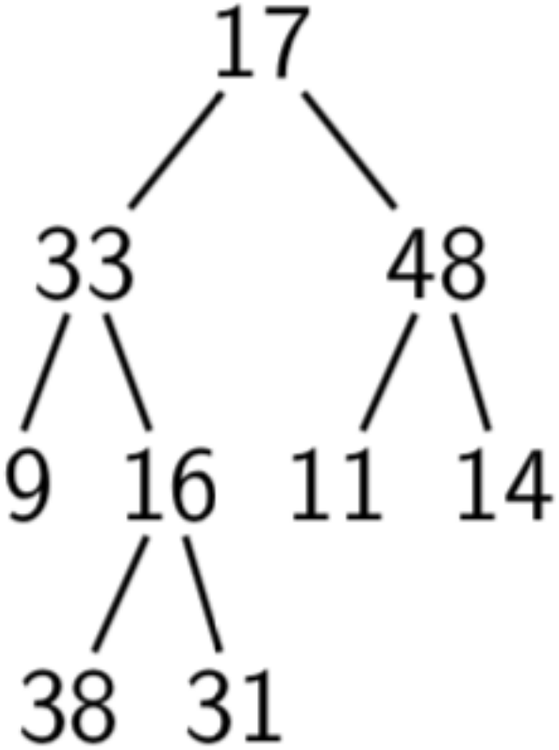
Postorder Traversal

Visit order: 19 38 31 16 33



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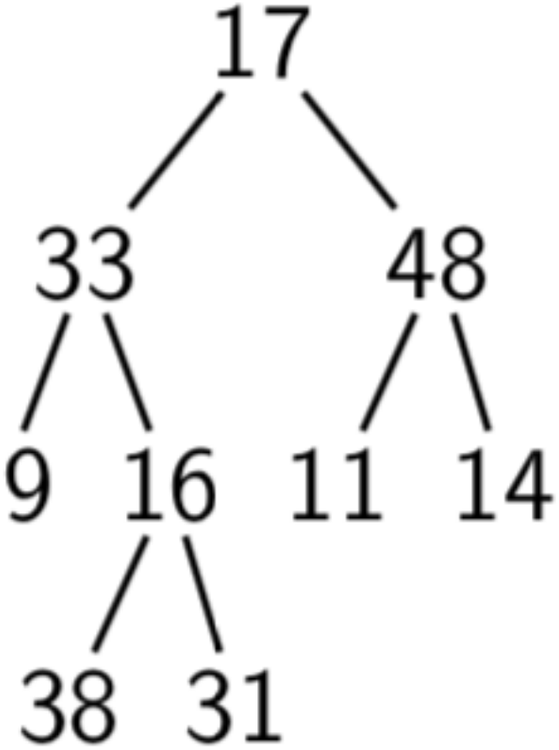
Postorder Traversal

Visit order: 19 38 31 16 33



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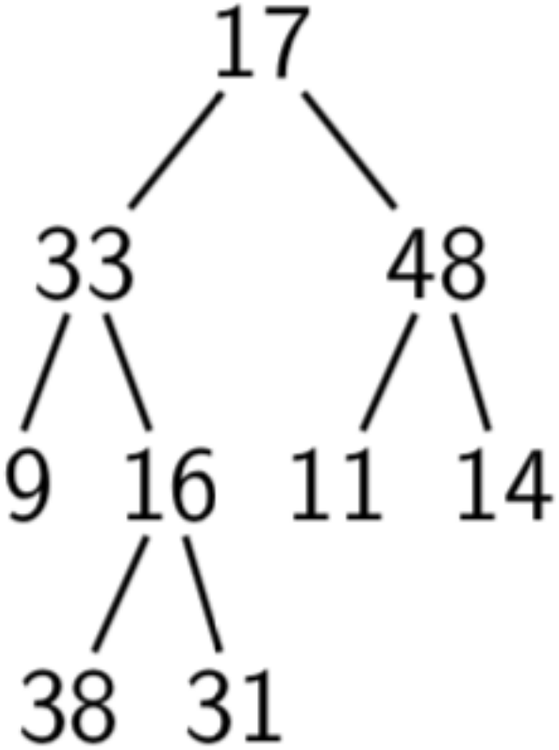
Postorder Traversal

Visit order: 19 38 31 16 33



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PostorderTraverse(48)

PostorderTraverse(17)

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Postorder Traversal

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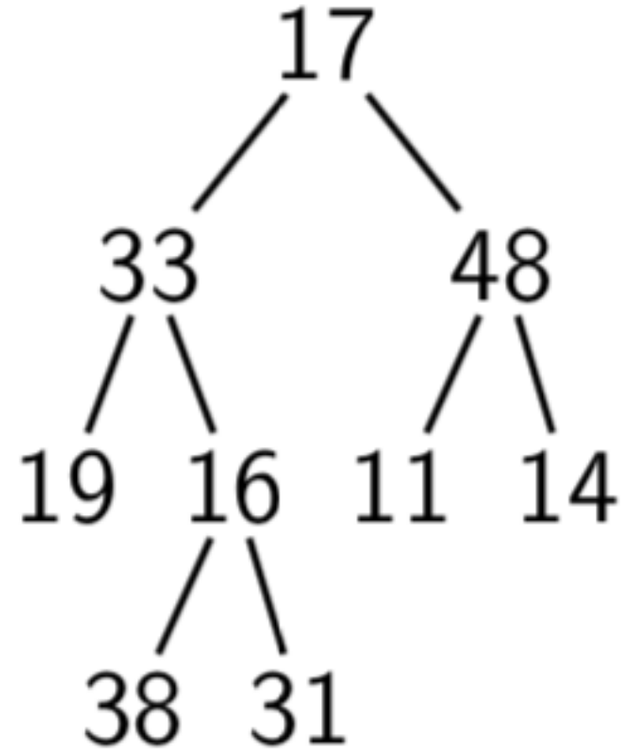
Visit order: 19 38 31 16 33



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PostorderTraverse(11)

PostorderTraverse(48)

PostorderTraverse(17)

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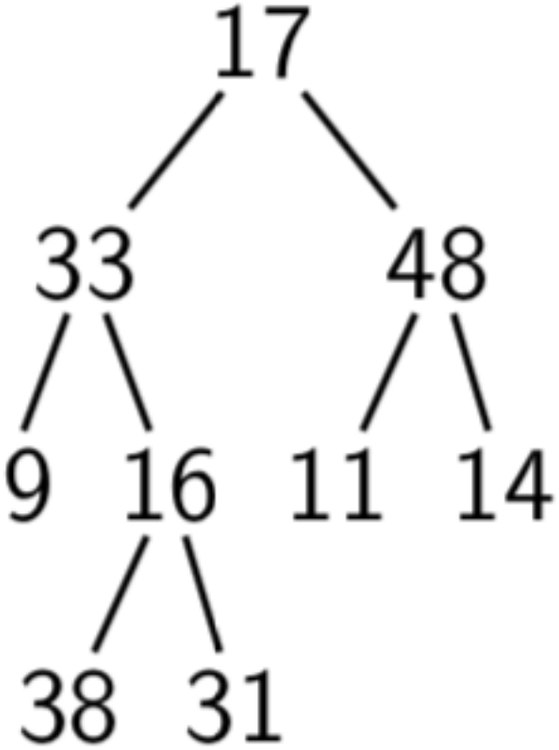
Postorder Traversal

Visit order: 19 38 31 16 33



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PostorderTraverse(48)

PostorderTraverse(17)

Call Stack

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Postorder Traversal

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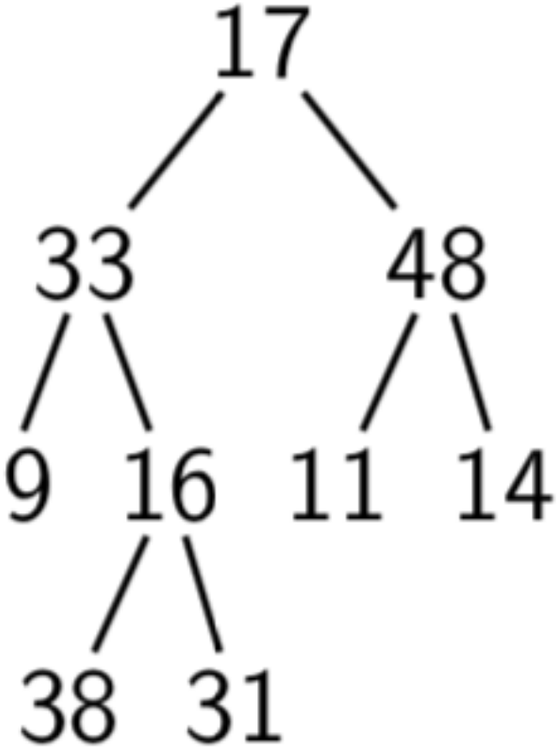
Visit order: 19 38 31 16 33 11



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Call Stack

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Postorder Traversal

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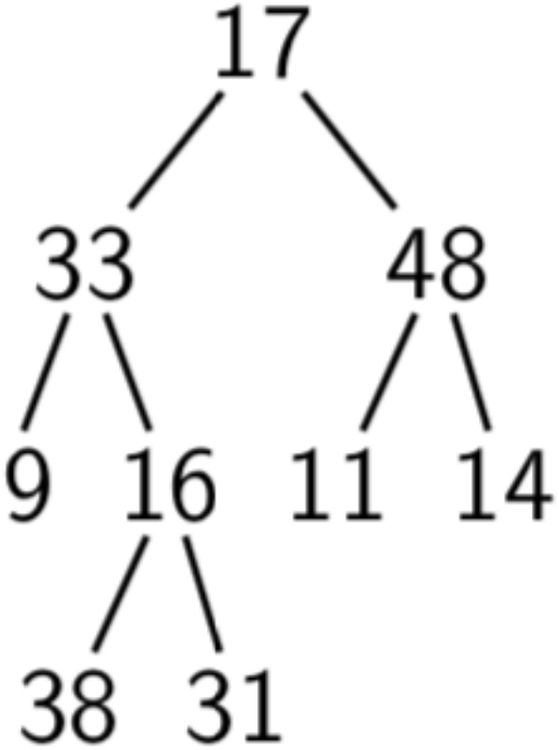

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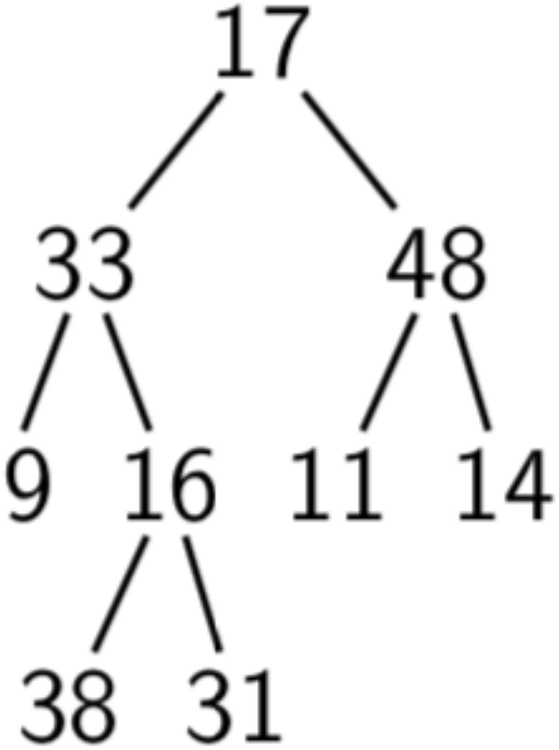
Visit order: 19 38 31 16 33 11



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Postorder Traversal

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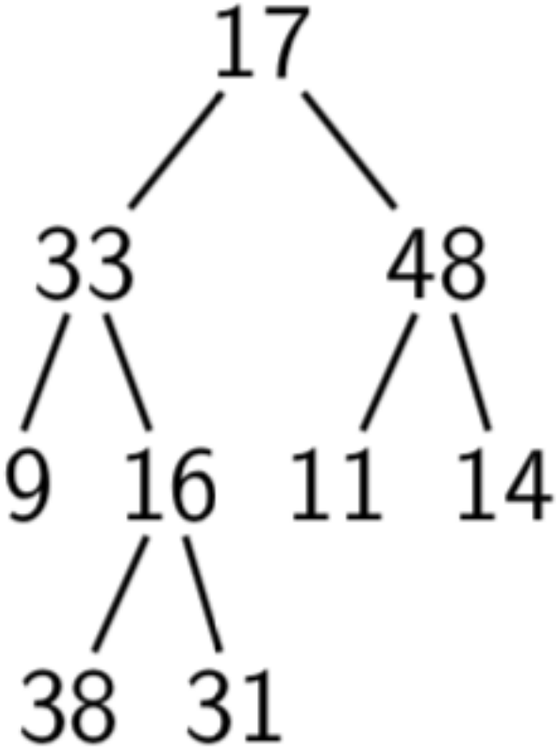

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PostorderTraverse(48)

PostorderTraverse(17)

Call Stack

(…skipping the calls to PostorderTraverse(null)…)

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Postorder Traversal

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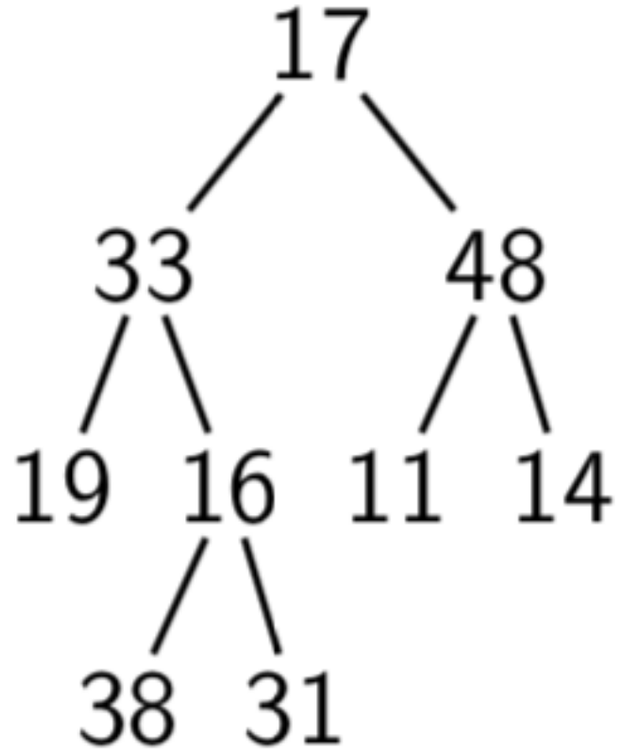
Visit order: 19 38 31 16 33 11 14



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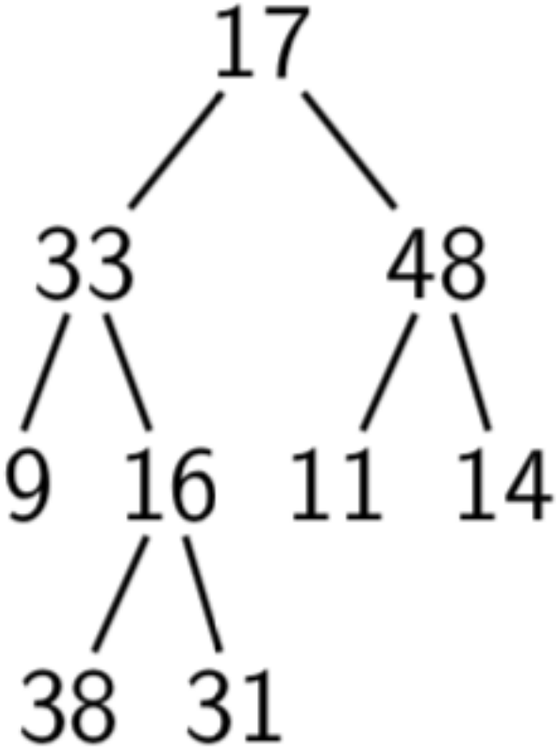

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Postorder Traversal

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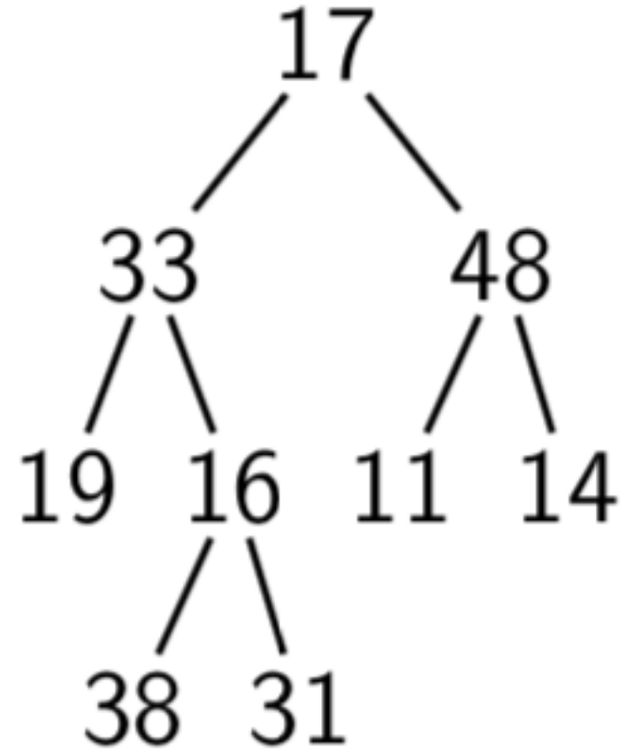

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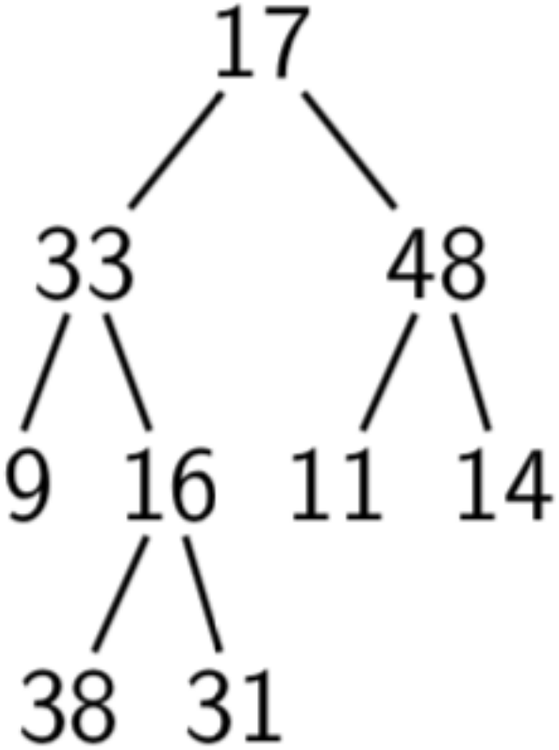

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Postorder Traversal

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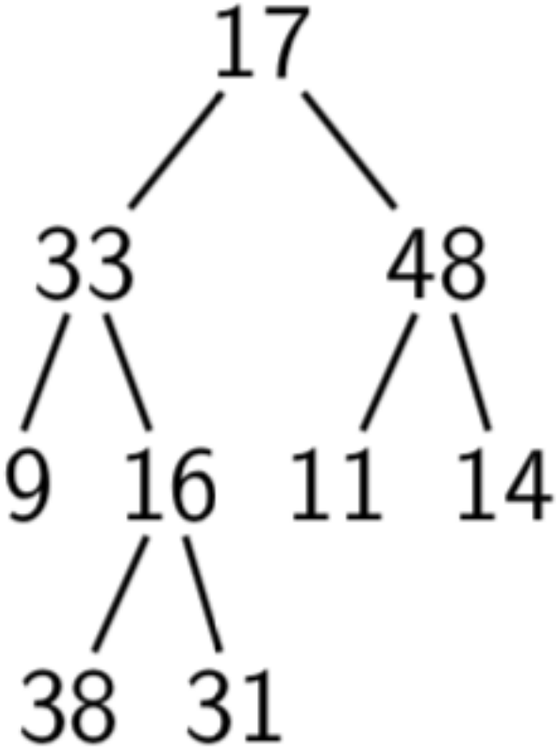

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Postorder Traversal

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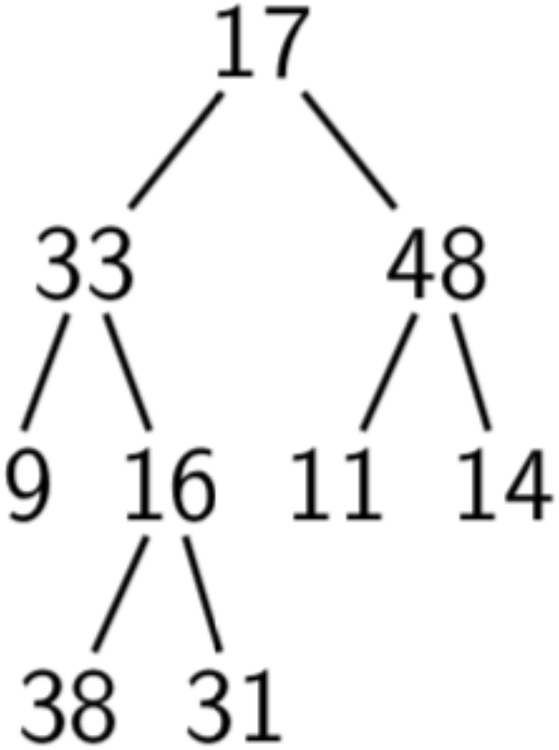

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Call Stack

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Preorder Traversal Using a Stack

- Explicitly maintain a stack of nodes

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- In an implementation, the elements placed onto the stack would not be whole trees, but **pointers** to the corresponding internal nodes

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Level-Order Traversal Using a Queue

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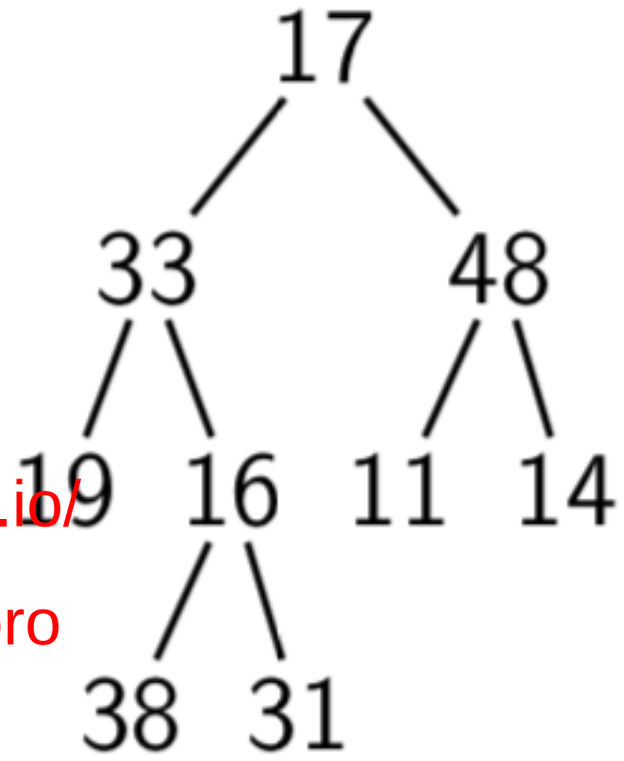
- Replace the stack with a **queue**



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Queue:

Traversal order:

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Level-Order Traversal Using a Queue

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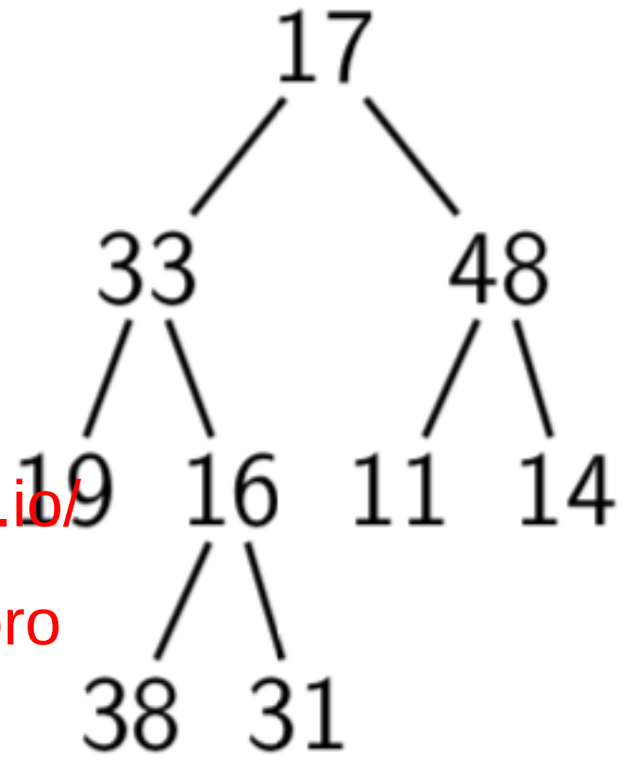
- Replace the stack with a **queue**



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Queue: 17

Traversal order:

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Level-Order Traversal Using a Queue

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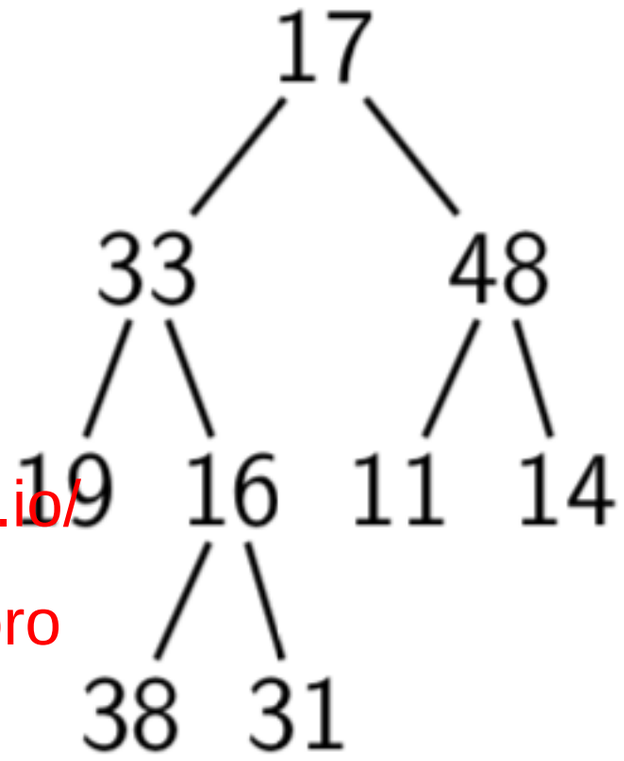
- Replace the stack with a **queue**



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Queue:

Traversal order:

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Level-Order Traversal Using a Queue

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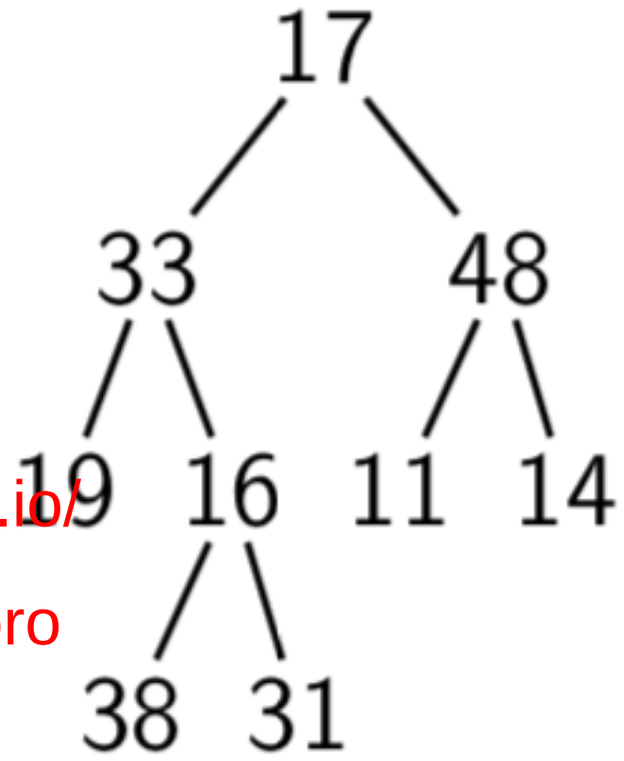
- Replace the stack with a **queue**



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Queue:

Traversal order: 17

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Level-Order Traversal Using a Queue

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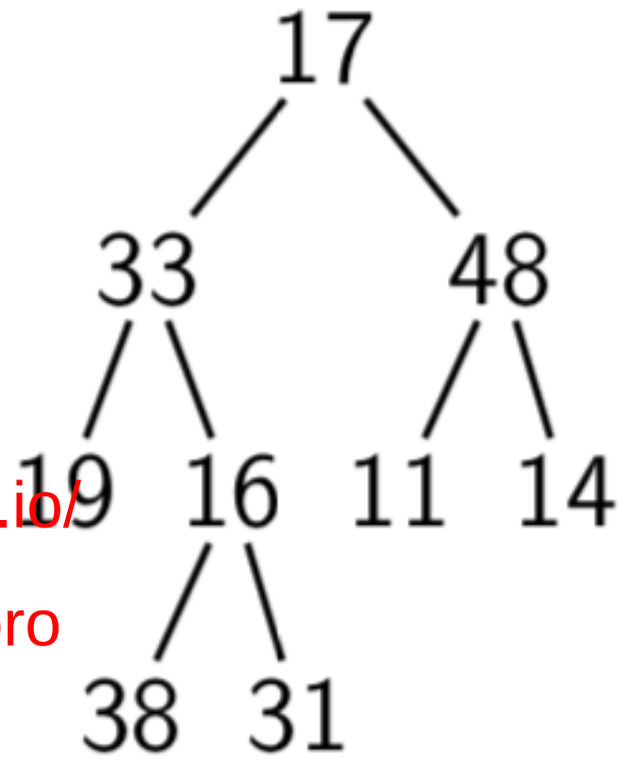

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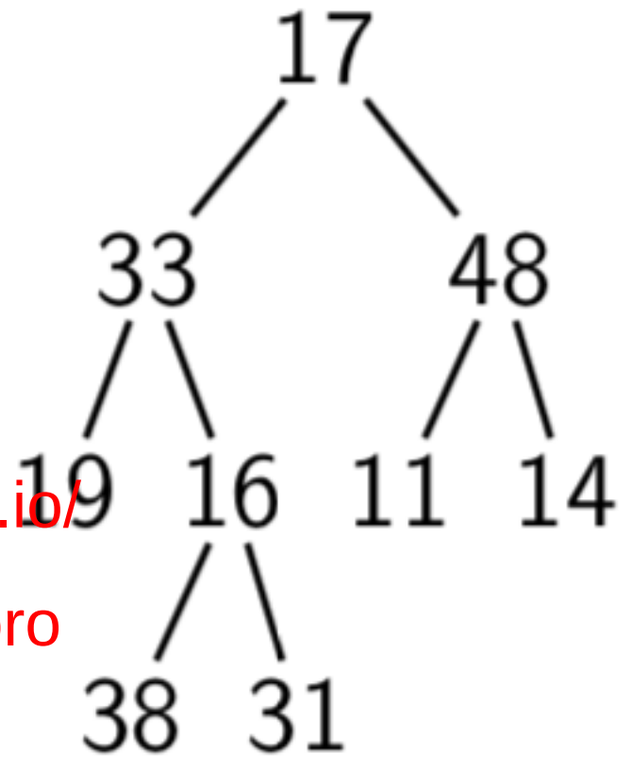

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Queue: 33 48

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Level-Order Traversal Using a Queue

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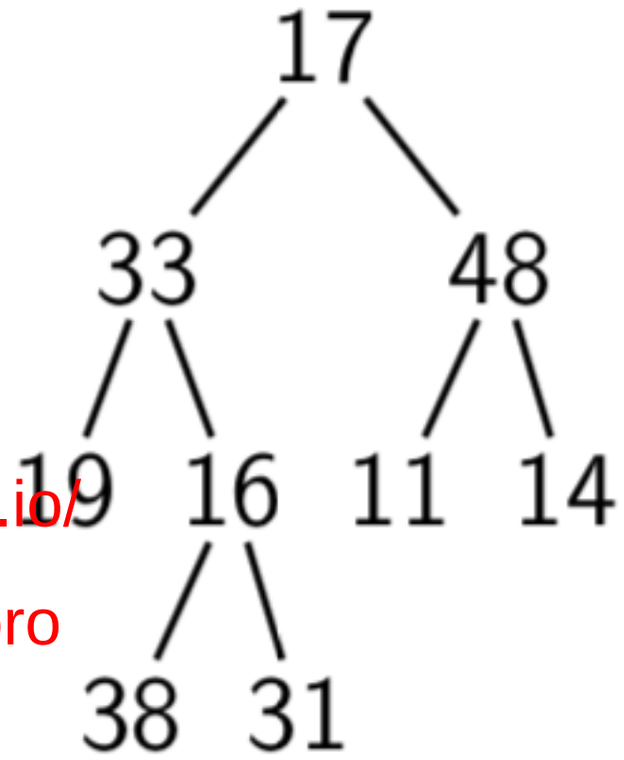

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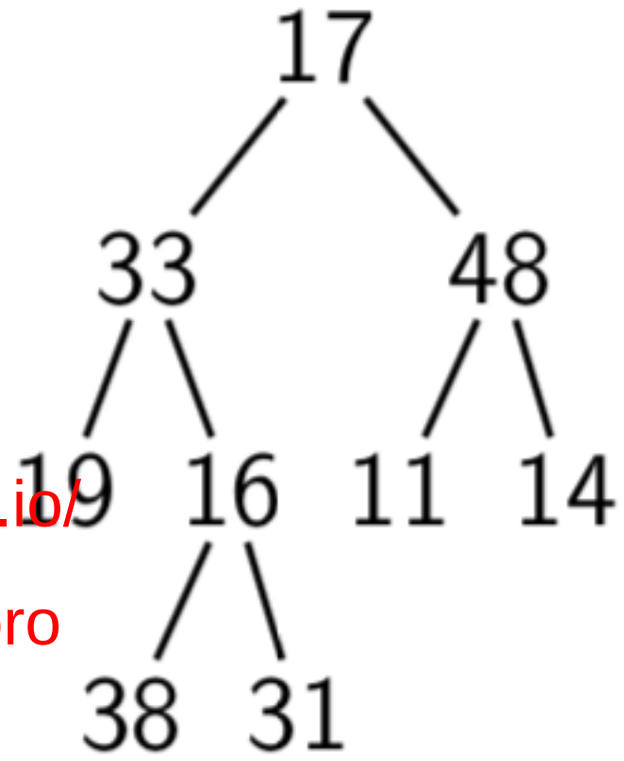

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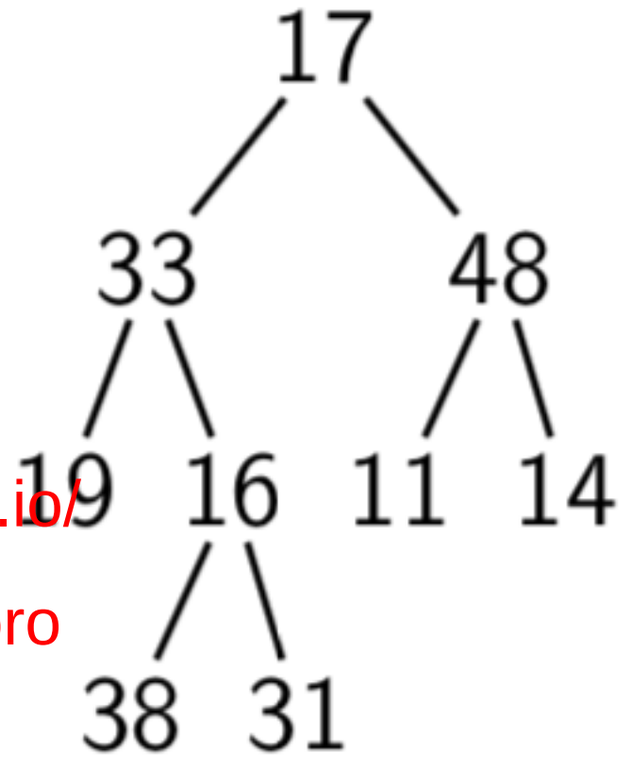

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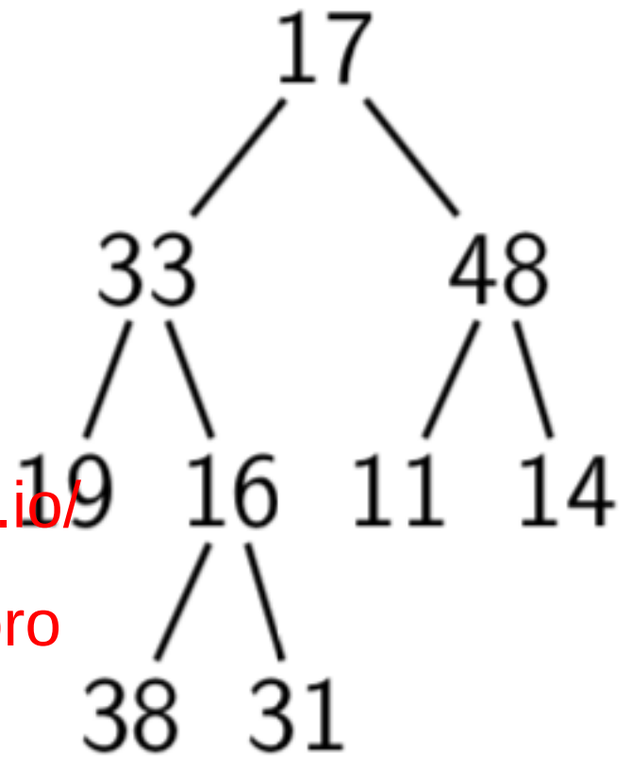

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Level-Order Traversal Using a Queue

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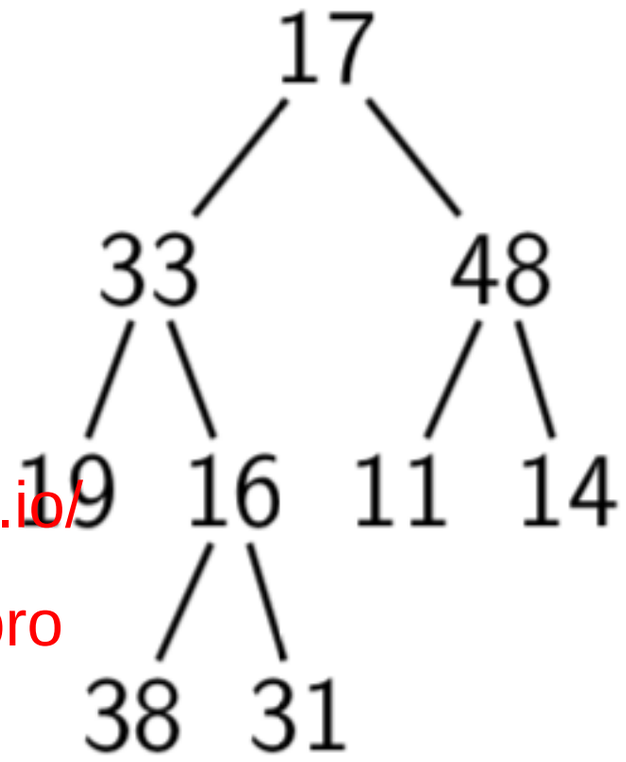

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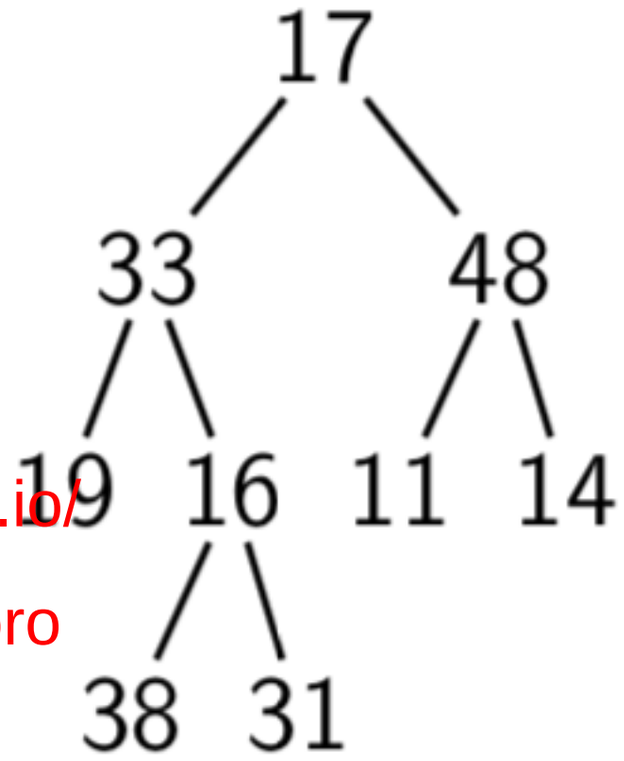

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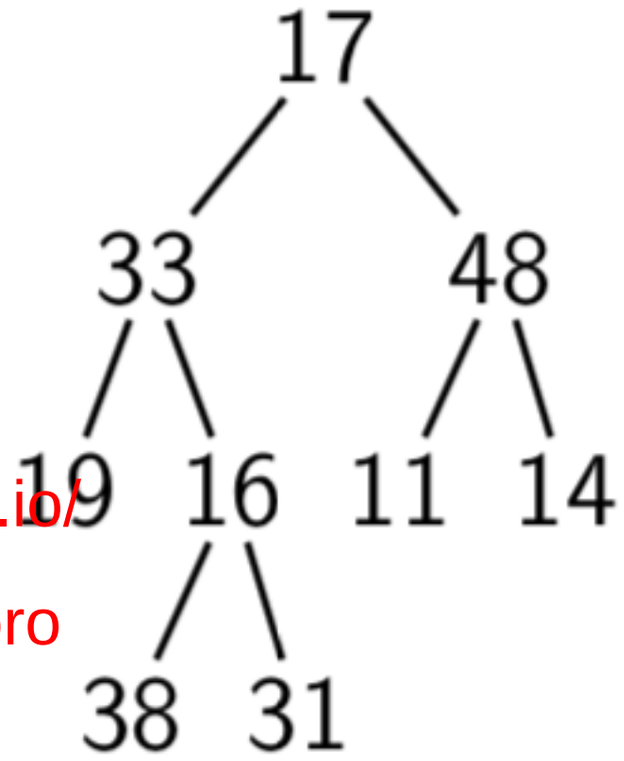

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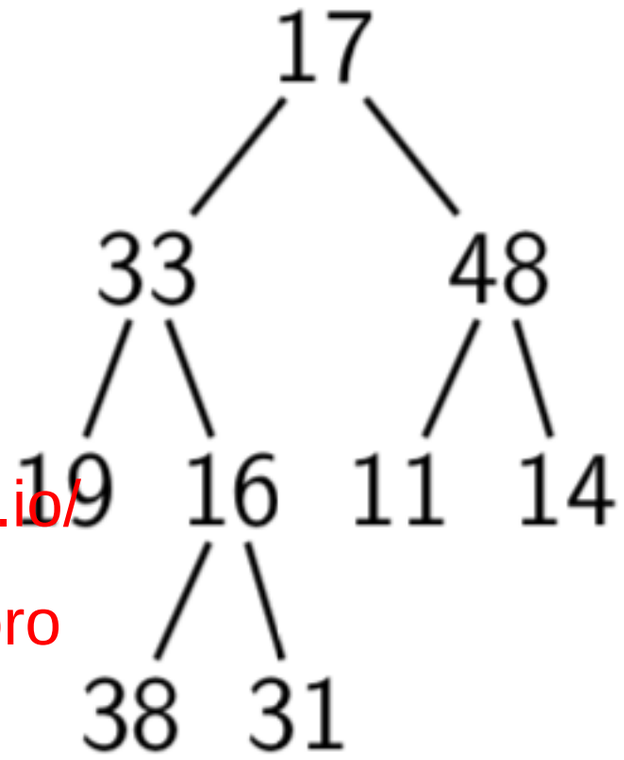

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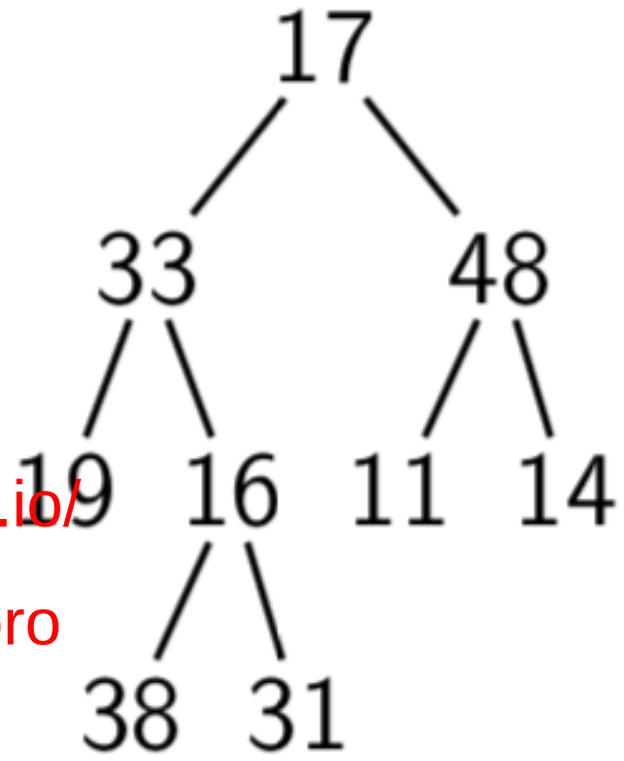

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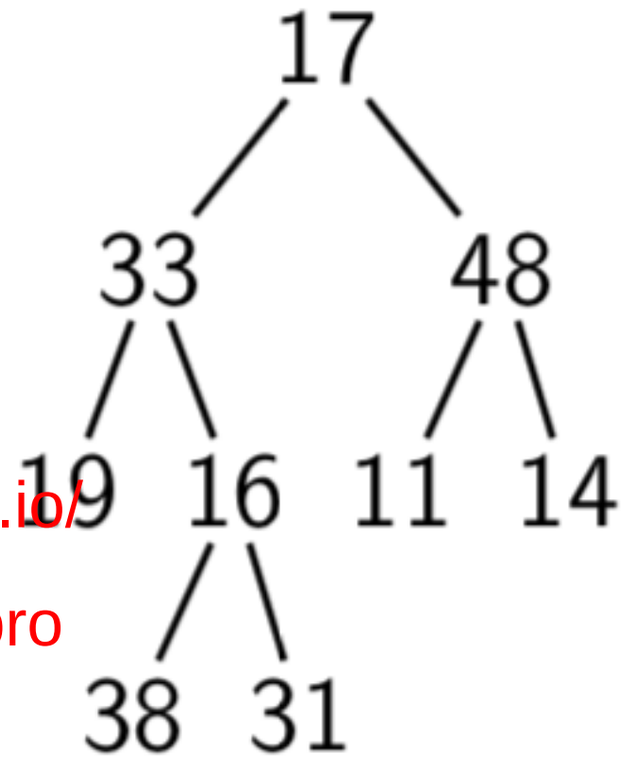

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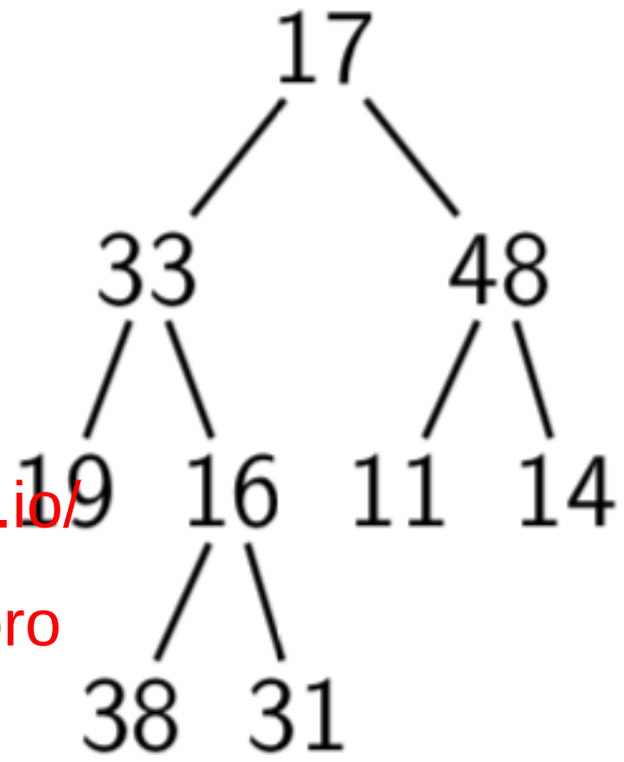

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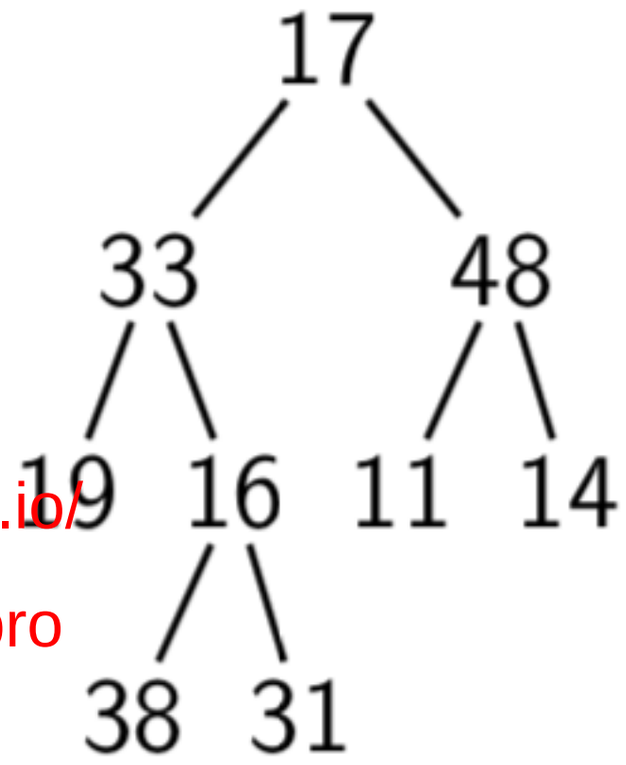

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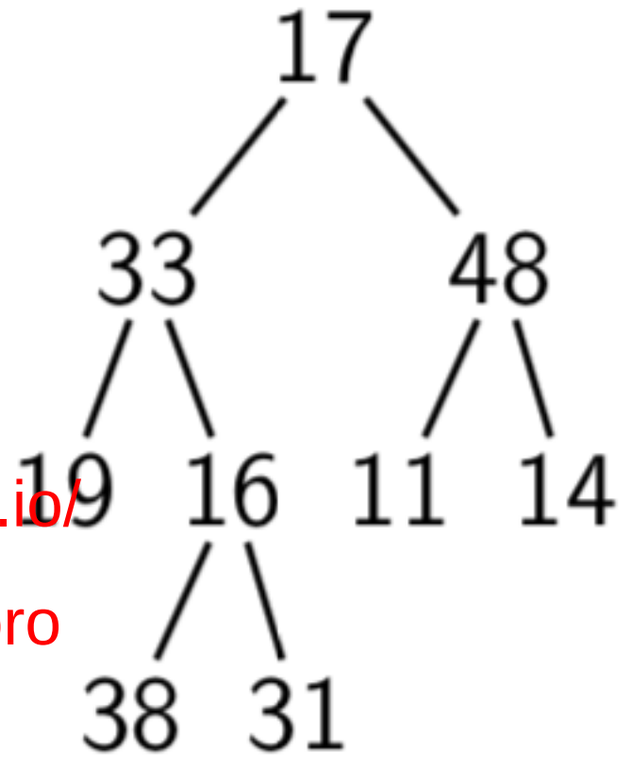

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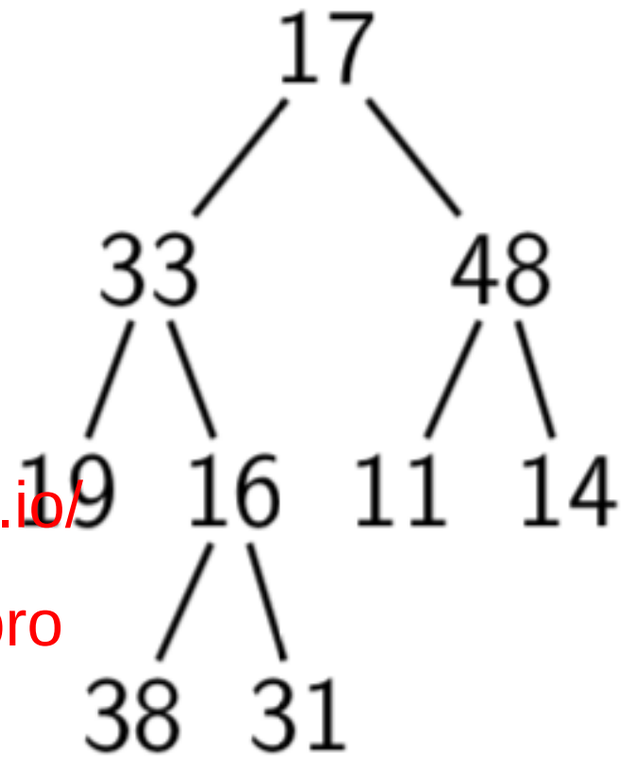

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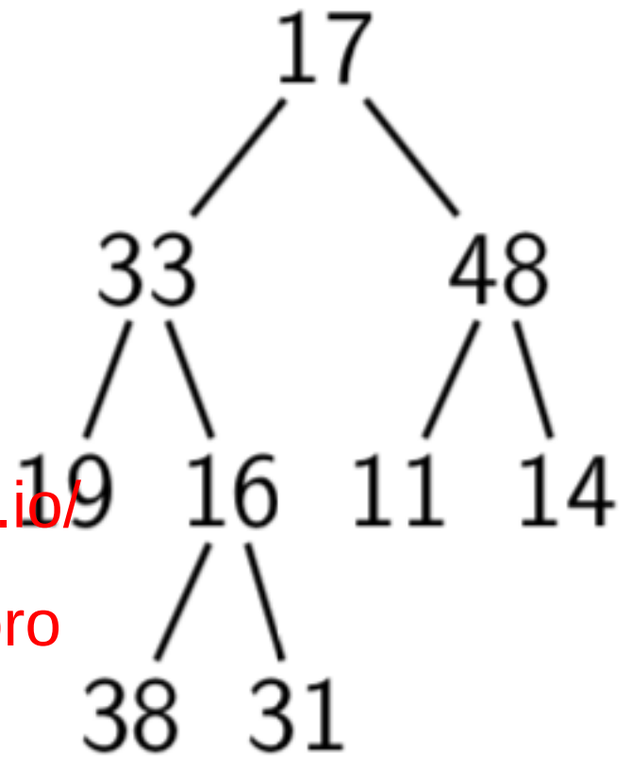

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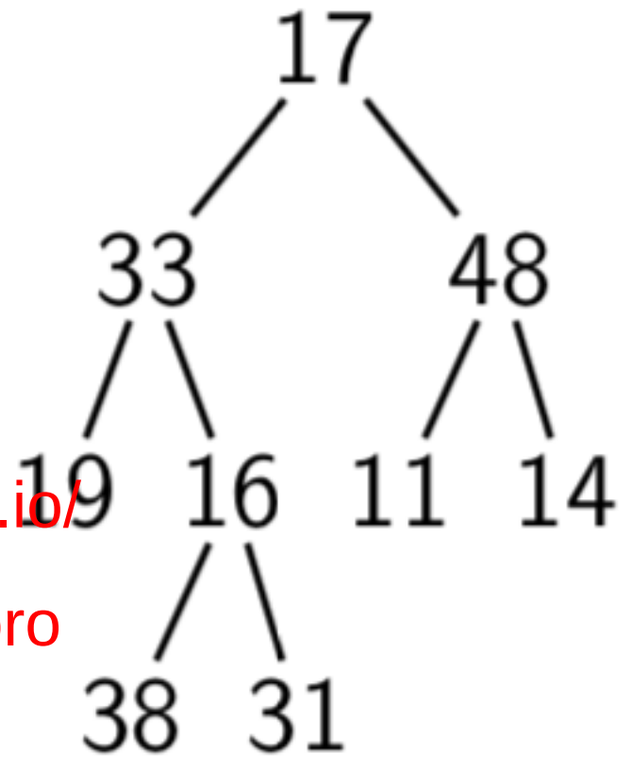

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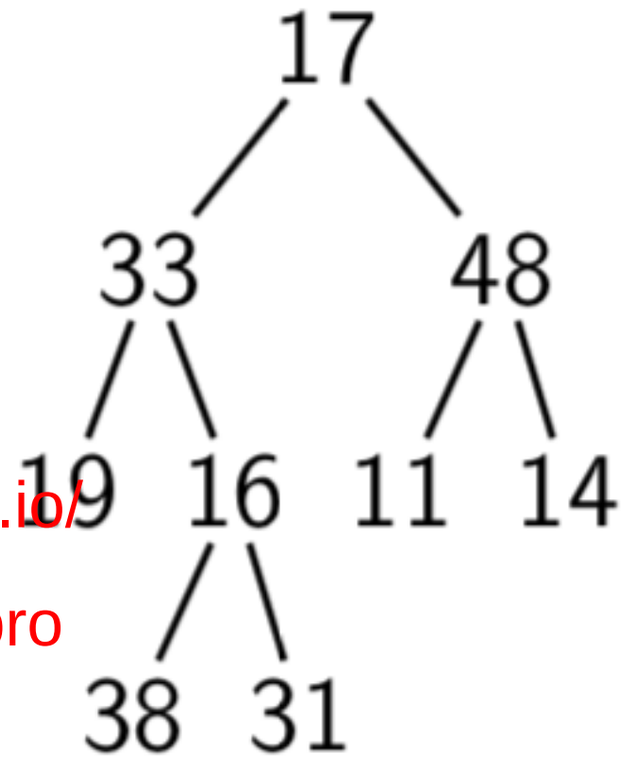

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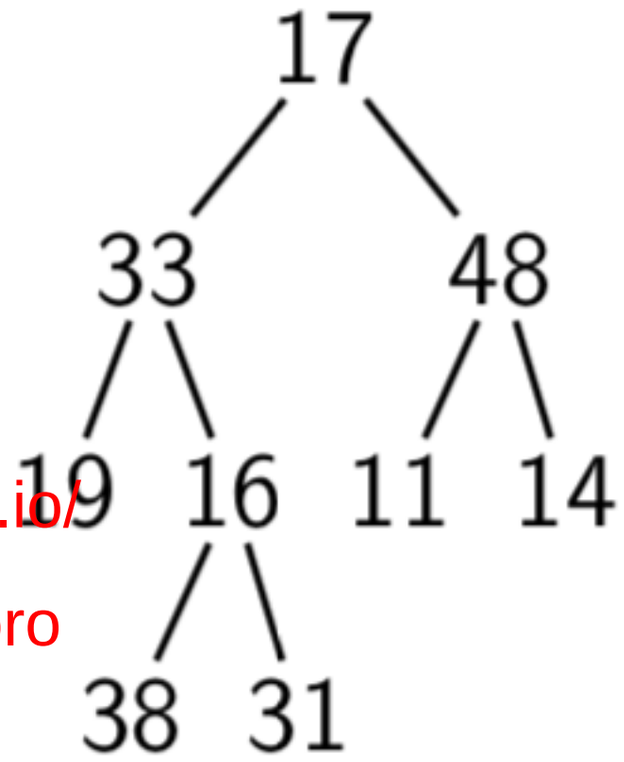

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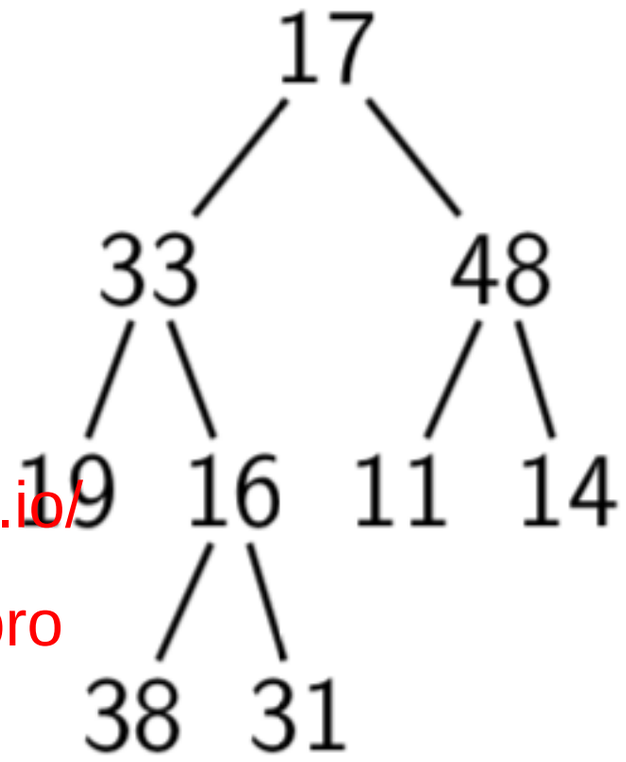

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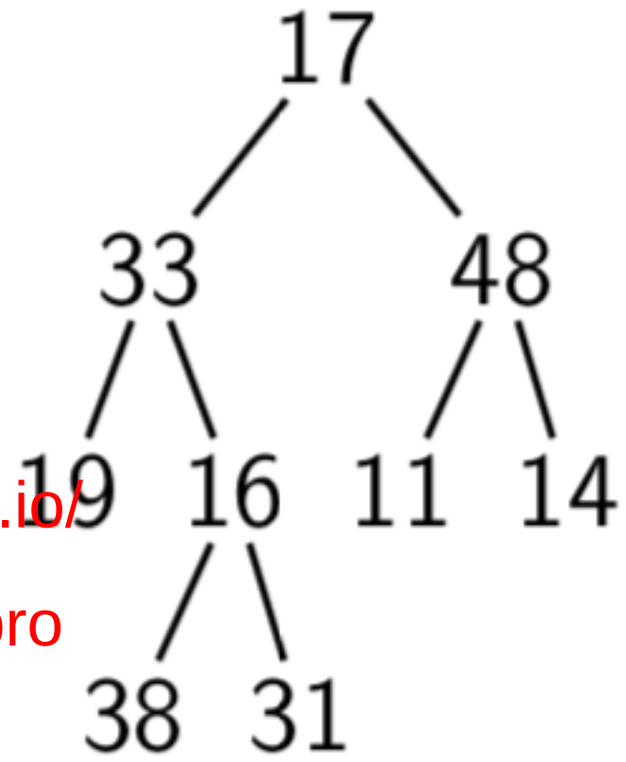

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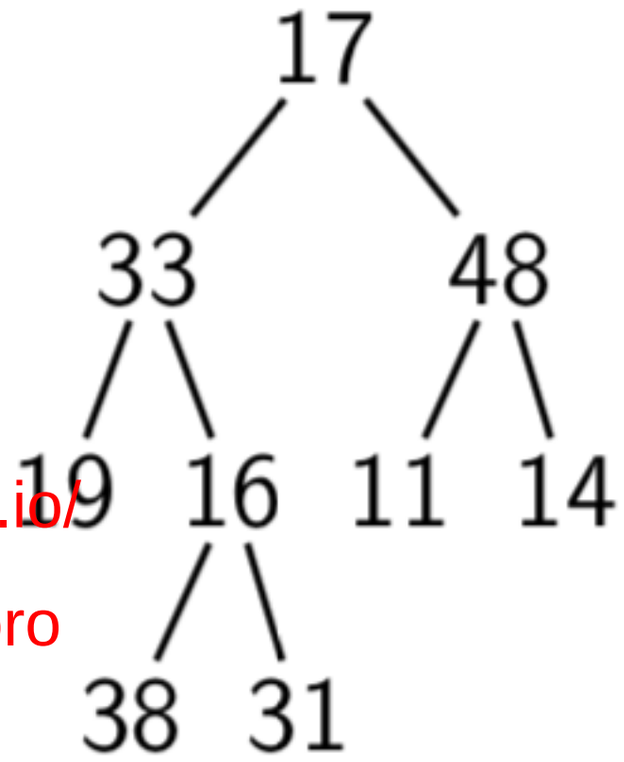

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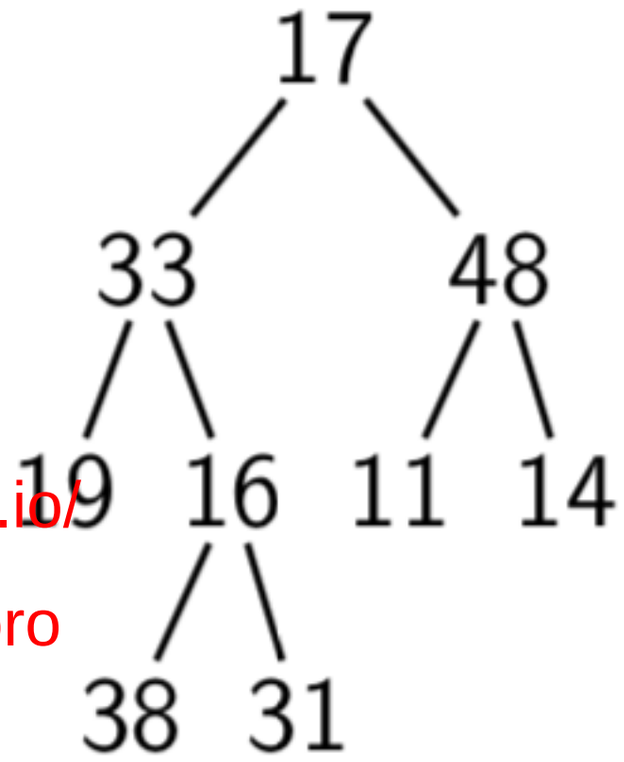

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Closest Pair Problem (2D) Revisited (see Lecture 5)

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Closest Pair Problem Revisited

- In Lecture 5 we gave a brute-force algorithm for the closest pair problem: Given n points in the Cartesian plane, find a pair with minimal distance.

- The brute-force method had complexity $\Theta(n^2)$. We can use divide-and-con namely $\Theta(n \log n)$.

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- First, sort the points by x value, re the result in array **byX**. Also sort the points by y value and store the result in array **byY**.

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- Now we can identify the x median, and recursively process the set P_L of points with lower x values, as well as the set P_R with higher x values.

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Closest Pair Problem Revisited

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Closest Pair Problem Revisited

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Closest Pair Problem Revisited

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Closest Pair Problem Revisited

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Closest Pair Problem Revisited

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Closest Pair Problem Revisited

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Closest Pair Problem Revisited

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Closest Pair Problem Revisited

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- The recursive calls will identify d_L, the shortest distance for pairs in P_L, and d_R, the shortest distance for pairs in P_R.

- Let m be the x median and let d = min(d_L,d_R). This d is a candidate for the smallest distance.

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- But d may not be the g re could be some close pair whose points are

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the median line x = m.

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- For candidates that may improve on d we only need to look at those in the band m – d ≤ x ≤ m + d.

- So pick out, from array byY, each point p with x-coordinate between m–d and m+d, and keep these in array S.

- For each point in S, consider just its “close” neighbours in S.

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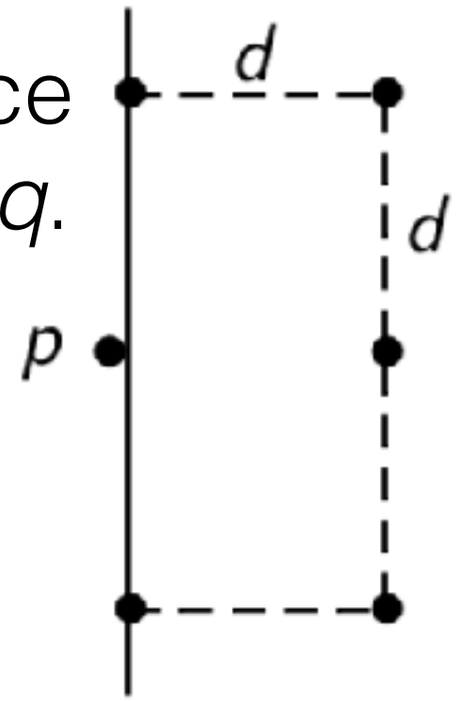
Closest Pair Problem Revisited



- The following calculates the smallest distance and leaves the (square of the) result in *minsq*.

- It can be shown that the while loop can execute **at most 3 times** for each *i* value—see diagram.

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You're Learning Heaps!

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- Next up: Priority nd heapsort.

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