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MIT WORLD PEACE UNIVERSITY | PUNE

TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

CET2001B Advanced Data Structures

S. Y. B. Tech CSE **Semester – IV**

SCHOOL OF COMPUTER ENGINEERING AND TECHNOLOGY

CET2001B: Advanced Data Structures

e-requisites: Fundamentals of Data Structures

Course Objectives:

1. Knowledge

i. Learn the nonlinear data structure and its fundamental concept.

2. Skills

i. Understand the different nonlinear data structures such as Trees and Graph.

ii. Study the concept of symbol table, heap, search tree and multiway search tree.

iii. Study the different ways of file organization and hashing concepts.

3. Attitude

i. Learn to apply advanced concepts of nonlinear data structure to solve real world problems.

Course Outcomes:

After completion of the course the students will be able to :-

1. To choose appropriate non-linear data structures to solve a given problem.

2. To apply advanced data structures for solving complex problems of various domains.

3. To apply various algorithmic strategies to approach the problem solution.

4. To compare and select different file organization and to apply hashing for implementing direct access organization.

CET2001B Advanced Data Structures: Assessment Scheme:

Class Continuous Assessment (CCA) - 30 Marks

Mid Term	Active Learning	Theory Assignment
15 Marks	10 Marks	5 Marks

Laboratory Continuous Assessment (LCA) - 30 Marks

Practical Performance	Additional Implementation/ On paper Design	End term Practical Examination
10 Marks	10 Marks	10 Marks

Term End Examination: 40 Marks

Syllabus

1. Hashing - Concepts-hash table, hash function, basic operations, bucket, collision, probe, synonym, overflow, open hashing, closed hashing, perfect hash function, load density, full table, load factor, rehashing, issues in hashing, hash functions- properties of good hash function, division, multiplication, extraction, mid-square, folding and universal, Collision resolution strategies- open addressing and chaining, Hash table overflow- open addressing and chaining.

2. Tree - Basic Terminology, Binary Tree- Properties, Converting Tree to Binary Tree, Representation using Sequential and Linked organization, Binary tree creation and Traversals, Operations on binary tree.
Binary Search Tree (BST) and its operations,
Threaded binary tree- Creation and Traversal of In-order Threaded Binary tree.
Case Study- Expression tree

3. Graph - Basic Terminology, Graphs (Directed, Undirected), Various Representations, Traversals & Applications of graph- Prim's and Kruskal's Algorithms, Dijsktra's Single source shortest path, Analysis complexity of algorithm, topological sorting.

Continued…

4. Heap - Heap as a priority queue, Heap sort. Symbol Table-Representation of Symbol Tables- Static tree table and Dynamic tree table, Weight balanced tree - Optimal Binary Search Tree (OBST), OBST as an example of Dynamic Programming, Height Balanced Tree- AVL tree.
Search trees: Red-Black Tree, AA tree, K-dimensional tree, Splay Tree.

5. Multiway search trees, B-Tree - insertion, deletion, B+Tree - insertion, deletion, use of B+ tree in Indexing, Trie Tree.

Files: concept, need, primitive operations. Sequential file organization - concept and primitive operations, Direct Access File- Concepts and Primitive operations, Indexed sequential file Organization-concept, types of indices, structure of index sequential file, Linked Organization - multi list files.

List of Assignments

1. Implement following polynomial Operations using Circular Linked List :
   1) Create 2) Display 3) Addition

2. Implement binary tree and perform following operations: Creation of binary tree and traversal recursive and non-recursive.

3. Implement a dictionary using a binary search tree where the dictionary stores keywords & its meanings. Perform following operations:
● Insert a keyword
● Delete a keyword
● Create mirror image and display level wise
● Copy
● Create mirror image and display level wise

4. Implement threaded binary tree. Perform inorder traversal on the threaded binary tree.

List of Assignments contd…

5. Consider a friend's network on Facebook social web site. Model it as a graph to represent each node as a user and a link to represent the friend relationship between them using adjacency list representation and perform DFS traversal. Perform BFS traversal for the above graph.

6. A business house has several offices in different countries; they want to lease phone lines to connect them with each other and the phone company charges different rent to connect different pairs of cities. (Create & display of Graph). Solve the problem using Prim's algorithm.

7. Read the marks obtained by students of second year in an online examination of a particular subject. Find the maximum and minimum marks obtained in that subject. Use heap data structure and heap sort.

8. Implement direct access file using hashing (linear probing with and without replacement) perform following operations on it a) Create Database b) Display Database c) Add a record d) Search a record e) Modify a record

9. Design a Project to implement a Smart text editor.

List of Assignments contd…

10. Department maintains a student information. The file contains roll number, name, division and address. Allow user to add, delete information of student. Display information of particular employee. If record of student does not exist an appropriate message is displayed. If it is, then the system displays the student details. Use sequential file to main the data.

11. Implement direct access file using hashing (linear probing with and without replacement) perform following operations on it a) Create Database b) Display Database c) Add a record d) Search a record e) Modify a record

12. Implement all the functions of a dictionary (ADT) using hashing and handle collisions using chaining with / without replacement. Data: Set of (key, value) pairs, Keys are mapped to values, Keys must be comparable, Keys must be unique Standard Operations: Insert (key, value), Find(key), Delete(key)

13 Design a Project to implement a Smart text editor.

Learning Resources

Text Books:

1. Fundamentals of Data Structures, E. Horowitz, S. Sahni, S. A-Freed, Universities Press.
2. Data Structures and Algorithms, A. V. Aho, J. E. Hopperoft, J. D. UIlman, Pearson.

Reference Books:

1. The Art of Computer Programming: Volume 1: Fundamental Algorithms, Donald E. Knuth.
2. Introduction to Algorithms, Thomas, H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, The MIT Press.
3. Open Data Structures: An Introduction (Open Paths to Enriched Learning), (Thirty First Edition), Pat Morin, UBC Press.

Supplementary Readings:

1. Aaron Tanenbaum, “Data Structures using C”, Pearson Education.
2. R. Gilberg, B. Forouzan, "Data Structures: A pseudo code approach with C", Cenage Learning, ISBN 9788131503140
3. R.G.Dromy, “How to Solve it by Computers”, Prentice Hall.

Learning Resources contd…

Web Resources:

Web links:

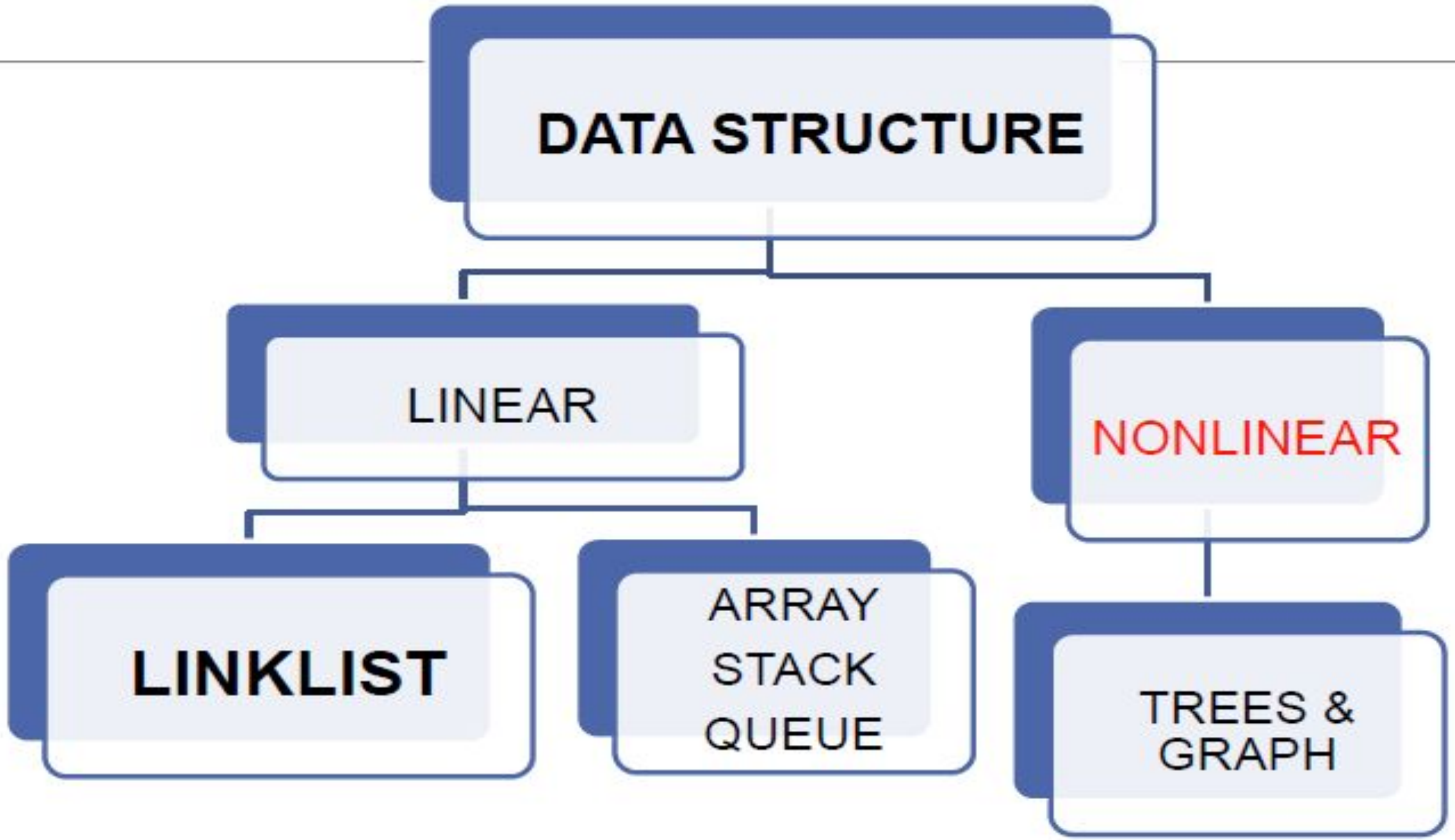
1. https://www.tutorialspoint.com/data_structures_algorithms/

MOOCs:

1. http://nptel.ac.in/courses/106102064/1

2. https://nptel.ac.in/courses/106103069/

Types of Data Structures

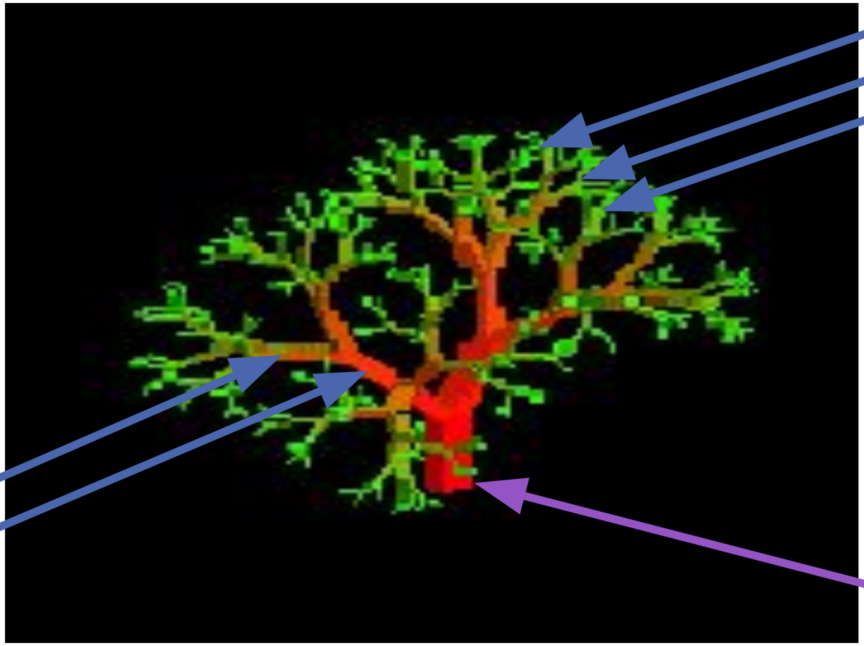


Tree

- Basic Terminology, Binary Tree- Properties
- Converting Tree to Binary Tree.
- Representation using Sequential and Linked organization .
- Binary tree creation and Traversals, Operations on binary tree.
- Binary Search Tree (BST) and its operations
- Threaded binary tree- Creation and Traversal of inorder Threaded Binary tree.
- **Case Study**- Expression tree.

Natural environment Tree

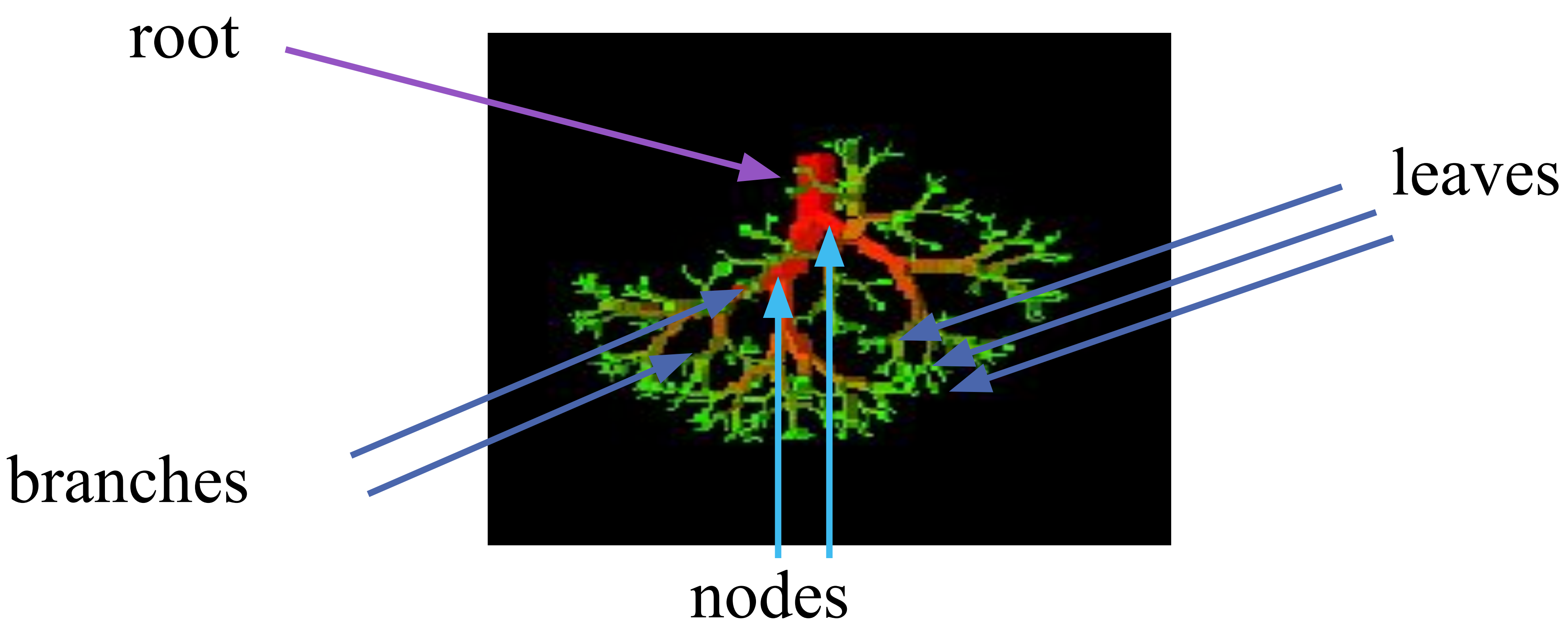
leaves



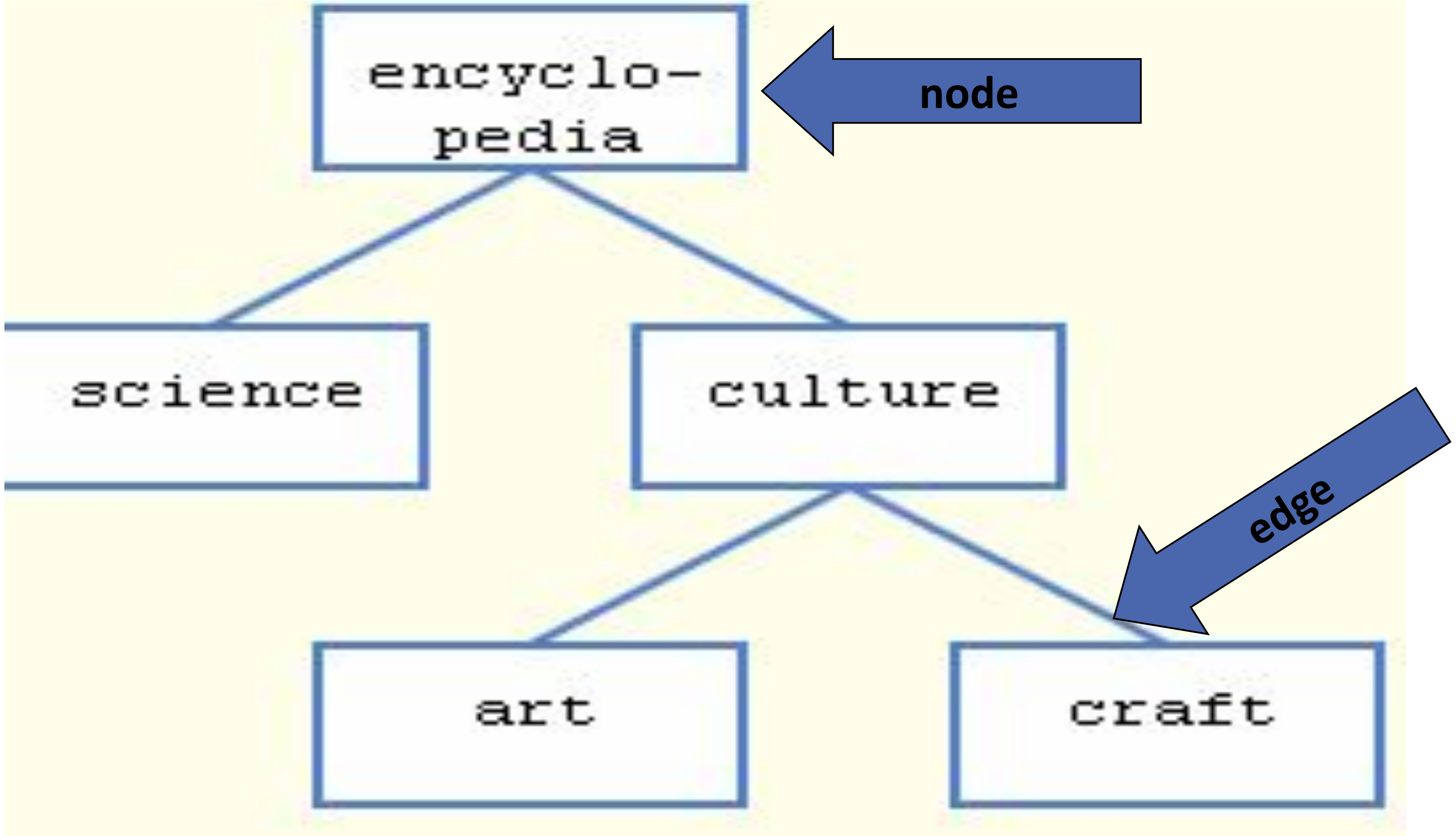
branches

root

Computer Scientist’s View



Tree (example)



General tree

A tree is a finite set of one or more nodes such that:

(i)There is a specially designated node called the root;

(ii) The remaining nodes are partitioned into n >=0 disjoint sets T1, ...,Tn where each of these sets is a tree. T1, ...,Tn are called the subtrees of the root.

Sample Tree

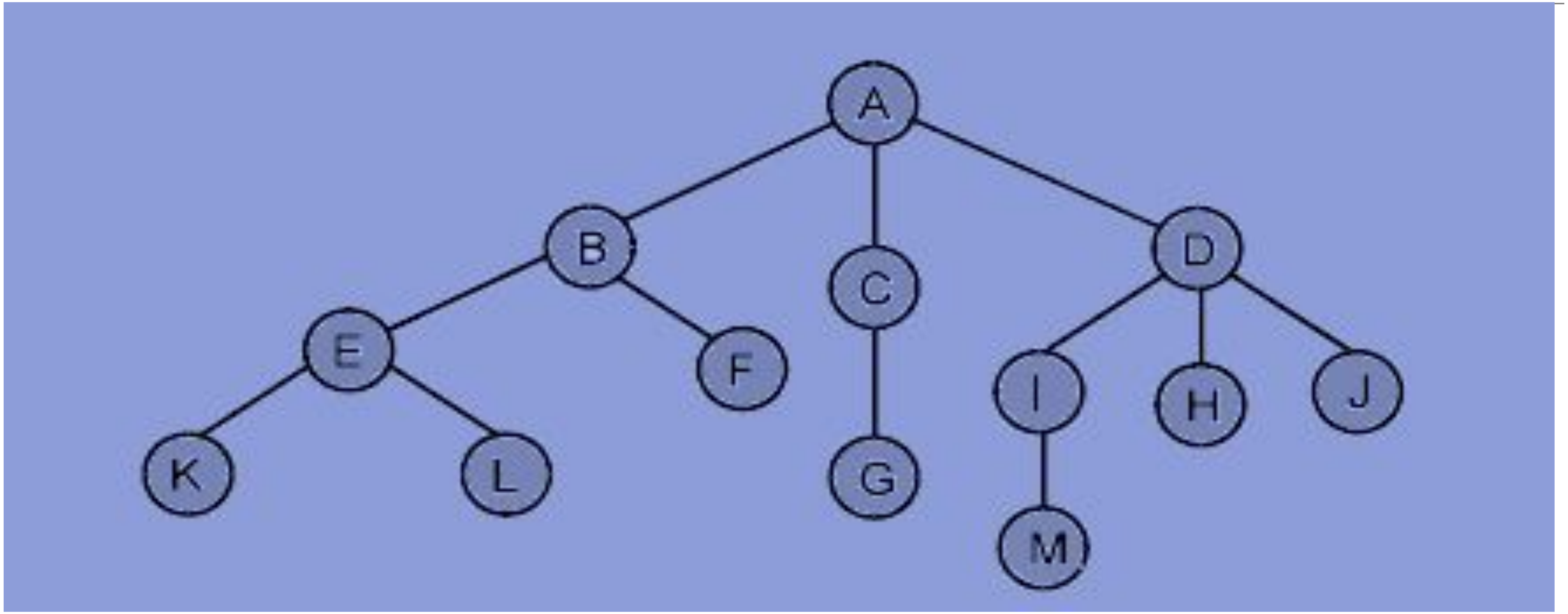


Figure 8: Sample Tree

Tree Terminology

Root: Node without parent (A)

Siblings: Nodes share the same parent

Ancestors of a node: all the nodes along the path from root to that node

Descendant of a node: child, grandchild, grand-grandchild, etc.

The height or depth of a tree is defined to be the maximum level of any node in the tree.(4)

Degree of a node: the number of subtrees(children) of a node is called degree

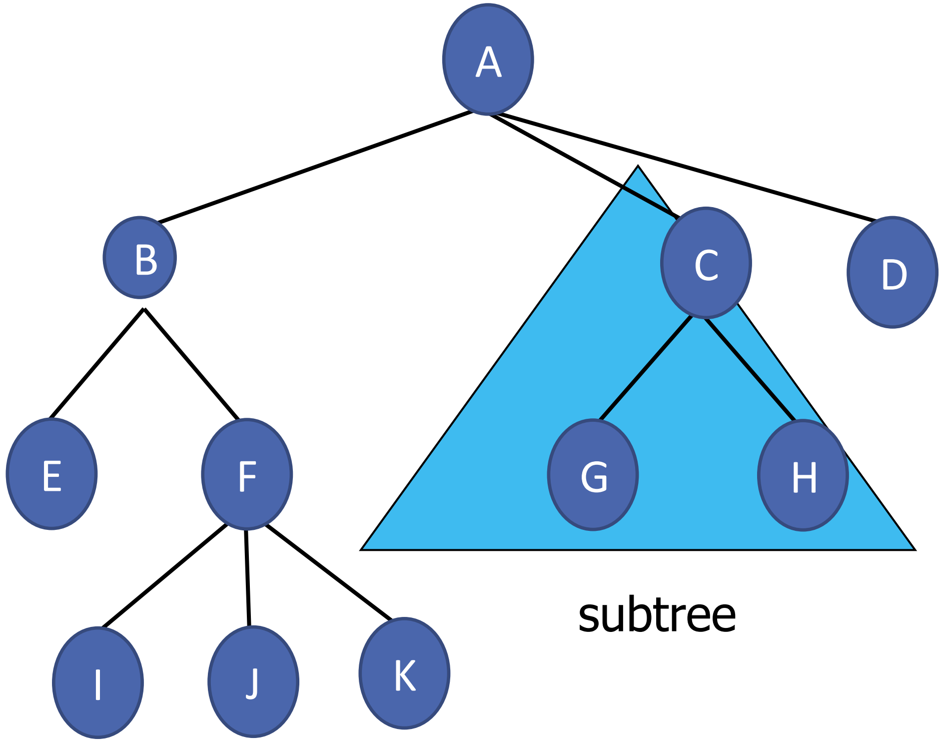
Degree of a tree: the maximum of the degree of the nodes in the tree.

Nonterminal nodes: other nodes

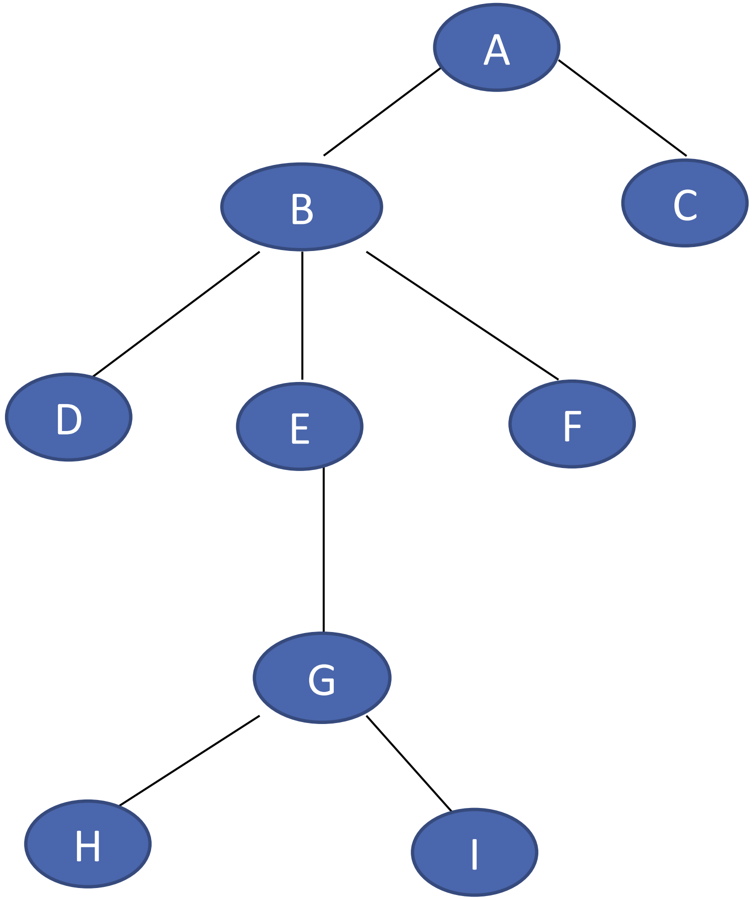
leaf or terminal node: Node that have degree zero (E, I, J, K, G, H, D)

The level of a node is defined by initially letting the root be at level one. If a node is at level l, then its children are at level l + 1.

Subtree: Tree consisting of a node and its descendants



Tree Properties



Property	**Value**
Number of nodes	9
Height	5
Root Node	A
Leaves	C,D,F,H,I
Interior nodes	B,E,G
Ancestors of H	A,B,E,G
Descendants of B	D,E,G,H,I,F
Siblings of E	D,F
Right subtree of A	A,C
Degree of this tree	3

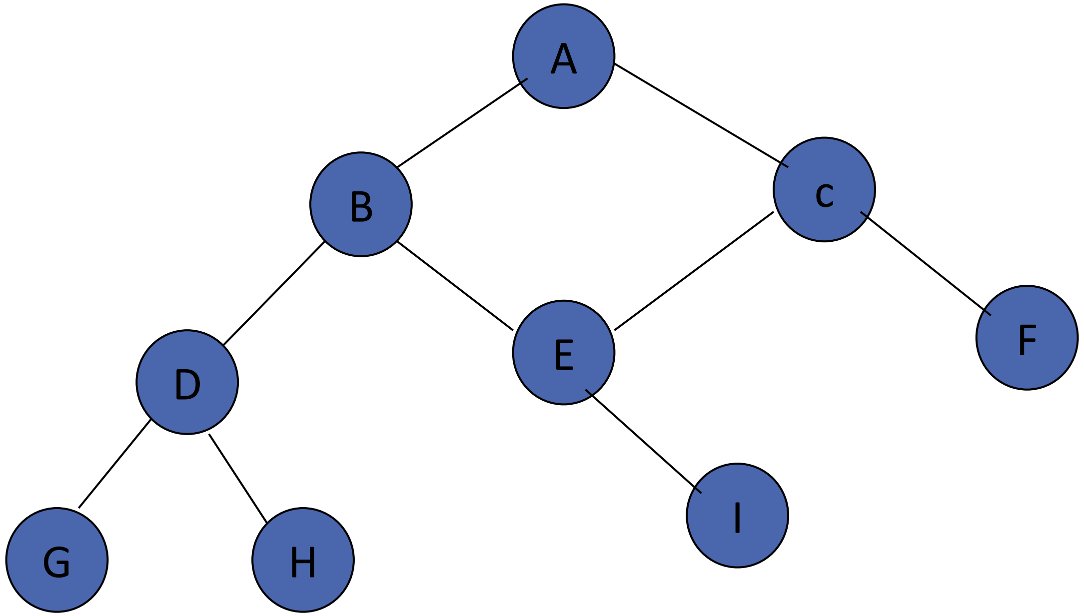
Binary Tree

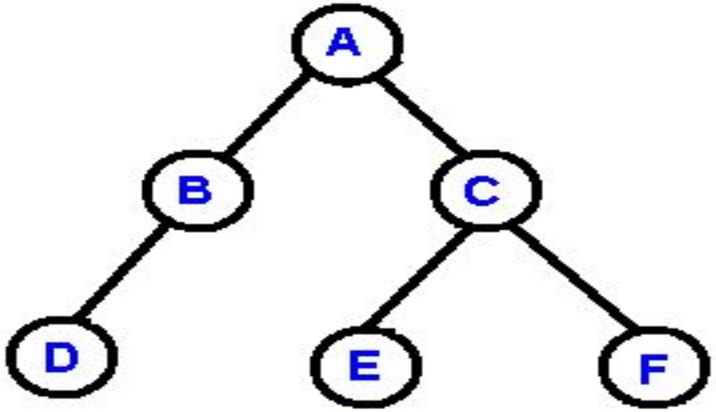
- Every node in a binary tree can have at most two children.

- A binary tree is a finite set of nodes that is either empty or consists of a root and two disjoint binary trees called *the left subtree* and *the right subtree*.

Structures that are not binary trees

Binary tree





Maximum Number of Nodes in BT

- The maximum number of nodes on level i of a binary tree is 2^{i-1}, i>=1.
- The maximum number of nodes in a binary tree of depth k is 2^k-1, k>=1.

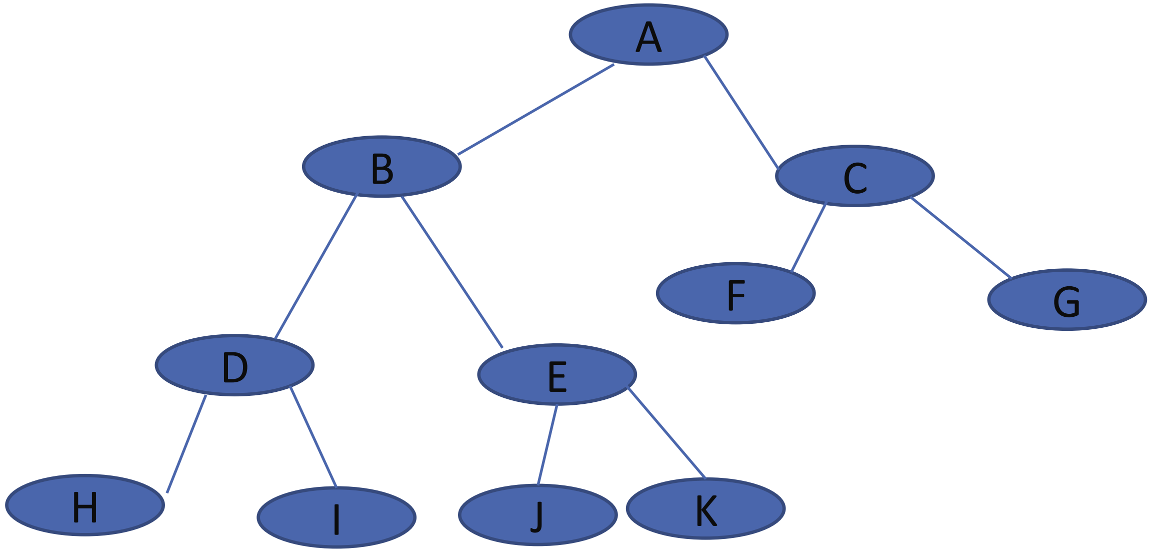
Binary Trees

- **A Full binary tree** of depth K is a binary tree of depth having 2^k-1 nodes k>=0

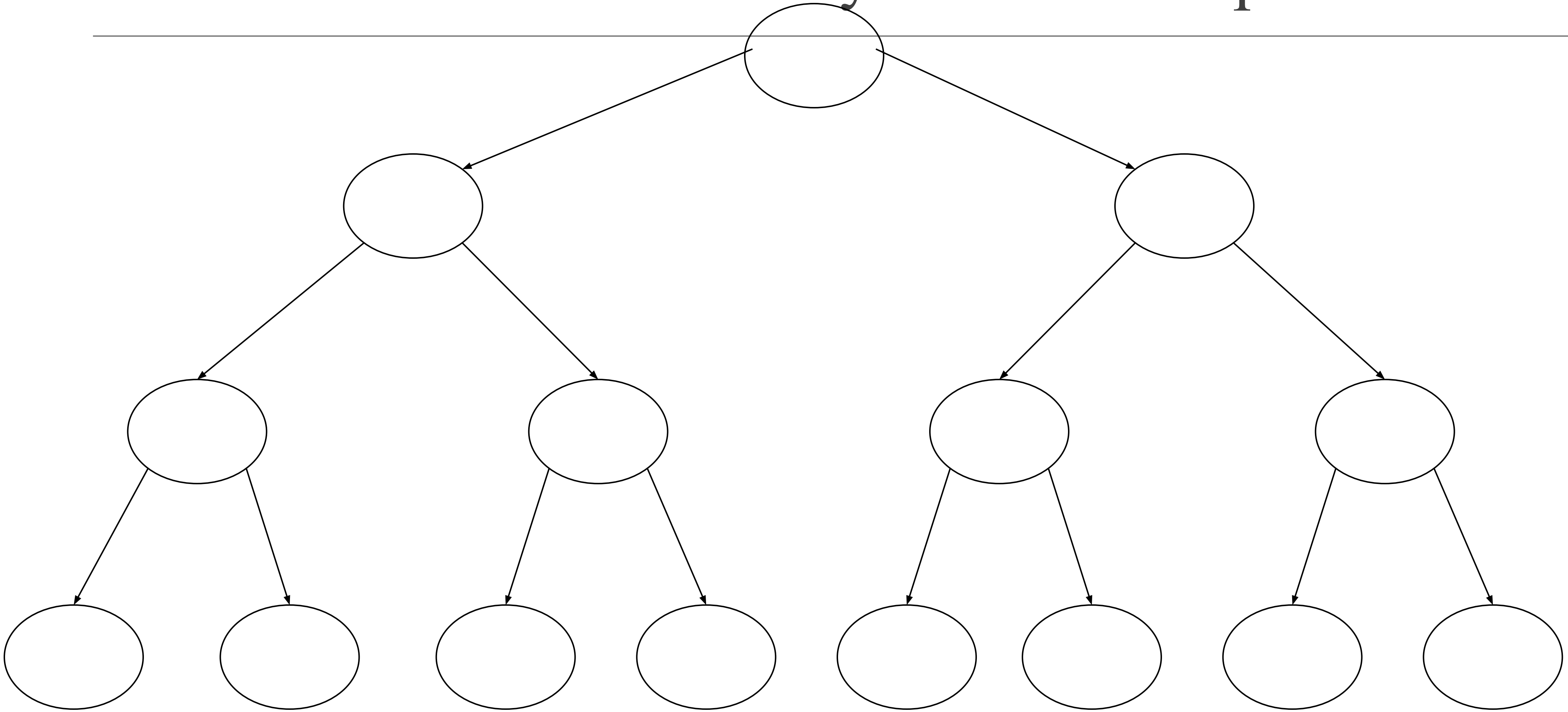
- **Complete Binary Tree**

  A binary tree T with n levels is *complete if all* levels except possibly the last are completely full, and the last level has all its nodes to the left side.

Complete Binary Trees - Example



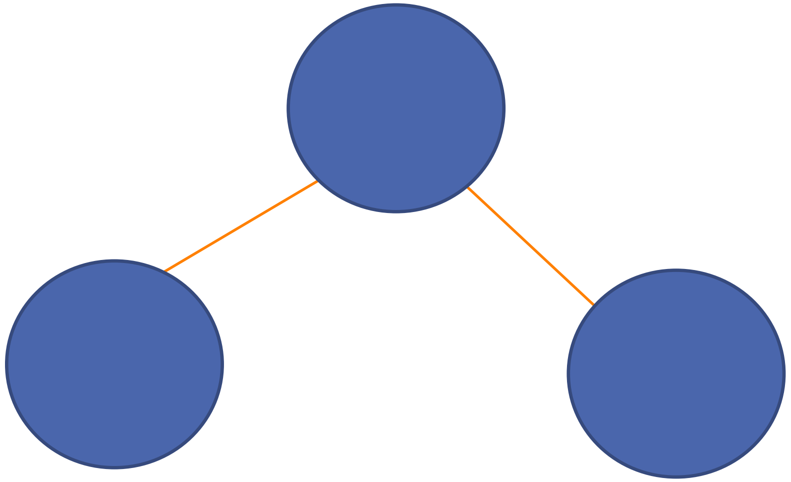
A Full Binary Tree - Example



Complete Binary Trees

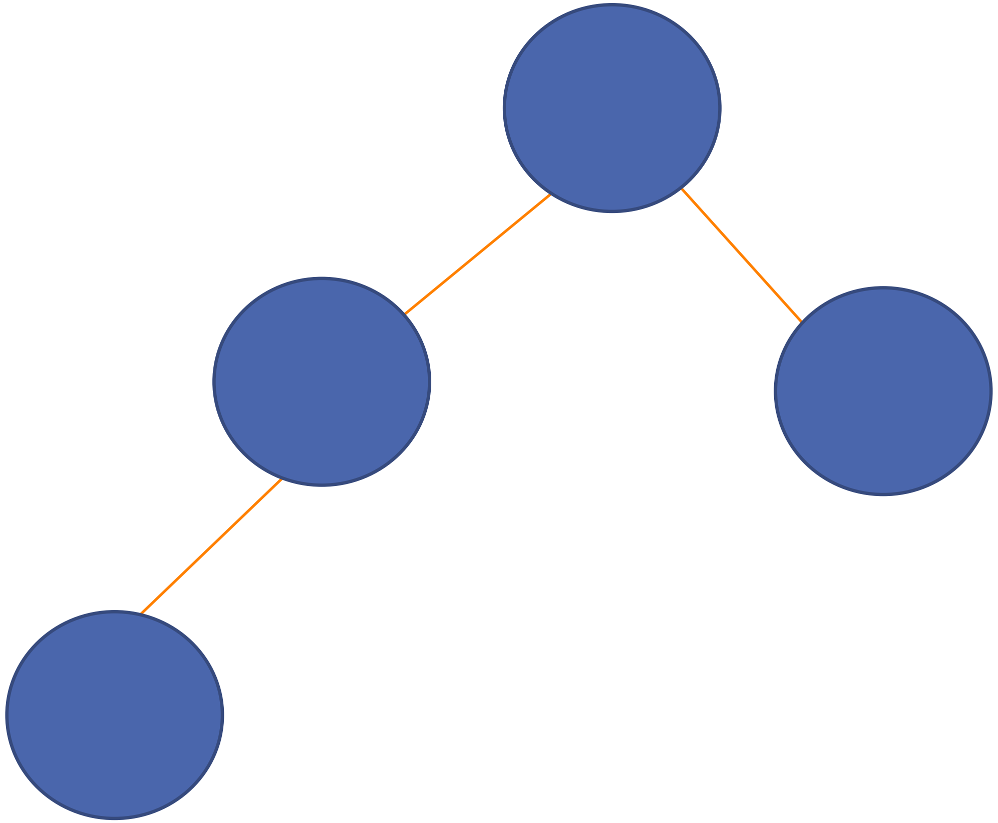
The second node of a complete binary tree is always the left child of the root...

... and the third node is always the right child of the root.



Complete Binary Trees

The next nodes must always fill the next level from left to right.



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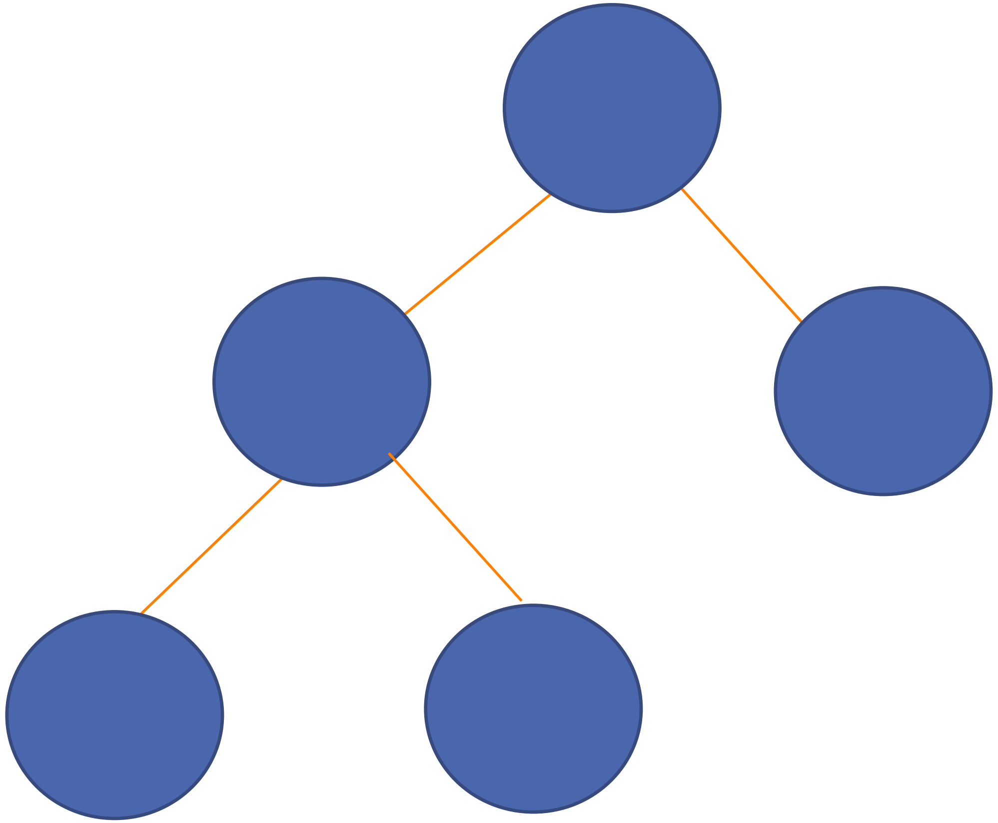

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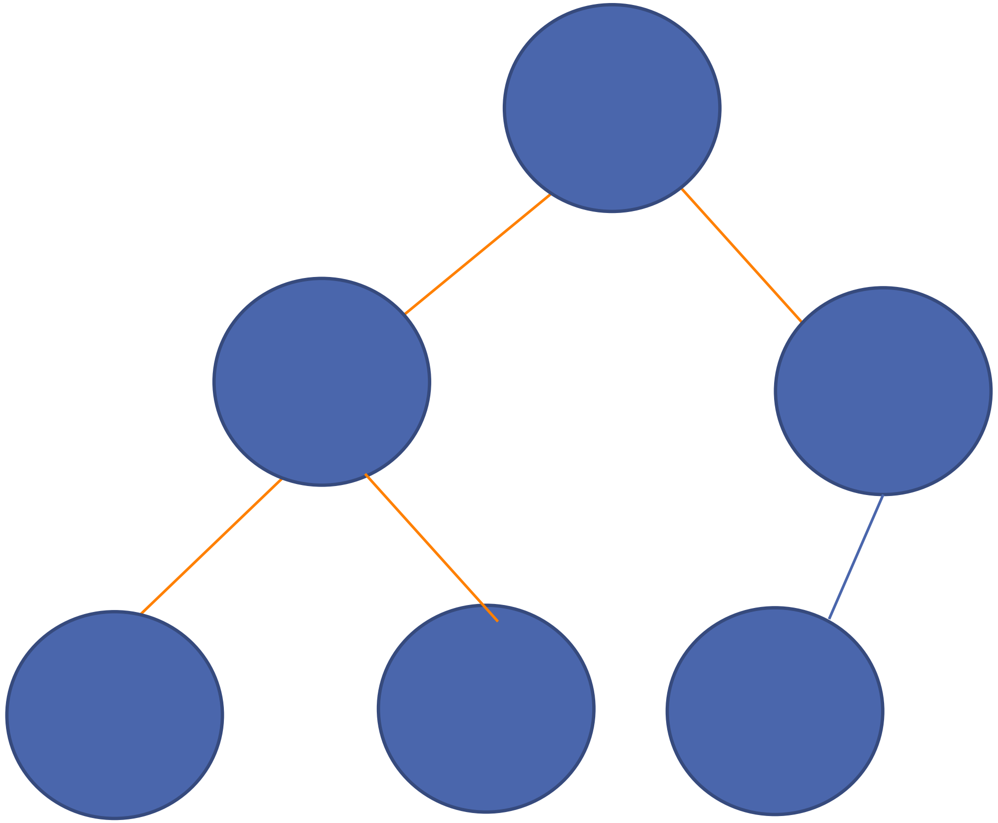

Complete Binary Trees

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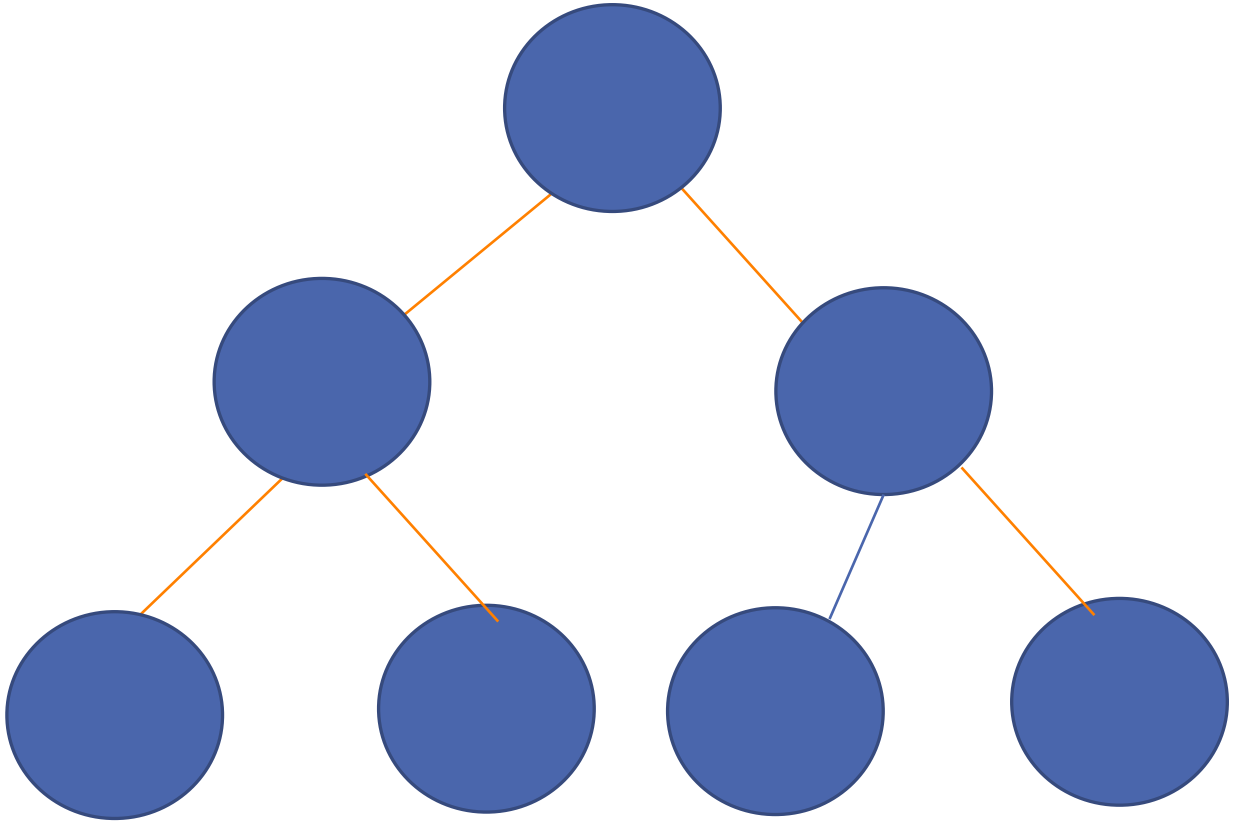

Complete Binary Trees

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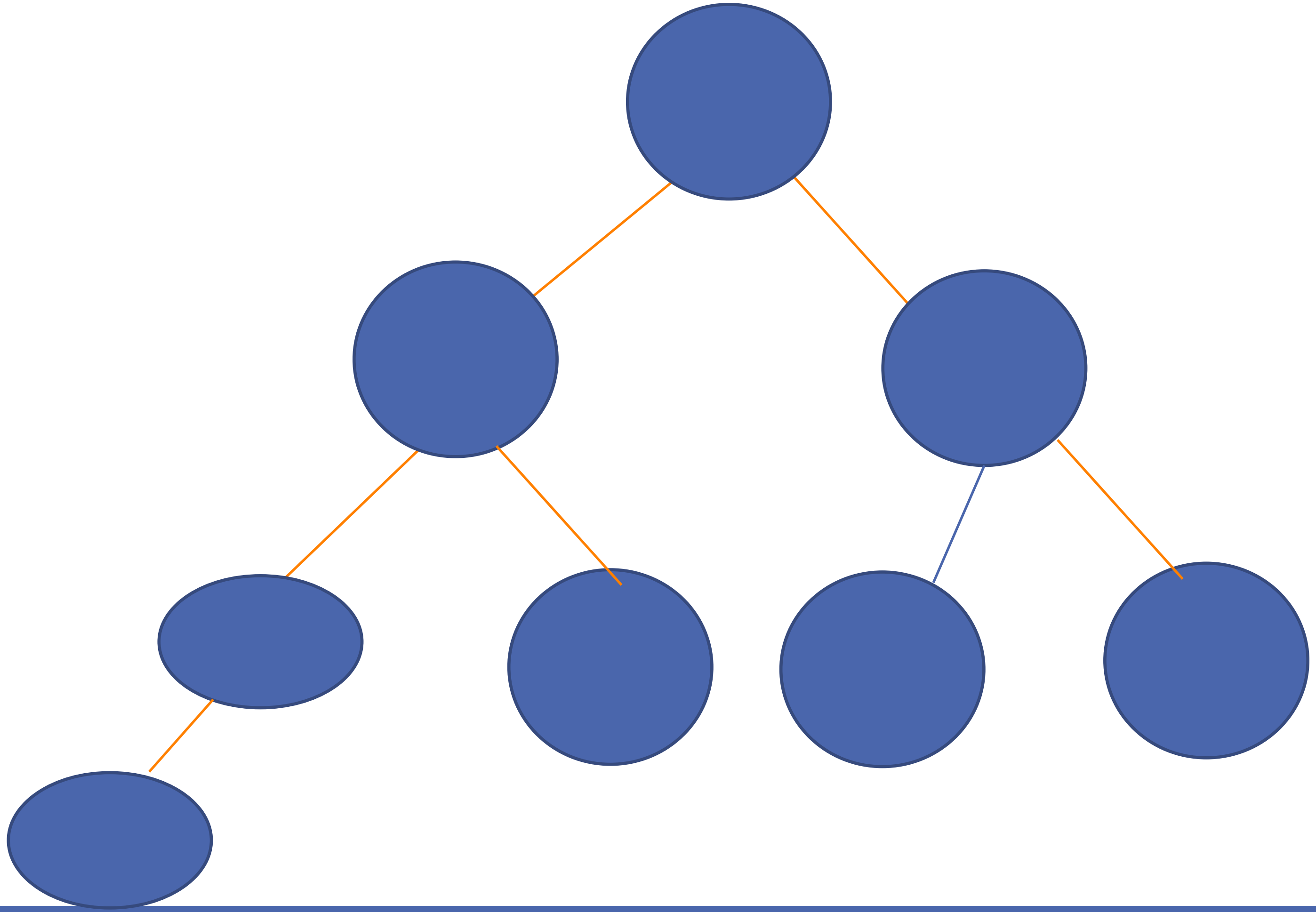

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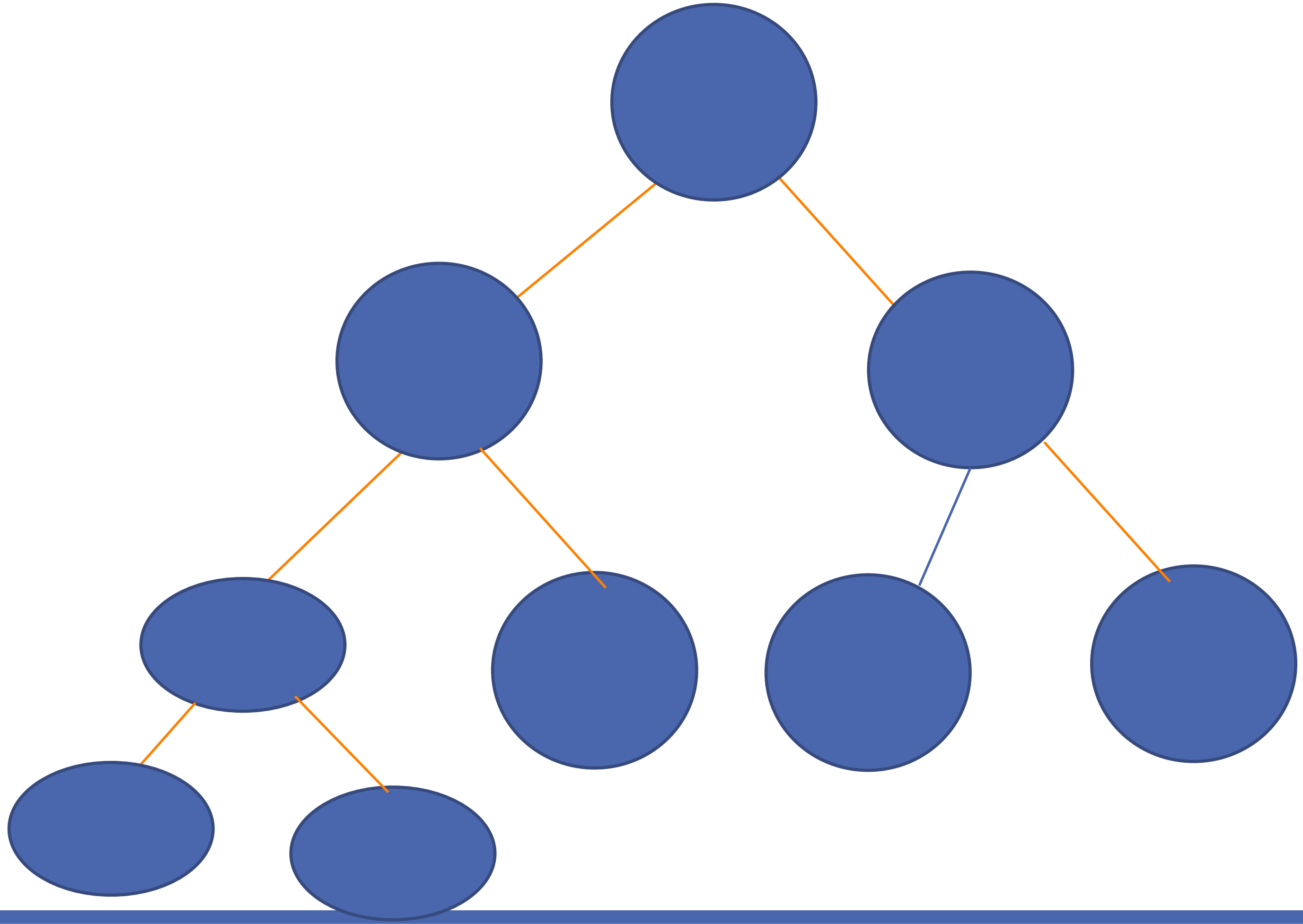
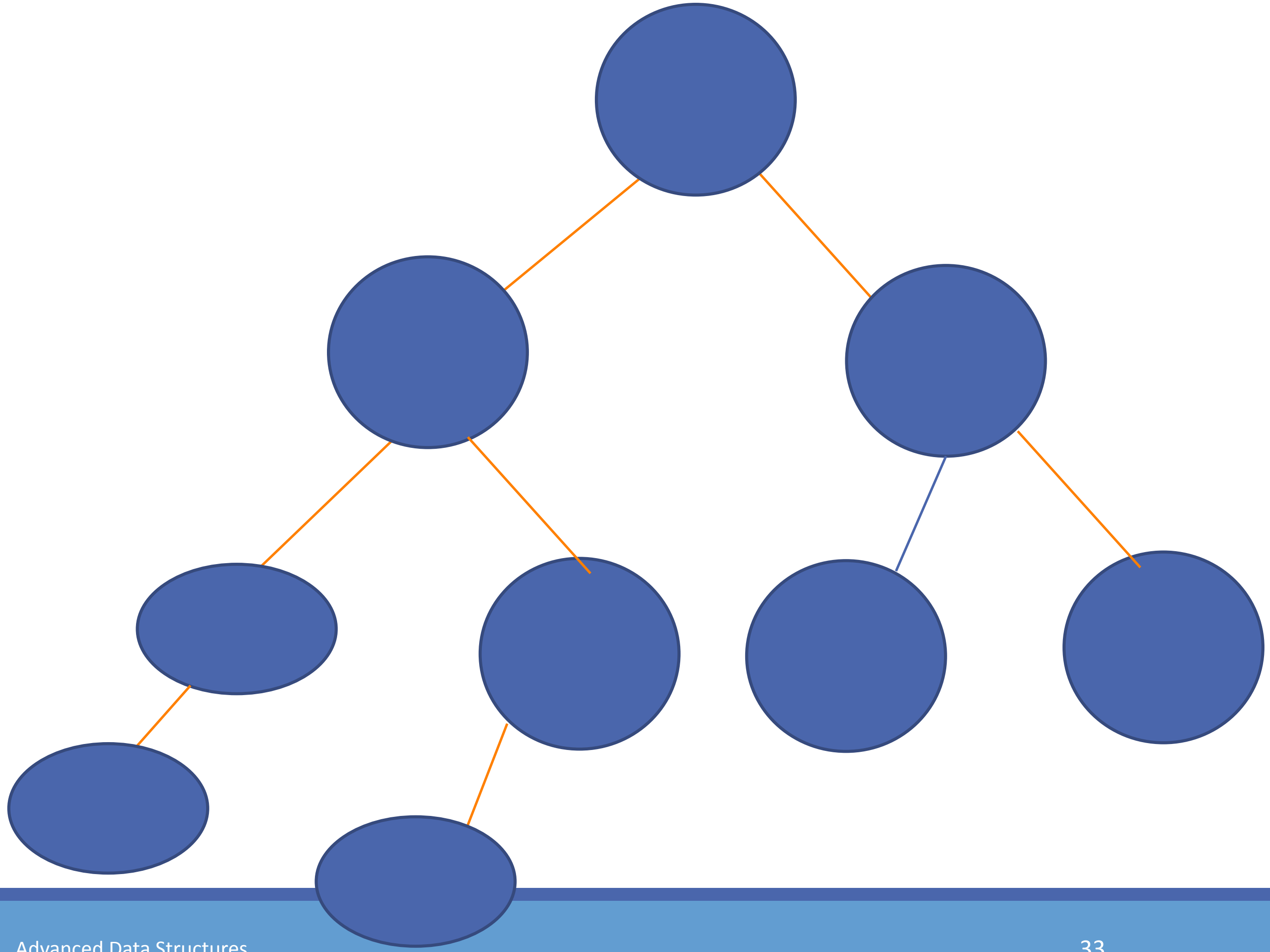
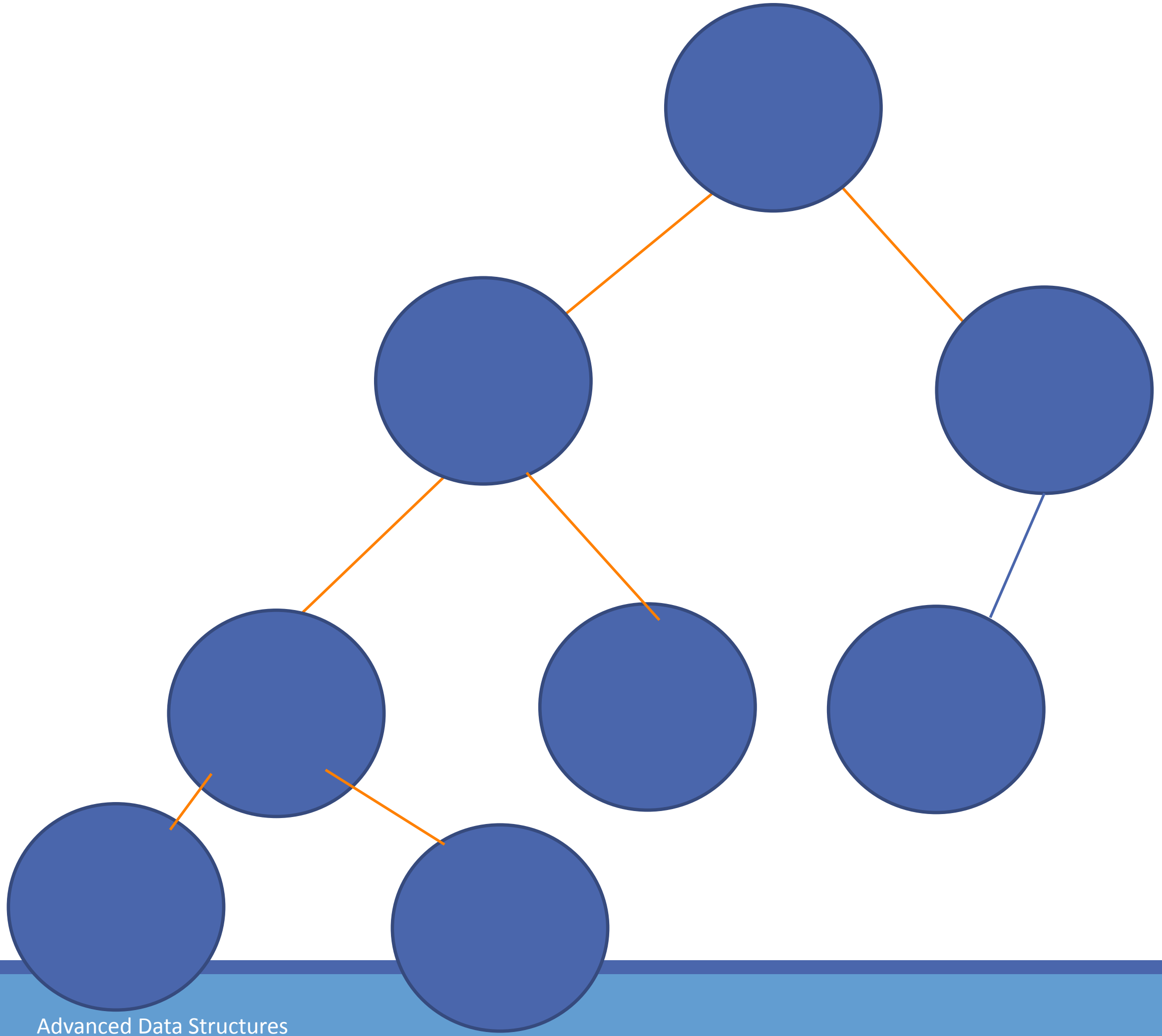


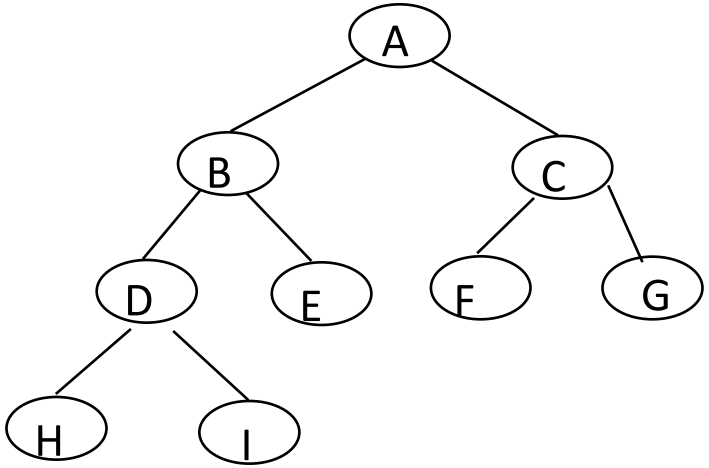
Is This Complete?



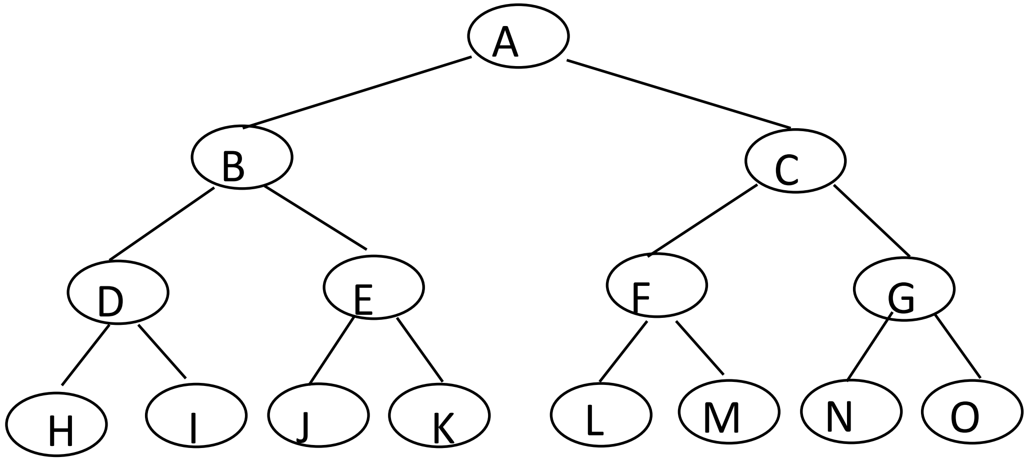
Is This Complete?



Full BT VS Complete BT

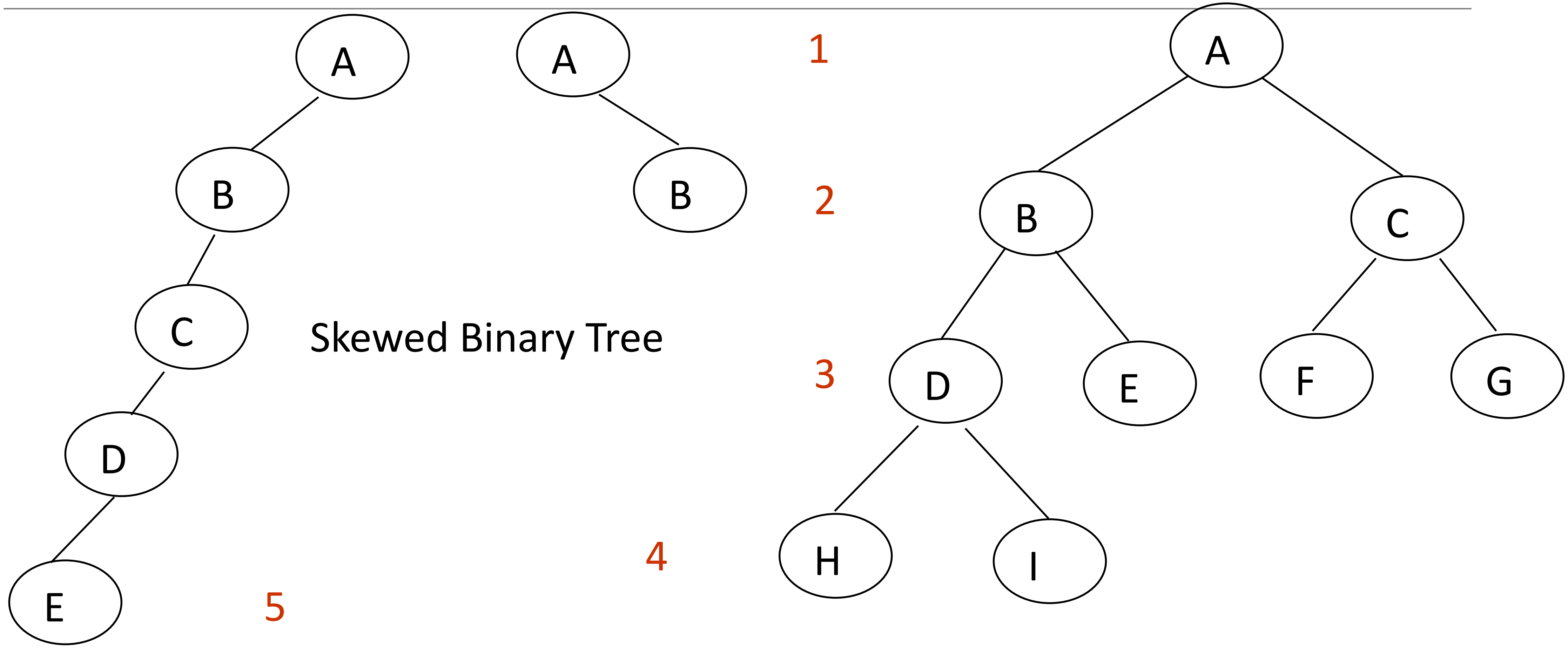


Complete binary tree



Full binary tree of depth 4

Samples of Trees



Skewed Binary Tree

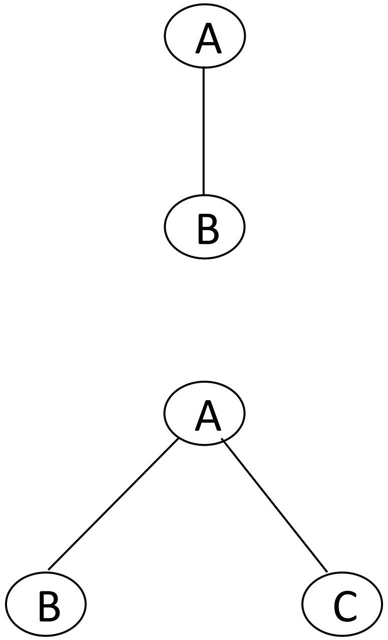
Complete Binary Tree

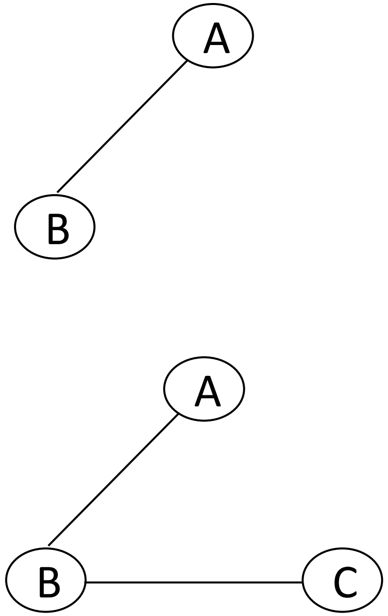
Converting tree to binary tree

- Any tree can be transformed into binary tree.
    - by left child-right sibling representation

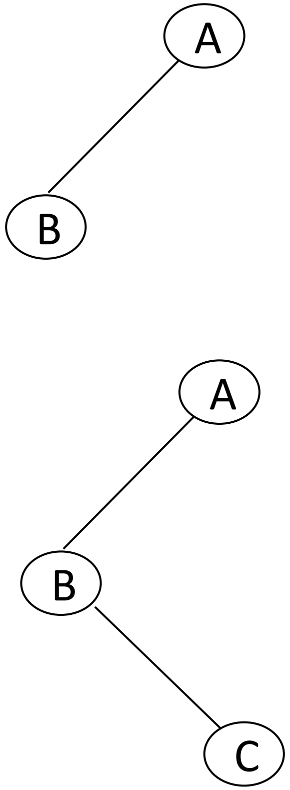
- The left subtree and the right subtree are distinguished.

Tree Representations





Left child-right sibling

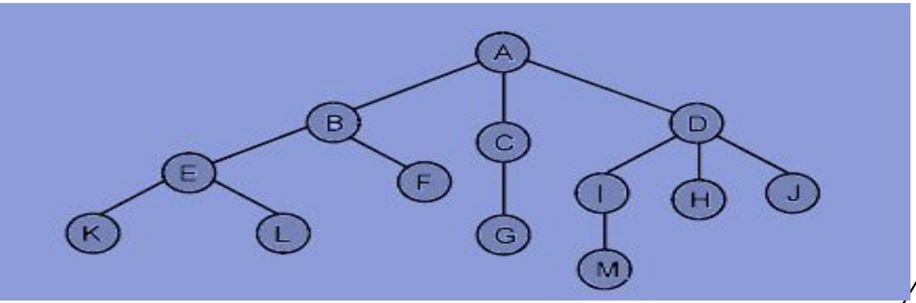


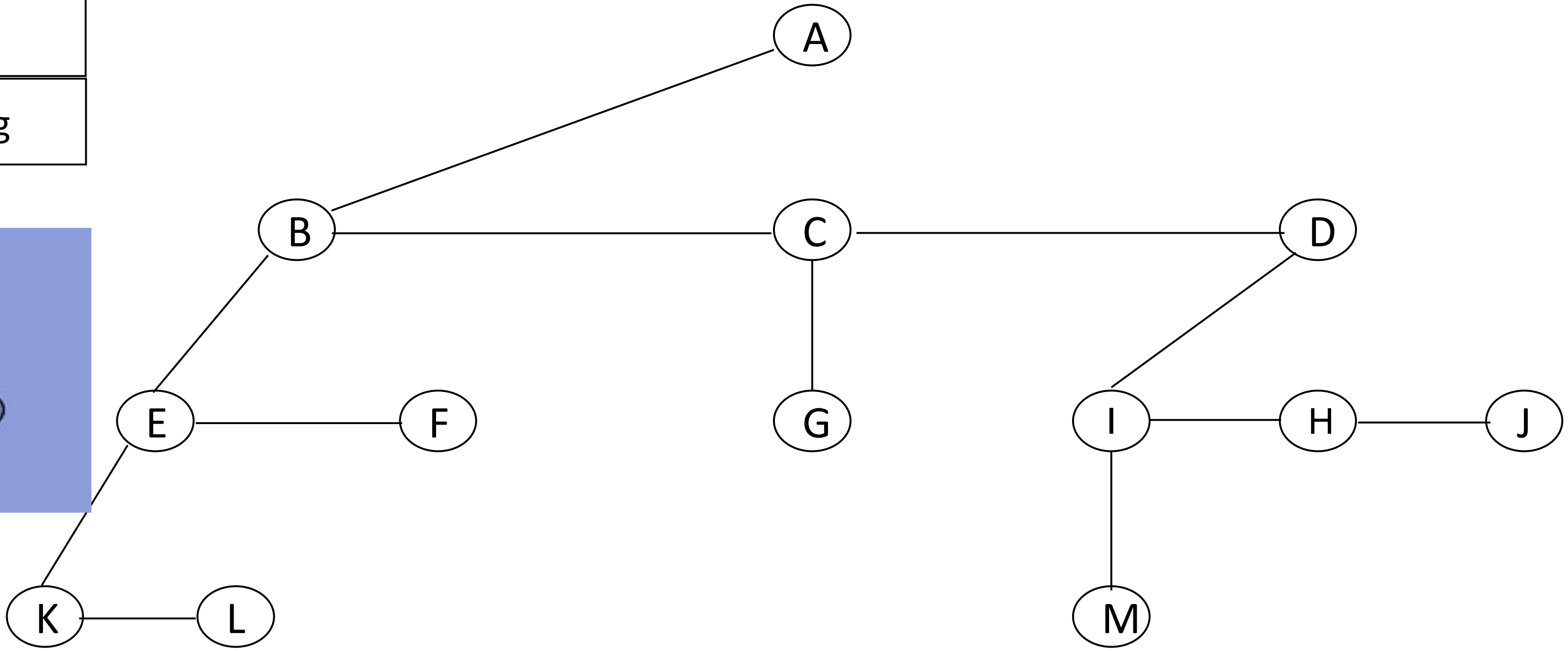
Binary tree

Representation of Trees

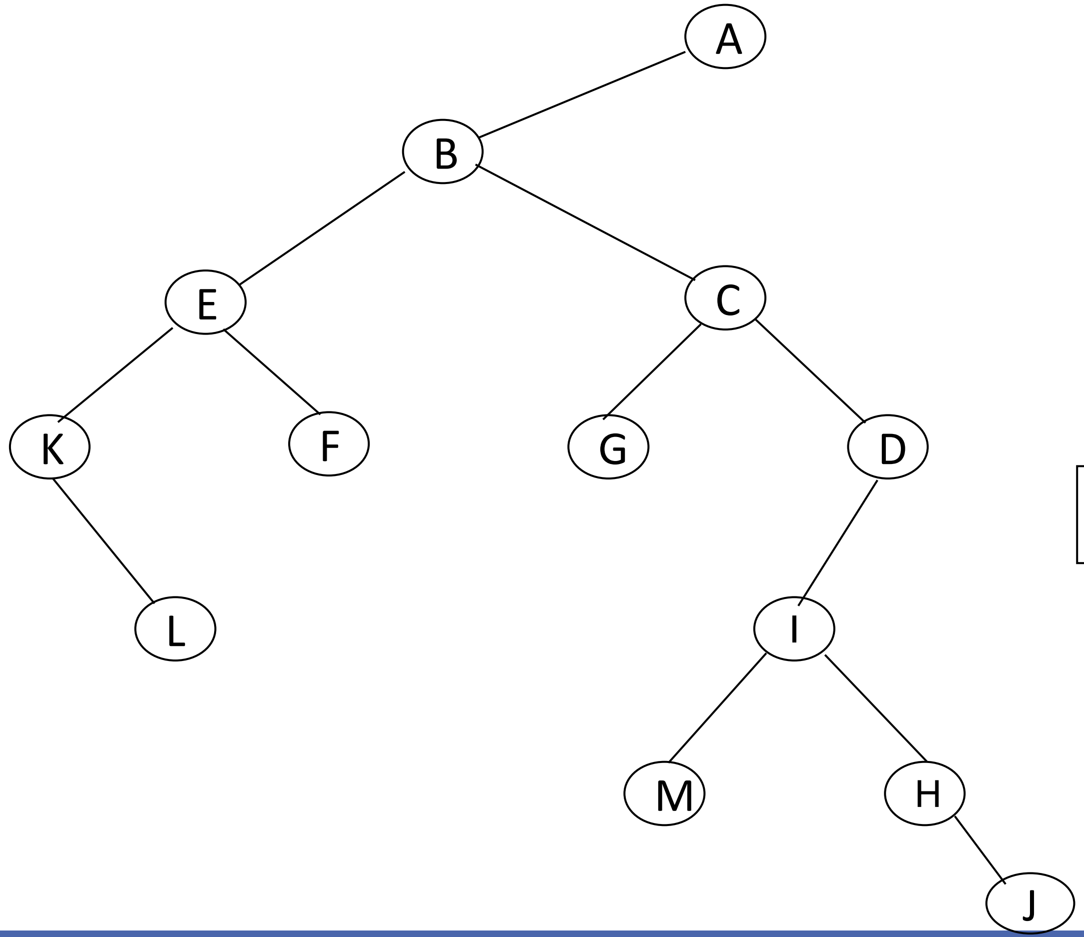
- Left Child-Right Sibling Representation
  - Each node has two links (or pointers).
  - Each node only has one leftmost child and one closest sibling.

data	
left child	right sibling





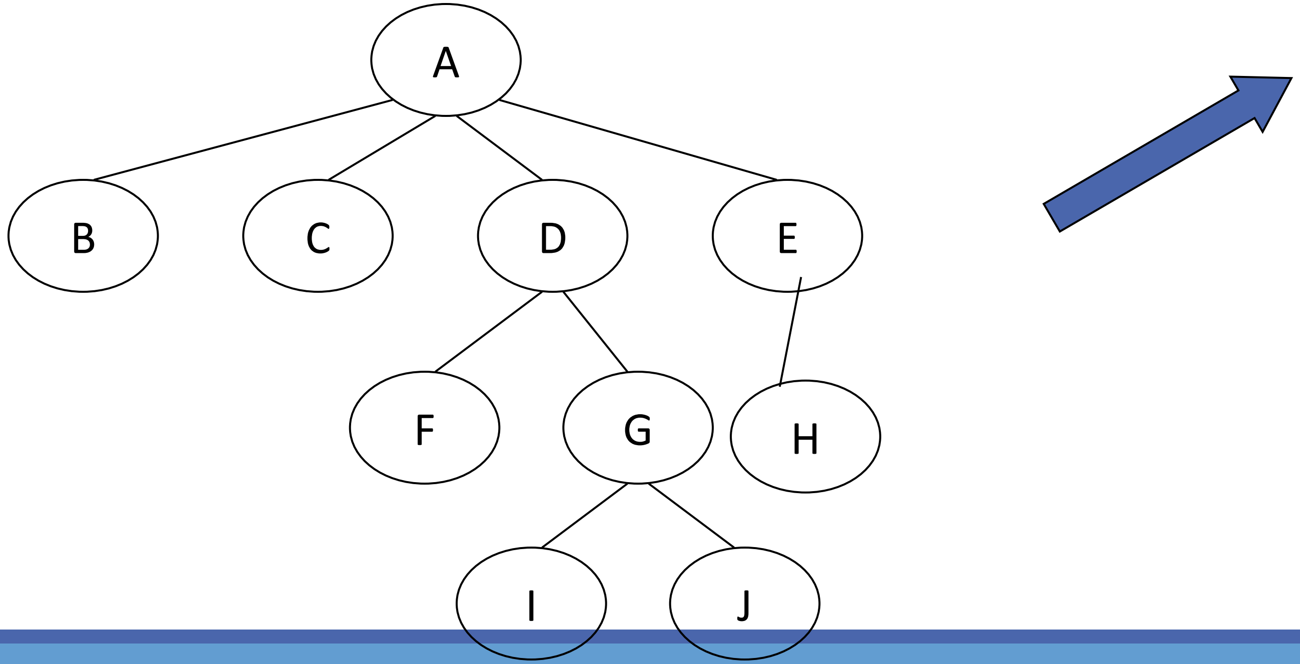
Degree Two Tree Representation

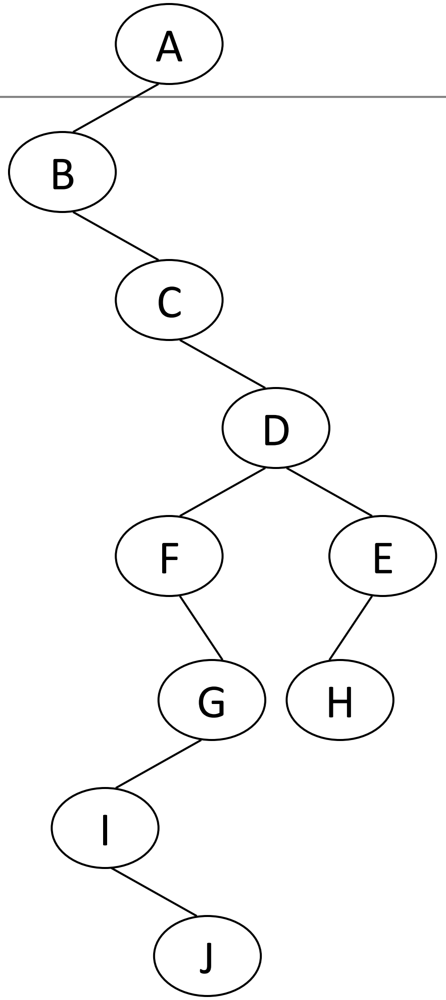


Binary Tree!

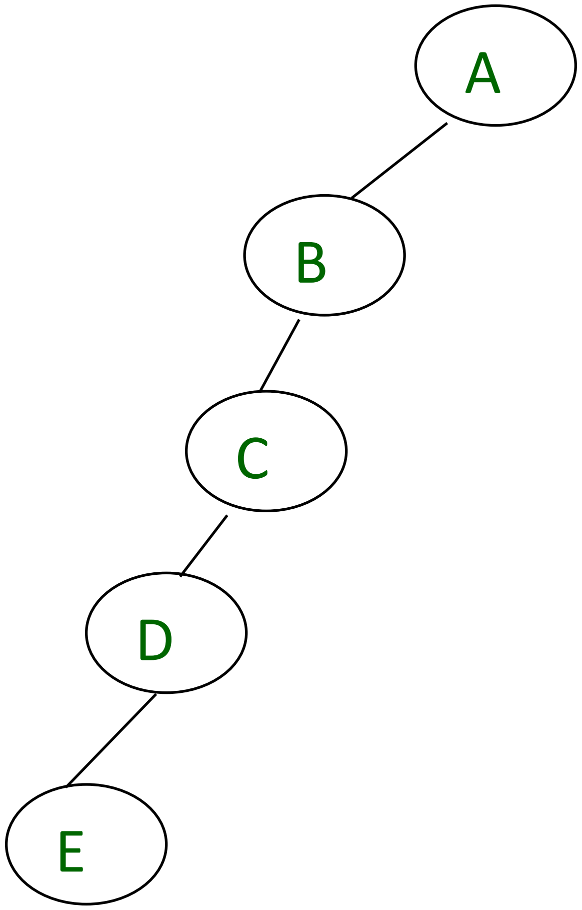
Converting to a Binary Tree

- Binary tree left child = leftmost child
- Binary tree right child= right sibling





Sequential Representation

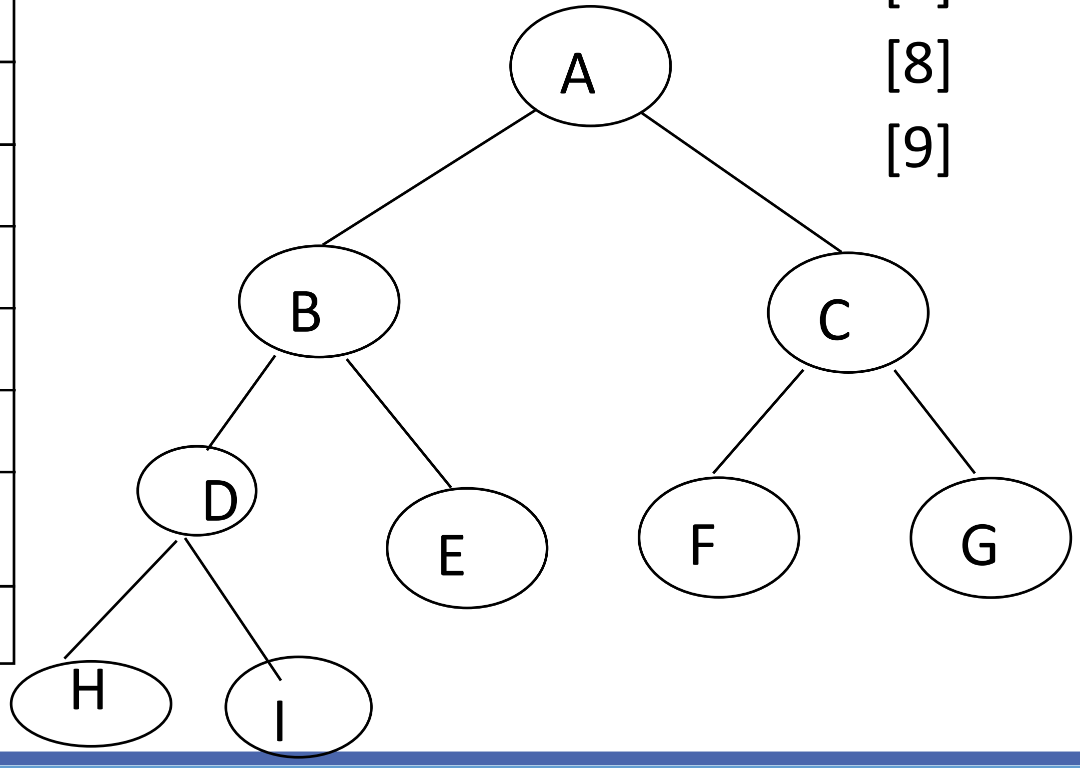


[1]	A
[2]	B
[3]	--
[4]	C
[5]	--
[6]	--
[7]	--
[8]	D
[9]	--
.	.
[16]	E

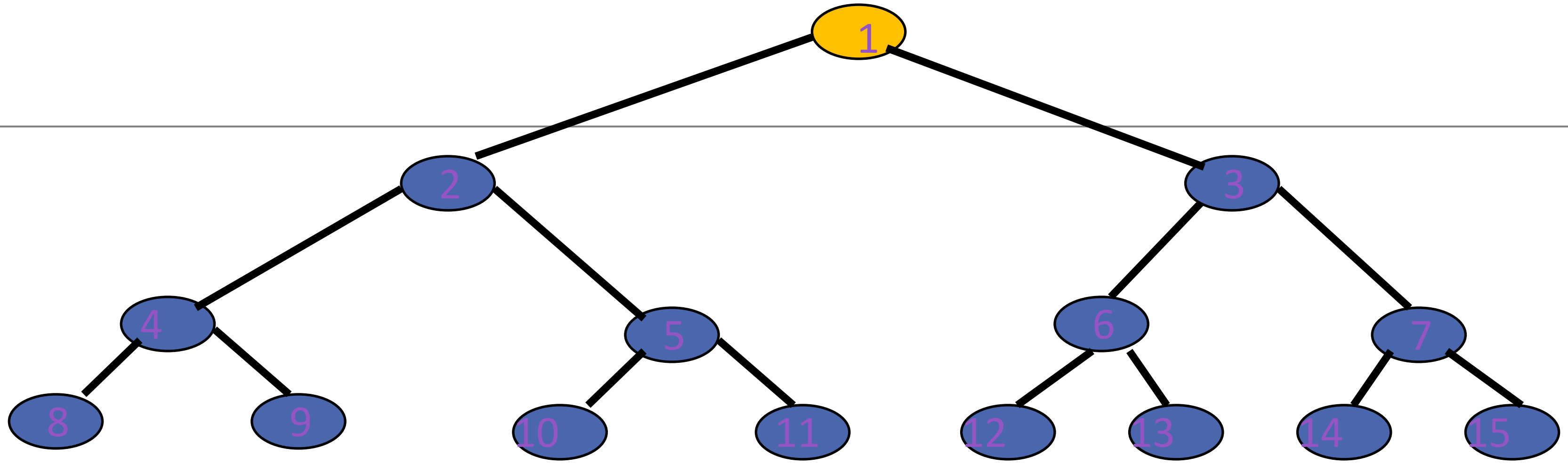
(1) waste space

(2) insertion/deletion problem

[1]	A
[2]	B
[3]	C
[4]	D
[5]	E
[6]	F
[7]	G
[8]	H
[9]	I



Node Number Properties



Parent of node i is node i/2

- But node 1 is the root and has no parent

Left child of node i is node 2i if 2i is <=n

- But if 2i > n, node i has no left child

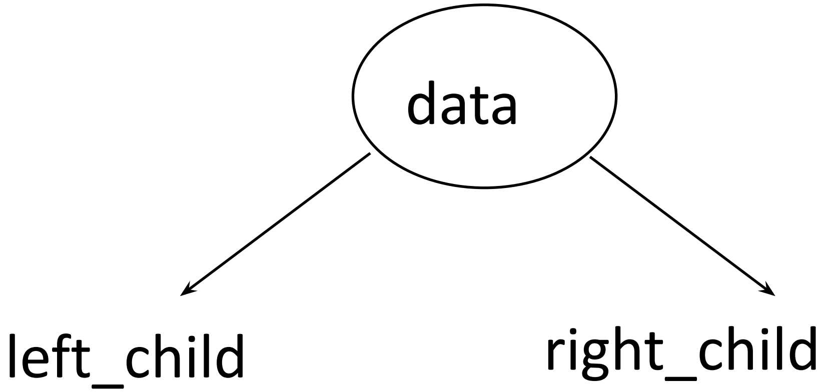
Right child of node i is node 2i+1 if 2i+1 is <=n

- But if 2i+1 > n, node i has no right child

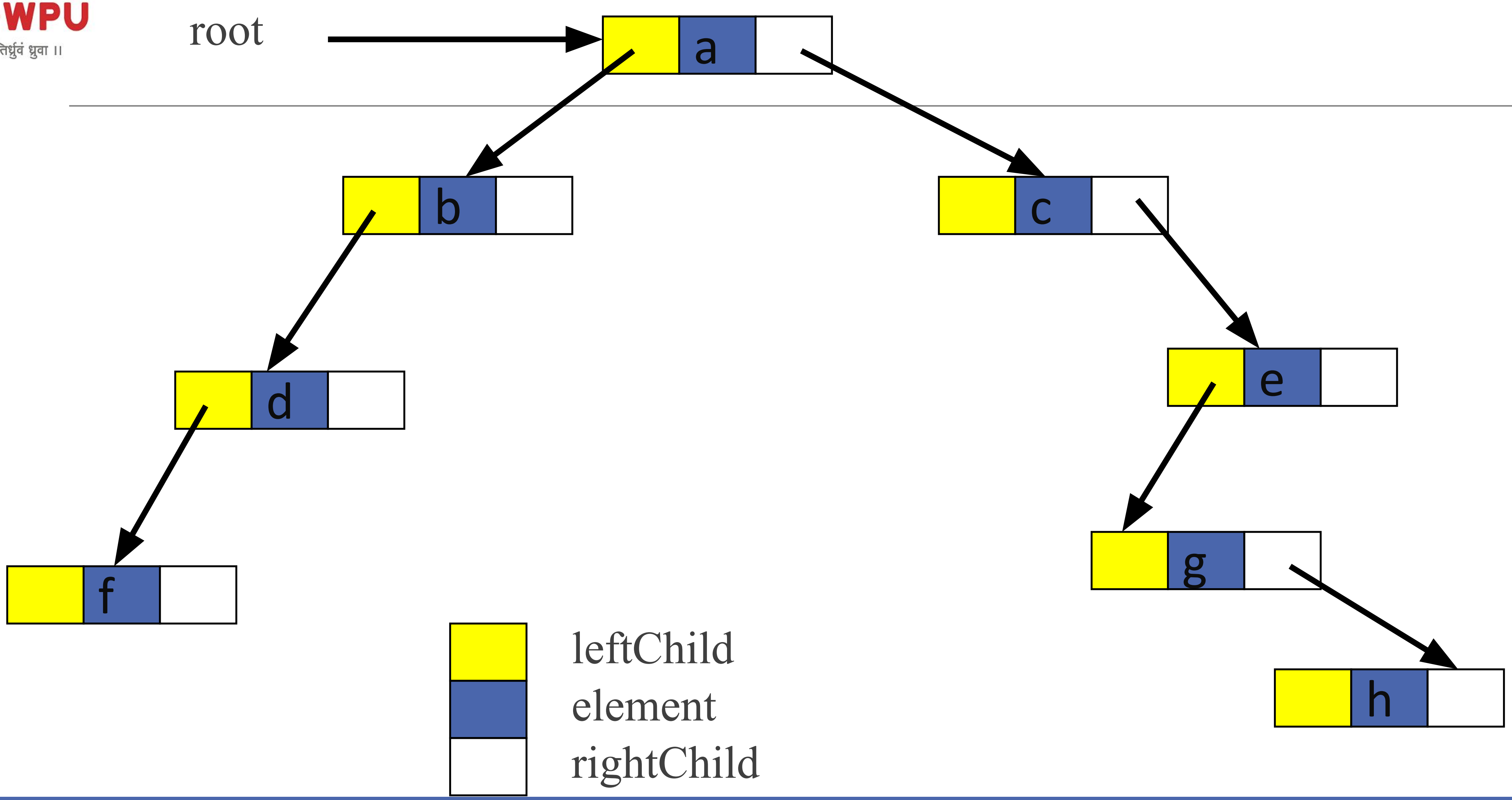
Linked Representation

```
class node{
   int data;
   node *lchild;
   node *rchild;
};
```

left_child	data	right_child



Linked Representation Example



Binary Tree Creation

```
class treenode
{
   char data[10];
   treenode *left;
   treenode *right;
   friend class tree;
}
class tree
{
   treenode *root;
   public:
     tree();
      void create_r();
      void create_r(treenode *);
  }
```

```
Algorithm create_r()     //Driver for creation
{
   Allocate memory for root and accept data;
    create_r(root);
 }
```

```
int main()
{
  tree bt;
  bt.create_r();
 }
```

```
tree::tree()      //constructor
{
   root=NULL;
 }
```

Algorithm create_r(treenode * temp) //workhorse for creation

```
{
  Accept choice whether data is added to left  of  temp->data;
   if ch='y'
  {
   Allocate a memory for curr and accept data;
   temp->left=curr;
   create_r(curr);
  }

  Accept choice whether data is added to right  of  temp->data;
   if ch='y'
  {
   Allocate a memory for curr and accept data;
   temp->right=curr;
   create_r(curr);
  }
}
```

```
Algorithm create_nr()
{
   if root=NULL
   {
    Allocate memory for root and accept the data;     }
do
   {
    temp=root;
    flag=0;
    allocate memory for curr and accept data;
    while(flag==0)
    {
     Accept choice to add node(left or right);
     if  ch='l'
     {
        if temp->left=NULL
        {    temp->left=curr;
             flag=1;
        }
          temp=temp->left;
     }
    else {
         if ch='r'
         {
            if temp->right=NULL
             {
                 temp->right=curr;
                 flag=1;
             }
              temp=temp->right;
         }
       }        //else end
    }//while flag
    Accept choice for continuation;
   }  // do while end
}// algo end
```

Binary Tree Traversals

- Let L, V/D and R stand for moving left, visiting the node, and moving right.
- There are six possible combinations of traversal
  - LVR, LRV, VLR, VRL, RVL, RLV
- Adopt convention that we traverse left before right, only 3 traversals remain
  - LVR, LRV, VLR
  - inorder, postorder, preorder

Binary Tree Traversals

- A traversal is where each node in a tree is visited once

- There are two very common traversals

  - Breadth First
  - Depth First

Breadth First

- In a breadth first traversal all of the nodes on a given level are visited and then all of the nodes on the next level are visited.
- Usually in a left to right fashion
- This is implemented with a queue

Depth First

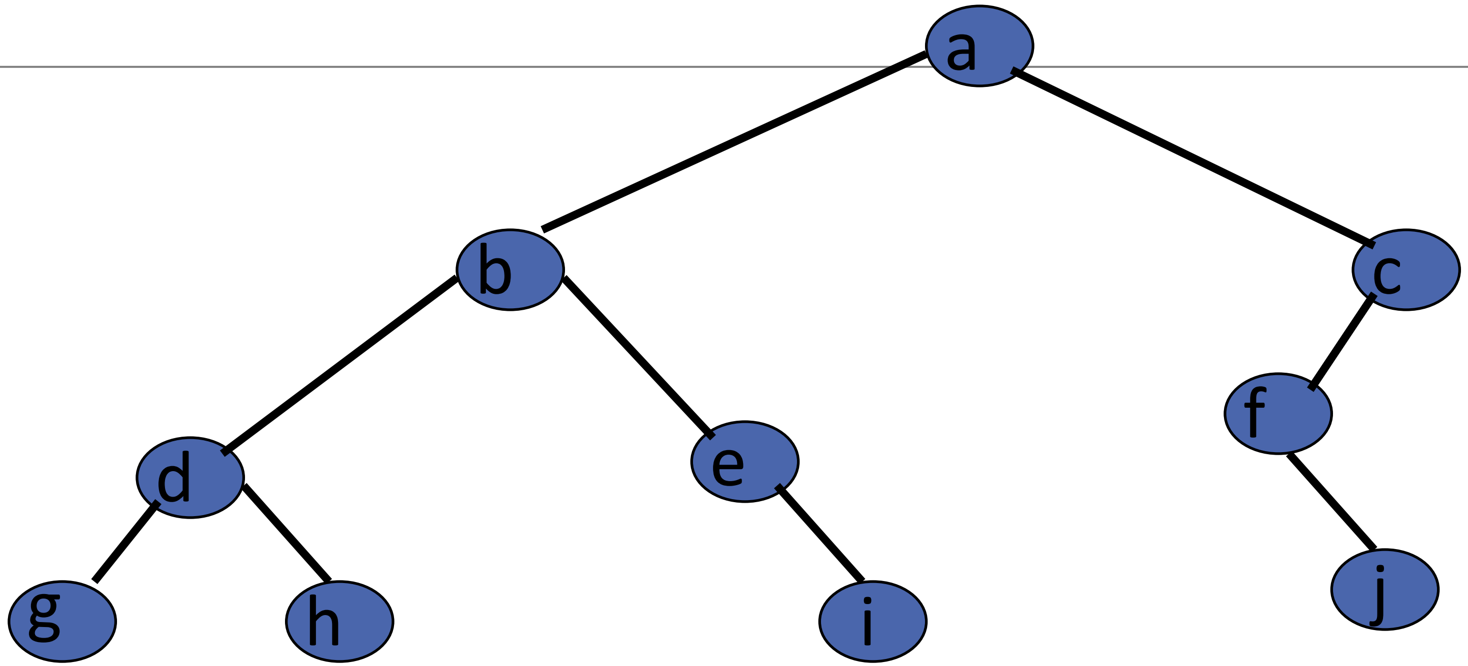
- In a depth first traversal all the nodes on a branch are visited before any others are visited

- There are three common depth first traversals

  - Inorder
  - Preorder
  - Postorder

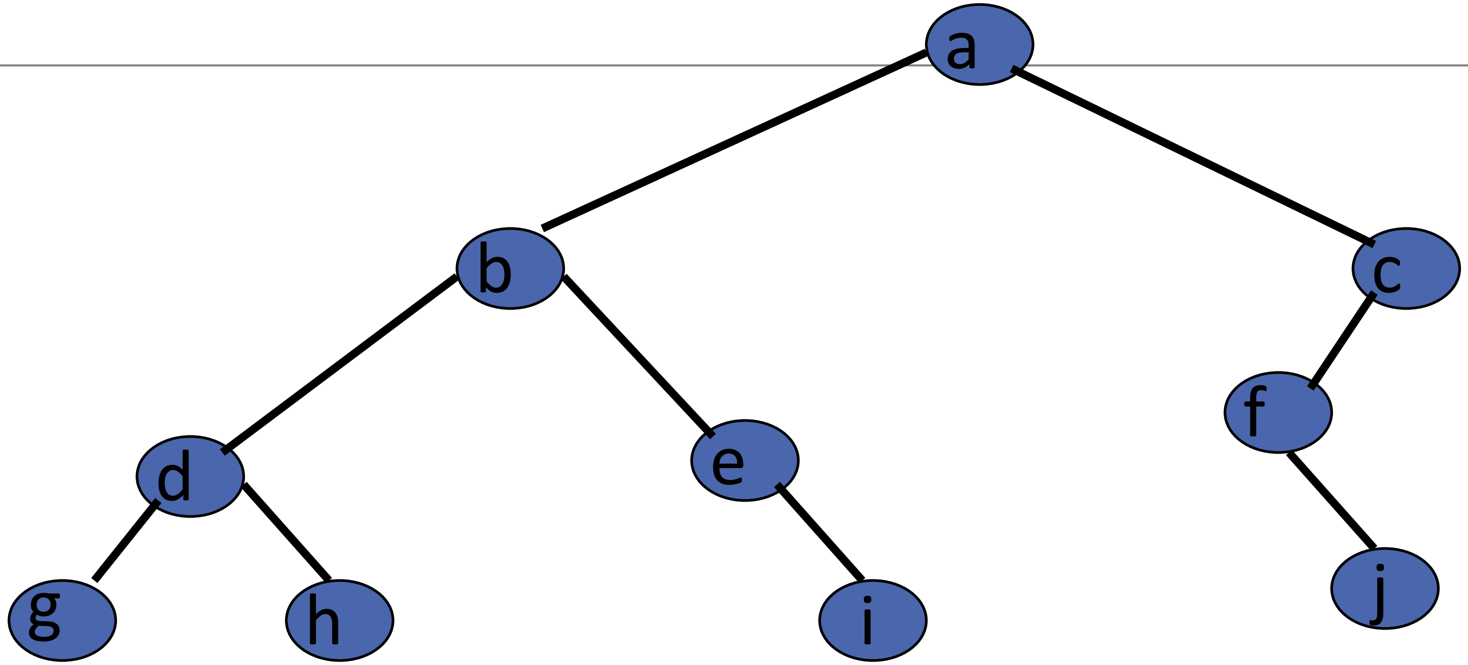
- Each type has its use and specific application

Inorder Example (Visit = print)



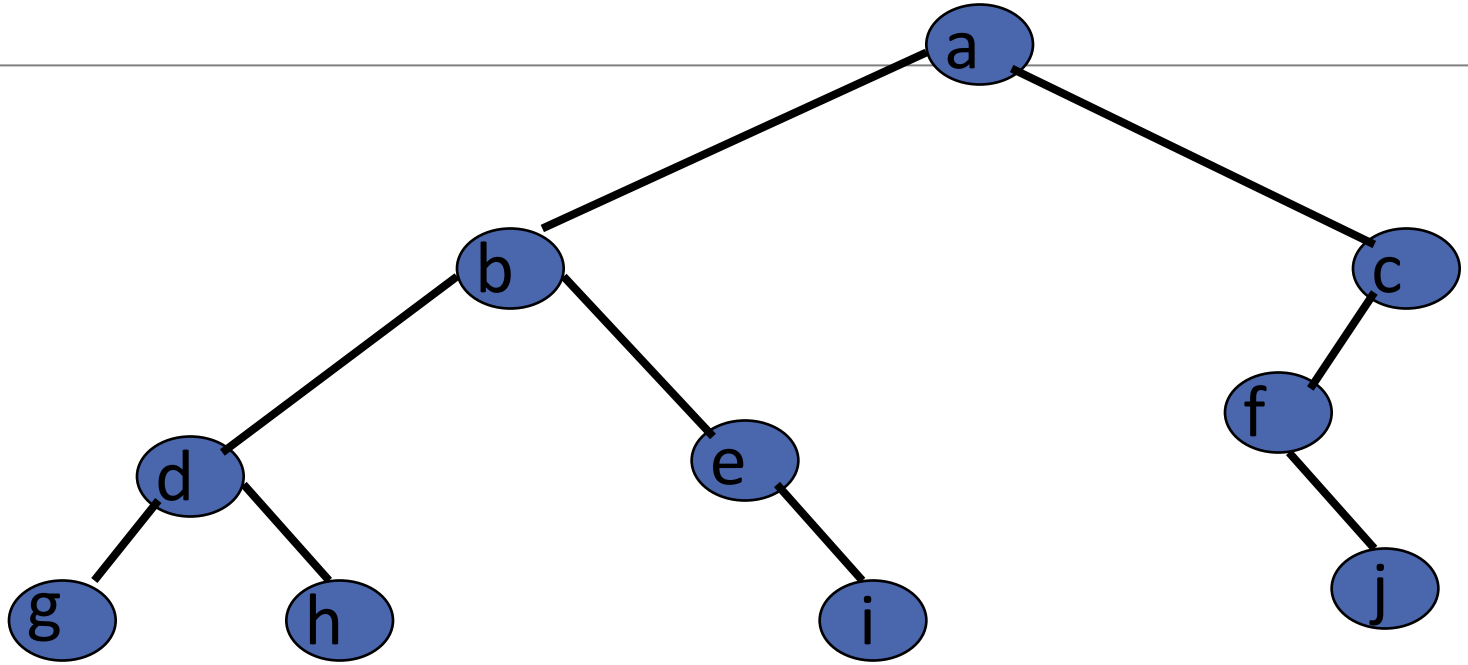
g d h b e i a f j c

Preorder Example (Visit = print)



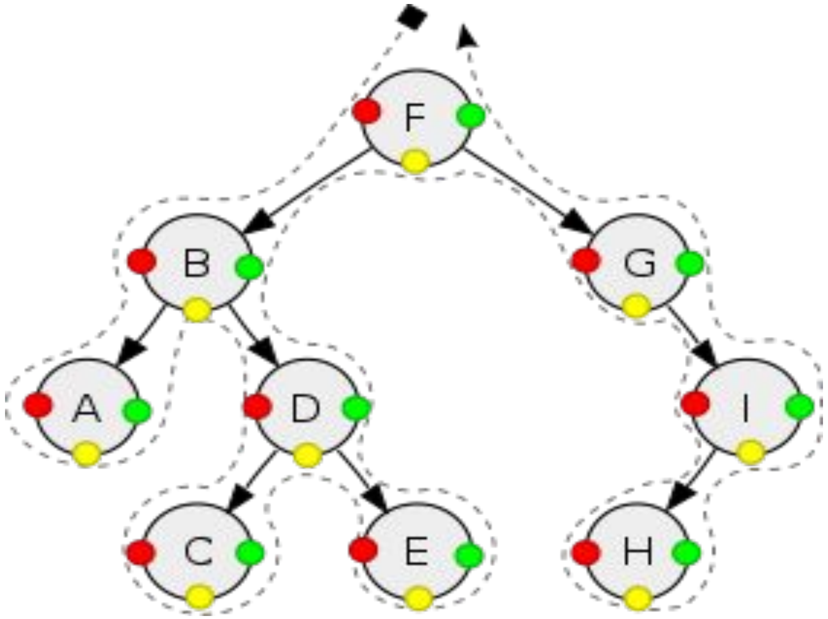
a b d g h e i c f j

Postorder Example (Visit = print)



g h d i e b j f c a

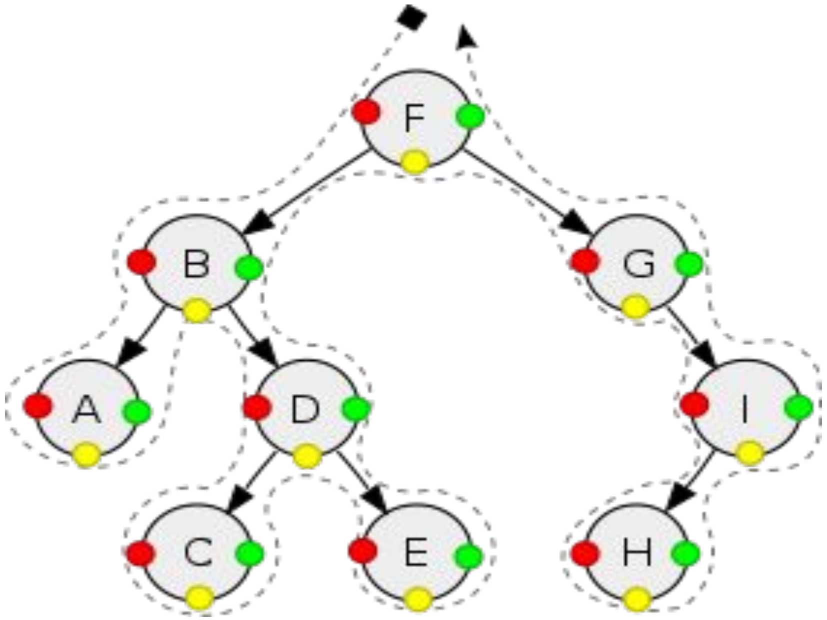
Depth first traversal



pre-order (red): F, B, A, D, C, E, G, I, H;
in-order (yellow): A, B, C, D, E, F, G, H, I;
post-order (green): A, C, E, D, B, H, I, G, F.

Inorder Traversal (recursive version)

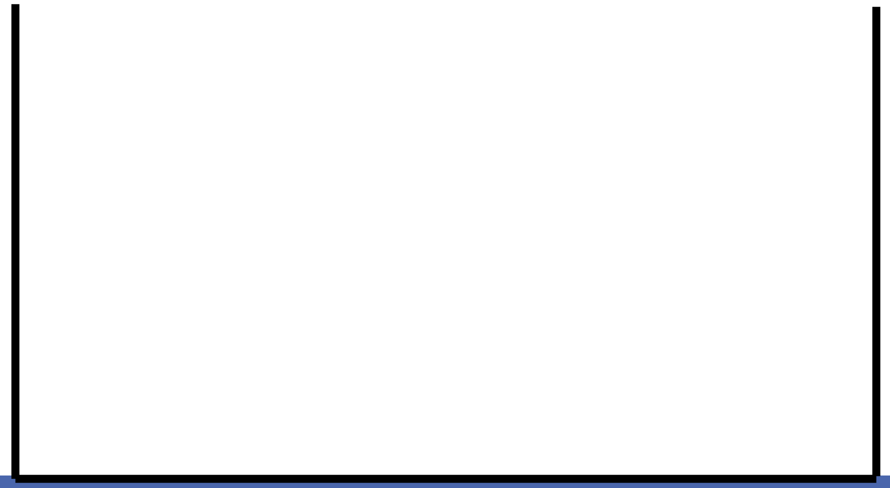
```
Algorithm inorder_r()    //Driver
{
  inorder_r(root);
}
 Algorithm inorder_r(treenode *temp)    // Workhorse
{
  if temp!=NULL
 {
   inorder_r(temp->left);
   Print temp->data;
   inorder_r(temp->right);
  }
}
```

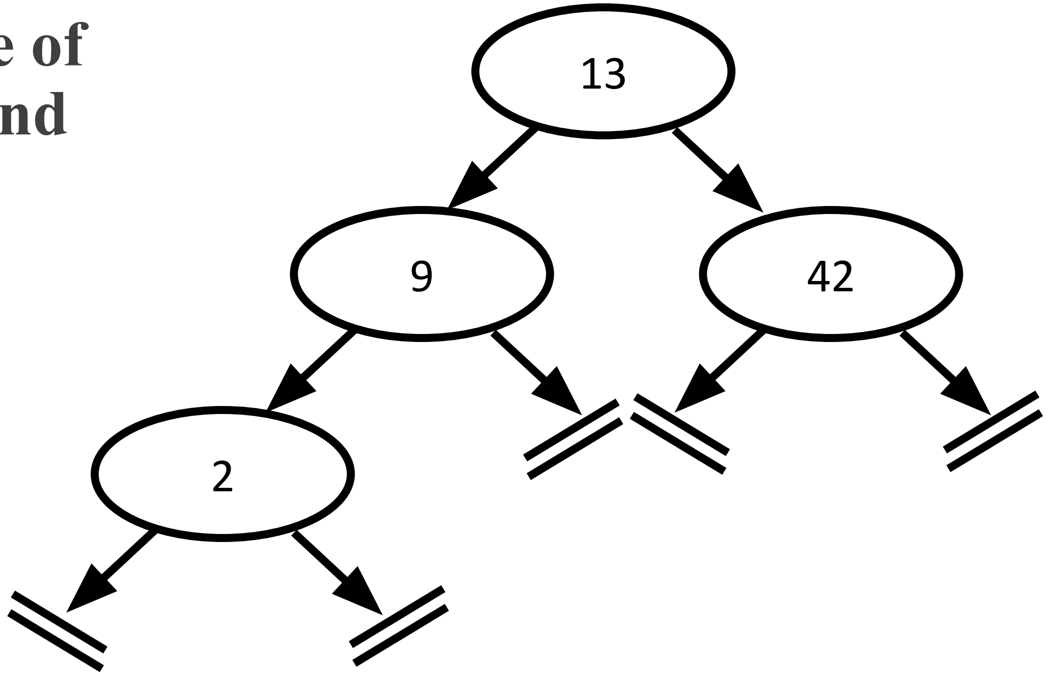


pre-order (red): F, B, A, D, C, E, G, I, H;
in-order (yellow): A, B, C, D, E, F, G, H, I;
post-order (green): A, C, E, D, B, H, I, G, F.

Use of the Activation Stack

With a recursive module, we can make use of the activation stack to visit the sub-trees and "remember" where we left off.





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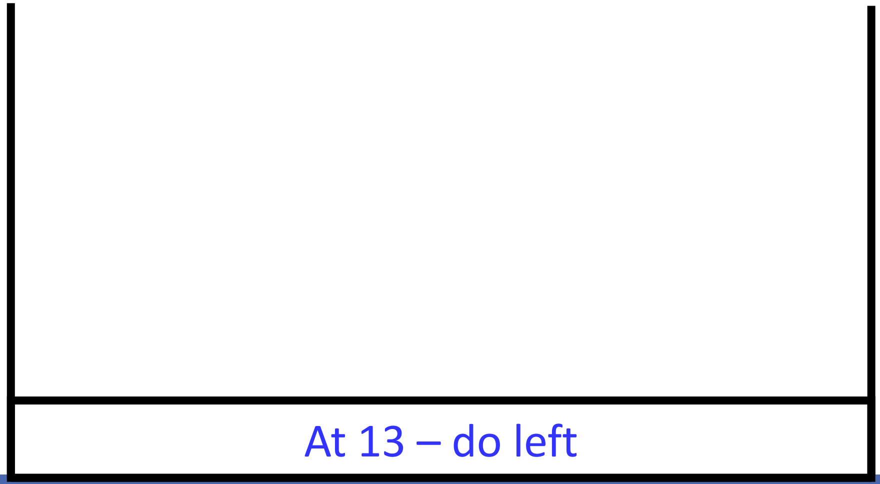

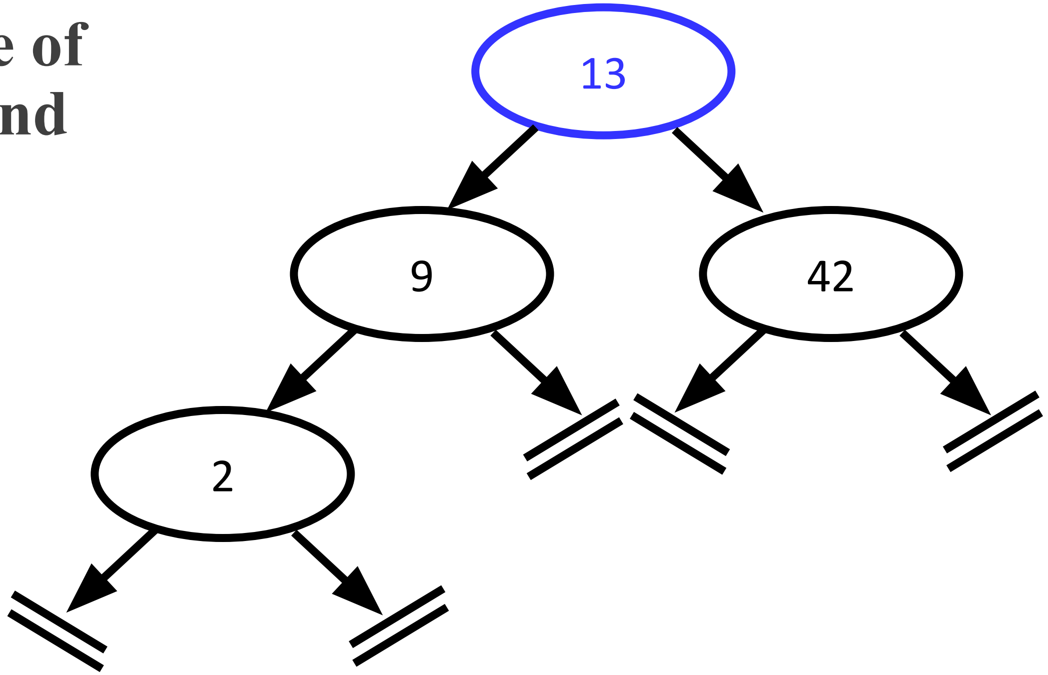

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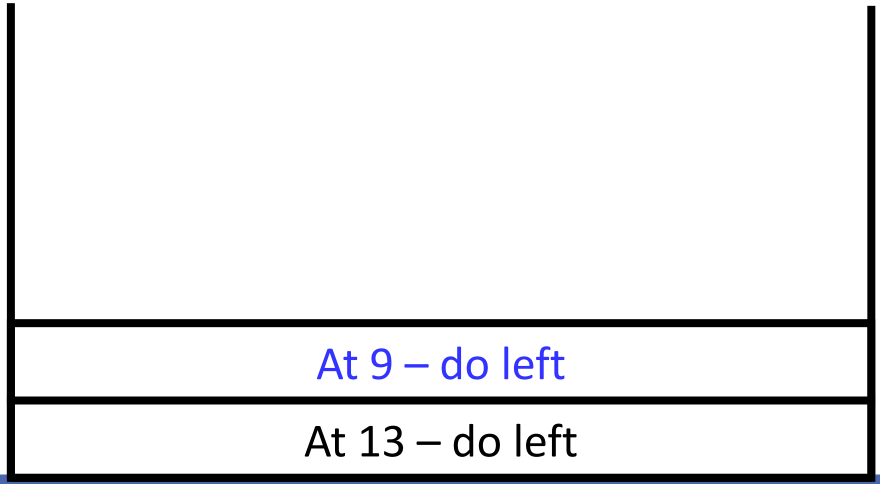

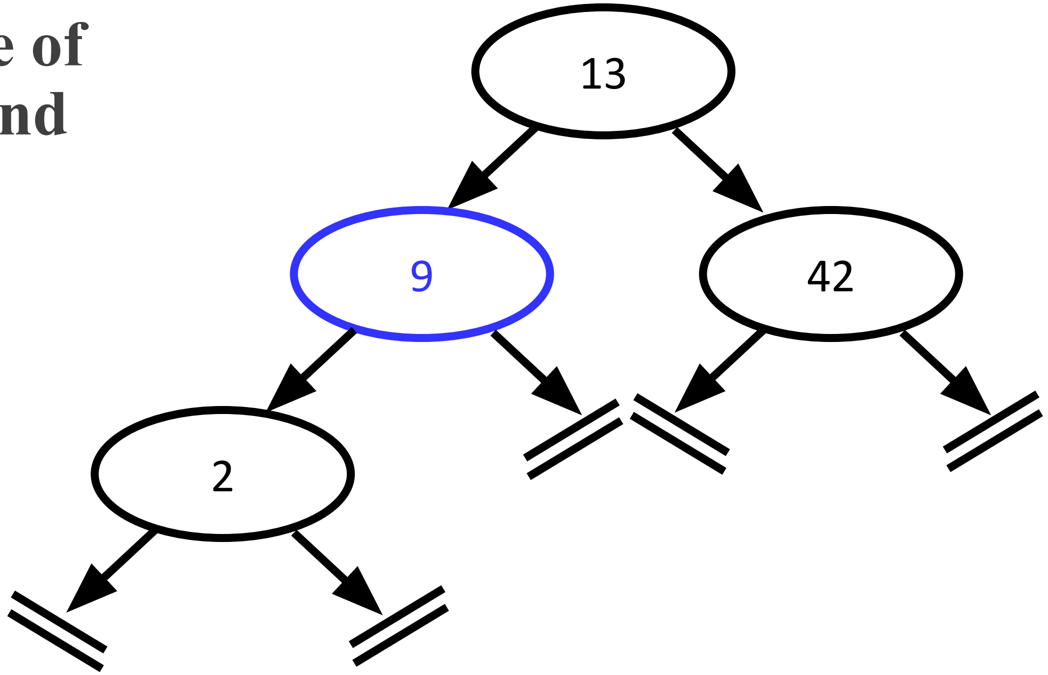

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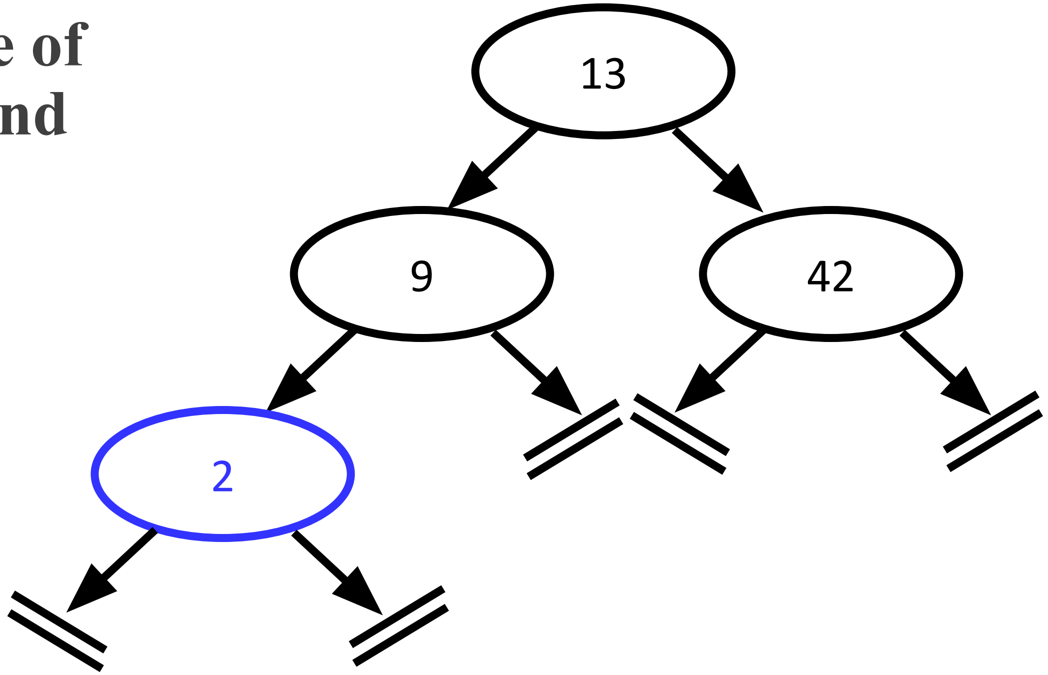

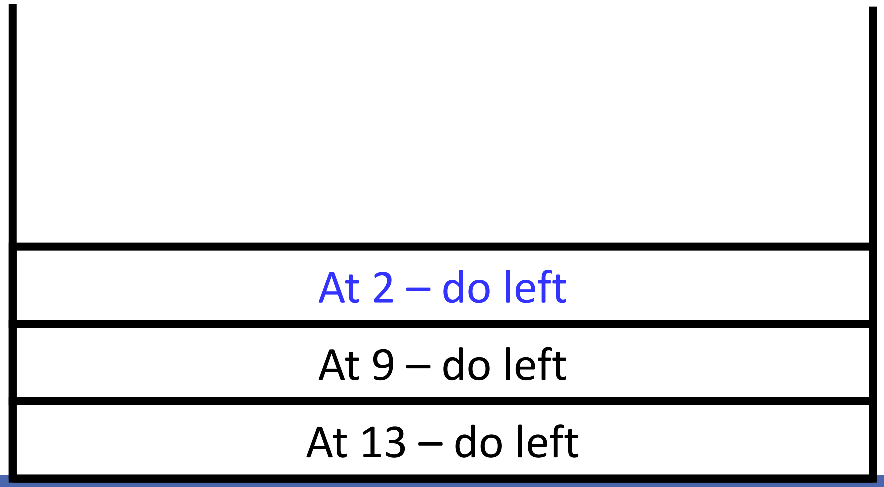

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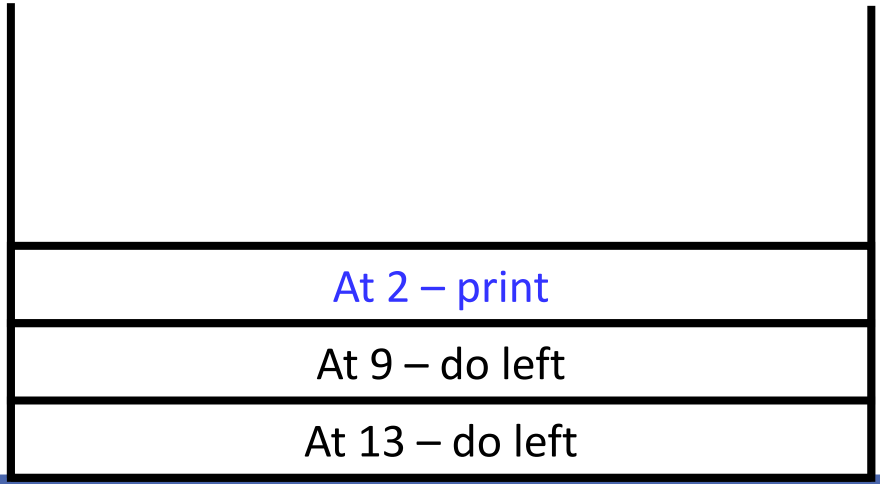

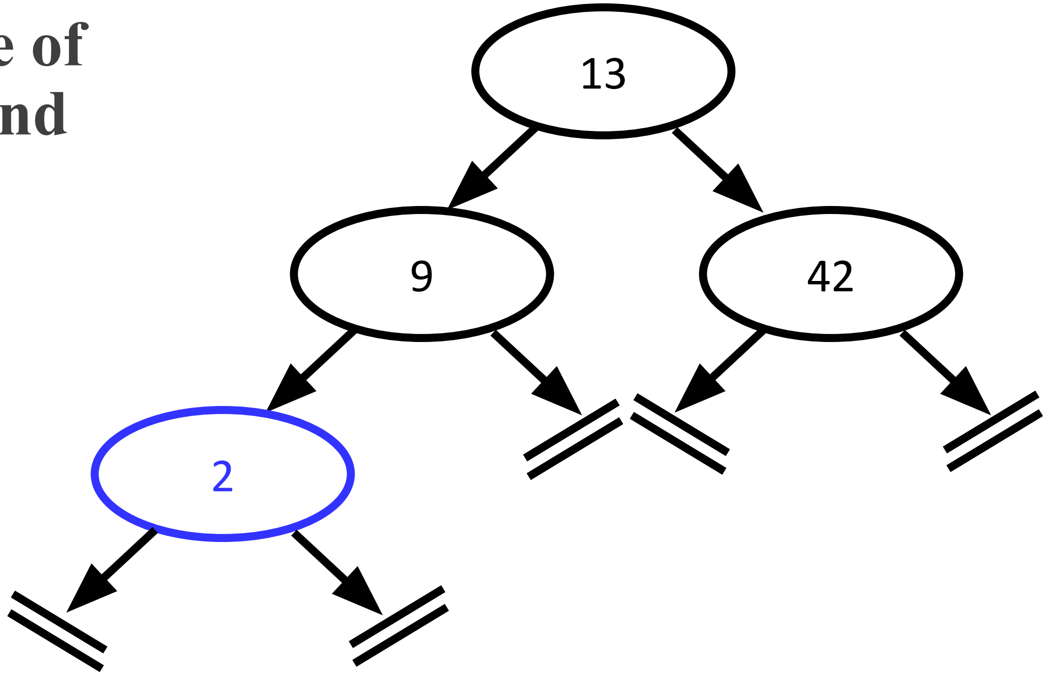

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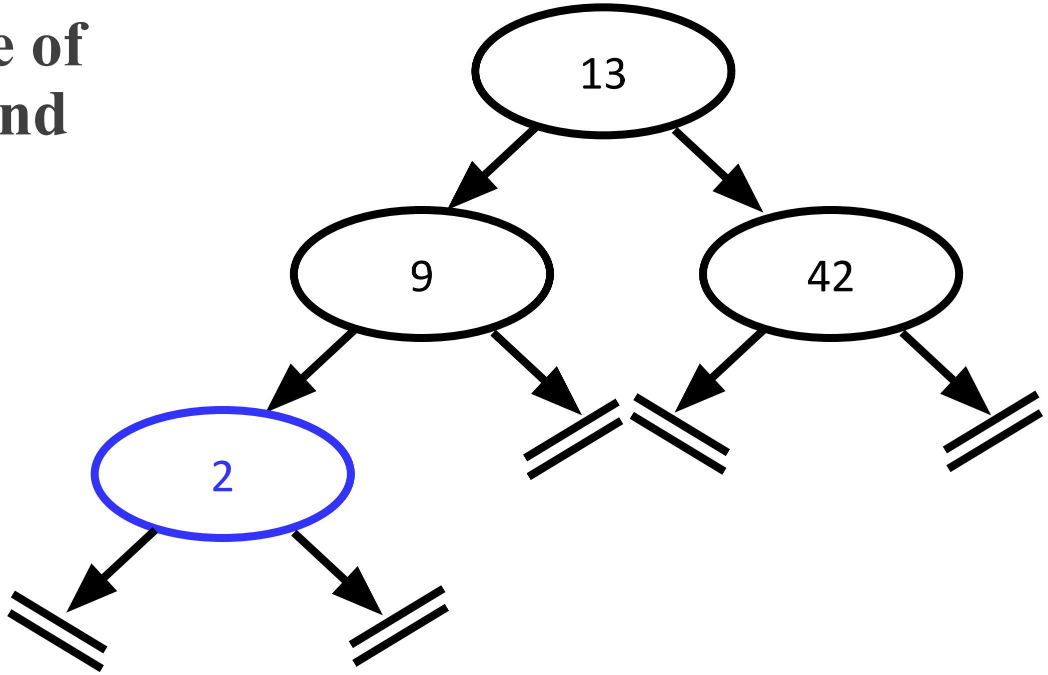

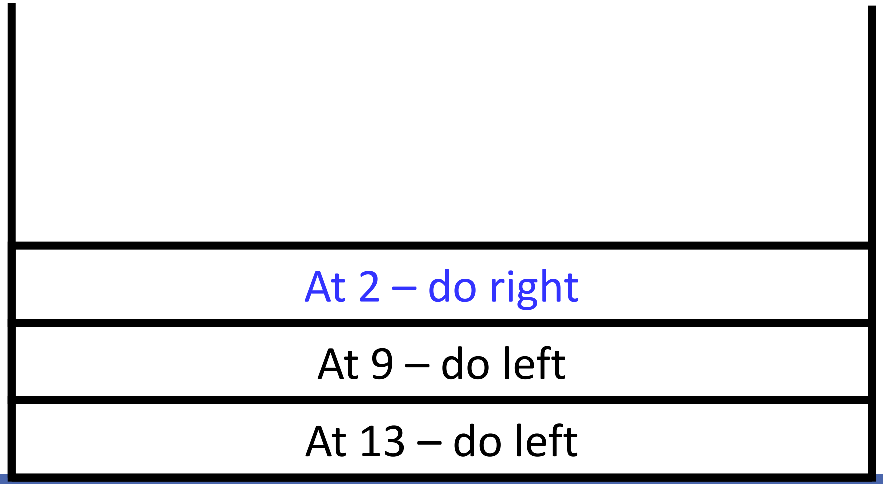

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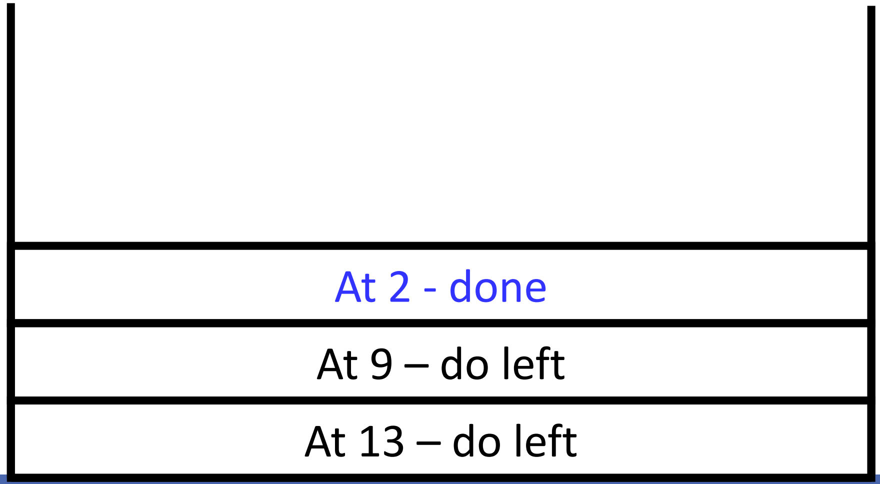
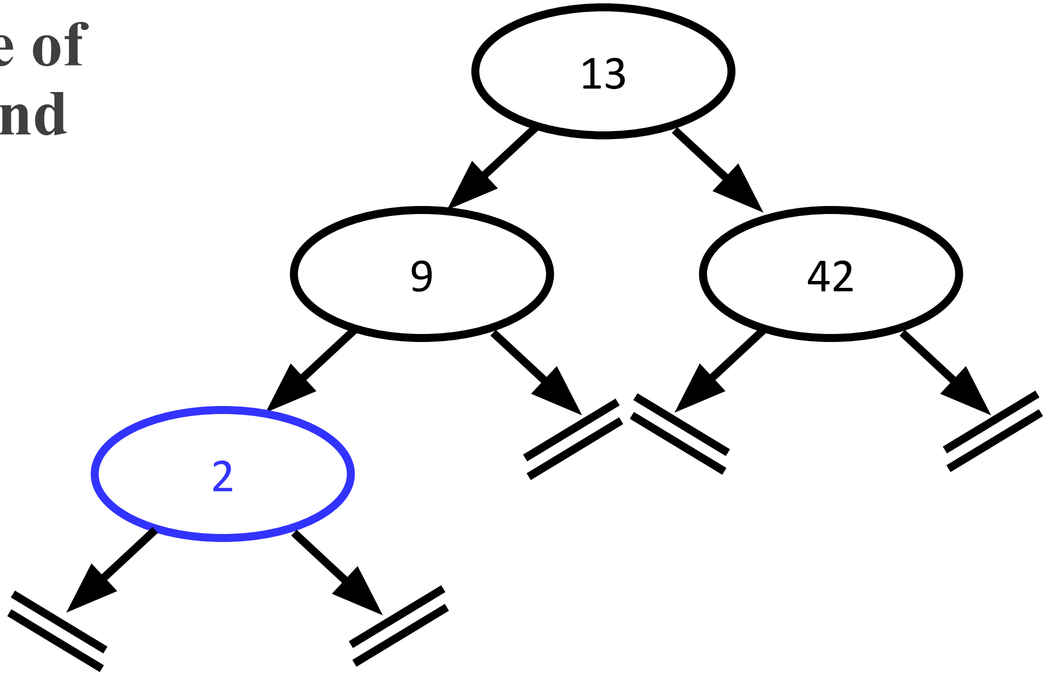
With a recursive module, we can make use of the activation stack to **visit the sub-trees** and **“remember” where we left off.**





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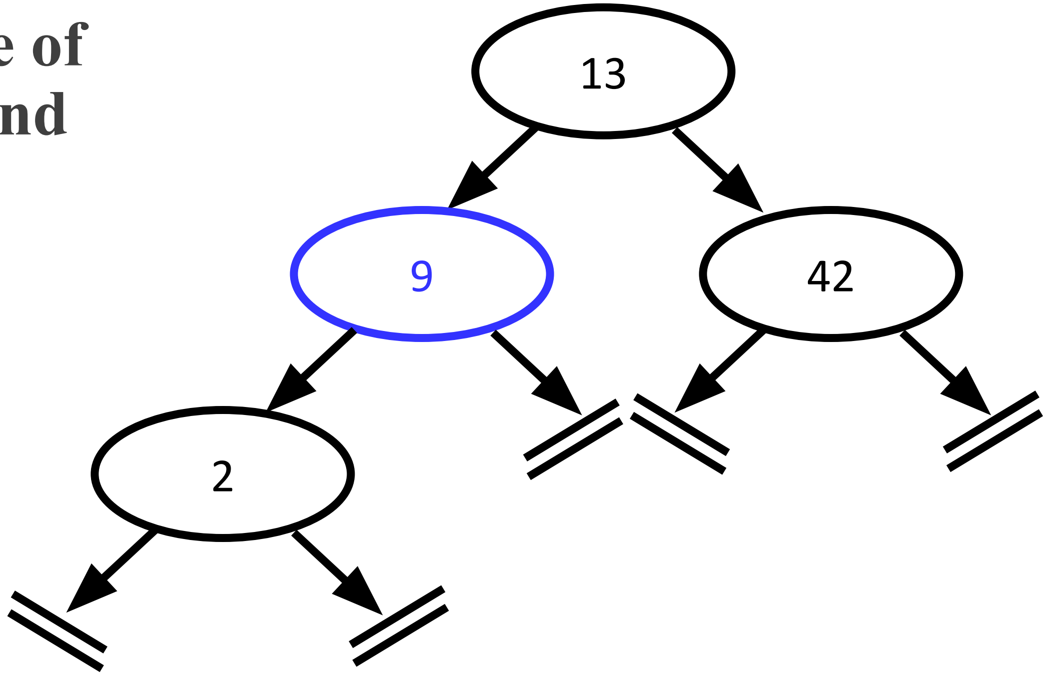

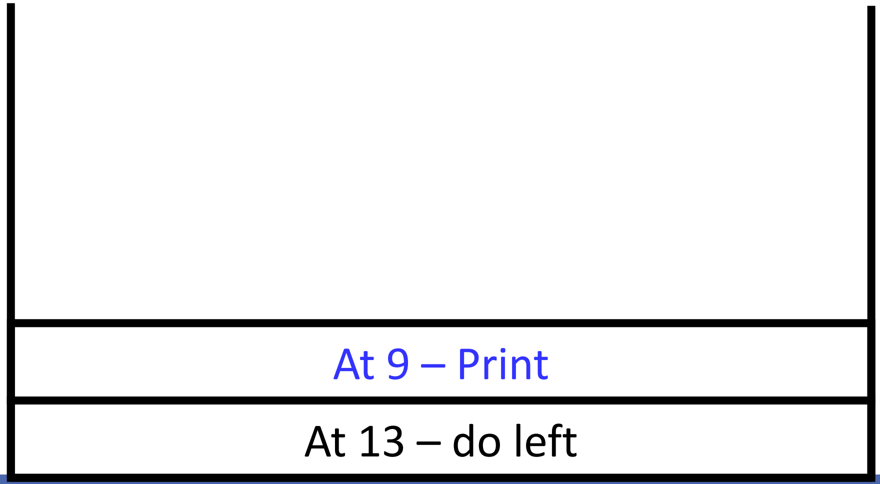

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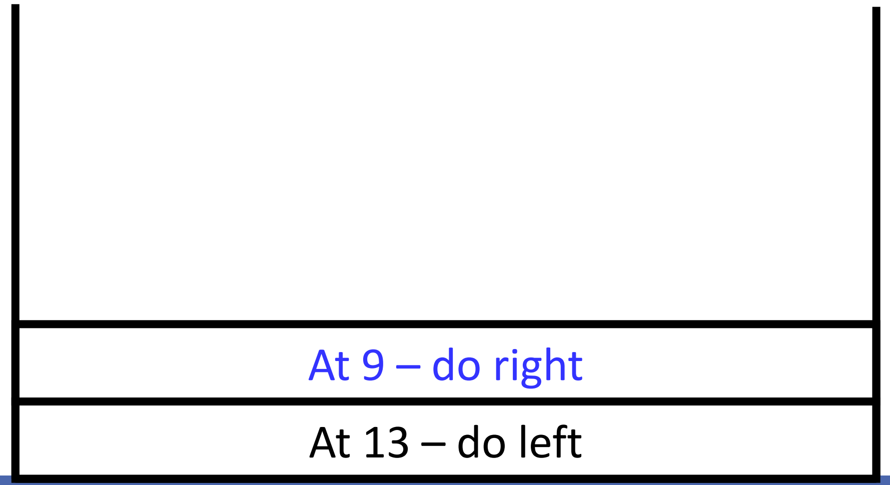

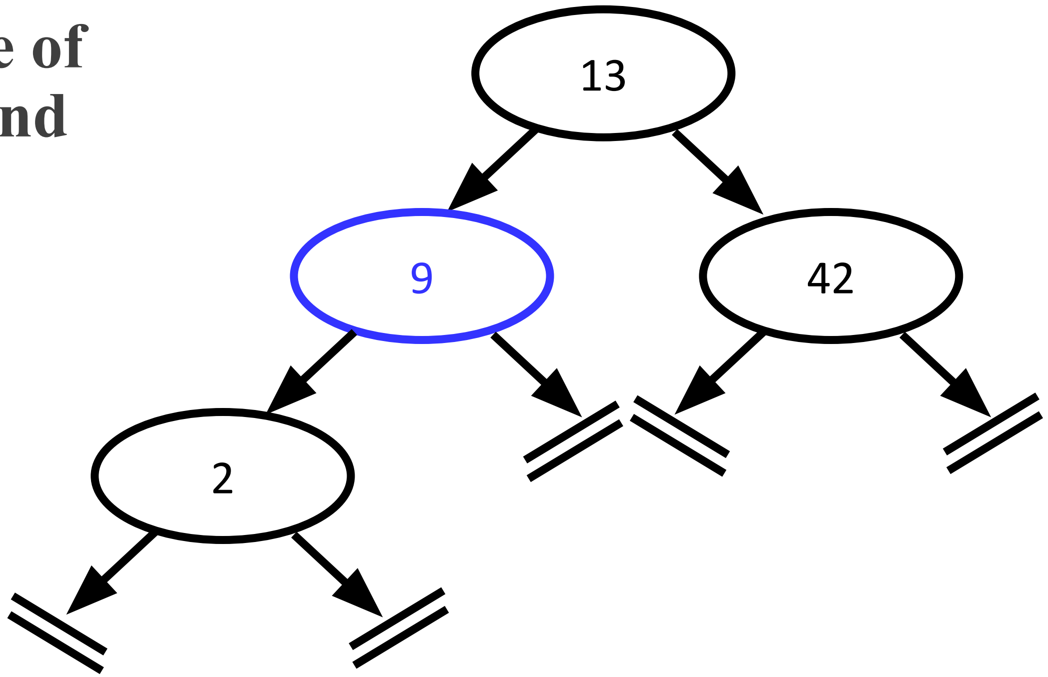

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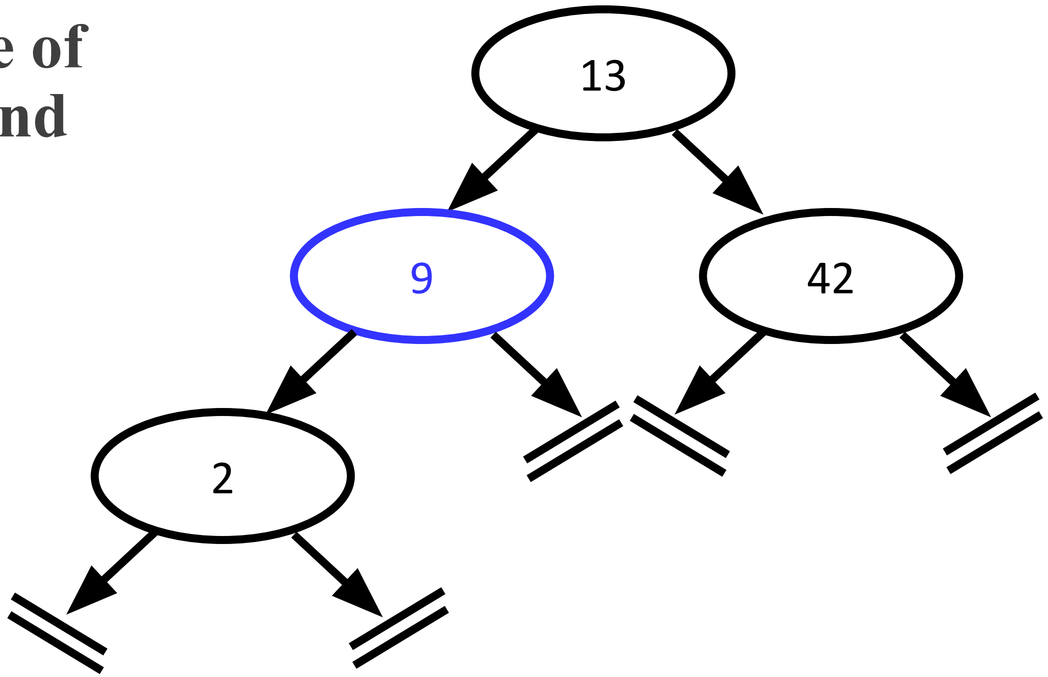

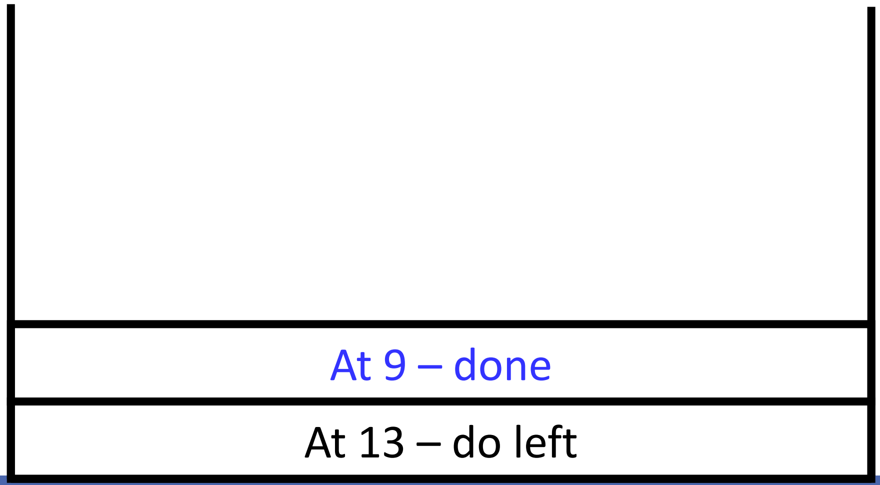

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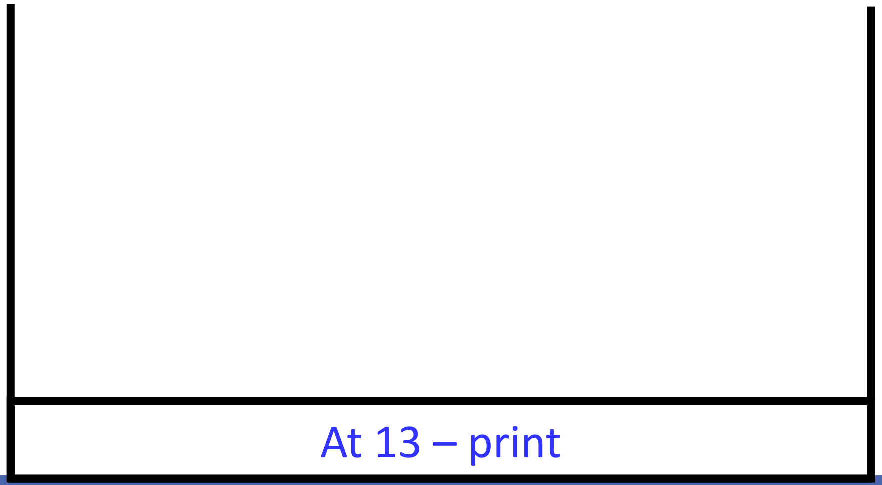

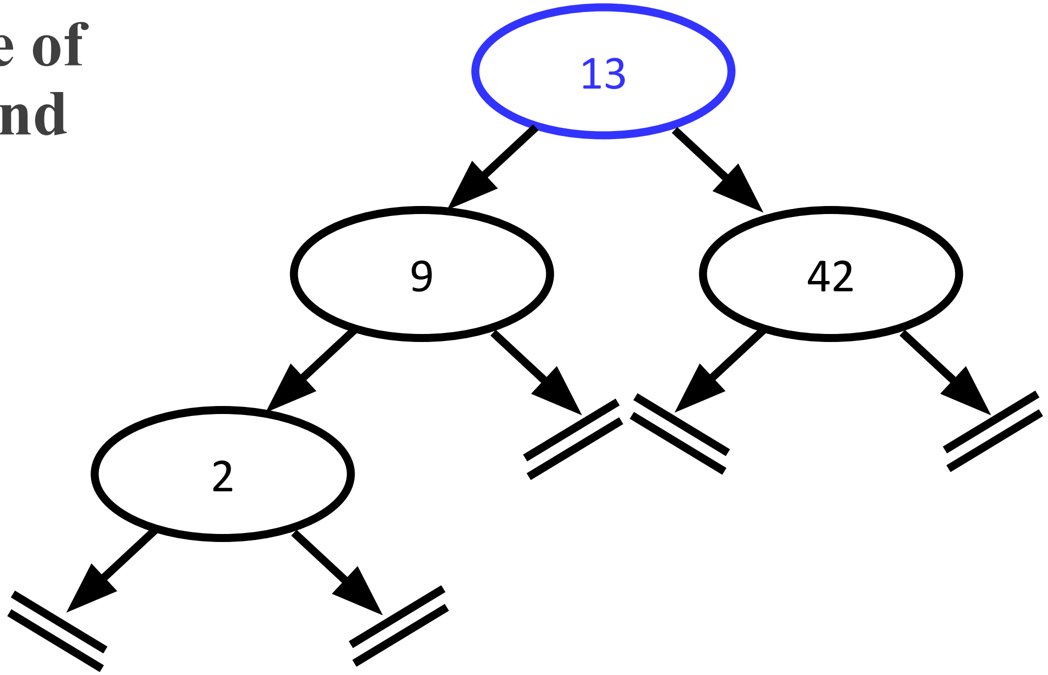

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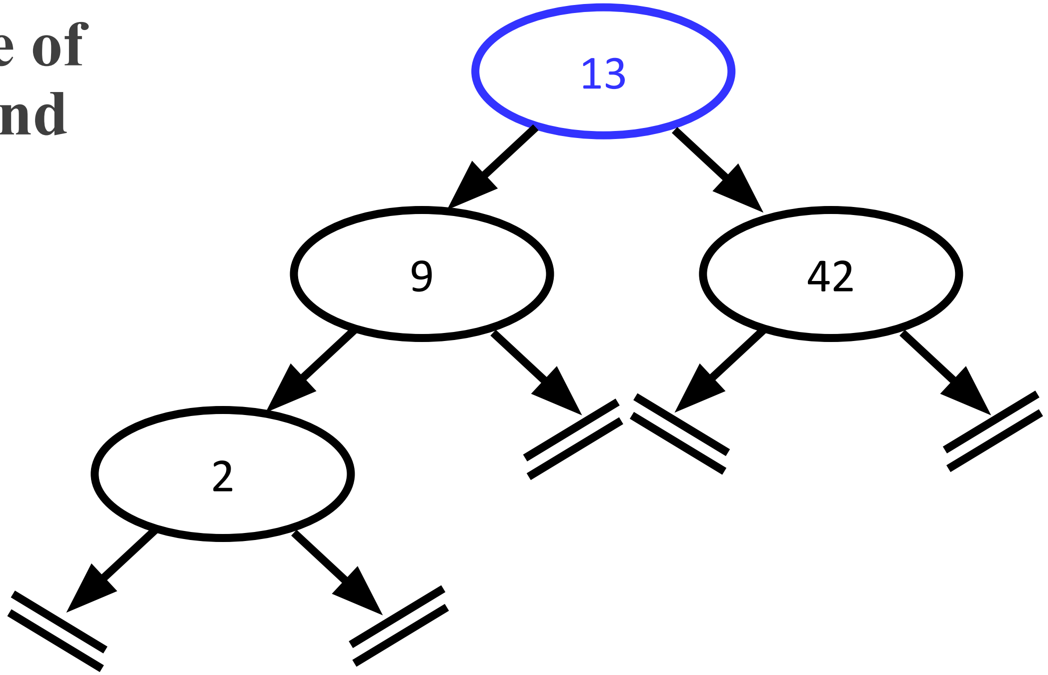

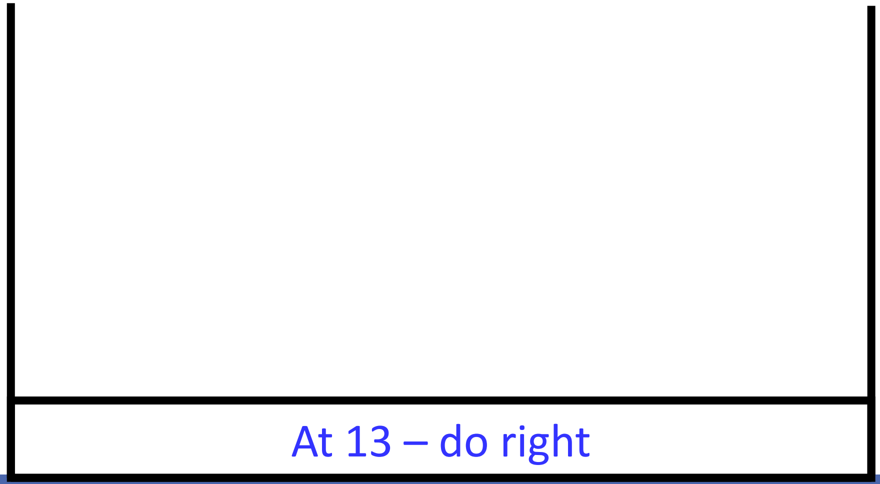

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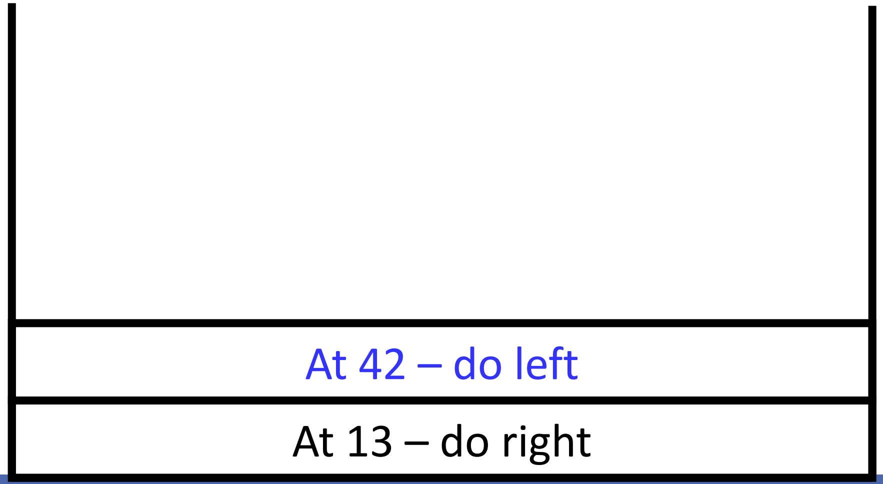

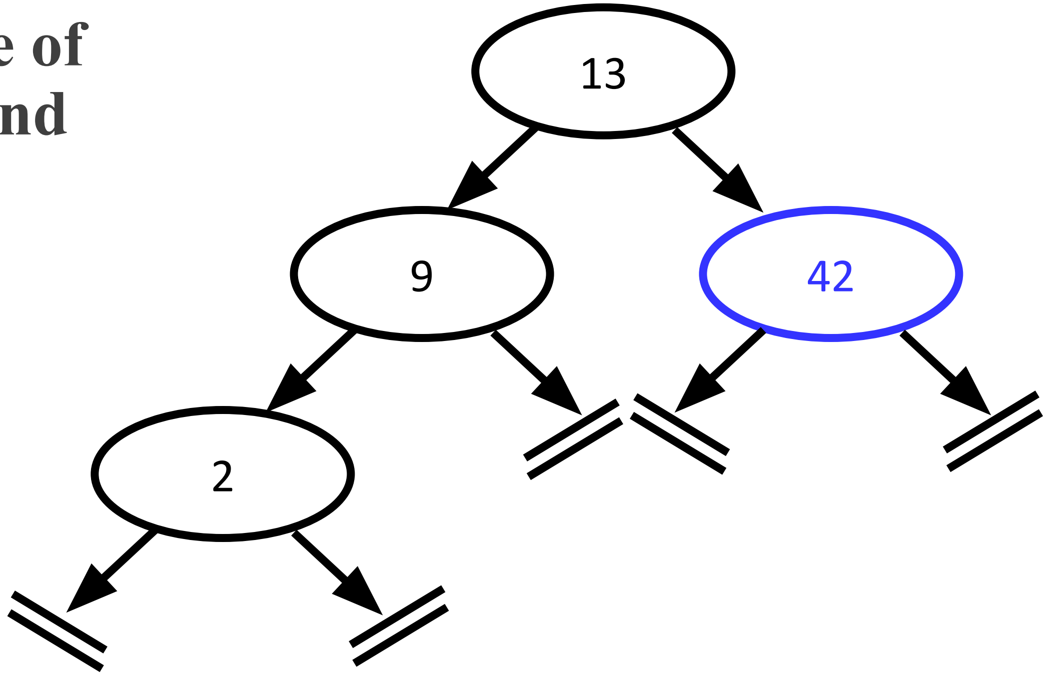

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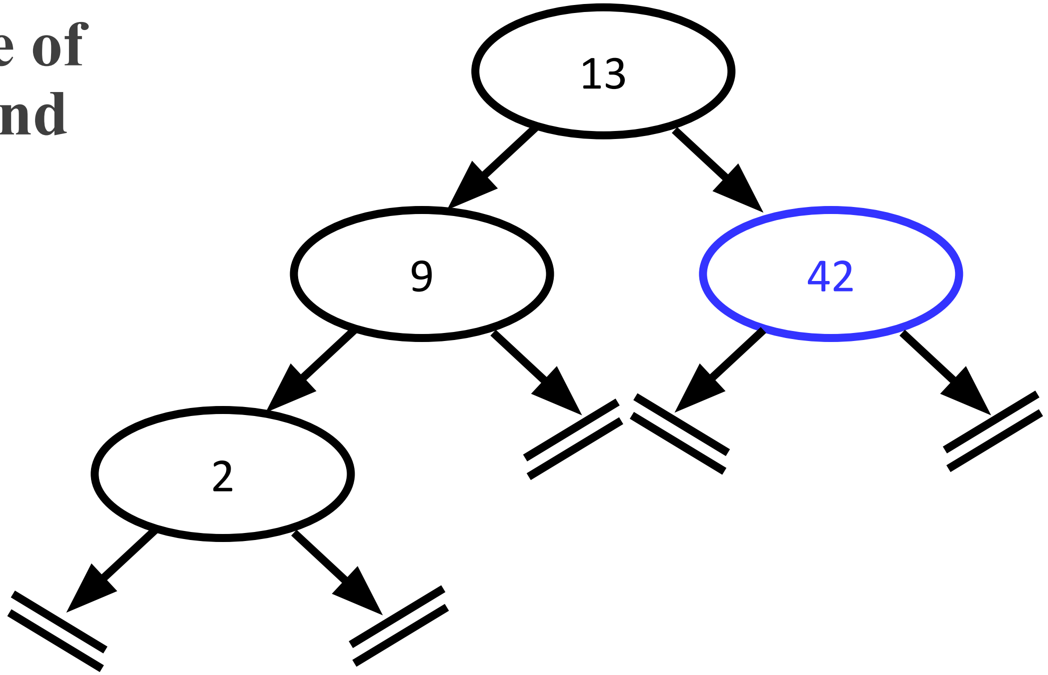

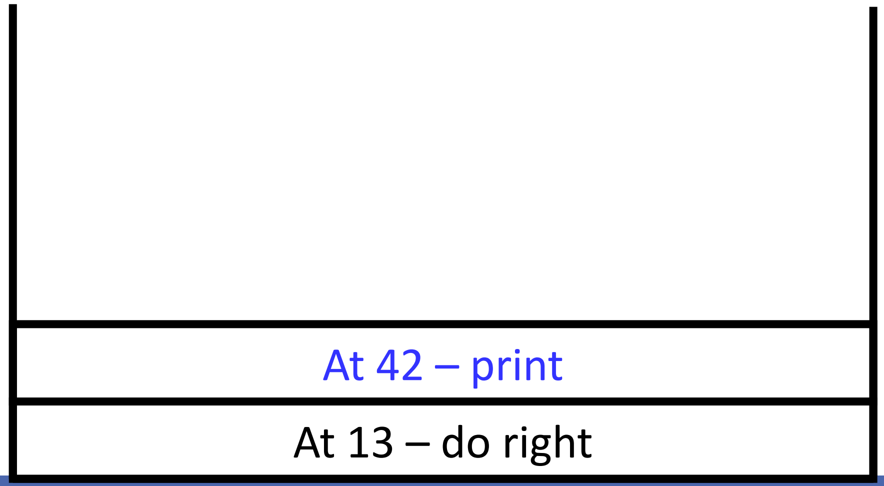

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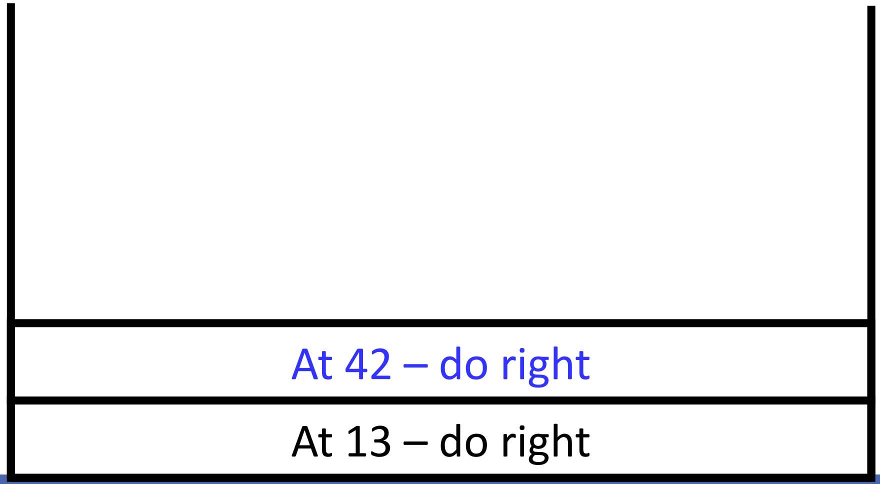

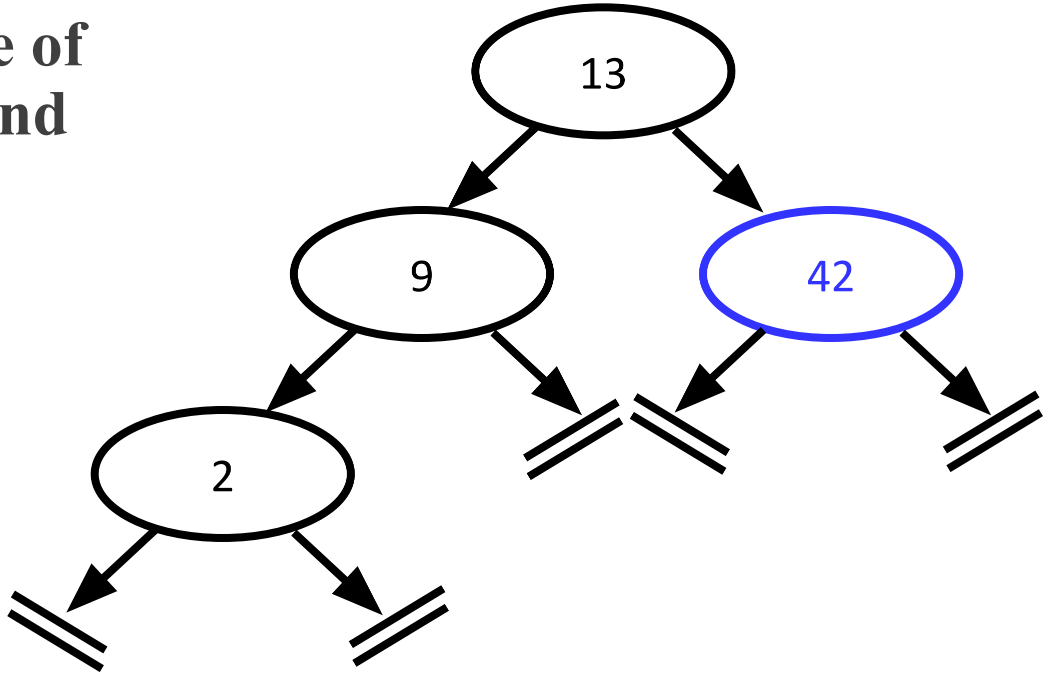

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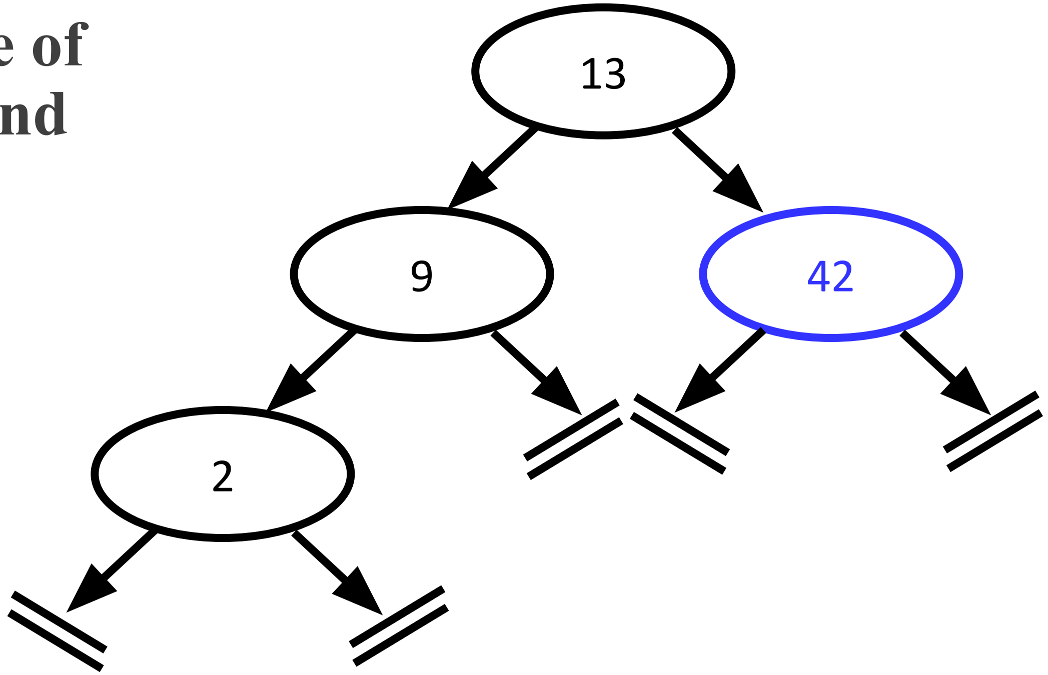

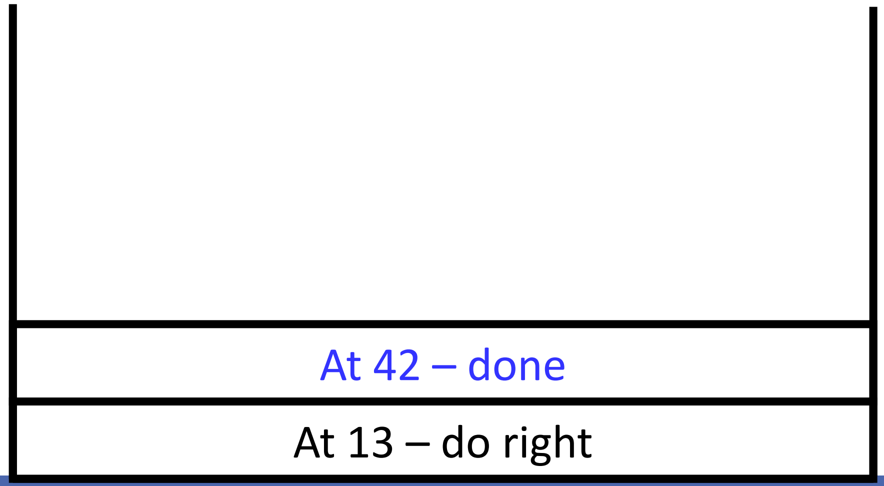

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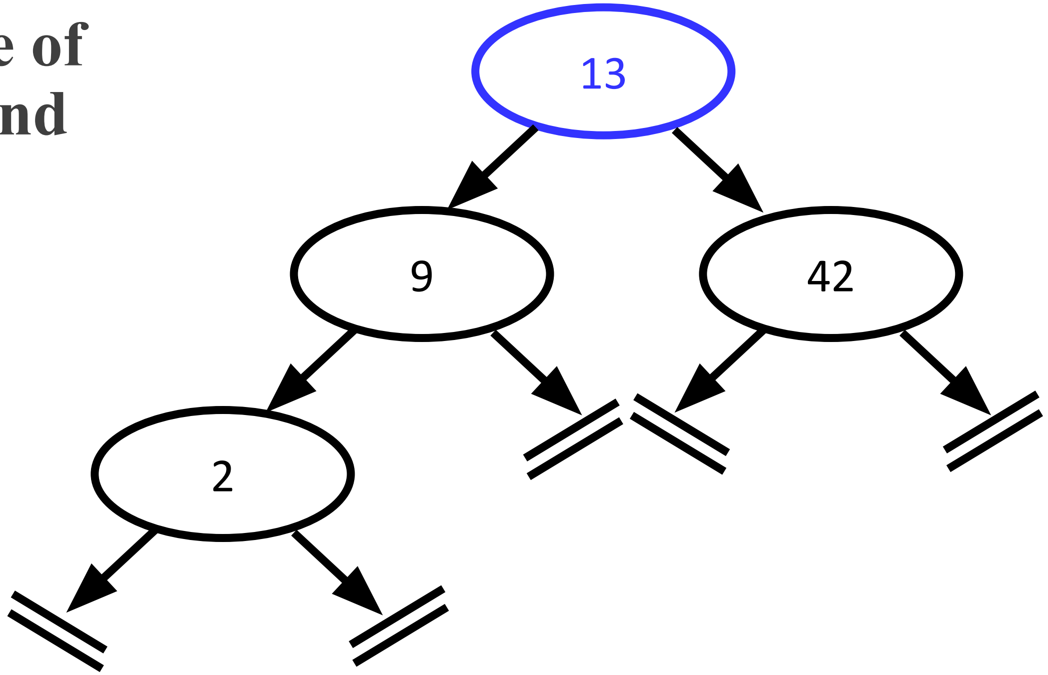
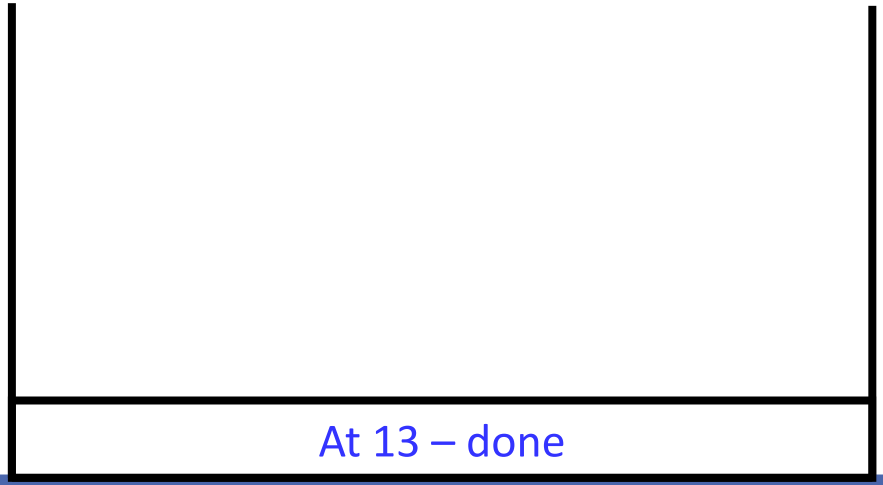
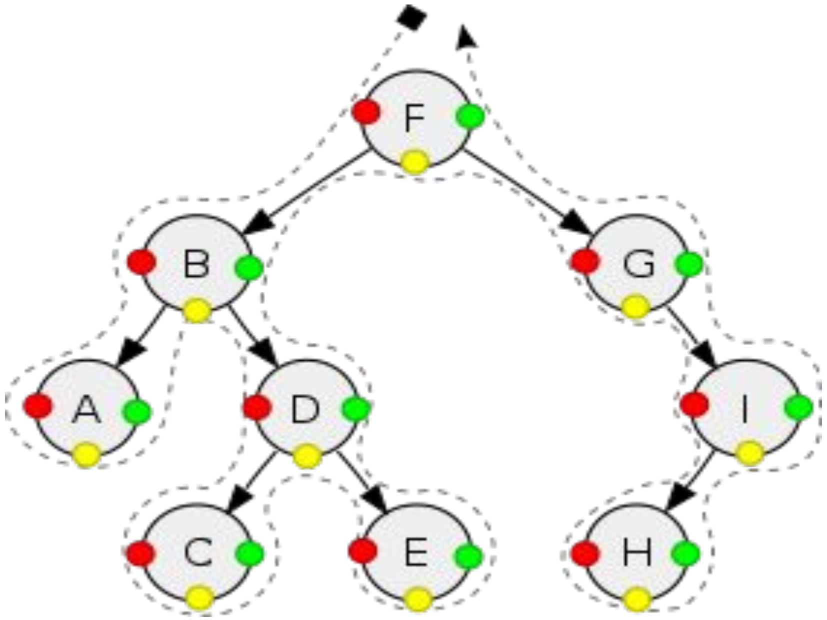




Preorder Traversal (recursive version)

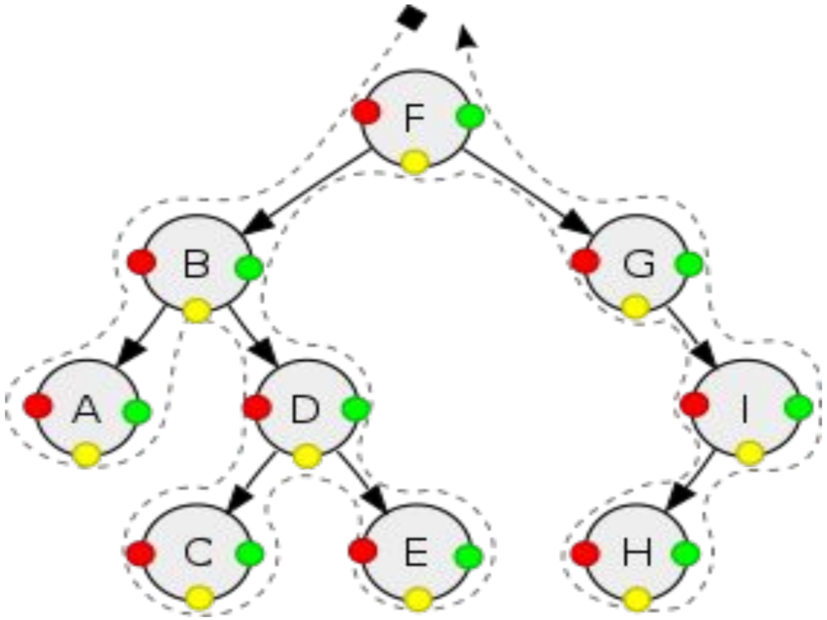
```
Algorithm preorder(treenode * temp)
/* preorder tree traversal */
{
    if (temp!=NULL) {
        print(temp->data);
        preorder(temp->left);
        predorder(temp->right);
    }
}
```



pre-order (red): F, B, A, D, C, E, G, I, H;
in-order (yellow): A, B, C, D, E, F, G, H, I;
post-order (green): A, C, E, D, B, H, I, G, F.

Postorder Traversal (recursive version)

```
Algorithm postorder(treenode * temp)
/* postorder tree traversal */
{
    if (temp!=NULL) {
        postorder(temp->left);
        postdorder(temp->right);
        print(temp->data);
    }
}
```



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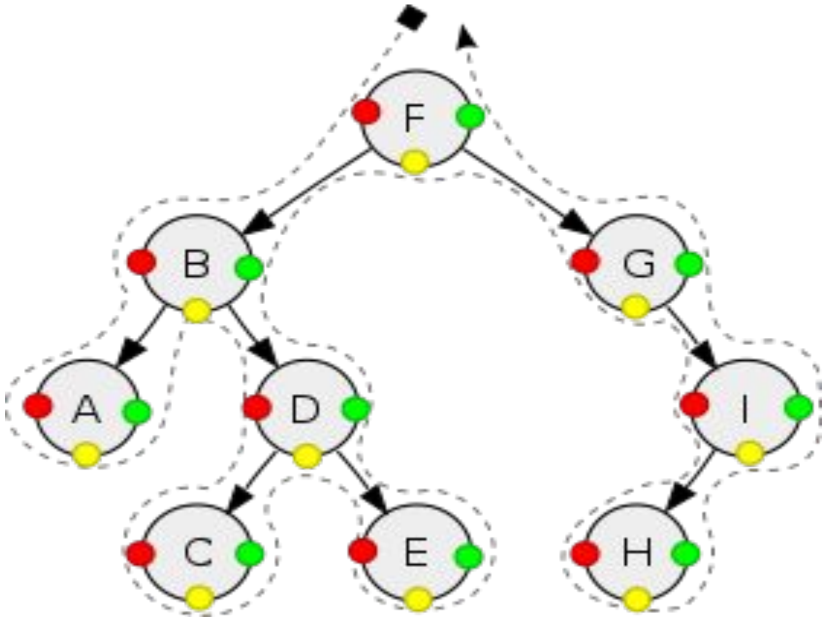
in-order (yellow): A, B, C, D, E, F, G, H, I;
post-order (green): A, C, E, D, B, H, I, G, F.

Stack for tree traversal

```
class stack
{
   int top;
   treenode *data[30];
   public:
    stack()
    {
       top=-1;
    }
    void push(treenode *temp);
     treenode *pop();
     int empty();
    friend class tree;
};
```

Nonrecursive Inorder Traversal

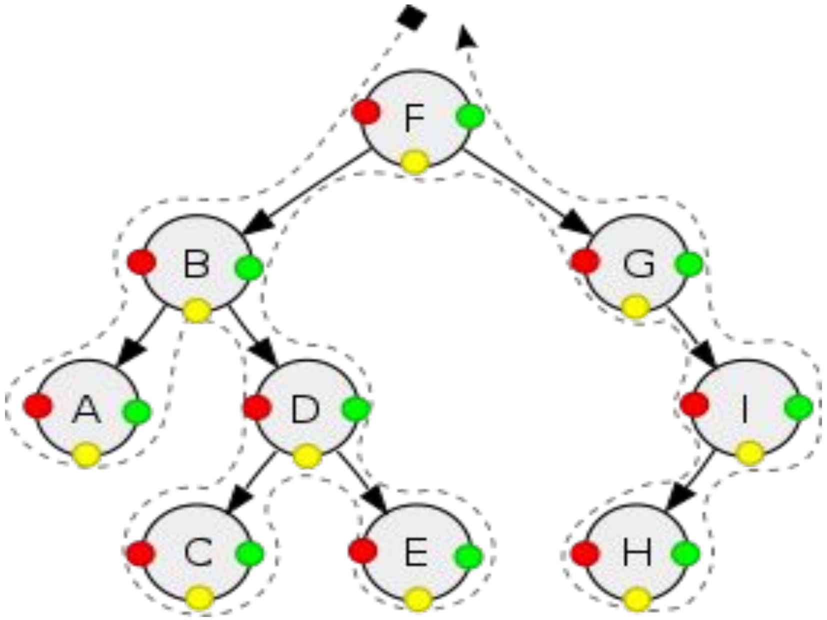
```
Algorithm inorder() {
      temp = root;  //start traversing the binary tree at the root node
      while(1)  {
        while(temp is not NULL)
        {
          push temp onto stack;
          temp = temp ->left;
        }
        if stack  empty
          break;
        pop stack into temp;
        visit temp;     //visit the node
        temp = temp ->right;     //move to the right child
      }   //end while
}   //end algorithm
```



pre-order (red): F, B, A, D, C, E, G, I, H;
in-order (yellow): A, B, C, D, E, F, G, H, I;
post-order (green): A, C, E, D, B, H, I, G, F.

Nonrecursive Preorder Traversal

```
Algorithm preorder() {
    temp = root;  //start the traversal at the root node
        while(1) {
          while(temp is not NULL)
          {
              visit temp;
              push temp onto stack;
            temp = temp ->left;
           }
          if stack  empty
             break;
         pop stack into temp;
        temp = temp ->right;    //visit the right subtree
      }  //end while
  }     //end algorithm
```



pre-order (red): F, B, A, D, C, E, G, I, H;

in-order (yellow): A, B, C, D, E, F, G, H, I;

post-order (green): A, C, E, D, B, H, I, G, F.

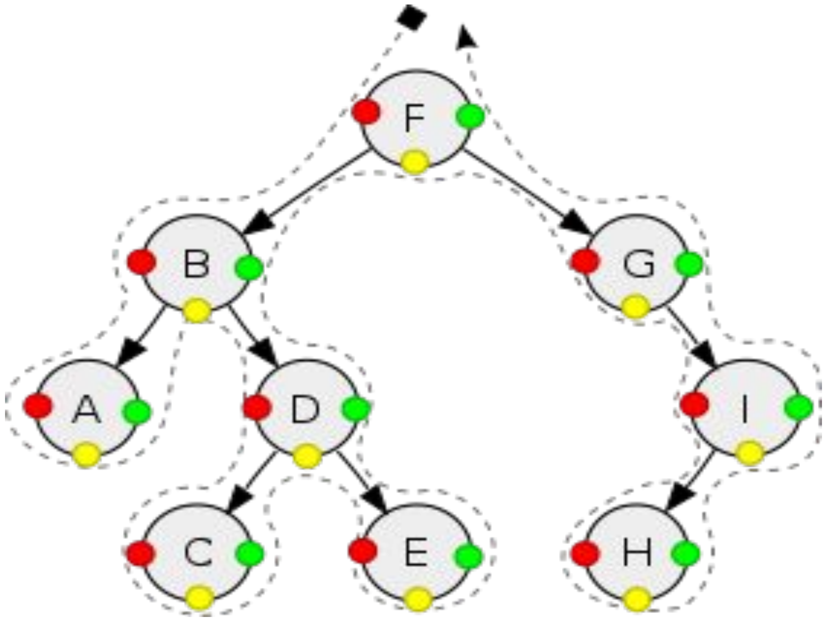
Nonrecursive Postorder Traversal

```
Algorithm postorder_nr()
{
  temp=root;
  while(1)
  {
    while(temp is not NULL)
    {
    push temp onto stack;
    temp = temp ->left;
    }
    if  stack top right is NULL
    {
     pop stack into temp;
     visit temp;
    }
    while(stack not empty && stack top right is temp)
     {
       pop stack into temp;
       visit temp
     }
     if stack  empty
          break;

     move temp to stack top right;
   }     // end while

}    // end algorithm
```

temp=st.data[st.top]->right



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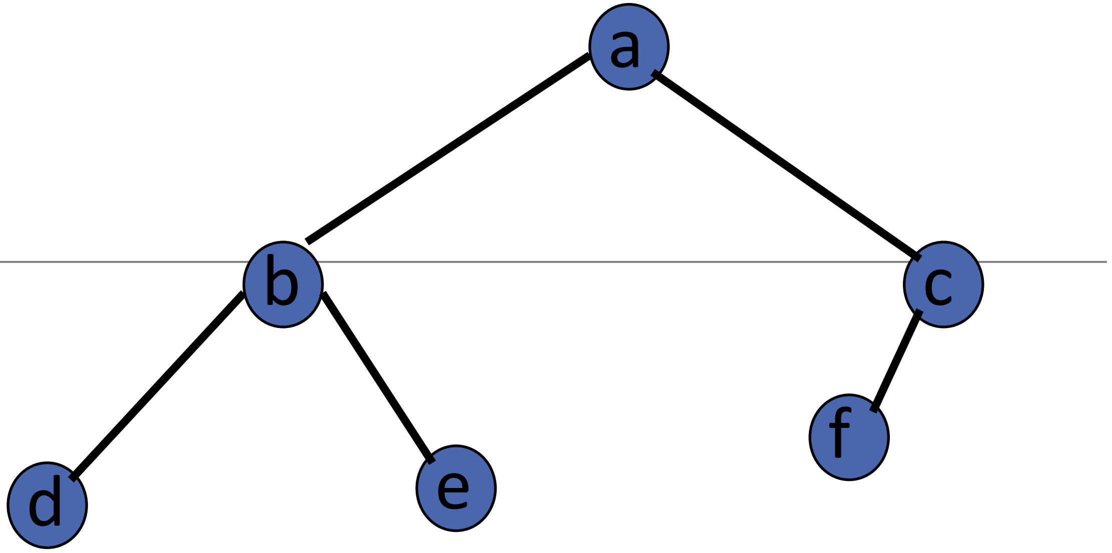
in-order (yellow): A, B, C, D, E, F, G, H, I;
post-order (green): A, C, E, D, B, H, I, G, F.

```
Algorithm BFS()
{
temp=root;
Insert temp into queue;
 while  Queue not empty
 {

     Remove from queue into temp;
      visit temp;
   if(temp->left is not NULL)
          insert temp->left into queue;
   if(temp->right is not NULL)
       insert temp->right into queue;

   }
 }
```



Queue

a

Answer

Algorithm BFS()

{

temp=root;

Insert temp into queue;

while Queue not empty

{

Remove from queue into temp;

visit temp;

if(temp->left is not NULL)

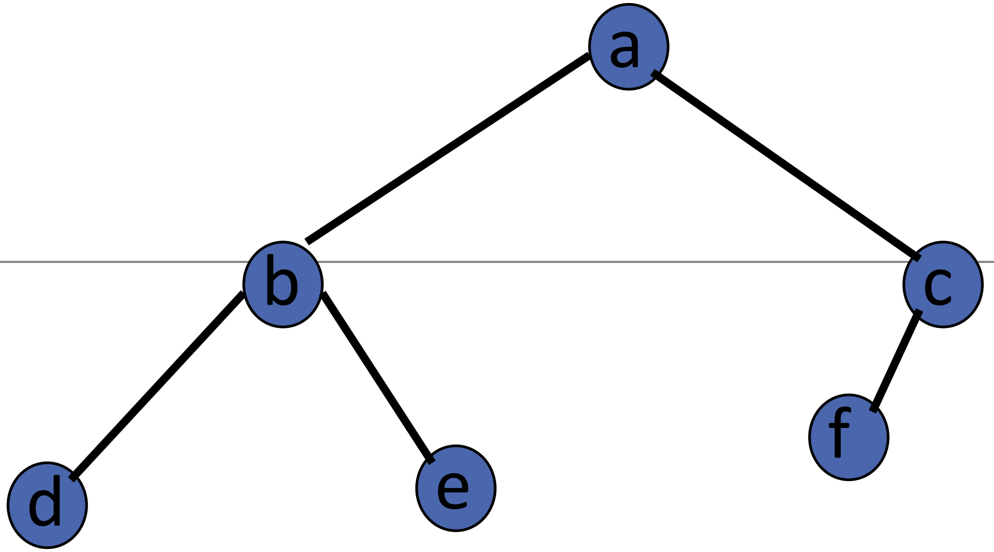
insert temp->left into queue;

if(temp->right is not NULL)

insert temp->right into queue;

}

}



Queue

Answer

a

Algorithm BFS()

```
{
temp=root;
Insert temp into queue;
 while  Queue not empty
 {

     Remove from queue into temp;
      visit temp;
   if(temp->left is not NULL)
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   if(temp->right is not NULL)
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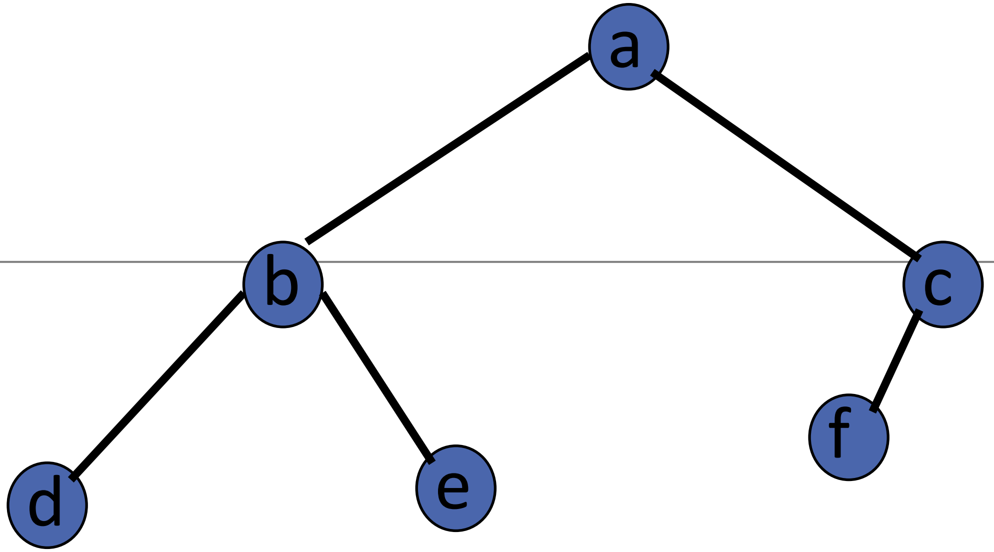
   }
 }
```



Queue

b c

Answer

a

```
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{
temp=root;
Insert temp into queue;
 while  Queue not empty
 {

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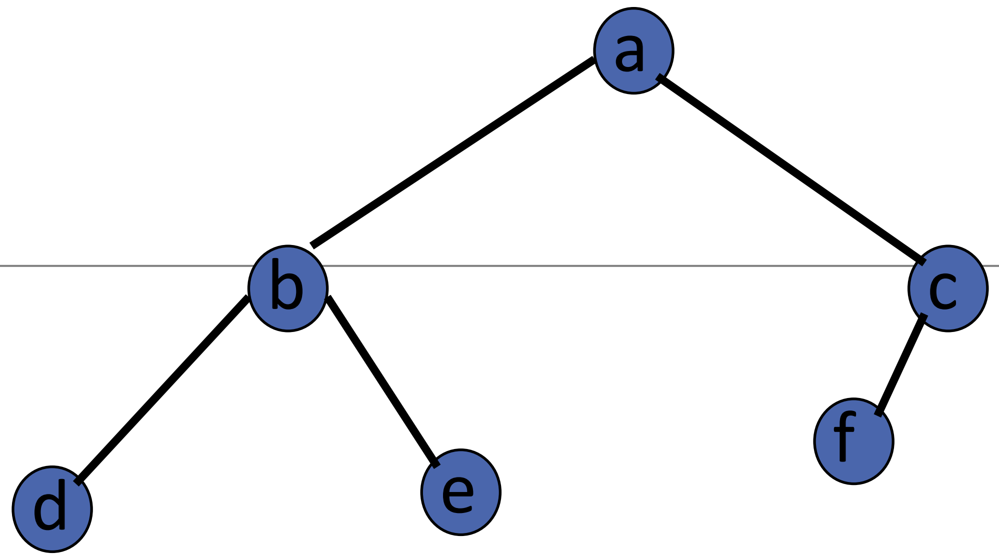
     visit temp;
   if(temp->left is not NULL)
         insert temp->left into queue;
   if(temp->right is not NULL)
      insert temp->right into queue;

   }
 }
```



Queue

c

Answer

a b

Algorithm BFS()

{

temp=root;

Insert temp into queue;

while Queue not empty

{

Remove from queue into temp;

visit temp;

if(temp->left is not NULL)

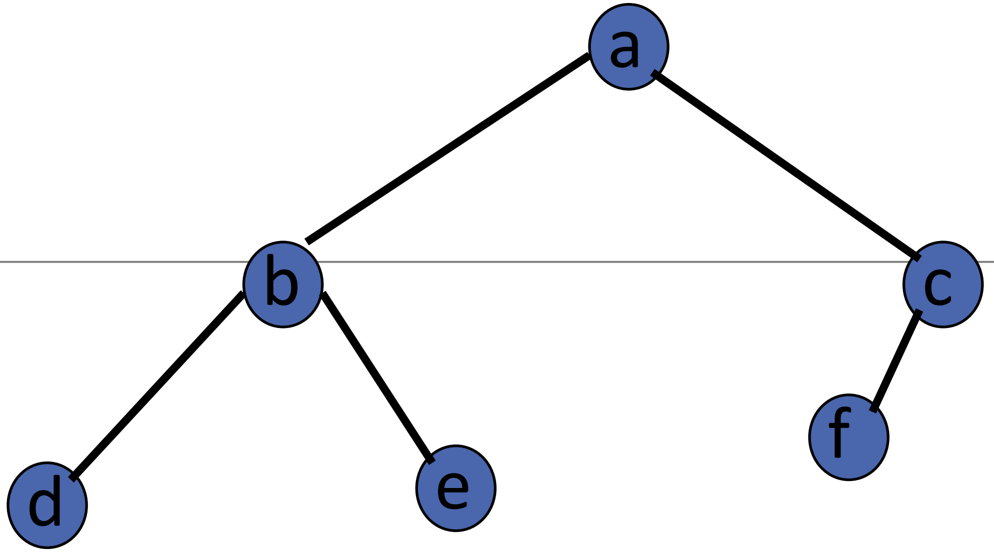
insert temp->left into queue;

if(temp->right is not NULL)

insert temp->right into queue;

}

}



Queue

c d e

Answer

a b

```
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{
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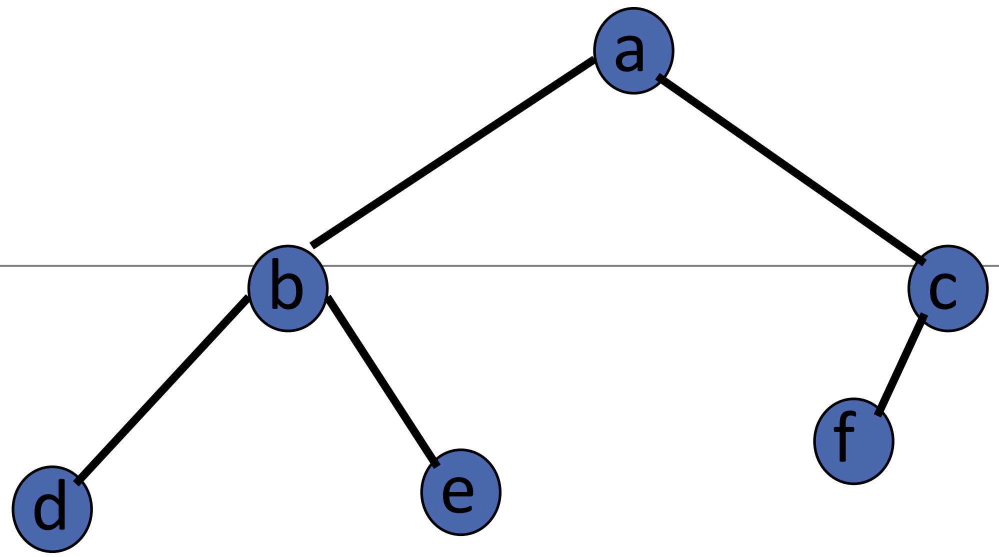
Insert temp into queue;
 while  Queue not empty
 {

    Remove from queue into temp;
     visit temp;
   if(temp->left is not NULL)
        insert temp->left into queue;
   if(temp->right is not NULL)
      insert temp->right into queue;

   }
 }
```



Queue

d e

Answer

a b c

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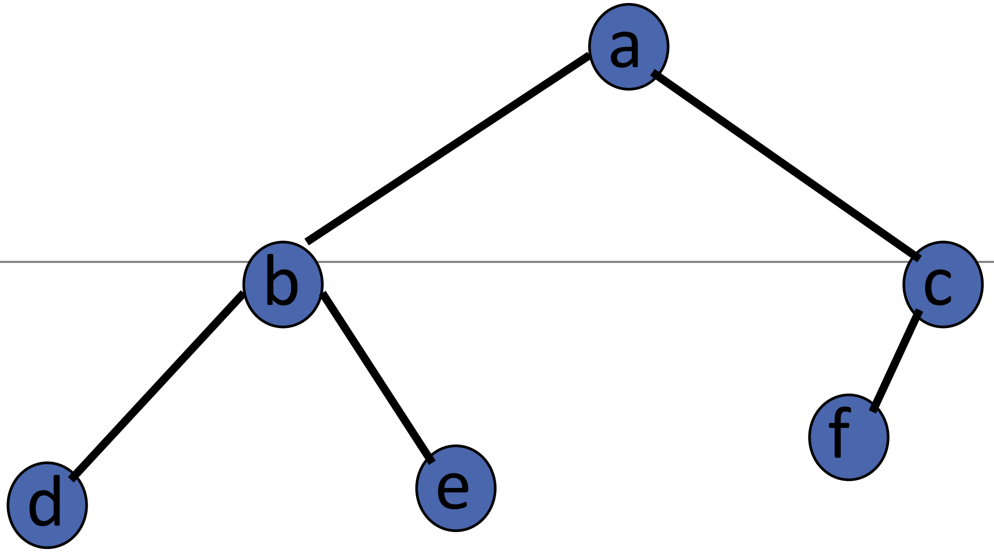
 {

    Remove from queue into temp;
     visit temp;
   if(temp->left is not NULL)
        insert temp->left into queue;
   if(temp->right is not NULL)
      insert temp->right into queue;

  }
}
```



Queue

d e f

Answer

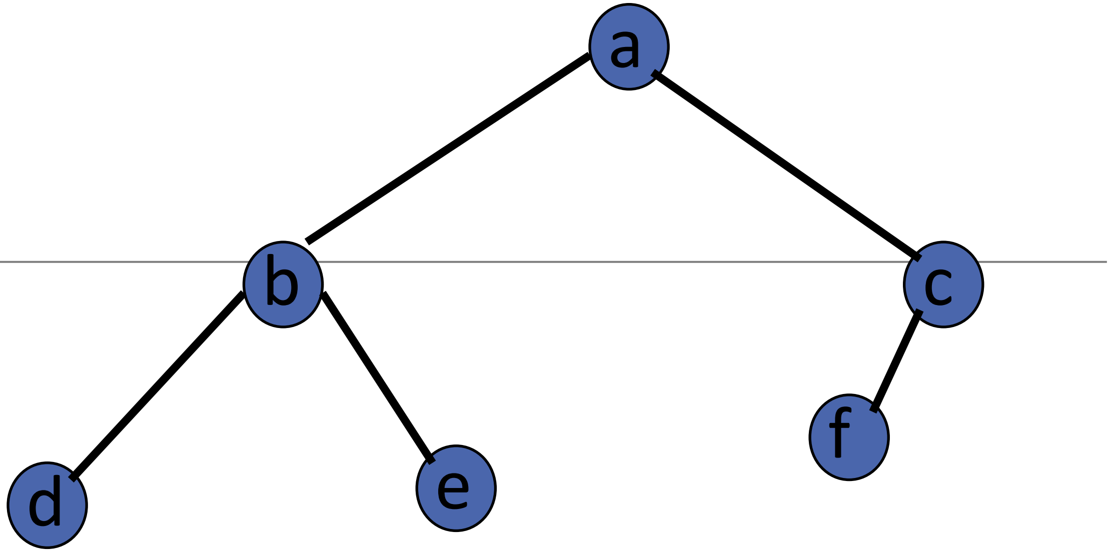
a b c

Algorithm BFS()

```
{
temp=root;
Insert temp into queue;
 while  Queue not empty
 {

    Remove from queue into temp;
     visit temp;
   if(temp->left is not NULL)
          insert temp->left into queue;
   if(temp->right is not NULL)
       insert temp->right into queue;

  }
 }
```



Queue

e f

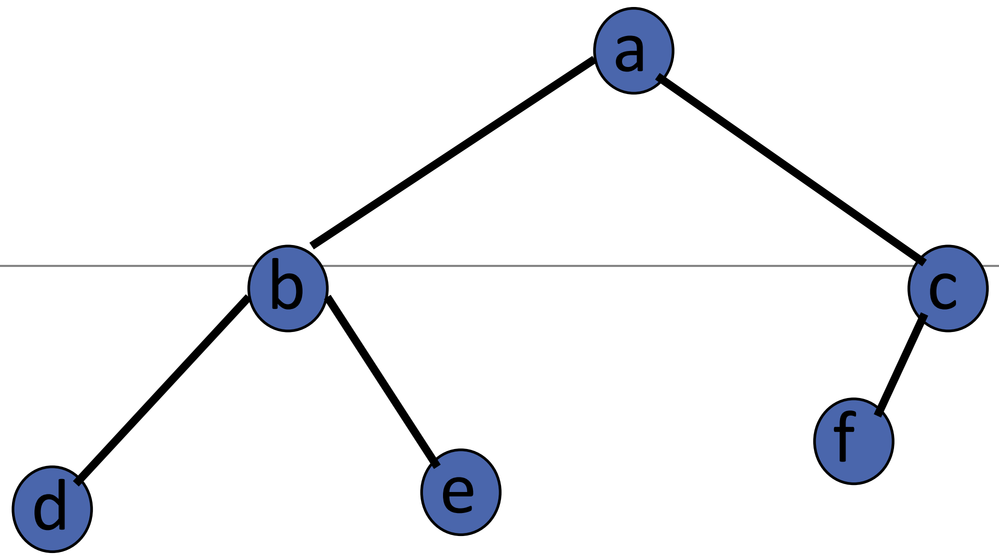
Answer

a b c d

```
Algorithm BFS()
{
temp=root;
Insert temp into queue;
 while  Queue not empty
 {

     Remove from queue into temp;
      visit temp;
   if(temp->left is not NULL)
         insert temp->left into queue;
   if(temp->right is not NULL)
      insert temp->right into queue;

   }
 }
```



Queue

f

Answer

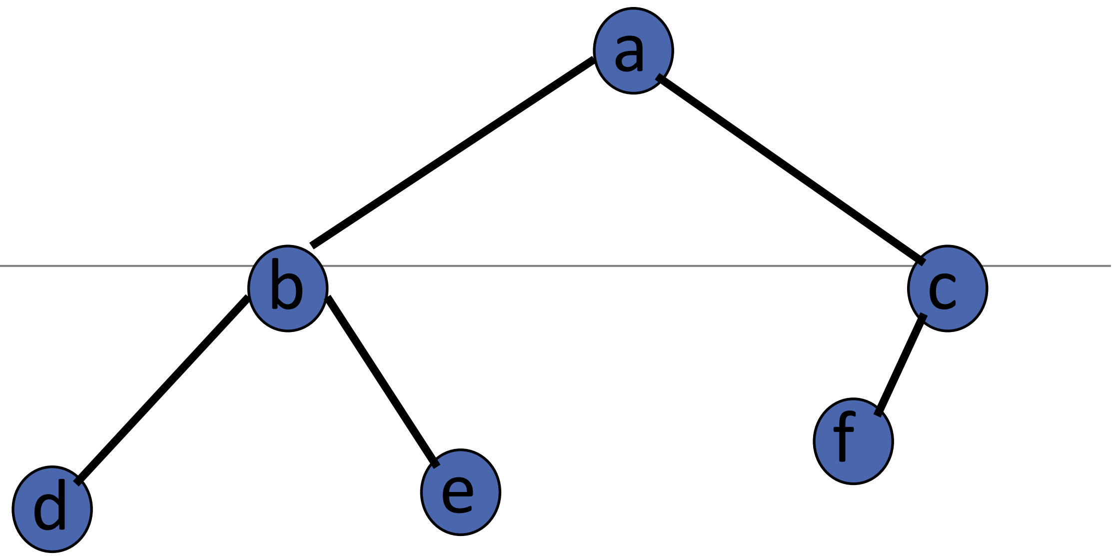
a b c d e

Algorithm BFS()

```
{
temp=root;
Insert temp into queue;
 while  Queue not empty
 {

    Remove from queue into temp;
     visit temp;
   if(temp->left is not NULL)
         insert temp->left into queue;
   if(temp->right is not NULL)
       insert temp->right into queue;

   }
 }
```



Queue

Answer

a b c d e f

Assignment no 1

2. Implement binary tree and perform following operations: Creation of binary tree and traversal recursive and non-recursive.

Operations on binary tree

Copying Binary Tree (recursive)

Copy of binary tree using non recursive is done through preorder

```
treenode  *copy(root)
{
   temp=NULL
   if (root!=NULL) {

     Allocate memory for temp
     temp->data=root->data;
     temp->left=copy(root->left);
     temp->right=copy(root->right);
   }
   return temp;
}
```

```
Algorithm copy_nr(tree t2)
{  //t2 is original tree
  Allocate memory for root
temp1=root;
temp2=t2.root;
copy(temp1->data,temp2->data);
while(1)
{
 while(temp2!=NULL)
 {
   if(temp2->left!=NULL)
   {
     Allocate memory for temp1->left;
    copy (temp1->left->data,temp2->left->data);
   }
   if(temp2->right!=NULL)
   {
     Allocate memory for temp1->right;;
    copy temp1->right->data,temp2->right->data);
   }
  s1.push(temp1);
  s2.push(temp2);
  Move temp1 to temp1->left
  Move temp2 to temp2->left
 }
 if stack empty     break;
  else
  {
    Pop to temp1
    Pop to temp2
    temp1=temp1->right;
    temp2=temp2->right;
  }
}           //end while
 }
```

Erasing nodes in binary tree

Use postorder

```
Algorithm depth_nr()
{
Initialize d to 0;
temp=root;
while(1)
{
 while(temp!=NULL)
 {
    push temp;
    move temp to temp->left;
  if(d<st.top)
   d=st.top;    }
 if(stack top right is NULL)
 {
      pop to temp;    }
  while(stack not empty && stack top right is temp)
  {
    pop to temp ;    }
 if  stack empty
   break;
 move temp to stack top right;
}
cout<<"\nDepth is "<<d+1; }
```

```
Algorithm depth_r()
 {

  d=depth_r(root);
  print d;
 }
Algorithm depth_r(treenode *root)
 {
   Initialize t1=0,t2=0;
   if(root==NULL)
      return 0;
  else
   {
   t1=depth_r(root->left);
   t2=depth_r(root->right);
  if(t1>t2)
   return ++t1;
  else
   return ++t2;
 }
}
```

```
Algorithm mirror_r()
{
 mirror_r(root);
 dispbfs();
 }
```

```
Algorithm mirror_r(treenode *root)
{
   swap left and right;
  if(root->left!=NULL)
  mirror_r(root->left);
  if(root->right!=NULL)
  mirror_r(root->right);
}
```

```
Algorithm mirror_nr()
{
    temp=root;
    q.insqueue(temp);
    while(!q.empty())
   {
      temp=q.delqueue();
      swap left and right;
      if(temp->left!=NULL)
     q.insqueue(temp->left);
     if(temp->right!=NULL)
     q.insqueue(temp->right);
   }
  dispbfs();
 }
```

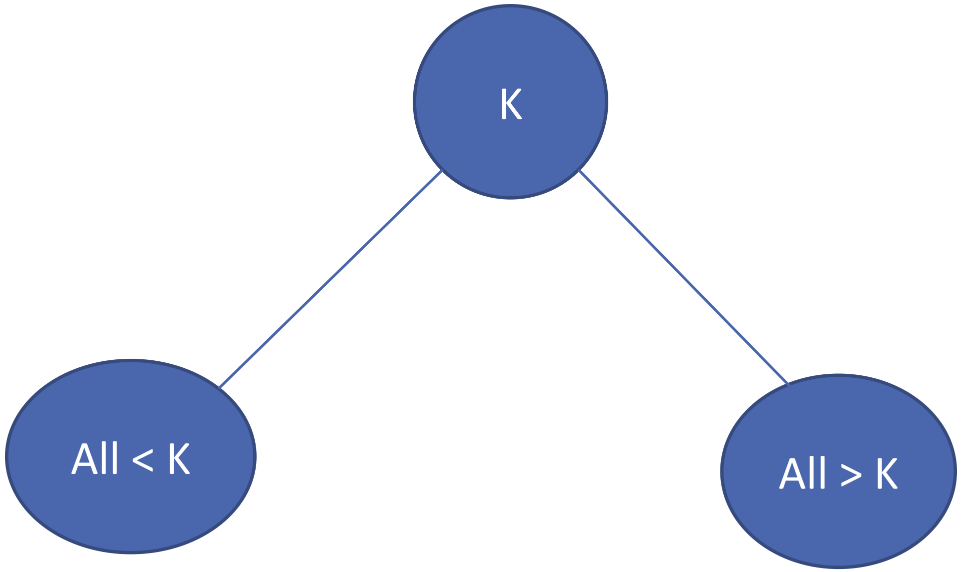
Binary search Trees

It is a binary tree.It may be empty.If it is not empty then it satisfies the following properties

- Every element has a unique key.
- The keys in a nonempty left subtree are smaller than the key in the root of subtree.
- The keys in a nonempty right subtree are larger than the key in the root of subtree.
- The left and right subtrees are also binary search trees.

- *Binary search trees provide an excellent structure for searching a list and at the same time for inserting and deleting data into the list.*

Binary Search Tree



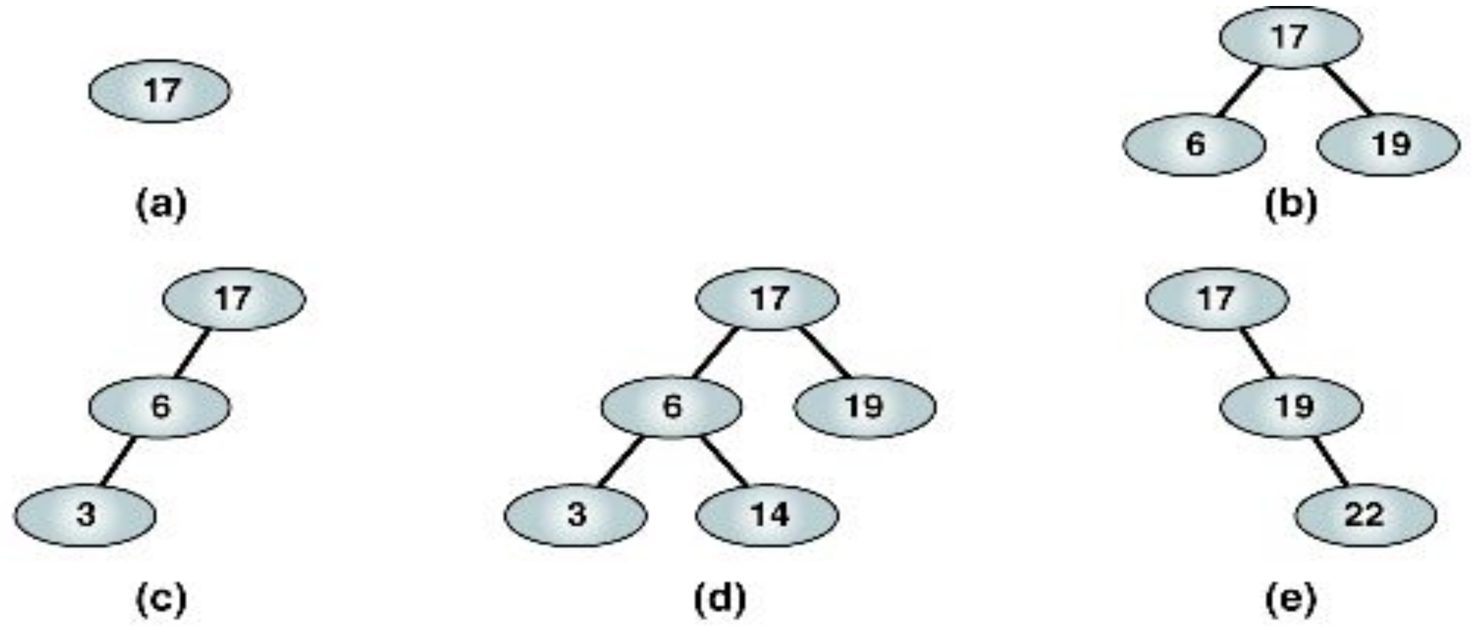


FIGURE 7-2 Valid Binary Search Trees

(a), (b) - complete and balanced trees;

(d) – nearly complete and balanced tree;

(c), (e) – neither complete nor balanced trees

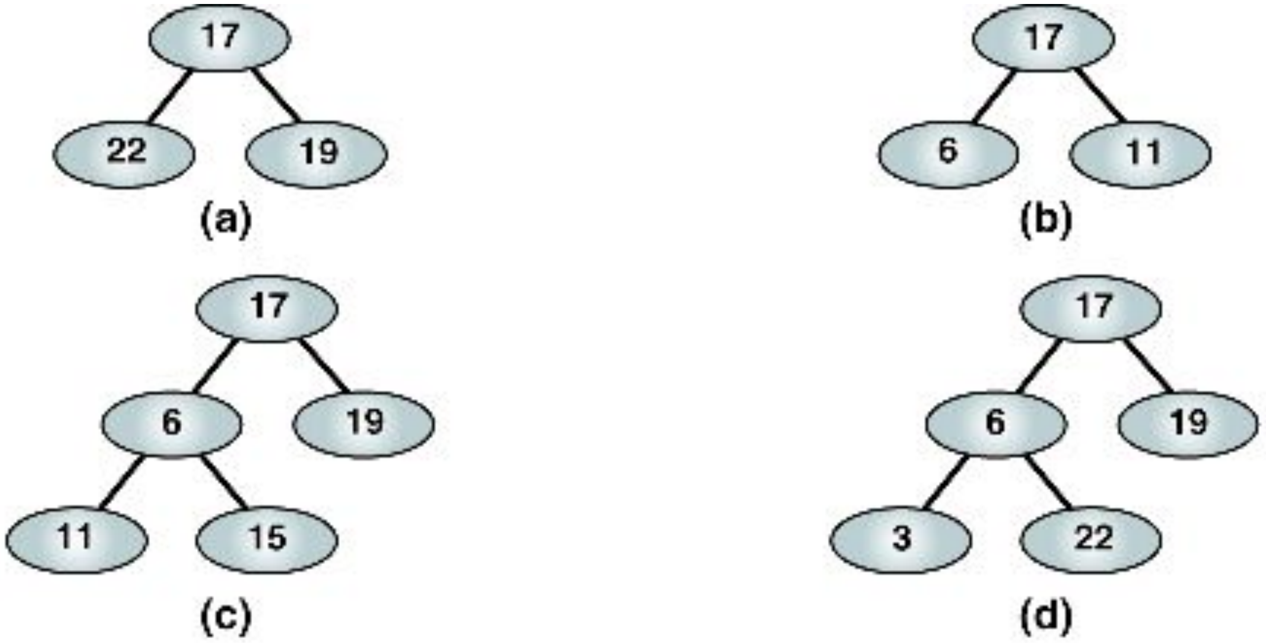


FIGURE 7-3 Invalid Binary Search Trees

```
Algorithm  create()
{
  allocate memory and accept the data for root node;
  do
  {
     temp=root;
     flag=0;
     allocate memory and accept the data for curr node;
     while(flag==0)
     {
      if(curr->data < temp->data)
      {
       if(temp->left=NULL)
       {
        temp->left=curr;
        flag=1;
       }
     else
      move temp to temp->left
    }  //end if compare
    else {
      if(temp->right=NULL)
      {
        temp->right=curr;
        flag=1;
      }
     else
      move temp to temp->right;
    }   //end else
   }  //end while flag
   Accept choice for adding more nodes;
  }while(choice =yes);   //end do
}   //end algorithm
```

binary search tree creation

Jyoti,Deepa,Rekha,Amit,Gilda,Anita,Abolee,Kaustubh,Teena,Kasturi,Saurabh

```
Algorithm search ()
{
  Initialize  flag=0;
  Accept string to be searched ;
  flag=search_r(root,str);
  if(flag=1)
    print found;
 else
   print not found;
}
```

```
Algorithm search_r(temp,  string)
{
 Initialize f to 0;
 if(temp!=NULL)
 {
   if(string =temp->data)
         return 1;
   if(string< temp->data)
         f=search_r(temp->left, str);
    if(string >temp->data)
        f=search_r(temp->right, str);
  }
  return f;
}
```

```
Algorithm search_nr()
{
 Initialize  flag to 0;
 temp=root;
 Accept string to be searched;
 while(flag=0)
 {
  if(string=temp->data)
  {
  flag=1;   break;
  }
 else if(string<temp->data)
    move temp to temp->left;
  else
    move temp to temp->right;
 }   //end while
 if(flag=1)
    Print found;
 else
   Print not found;
}   //end algo
```

Function DeleteItem

First, find the item; then, delete it

Important: binary search tree property must be preserved!!

We need to consider following different cases:

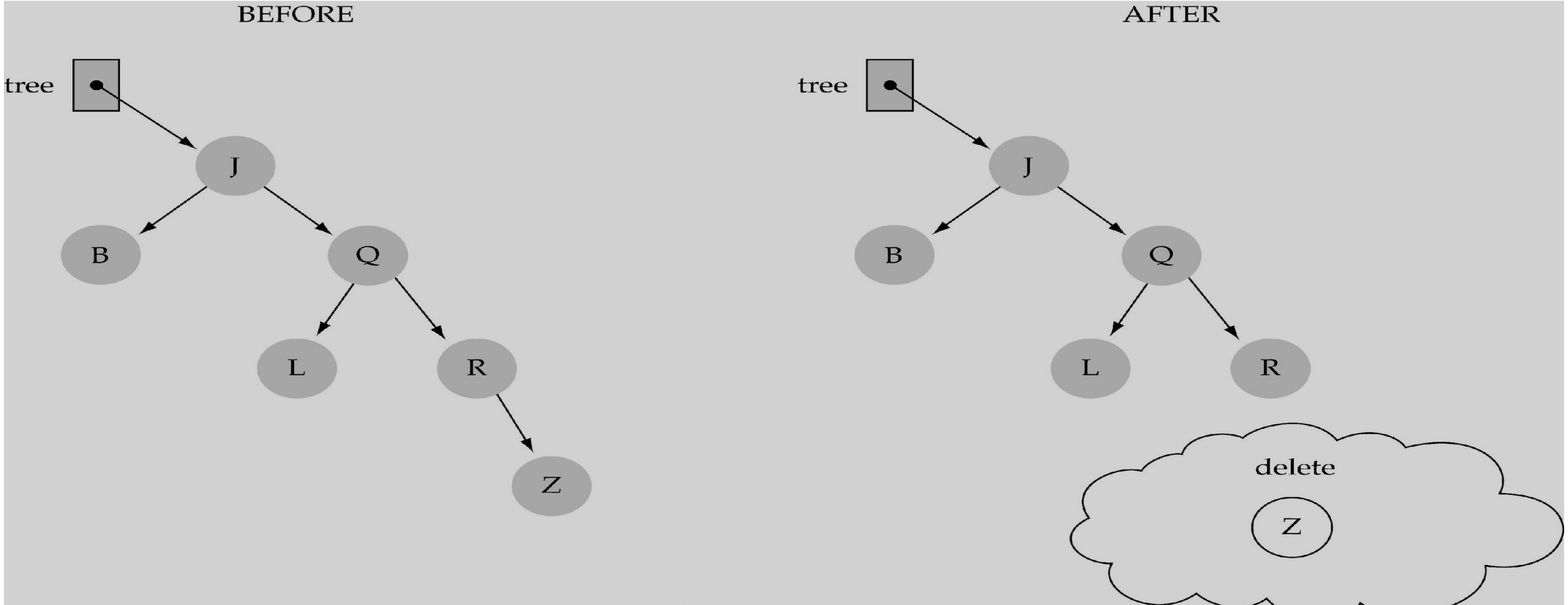
(1) Deleting a leaf

(2) Deleting a node with only one child

(3) Deleting a node with two children

(4) Deleting the root node

(1) Deleting a leaf

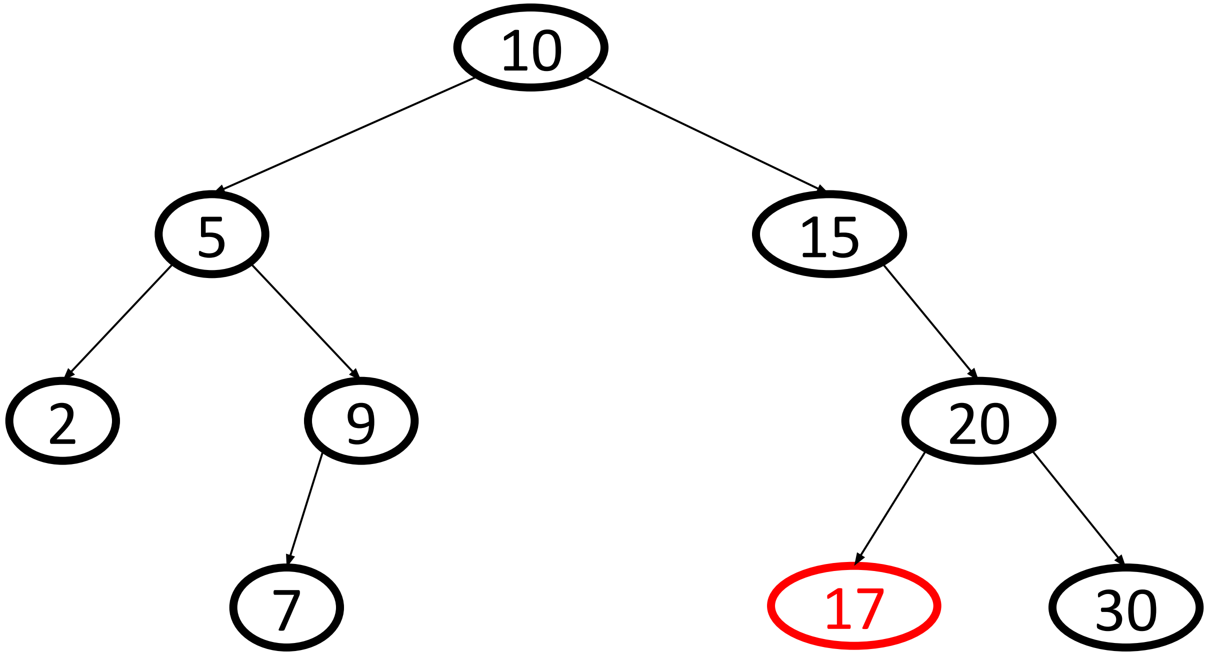


Delete the node containing Z

Deletion - Leaf Case

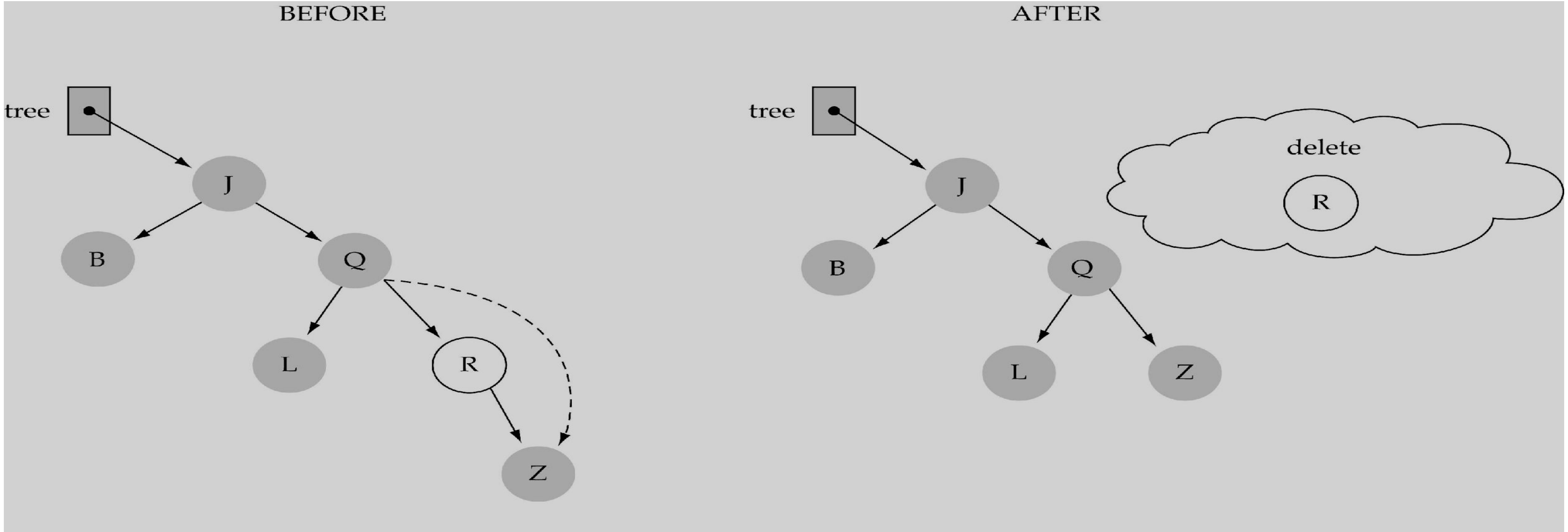
Algorithm sets corresponding link of the parent to NULL and disposes the node

Delete(17)



(2) Deleting a node with only one child

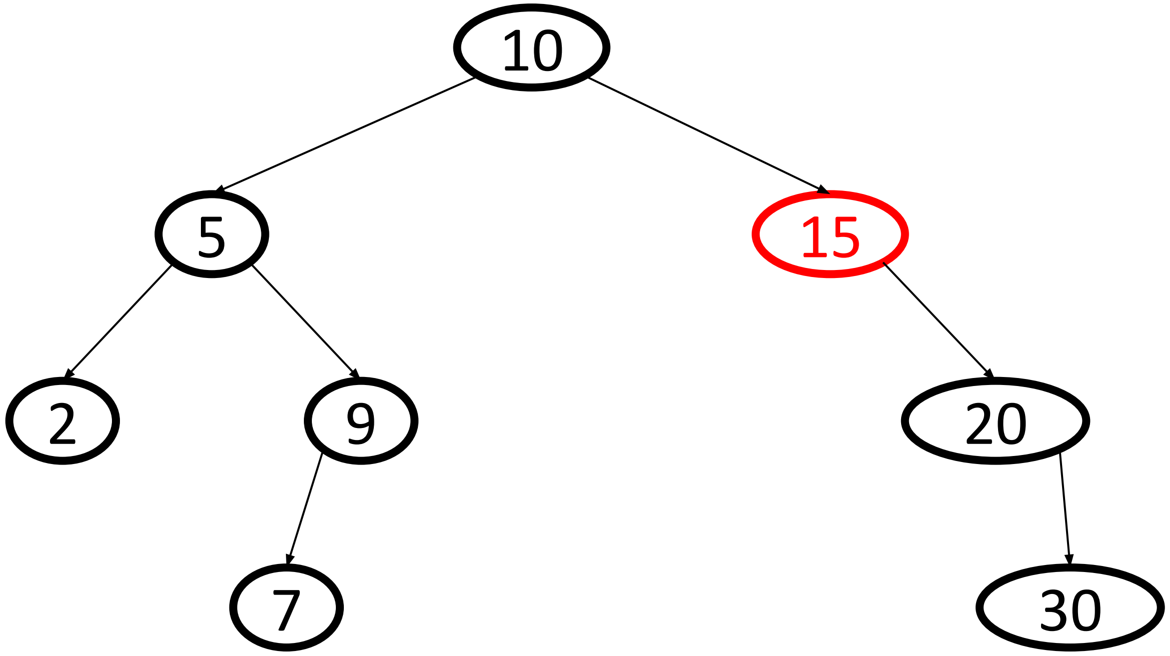
It this case, node is cut from the tree and algorithm links single child (with it's subtree) directly to the parent of the removed node.



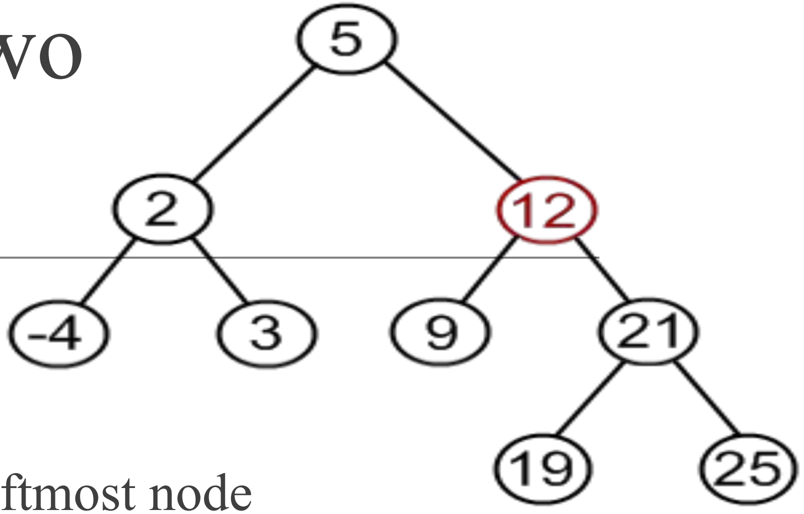
Delete the node containing R

Deletion - One Child Case

Delete(15)



(3) Deleting a node with two children (contd…)



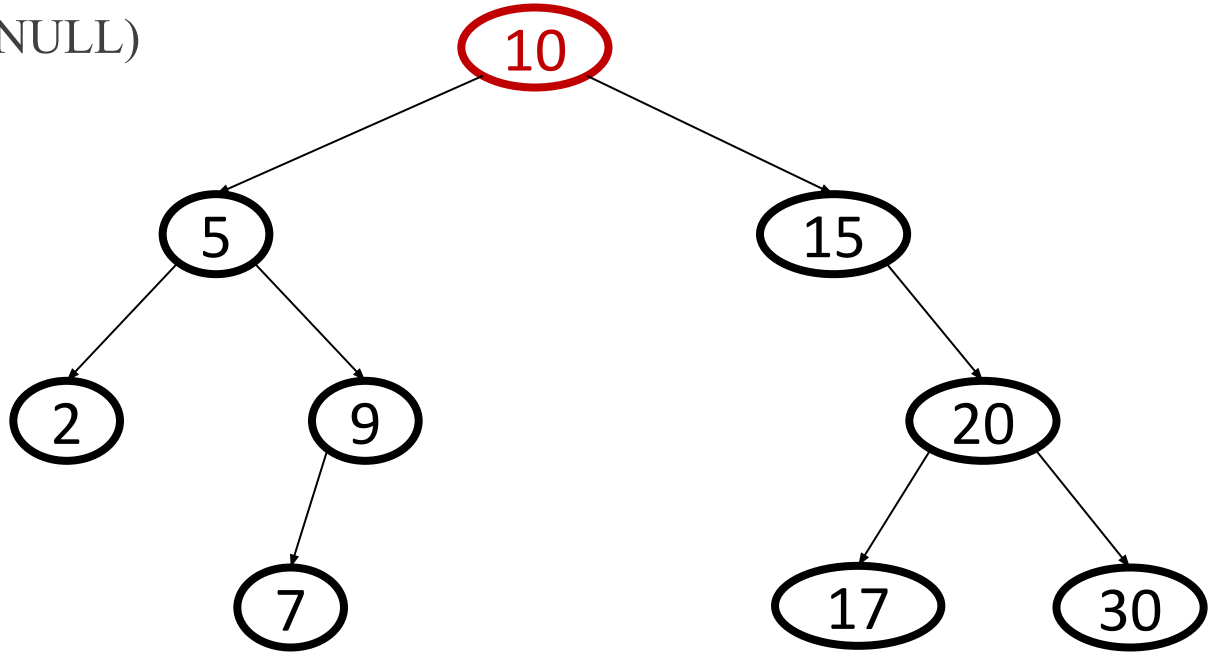
Find inorder successor

- Go to the right child and then move to the left till we get NULL for the leftmost node

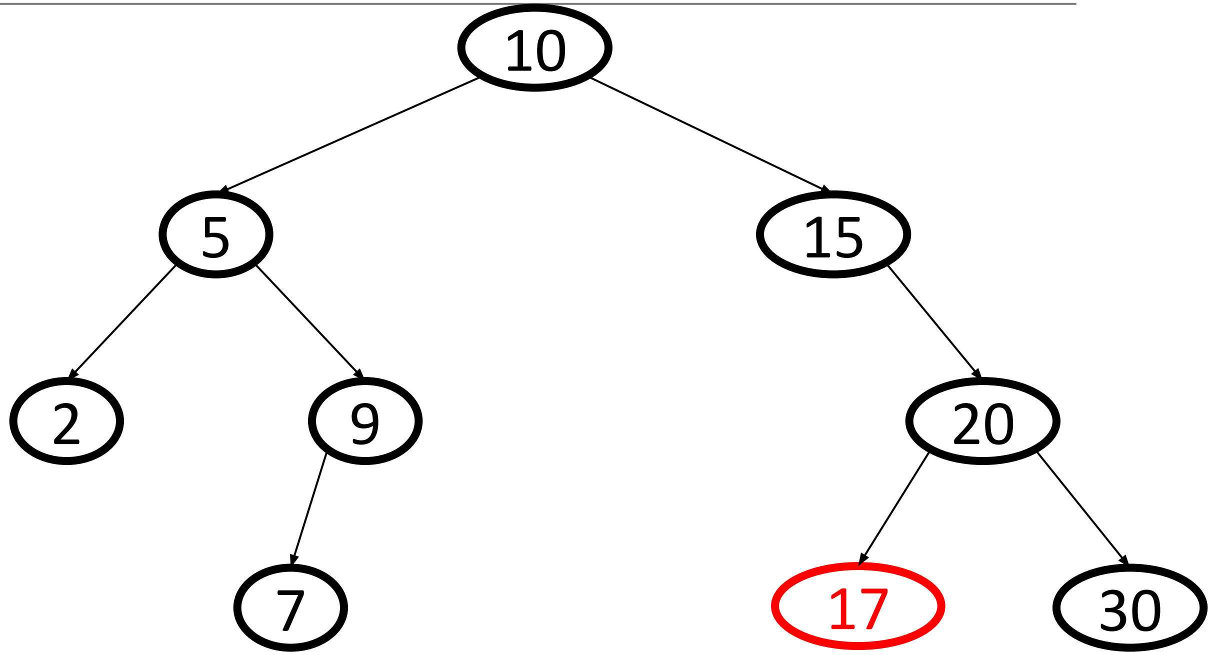
- To the inorder's successor ,attach the left of the node which we want to delete

//deletion of root

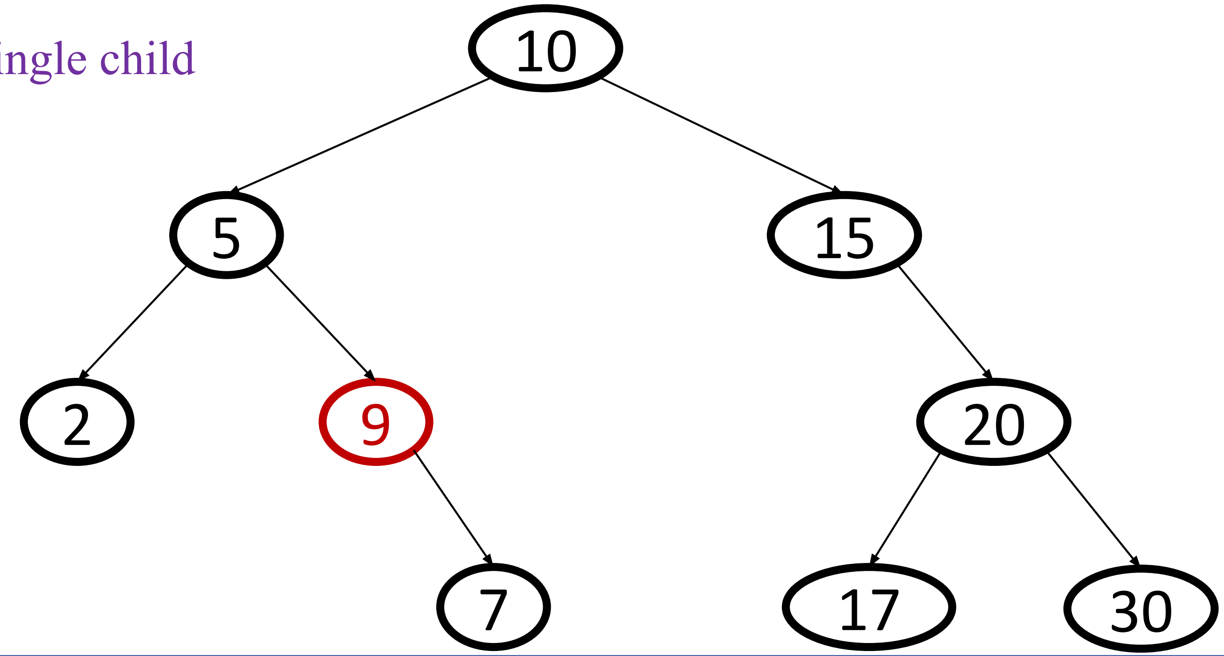
```
if(curr==root)
{
 if(curr->rightc==NULL)
      root=root->leftc;
 else if(curr->leftc==NULL)
      root=root->rightc;
 else if(curr->rightc!=NULL && curr->leftc!=NULL)
 {
      temp=curr->leftc;
      root=curr->rightc;
      s=curr->rightc;
      while(s->leftc!=NULL)
      {
            s=s->leftc;
      }
      s->leftc=temp;
 }
}
```



```
else if(curr!=root)            //deletion of node which is not root
{
 if(curr left and right is NULL )       //deletion of a leaf
 {
      if(parent->leftc==curr)
      parent->leftc=NULL;
      else
      parent->rightc=NULL;
 }
```

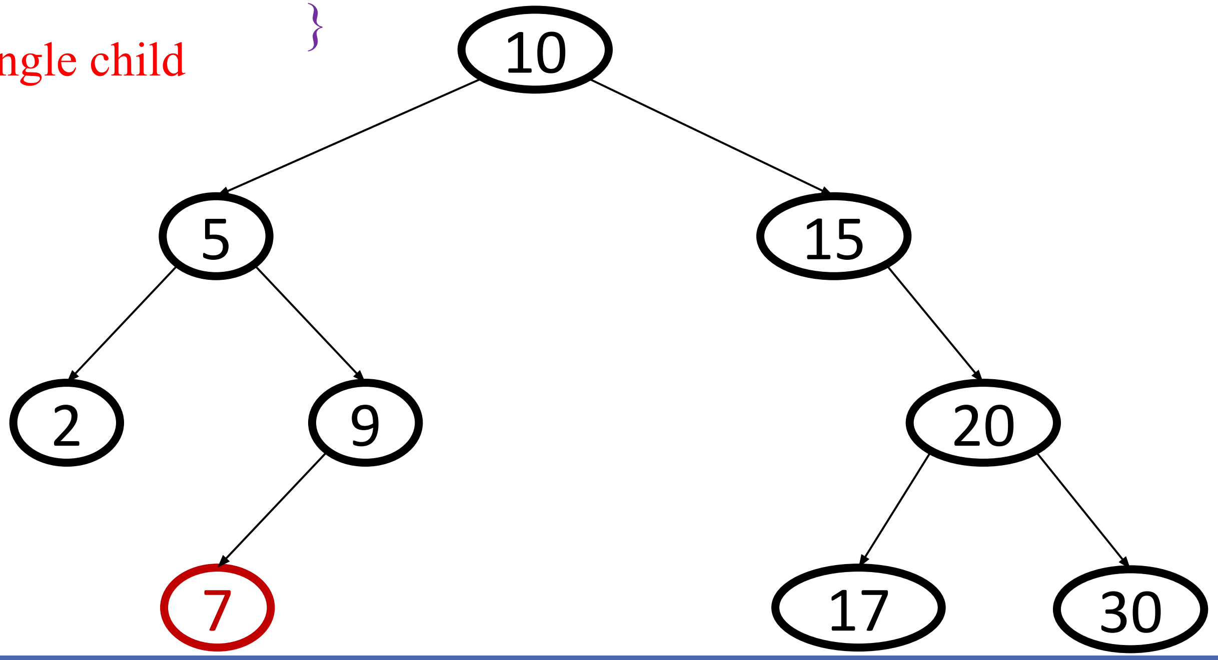


```
else if(curr!=root)            //deletion of node which is not root
{
 if(curr left and right is NULL )        //deletion of a leaf
 {
     if(parent->leftc==curr)
     parent->leftc=NULL;
     else
     parent->rightc=NULL;
 }
 else if(curr->leftc is NULL)       //deletion of a single child
 {
     if(parent->leftc==curr)
     parent->leftc=curr->rightc;
     else
     parent->rightc=curr->rightc;
 }
```



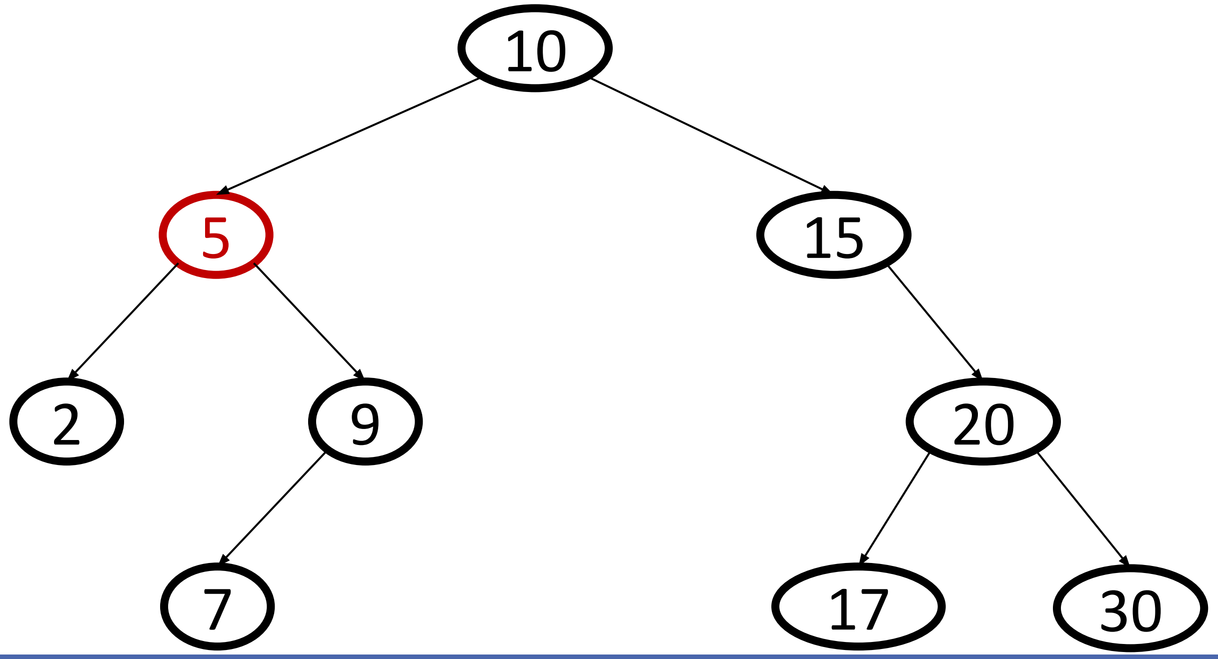
```
else if(curr!=root)          //deletion of node which is not root
{
 if(curr left and right is NULL )       //deletion of a leaf
 {
      if(parent->leftc==curr)
      parent->leftc=NULL;
      else
      parent->rightc=NULL;
 }
 else if(curr->leftc is NULL)      //deletion of a single child
 {
      if(parent->leftc==curr)
      parent->leftc=curr->rightc;
      else
      parent->rightc=curr->rightc;
 }
```

```
else if(curr->rightc is NULL)  //deletion of a single child
{
     if(parent->leftc==curr)
     parent->leftc=curr->leftc;
     else
     parent->rightc=curr->leftc;
}
```



//deletion of a node having two child

```
else
 {
      s=curr->rightc;
      temp=curr->leftc;
      while(s->leftc!=NULL)
      {
           s=s->leftc;
      }
      s->leftc=temp;
      if(parent->leftc==curr)
           parent->leftc=curr->rightc;
      else
           parent->rightc=curr->rightc;
 }
}
Assign curr left and right to NULL;
delete curr;
}
```



Assignment no 2

Implement dictionary using binary search tree where dictionary stores keywords & its meanings. Perform following operations:

1. Insert a keyword
2. Delete a keyword
3. Create mirror image and display level wise
4. Copy