eDMC MAY-2021

ALGORITHMS & DATA STRUCTURES

Data Structures: Introduction

+ Introduction

- Data structure & its types
- Algorithm & its types (recursive & non-recursive algorithms)
- Analysis of an algorithm: space complexity & time complexity

+ Array

- Concept & definition
- **Searching Algorithms:**

1. Linear Search (algorithm, analysis & implementation)
2. Binary Search (algorithm, analysis & implementation)

- Sorting Algorithms:

1. Selection Sort (algorithm, analysis & implementation)
2. Bubble Sort (algorithm, analysis & implementation)
3. Insertion Sort (algorithm, analysis & implementation)
4. Quick Sort (algorithm, analysis & implementation)
5. Merge sort (algorithm, analysis & implementation)

Data Structures: Introduction

+ Linked List

- Concept & definition
- Types of Linked List: singly linked list & doubly linked list
- Operations on Linked List: addition, deletion, traversal etc...
- Miscellaneous problems
- Differnce between an array data structure and linked list data structure

+ Stack

- Concept & definition
- Implementation of stack data structure
- Stack applications algorithms & implementation

1. Conversion of infix expression into its equivalent prefix
2. Conversion of infix expression into its equivalent postfix
3. Postfix expression evalution

Data Structures: Introduction

+ Queue

- Concept & definition
- Types of queue: linear queue, circular queue, priority queue & double ended queue.
- Implementation of queue data structure
- Applications of queue

+ Tree

- Concept & definition
- Tree (terminologies)
- Binary Search Tree: Operations on BST: addition, deletion, searching, tree traversal methods
- AVL Tree

Data Structures: Introduction

+ Graph

- concept & definition
- graph terminologies and types of graph
- graph representation methods: adjancency matrix & adjancency list
- graph basic algorithms: pathlength, to check connectedness, dfs spanning , bfs spanning etc...
- shortest path algorithms: dijsktra's, prim's etc...
- minimum spanning tree algorithms: prim's, kruskal's algorithm etc...

+ Hash Table

- concept & definition
- terminolgies
- implementation of hashing using chaining

Data Structures: Introduction

Q. Why there is a need of data structure?

- There is a need of data structure to achieve 3 things in programming:

  1. efficiency

  2. abstraction

  3. reusability

Q. What is Data Structure?

Data Structure is a way to store data elements into the memory (i.e. into the main memory) in an organized manner so that operations like addition, deletion, traversal, searching, sorting etc... can be performed on it efficiently.

Data Structures: Introduction

Two types of **Data Structures** are there:

1. Linear/Basic: data elements gets stored into the memory in a linear manner (e.g. sequentially) and hence can be accessed linearly/sequentially.

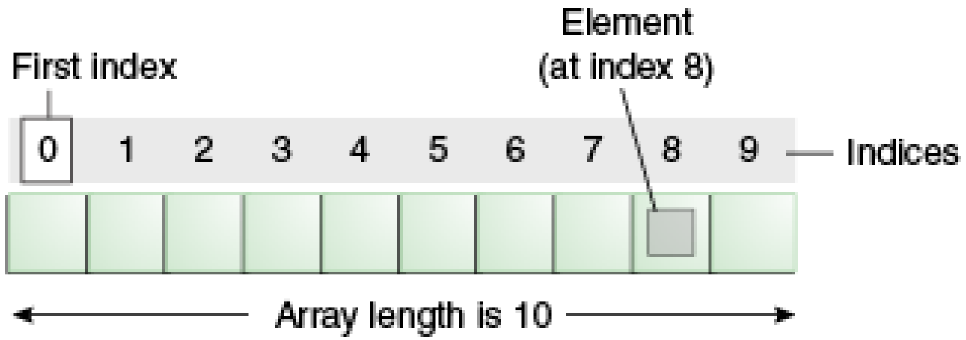
- Array
- Structure & Union
- Class
- Linked List
- Stack
- Queue

2. Non-linear/Advanced: data elements gets stored into the memory in a non-linear manner (e.g. hierarchical) and hence can be accessed non-linearly.

- Tree (Hierarchical)
- Graph
- Hash Table
- Binary Heap

Data Structures: Introduction

Array: It is **basic/linear data structure**, which is a **collection/list of logically related similar type of data elements gets stored into the memory at contiguos locations.**



Structure: It is **basic/linear data structure**, which is a **collection/list of logically related similar and disimmilar type of data elements gets stored into the memory collectively (as a single entity / record).**

Sizeof of the structure = sum of size of all its members.

Union: Union is same like structure, except, memory allocation i.e. size of union is the size of max size member defined in it and that memory gets shared among all its members for effective memory utilization (can be used in a special case only).

Data Structures: Introduction

Q. What is a Program?

- Program is a finite set of instructions written in any programming language (like C, C++, Java, Python, Assembly etc...) given to the machine to do specific task.

Q. What is an Algorithm?

- An algorithm is a finite set of instructions written in human understandable language (like english), if followed, acomplishesh a given task.

- An algorithm is a finite set of instructions written in human understandable language (like english) **with some programming constraints**, if followed, acomplishesh a given task, such an algorithm also called as **pseudocode.**

- An algorithm is a template whereas a program is an implementation of an algorithm.

Data Structures: Introduction

- An algorithm is a solution of a given problem.

- Algorithm = Solution

- One problem may has many solutions

Example: **Searching** - can be done by two using two algorithms : linear search & binary search.

Sorting – can be done by following algorithms: selection sort, bubble sort, insertion sort, quick sort, merge sort etc...

- When one problem has many solutions / algorithms there is need to select an efficient solution / algorithm, for deciding efficiency of an algorithms analysis of algorithms can be done.

- **Analysis of an algorithm** is a work of determining / calculating amount of **time** i.e. computer time and **space** i.e. computer memory it needs to run to completion.

- There are two measures of analysis of an algorithm:

- There are two measures of an analysis of an algorithms:

1. Time Complexity of an algorithm is the amount of time i.e. computer time required for it to run to completion.

2. Space Complexity of an algorithm is the amount of space i.e. computer memory required for an algorithm to run to completion.

Data Structures: Introduction

There are two types of algorithms:

1. Iterative / Non-recursive

2. Recursive

Example: Algorithm to do sum of array elements

Iterative Approach:

```
Algorithm ArraySum(A, n){
    sum=0;
    for( index = 1 ; index <= n ; index++ ){
        sum += A[ index ];
    }
    return sum;
}
```

Example: Algorithm to do sum of all array elements

Recursive Approach

```
Algorithm RecArraySum(A, n, index){
    if( index == n )
        return 0;
    return ( A[ index ] + RecArraySum(A, n, index+1 ) );
}
```

- **Recursion:** it is a process which can be defined in terms of itself. OR It is a process in which function calls itself within itself such a function is called as **recursive function.**

Data Structures: Introduction

- Recursion is a process in which function gets called within itself, and such function call is called as a **recursive function call.**

- While writing recursive function we need to take care about three things:

1. initialization: at the time of first time function calling

2. base condition: at the begining of the recursive function definition

3. modification: at the time of recursive function call

- There are two types of recursion:

1. tail-recursive: recursive function in which recursive function call is the last executable statement.

2. nontail-recursive: recursive function in which recursive function call is not the last executable statement.

Data Structures: Introduction

Space Complexity = data space + code space + stack space (applicable in recursive algorithm).

data space = space required for contants, variables and instance characteristics

code space = instruction space

stack space = space required for function activation records.

- Space complexity has two components:

1. Fixed components: data space (space required for constants & variables) + code space (space required for instructions).

2. Variable components: space required for instance characteristics and stack space (applicable in recursive algorithms).

Asymptotic Analysis: It is a **mathematical** way to calculate time complexity and space complexity of an algorithm **without implementing it in any programming language.**

- In this type of analysis, analysis can be done on the basis of **basic operation** in that algorithm.

e.g. in searching & sorting algorithms comparison is the basic operation and hence analysis gets done on the basis of no. of comparisons, in addition of matrices algorithms addition is the basic operation and hence on the basis of addition operation.

Data Structures: Introduction

"Best case time complexity": if an algo takes min amount of time to run to completion then it is referred as best case time complexity.

"Worst case time complexity": if an algo takes max amount of time to to run to completion then it is referred as worst case time complexity.

"Average case time complexity": if an algo takes neither min nor max amount of time to run to completion then it is referred as an average case time complexity.

"Asympotic Notations":

1. Big Omega (Ω): this notation is used to denote best case time complexity – also called as **asymptotic lower bound**

2. Big Oh (O): this notation is used to denote worst case time complexity - also called as **asymptotic upper bound**

3. Big Theta (θ): this notation is used to denote an average case time complexity - also called as **asymptotic tight bound**

Data Structures: Introduction

Assumptions in Asymptotic Analysis:
<u>+ O(1) :</u>

- if an algorithm / function do not contains any loop or call to non-constant function or call to any recursive function, we will get time complexity of that algorithm / function in terms of O(1).

```
void swap(int *ptr1, int *ptr2){
    int temp = *ptr1;
    *ptr1 = *ptr2;
    *ptr2 = temp;
}
```

- if in an algorithm / function, statement/s inside the loop executes constant number / amount of time, then time complexity get in terms of O(1).

```
for( int i = 1 ; i <= c ; i++ ){//whereas c is any constant
        //O(1) statement/s
}
```

Data Structures: Introduction

Assumptions in Asymptotic Analysis:
+ O(n) :

- if in an algo/function, statement/s inside the loop executes "n" no. of of times, then time complexity gets in terms of O(n).

```
for( int i = 1 ; i <= n ; i++ ){//n is an instance var
    //O(1) statement/s
}
```

- if an algorithm / function contains a loop, and in a loop counter var is either incremented/decremented by a constant value, then time complexity gets in terms of O(n).

```
for( int i = 1 ; i <= n ; i += c ){
    //O(1) statement/s
}
OR
for( int i = n ; i > 0 ; i -= c ){
    //O(1) statement/s
}
```

Data Structures: Introduction

Assumptions in Asymptotic Analysis:

+ O(n) :

- if in an algo/function, it contains consecutive loops, then time complexity of that algo/function gets in terms of O(n).

```
for( int i = 1 ; i <= n ; i++ ){//n is an instance var
//O(1) statement/s
}

for( int i = 1 ; i <= m ; i++ ){//m is an instance var
//O(1) statement/s
}
```

T(n) = O(n) + O(m)

T(n) = O(m+n)

T(n) = O(2n) ..... for m = n,

T(n) = O(n).

Data Structures: Introduction

Assumptions in Asymptotic Analysis:

- if running time of an algorithm contains an additive / substractive / multiplicative / divisive constant, it can be neglected.

Example:

O(n+3) => O(n)

O(n-4) => O(n)

O(n/2) => O(n)

O(n*3) => O(n)

- if running time of an algorithm contains a polynomial then only leading term is considered in its time complexity.

Example:

$O(n^2 + n + 2) \Rightarrow O(n^2)$

$O(n^3 + n^2 + 2) \Rightarrow O(n^3)$

Assumptions in Asymptotic Analysis:
+ O(log n):

- if in an algo/function, loop counter var is either getting multiplied/divided by a constant value, then time complexity of such algo/function gets in terms of O(log n).

e.g.

```
for( int i = 1 ; i <= n ; i *= c ){
    //O(1) statement/s
}
OR
for( int i = n ; i > 0 ; i /= c ){
    //O(1) statement/s
}
```

1. Linear Search/Sequential Search:

step-1: accept key from the user

step-2: start traversal of an array and compare value of the key with each array element from first element either till match not is not found or max till last element, if key is matches with any of array element then return true otherwise return false.

```
Algorithm LinearSearch(A, size, key){
    for( int index = 1 ; index <= size ; index++ ){
    if( arr[ index ] ==  key )
    return true;
    }
    return false;
}
```

Best Case: If key is found at very first position in only 1 no. of comparison then it is considered as a best case and running time of an algorithm in this case is O(1) => and hence time complexity = **Ω(1)**

Worst Case: If either key is found at last position or key does not exists, maximum **n** no. of comparisons takes place, it is considered as a worst case and running time of an algorithm in this case is O(n) => and hence time complexity = **O(n)**

Average Case: If key is found at any in between position it is considered as an average case and running time of an algorithm in this case is O(n/2) => and hence time complexity = **θ(n)**

2. Binary Search/Logarithmic Search:

- This algorithm follows **divide-and-conquer** approach.
- To apply binary search on an array prerequisite is that array elements must be in a sorted manner.

step-1: accept key from the user

step-2: in first iteration, find mid position by the formula **mid=(left+right)/2**, (by means of finding mid position big size array gets divided logically into two subarrays, left subarray and right subarray. **Left subarray = left to mid-1** & **right subarray = mid+1 to right**).

step-3: compare value of key with an element which is at mid position, if key matches in very first iteration in only one comparison then it is considered as a **best case**, if key do not matches then we have to go to next iteration, and in next iteration we go to search key either into the left subarray or into the right subarray.

step-4: repeat step-2 & step-3 till either key is not found or max till subarray is valid, if subarray is not valid then key is not found in this case we need to return false.

Data Structures: Searching Algorithms

- As in every iteration this algo does 1 comparison and divides array into two sub-arrays and key element gets searched either into the left subarray or into right the subarray i.e. either one of the array.

=> T(n) = T(n/2) + 1

for n = 1 => T(n) = T(1) + 1

i.e. running time of an algo is **O(1)**. --- trivial case

for n > 1

T(n) = T(n/2) + 1 ..... (I)

to get the value of T(n/2) put n = n/2 in eq-I we get,

=> T(n/2) = T(n/2 / 2) + 1

=> T(n/2) = T(n/4) + 1 .....(II)

substitute the value of T(n/2) in eq-I we get,

=> T(n) = [T(n/4) + 1] + 1

=> T(n) = T(n/4) + 2 .....(III)

to get the value of T(n/2) put n = n/2 in eq-II we get,

=> T((n/2) / 2) = T((n/4) / 2) + 1

=> T(n/4) = T(n/8) + 1 .... (IV)

Data Structures: Searching Algorithms

substitute the value of $T(n/4)$ in eq-III we get,

$\Rightarrow T(n/4) = [\ T(n/8) + 1\ ] + 2$

$\Rightarrow T(n/4) = T(n/8) + 3$ ......(V)

after k iterations: => **$T(n) = T(n/2^k) + k$**

for $n = 2^k$

$\log n = \log 2^k$ .... by taking log on both side

$\log n = k \log 2$

therefore, **$k = \log n$**

Substitute the value of $n = 2^k$ and $k = \log n$ into the equation, we get

$\Rightarrow T(n) = T(2^k / 2^k) + \log n$

$\Rightarrow T(n) = T(1) + \log n$

$\Rightarrow T(n) = \log n$

and hence, **$T(n) = O(\log n)$.**

Best Case: if the key is found in very first iteration at mid position in only 1 no. of comparison it is considered as a best case and running time of an algorithm in this case is O(1) = **Ω(1).**

Worst Case: if either key is not found or key is found at leaf position it is considered as a worst case and running time of an algorithm in this case is O(log n) = **O(log n).**

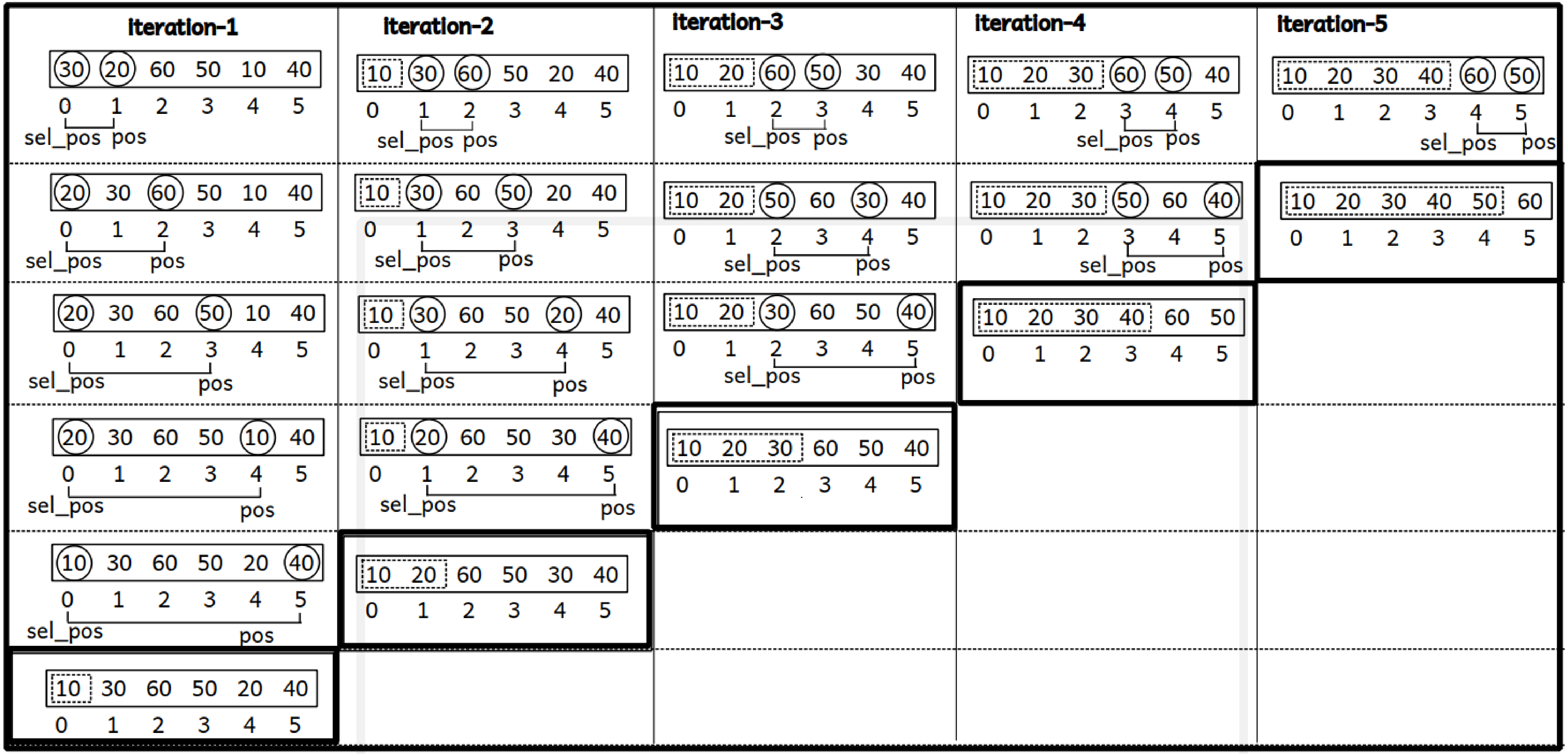
Average Case: if key is not found in the first iteration and it is found at non-leaf position it is considered as an average case and running time of an algorithm in this case is O(log n) = **θ(log n).**

1. Selection Sort:

- In this algorithm, in first iteration, first position gets selected and element which is at selected position gets compared with all its next position elements, if selected position element found greater than any other position element then swapping takes place and in first iteration smallest element gets setteled at first position.

- In the second iteration, second position gets selected and element which is at selected position gets compared with all its next position elements, if selected position element found greater than any other position element then swapping takes place and in second iteration second smallest element gets setteled at second position, and so on in maximum **(n-1)** no. of iterations all array elements gets arranged in a sorted manner.

Data Structures: Sorting Algorithms



Data Structures: Sorting Algorithms

- In this algorithm, logically two lists will be maintained, **initially first list contains all elements to be sorted** and **second list is empty.**

- In first iteration the smallest element from first list will be selected and gets added into the second list at first position, in second iteration next smallest element from first list will be selected and gets added into the second list at second position, and so on, in max **(n-1) no. of iterations** all elements from first list gets added into the second list in a sorted manner.

+ Features of Sorting algorithms:

1. adaptive: if sorting algo works efficiently for already sorted input then it is referred as adaptive.

2. stable: in a sorting algo, if relative order of two elements having same key value remains same even after sorting then it is referred as a stable.

3. inplace: if sorting algo do not takes extra space for sorting **n** no. of elements then it is referred as inplace.

Best Case : $\Omega(n^2)$

Worst Case : $O(n^2)$

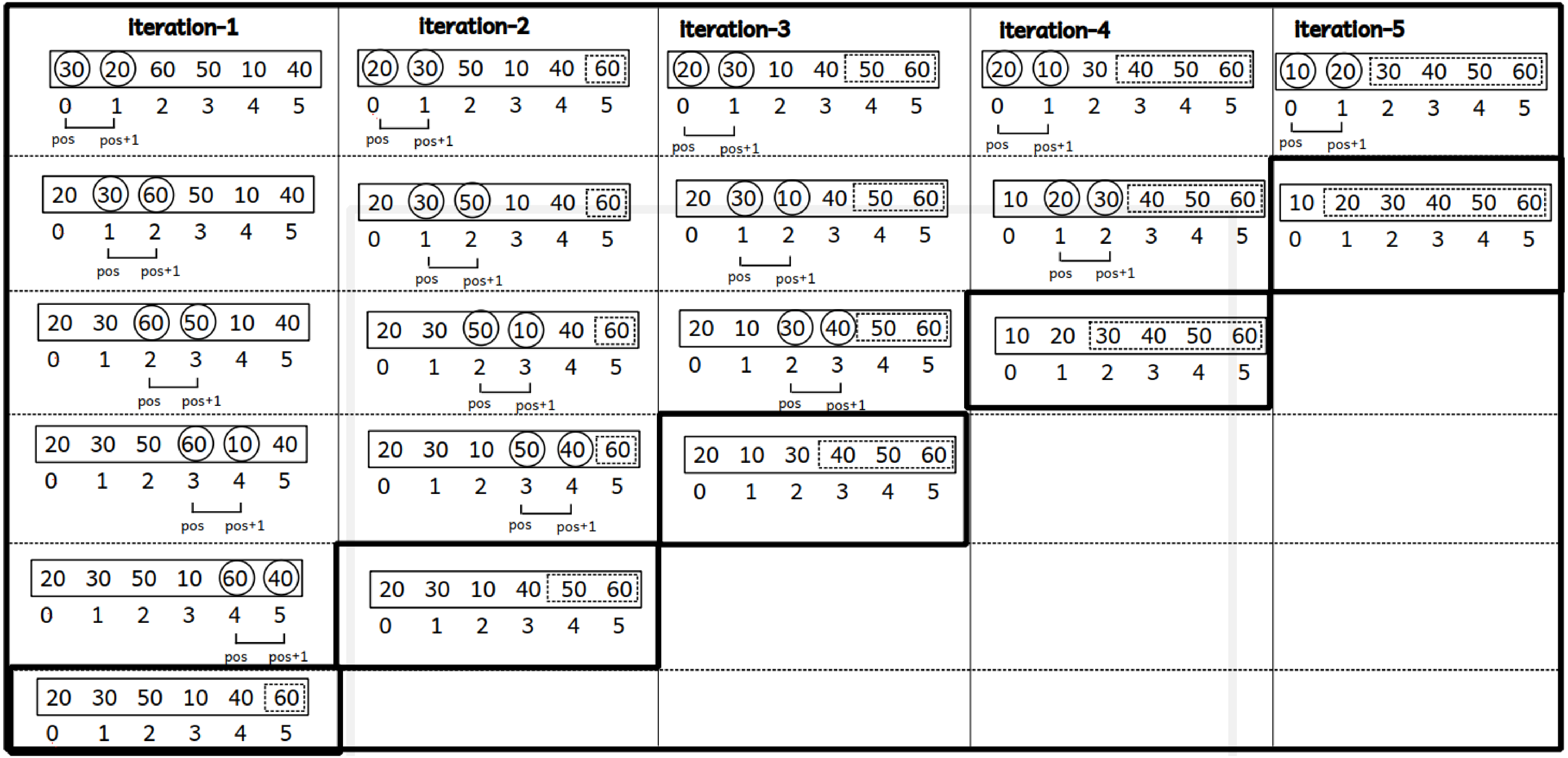
Average Case : $\theta(n^2)$

- Magnitudes of time complexities in all cases is same.

2. Bubble Sort:

- In this algorithm, in every iteration elements which are at two consecutive positions gets compared, if they are already in order then no need of swapping between them, but if they are not in order i.e. if prev position element is greater than its next position element then swapping takes place, and by this logic in first iteration largest element gets setteled at last position, in second iteration second largest element gets setteled at second last position and so on, in max **(n-1)** no. of iterations all elements gets arranged in a sorted manner.

Data Structures: Sorting Algorithms



- In this algorithm, logically two lists will be maintained, **initially first list contains all elements to be sorted** and **second list is empty.**

- In first iteration the largest element from first list will be selected and gets added into the second list at last position, in second iteration next largest element from first list will be selected and gets added into the second list at second last position, and so on, in max **(n-1) no. of iterations** all elements from first list gets added into the second list in a sorted manner.

Best Case : $\Omega(n)$ – if array elements are already arranged in a sorted manner.

Worst Case: $O(n^2)$

Average Case : $\theta(n^2)$

3. Insertion Sort:

Best Case : $\Omega(n)$ – if array elements are already arranged in a sorted manner.

Worst Case : $O(n^2)$

Average Case: $\theta(n^2)$

- Insertion sort algortihm is an efficient algorithm for smaller input size array.

Data Structures: Linked List

- Limitations of an array data structure:

1. Array is static, i.e. size of an array is fixed, its size cannot be either grow or shrink during runtime.

2. Addition and deletion operations on an array are not efficient as it takes O(n) time, and hence to overcome these two limitations of an Array **Linked List** data structure has been designed.

Linked List: It is a collection/list of logically related similar type of elements in which,

- an address of first element in a collection/list is stored into a pointer variable referred as a head pointer.

- each element contains data and an address of its next (as well as its previous element).

- An element in a Linked List is also called as a **Node.**

- Four types of linked lists are there: **Singly Linear Linked List, Singly Circular Linked List, Doubly Linear Linked List and Doubly Circular Linked List.**

Data Structures: Linked List

- Basically we can perform **addition, deletion, traversal** etc... operations on linked list data structure.

- We can add and delete node by three ways: we can add node into the linked list at last position, at first position and at any specific position, simillarly we can delete node from linked list which is at first position, last position and at any specific position.

1. Singly Linear Linked List: It is a linked list in which

- head always contains an address of first element, if list is not empty.

- each node has two parts:

i. data part: contains data of any primitive/non-primitive type.

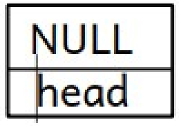
ii. pointer part(next): contains an address of its next element/node.

- last node points to NULL, i.e. next part of last node contains NULL.

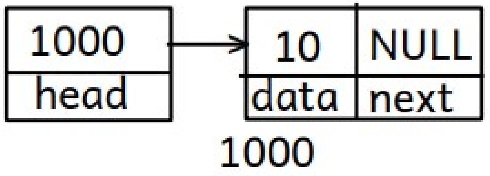
Data Structures: Linked List

SINGLY LINEAR LINKED LIST

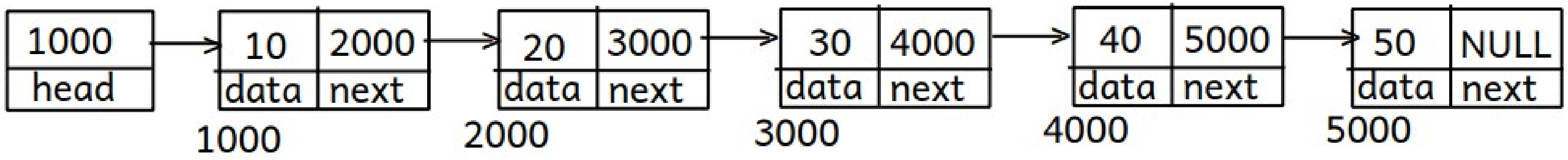
1) singly linear linked list --> list is empty



2) singly linear linked list --> list contains only one node



3) singly linear linked list --> list contains more than one nodes



Data Structures: Linked List

Limitations of Singly Linear Linked List:

- Add node at last position & delete node at last position operations are not efficient as it takes O(n) time.

- We can starts traversal only from first node and can traverse the SLLL only in a forward direction.

- Previous node of any node cannot be accesed from it.

- Any node cannot be revisited – to overcome this limitation Singly Circular Linked List has been designed.

2. Singly Circular Linked List: It is a linked list in which

- head always contains an address of first element, if list is not empty.

- each node has two parts:

i. data part: contains data of any primitive/non-primitive type.

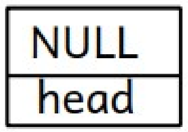
ii. pointer part(next): contains an address of its next element/node.

- last node point to first node, i.e. next part of last node contains an address of first node.

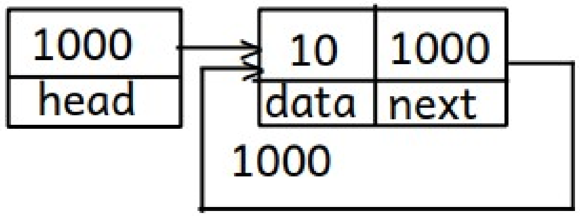
Data Structures: Linked List

SINGLY CIRCULAR LINKED LIST

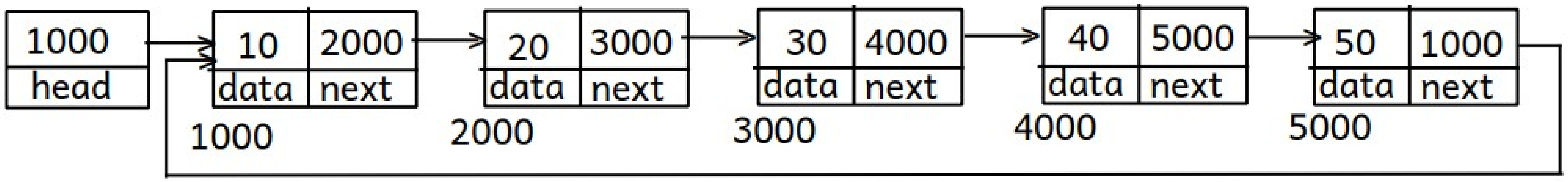
1) singly circular linked list --> list is empty



2) singly circular linked list --> list contains only one node



3) singly circular linked list --> list contains more than one nodes



Data Structures: Linked List

Limitations of Singly Circular Linked List:

- Add last, delete last & add first, delete first operations are not efficient as it takes O(n) time.

- We can starts traversal only from first node and can traverse the SCLL only in a forward direction.

- Previous node of any node cannot be accesed from it – to overcome this limitation Doubly Linear Linked List has been designed.

3. Doubly Linear Linked List: It is a linked list in which

- head always contains an address of first element, if list is not empty.

- each node has three parts:

i. data part: contains data of any primitive/non-primitive type.

ii. pointer part(next): contains an address of its next element/node.

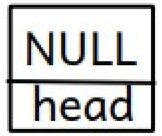
iii .pointer part(prev): contains an address of its previous element/node.

- next part of last node & prev part of first node point to NULL.

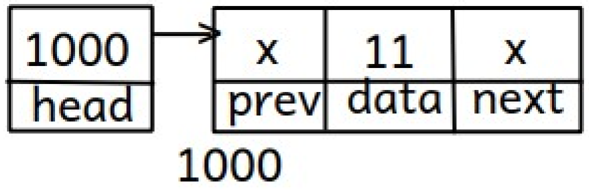
Data Structures: Linked List

DOUBLY LINEAR LINKED LIST

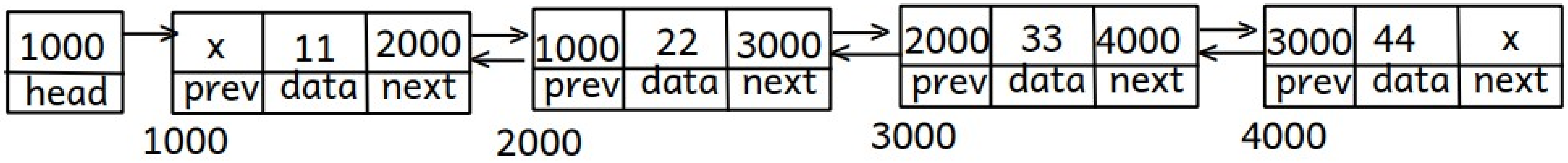
1. doubly linear linked list --> list is empty



2. doubly linear linked list --> list is contains only one node



3. doubly linear linked list --> list is contains more than one nodes



Data Structures: Linked List

Limitations of Doubly Linear Linked List:

- Add last and delete last operations are not efficient as it takes O(n) time.

- We can starts traversal only from first node, and hence to overcome these limitations Doubly Circular Linked List has been designed.

4. Doubly Circular Linked List: It is a linked list in which

- head always contains an address of first node, if list is not empty.

- each node has three parts:

i. data part: contains data of any primitive/non-primitive type.

ii. pointer part(next): contains an address of its next element/node.

iii .pointer part(prev): contains an address of its previous element/node.

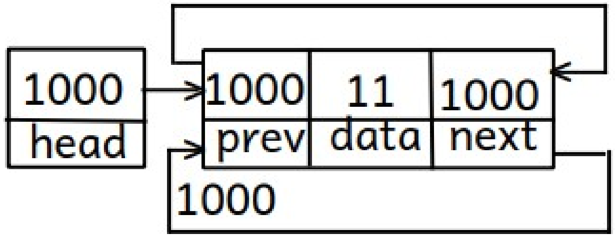
- next part of last node contains an address of first node & prev part of first node contains an address of last node.

Data Structures: Linked List

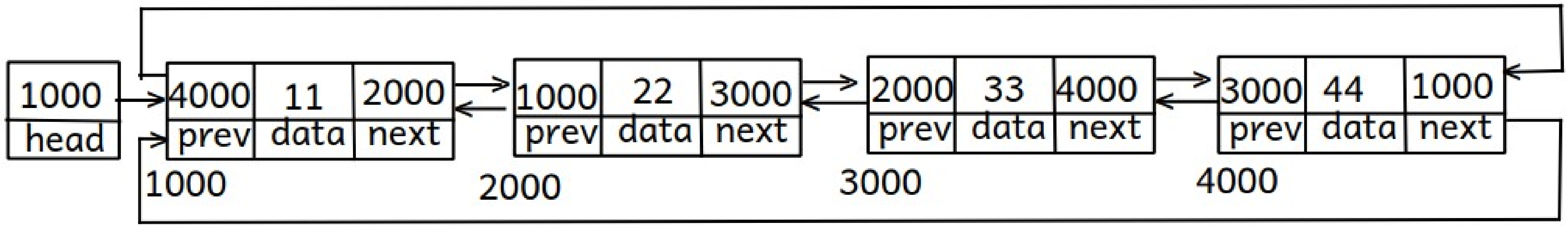
DOUBLY CIRCULAR LINKED LIST

1. doubly circular linked list --> list is empty

2. doubly circular linked list -> list is contains only one node



3. doubly circular linked list --> list is contains more than one nodes



Data Structures: Linked List

Advantages of Doubly Circular Linked List:

- DCLL can be traverse in forward as well as in a backward direction.

- Add last, add first, delete last & delete first operations are efficient as it takes O(1) time and are convenient as well.

- Traversal can be start either from first node or from last node.

- Any node can be revisited.

- Previous node of any node can be accessed from it

Array v/s Linked List:

- Array is **static** data structure whereas linked list is dynamic data structure.

- Array elements can be accessed by using **random access** method which is efficient than linked list elements which can be accessed by **sequential access** method.

- Addition & Deletion operations are efficient on linked list than on an array.

- Array elements gets stored into the **stack section**, whereas linked list elements gets stored into **heap section.**

- In a linked list extra space is required to maintain link between elements, whereas in an array to maintain link between elements is the job of **compiler**.

Data Structures: Stack

Stack: It is a collection/list of logically related similar type elements into which data elements can be added as well as deleted from only one end referred **top** end.

- In this collection/list, element which was inserted last only can be deleted first, so this list works in **last in first out/first in last out** manner, and hence it is also called as **LIFO list**/FILO list.

- We can perform basic three operations on stack in **O(1)** time: **Push, Pop & Peek.**

1. Push : **to insert/add an element onto the stack at top position**

step1: check stack is not full

step2: increment the value of top by 1

step3: insert an element onto the stack at top position.

2. Pop : to delete/remove an element from the stack which is at top position

step1: check stack is not empty

step2: decrement the value of top by 1.

Data Structures: Stack

3. Peek : to get the value of an element which is at top position without push & pop.

step1: check stack is not empty

step2: return the value of an element which is at top position

Stack Empty : top == -1

Stack Full : top == SIZE-1

 # Applications of Stack:

- Stack is used by an OS to control of flow of an execution of program.
- In recursion internally an OS uses a stack.
- undo & redo functionalities of an OS are implemented by using stack.
- Stack is used to implement advanced data structure algorithm like **DFS: Depth First Search** traversal in tree & graph.
- Stack is used in an algorithms to covert given infix expression into its equivalent postfix and prefix, and for postfix expression evaluation.

Data Structures: Stack

- Algorithm to convert given infix expression into its equivalent postfix expression:

Initially we have, an Infix expression, an empty Postfix expression & empty Stack.

```
# algorithm to convert given infix expression into its equivalent postfix expression
step1: start scanning infix expression from left to right
step2:
    if( cur ele is an operand )
        append it into the postfix expression
    else//if( cur ele is an operator )
    {
        while( !is_stack_empty(&s) && priority(topmost ele) >= priority(cur ele) )
        {
            pop an ele from the stack and append it into the postfix expression
        }

        push cur ele onto the stack
    }
step3: repeat step1 & step2 till the end of infix expression
step4: pop all remaining ele's one by one from the stack and append them into the
postfix expression.
```

- Algorithm to convert given infix expression into its equivalent prefix expression:

Initially we have, an Infix expression, an empty Prefix expression & empty Stack.

```
# algorithm to convert given infix expression into its equivalent prefix:
step1: start scanning infix expression from right to left
step2:
    if( cur ele is an operand )
        append it into the prefix expression
    else//if( cur ele is an operator )
    {
        while( !is_stack_empty(&s) && priority(topmost ele) > priority(cur ele) )
        {
            pop an ele from the stack and append it into the prefix expression
        }

        push cur ele onto the stack
    }
step3: repeat step1 & step2 till the end of infix expression
step4: pop all remaining ele's one by one from the stack and append them into the
prefix expression.
step5: reverse prefix expression - equivalent prefix expression.
```

Data Structures: Queue

Queue: It is a collection/list of logically related similar type of elements into which elements can be added from one end referred as **rear** end, whereas elements can be deleted from another end referred as a **front** end.

- In this list, element which was inserted first can be deleted first, so this list works in **first in first out** manner, hence this list is also called as **FIFO list/LILO list.**

- Two basic operations can be performed on queue in O(1) time.

1. Enqueue: to insert/push/add an element into the queue from rear end.

2. Dequeue: to delete/remove/pop an element from the queue which is at front end.

- There are different types of queue:

1. Linear Queue (works in a fifo manner)

2. Circular Queue (works in a fifo manner)

3. Priority Queue: it is a type of queue in which elements can be inserted from rear end randomly (i.e. without checking priority), whereas an element which is having highest priority can only be deleted first.

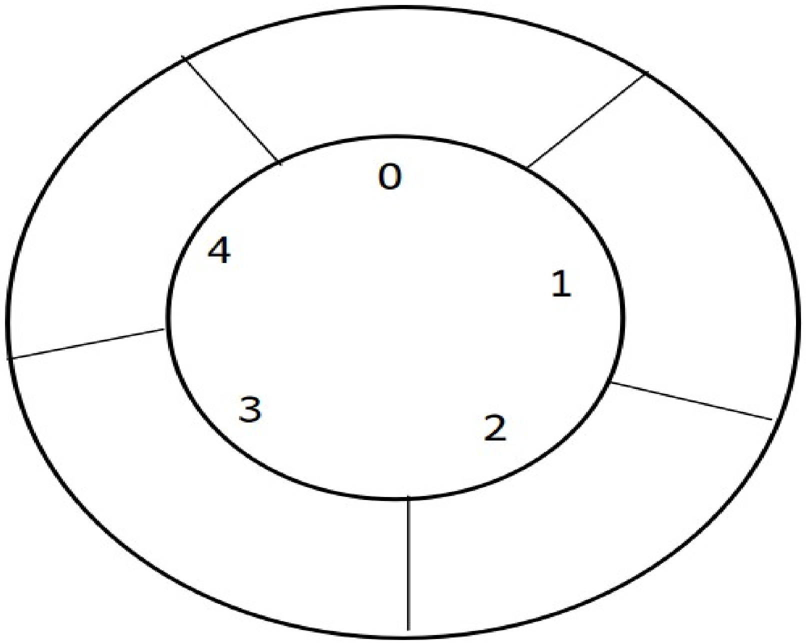
- Priority queue can be implemented by using linked list, whereas it can be implemented efficiently by using **binary heap.**

4. Double Ended Queue (deque) : it is a type of queue in which elements can added as well as deleted from both the ends.

Data Structures: Queue

front=-1

rear=-1



\# Circular Queue

is_queue_full : front == (rear+1)%SIZE

is_queue_empty : rear == -1 && front == rear

1. "enqueue": to insert/add/push an element into the queue from rear end:

step1: check queue is not full

step2: increment the value of rear by 1 [rear = (rear+1)%SIZE]

step3: push/add/insert an ele into the queue at rear position

step4: if(front == -1)

front = 0

2. "dequeue": to remove/delete/pop an element from the queue which is at front position.

step1: check queue is not empty

step2:

if(front == rear)//if we are deleting last ele

front = rear = -1;

else

increment the value of front by 1 [i.e. we are deleting an ele from the queue]. [front = (front+1)%SIZE]

Data Structures: Queue

Applications of Queue:

- Queue is used to implement OS data structures like **job queue, ready queue, message queue, waiting queue** etc...

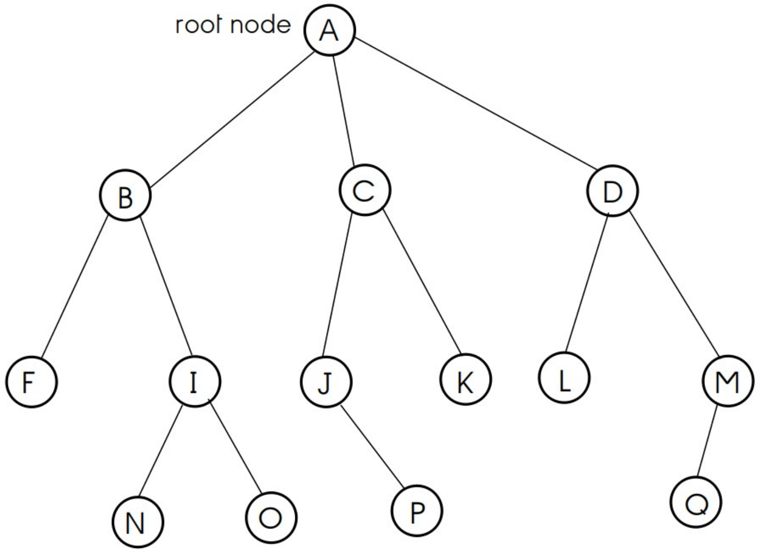
- Queue is used to implement OS algorithms like **FCFS CPU Scheduling, Priority CPU Scheduling, FIFO Page Replacement** etc...

- Queue is used to implenent an advanced data structure algorithms like **BFS: Breadth First Search** Traversal in tree and graph.

- Queus is used in any application/program in which list/collection of elements should works in first in first out manner.

Data Structures: Tree

Tree: It is a **non-linear**, **advanced** data structure which is a collection of finite no. of logically related similar type of elements in which, there is a first specially designated element referred as a **root element**, and remaining all elements are connected to it in a **hierarchical manner**, follows **parent-child relationship**.



Tree: Data Structure

Data Structures: Tree

- **siblings/brothers:** child nodes of same parent are called as siblings.
- **ancestors:** all the nodes which are in the path from root node to that node.
- **descedents:** all the nodes which can be accessible from that node.
- **degree of a node** = no. of child nodes having that node
- **degree of a tree** = max degree of any node in a given tree
- **leaf node/external node/terminal node:** node which is not having any child node OR node having degree 0.
- **non-leaf node/internal node/non-terminal node:** node which is having any no. of child node/s OR node having non-zero degree.
- **level of a node** = level of its parent node + 1
- **level of a tree** = max level of any node in a given tree (by assuming level of root node is at level 0).
- **depth of a tree** = max level of any node in a given tree.
- as tree data structure can grow upto any level and any node can have any number of child nodes, operations on it becomes unefficient, so restrictions can be applied on it to achieve efficiency and hence there are diefferent types of tree.

Data Structures: Tree

- **Binary tree:** it is a tree in which each node can have max 2 number of child nodes, i.e. each node can have either 0 OR 1 OR 2 number of child nodes.

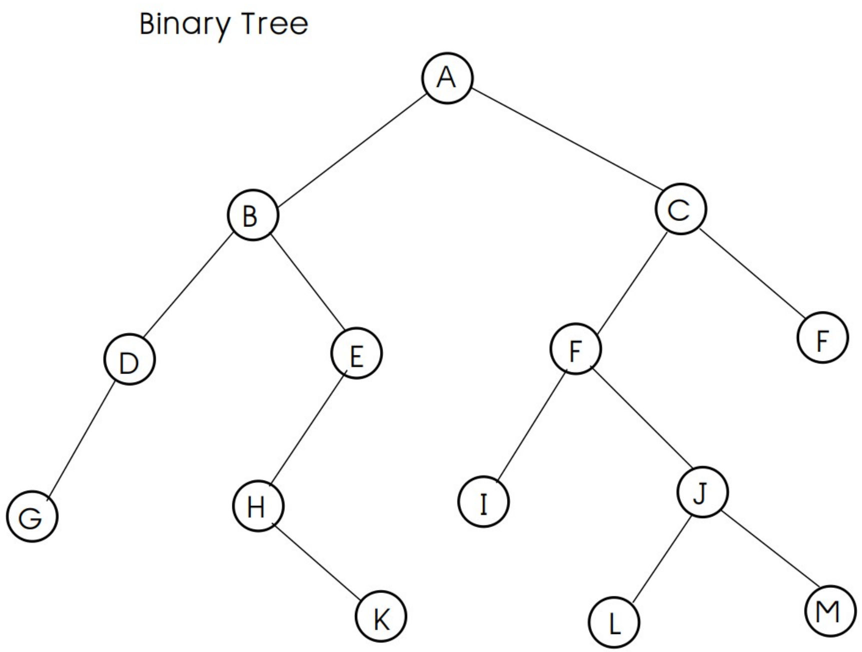
OR

Binary tree: it is a set of finite number of elements having three subsets:

1. root element

2. left subtree (may be empty)

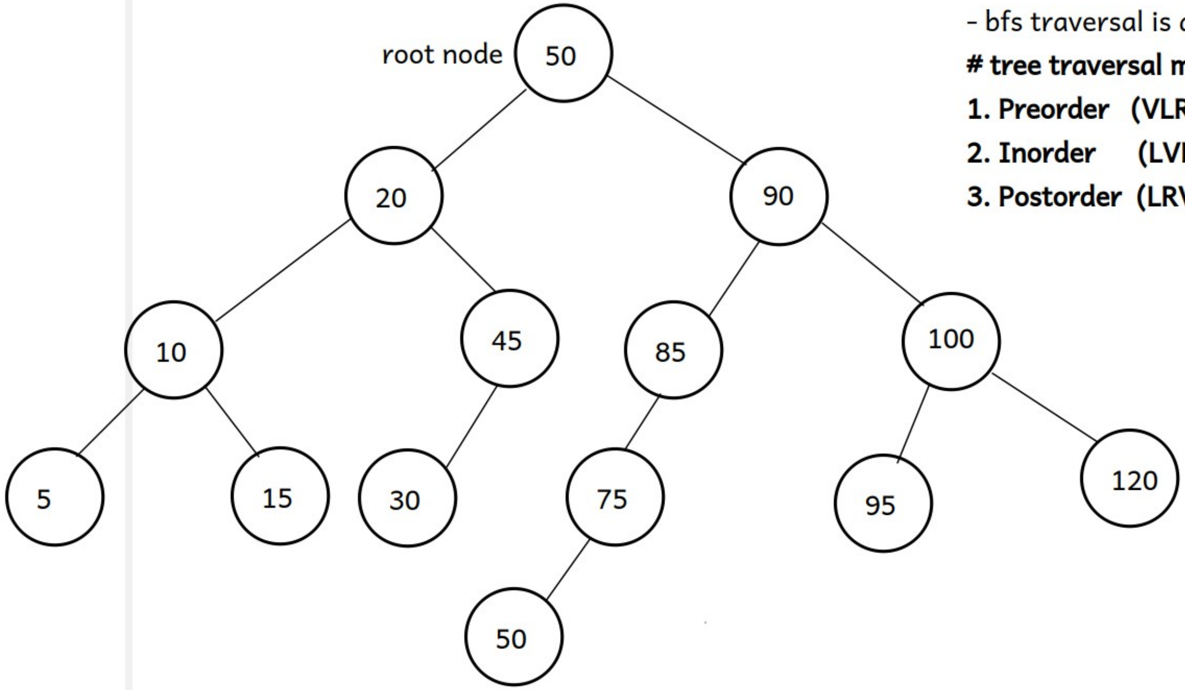
3. right subtree (may be empty)



Data Structures: Tree

- Binary Search Tree(BST): it is a **binary tree** in which left child is always smaller than its parent and right child is always greater than or equal to its parent.

input order of an ele's for BST: 50 20 90 85 10 45 30 100 15 75 95 120 5 50



1. dfs traversal: 50 20 10 5 15 45 30 90 85 75 50 100 95 120

2. bfs traversal: 50 20 90 10 45 85 100 5 15 30 75 95 120 50

- bfs traversal is also called as "levelwise traversal".

 # tree traversal methods on BST:

1. Preorder (VLR) : 50 20 10 5 15 45 30 90 85 75 50 100 95 120

2. Inorder (LVR): 5 10 15 20 30 45 50 50 75 85 90 95 100 120

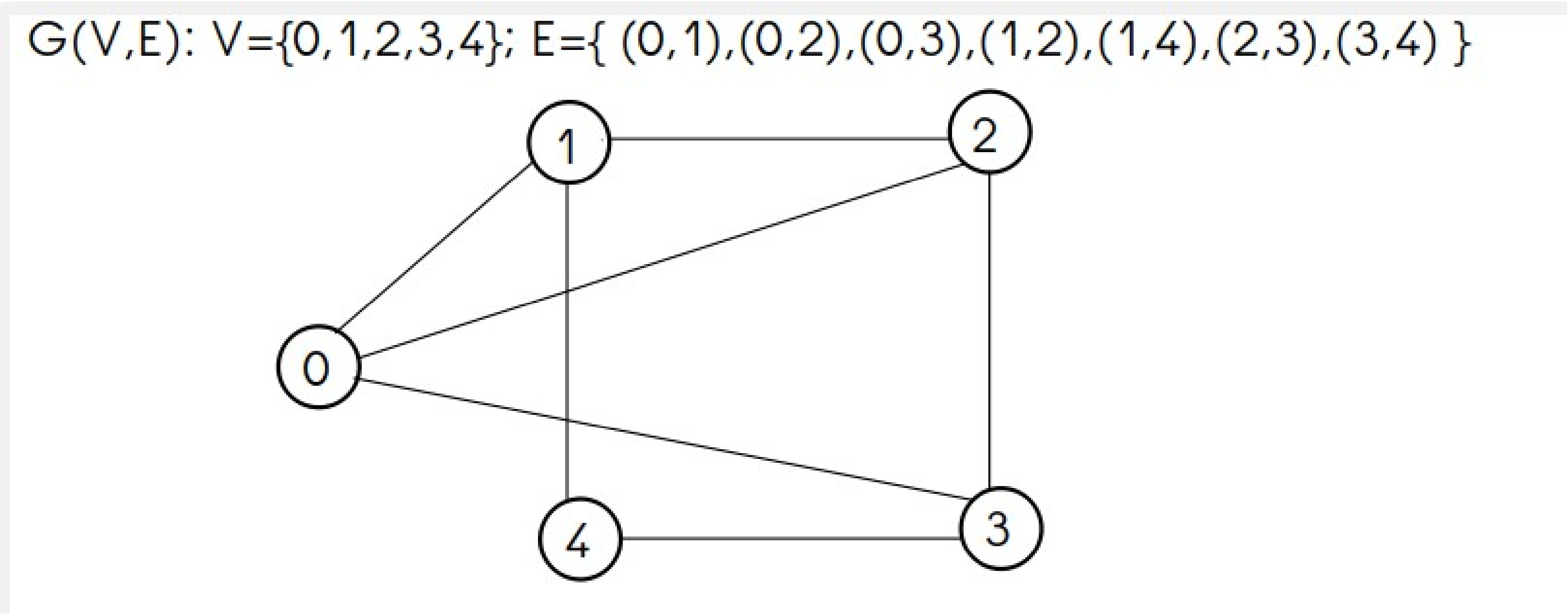
3. Postorder (LRV): 5 15 10 30 45 20 50 75 85 95 120 100 90 **50**

Data Structures: Graph

Graph: It is **non-linear**, **advanced** data structure, which is a collection of logically related similar and disimmilar type of elements which contains:

- set of finite no. of elements referred as a **vertices**, also called as **nodes**, and

- set of finite no. of ordered/unordered pairs of vertices referred as an **edges**, also called as an **arcs**, whereas it may carries weight/cost/value (cost/weight/value may be -ve).



Data Structures: Graph

- If there exists a direct edge between two vertices then those vertices are referred as **adjacent vertices** otherwiese **non-adjacent**.

- if we can represent any edge either (u,v) OR (v,u) then it is referred as **unordered pair of vertices i.e. undirected edge.**

(u,v) == (v,u) --> unordered pair of vertices -> undirected edge -> undirected graph

- if we cannot represent any edge either (u,v) OR (v,u) then it is referred as **unordered pair of vertices** i.e. directed edge.

(u,v) != (v,u) --> ordered pair of vertices -> directed edge -> directed graph (di-graph).

- complete graph: if all the vertices are adjacent to remaining all vertices in a given graph.

- connected vertices: if path exists between two vertices then those two vertices are referred as a connected vertices otherwise not-connected.

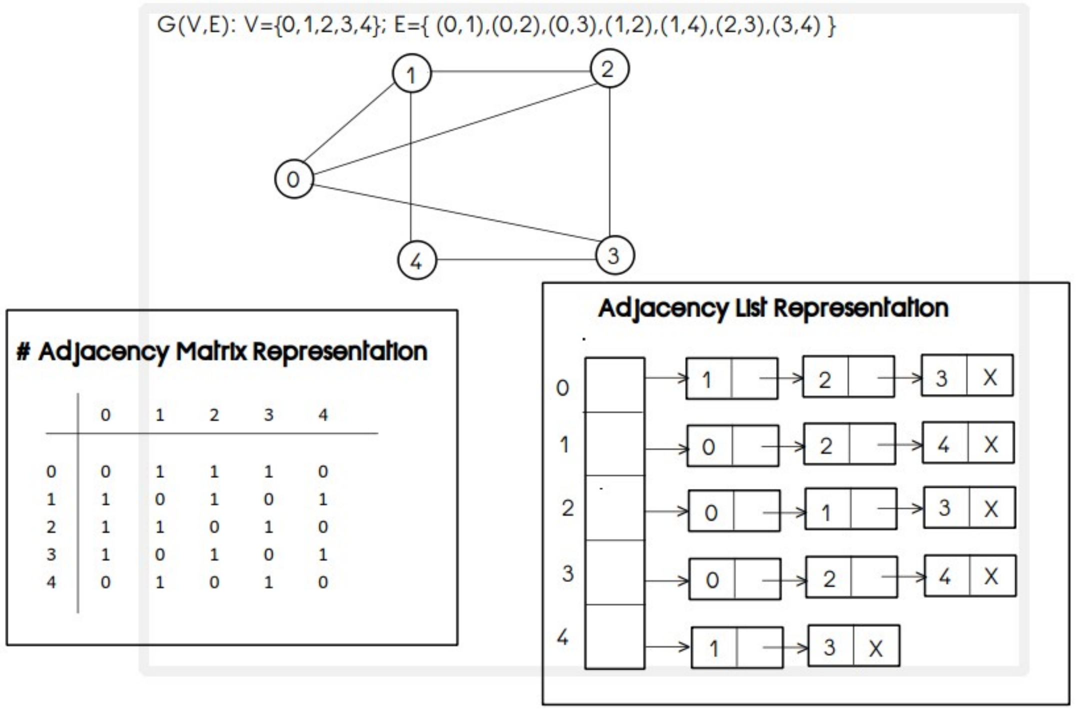
- connected graph: if any vertex is connected to remaining all vertices in a given graph

Data Structures: Graph

- There are two graph representation methods:

1. Adjacency Matrix Representation (2-D Array)

2. Adjacency List Representation (Array of Linked Lists)



	0	1	2	3	4
0	0	1	1	1	0
1	1	0	1	0	1
2	1	1	0	1	0
3	1	0	1	0	1
4	0	1	0	1	0