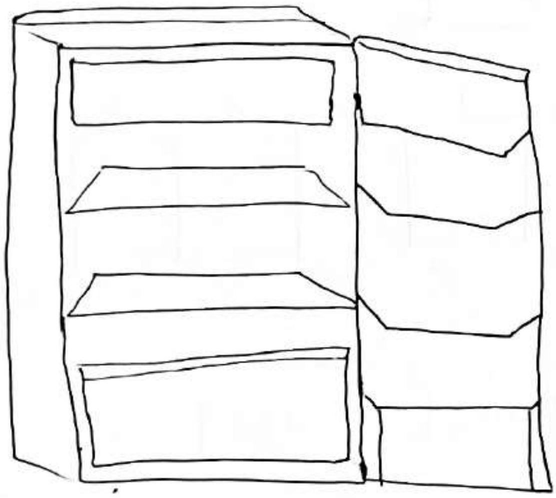
→ Introduction
→ Array
→ Linked List
→ stack
→ Queue
→ Tree
→ Heap
→ Graph
→ Hashing

① What is Data structure?

→



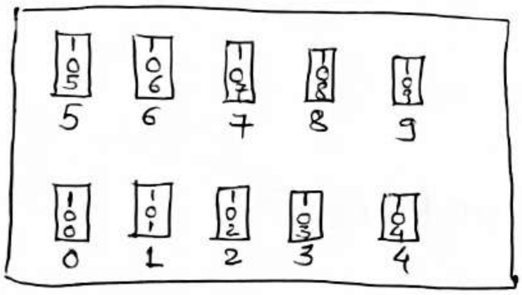
① store
② Organize
③ Access
④ Manipulate

② LDS vs NLDS

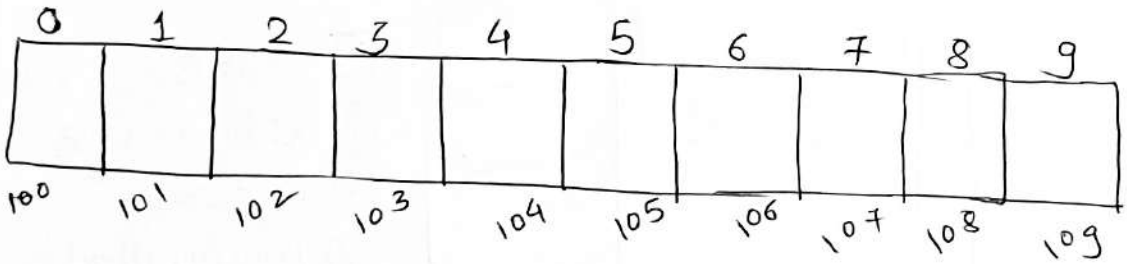
LDS	NLDS
→ Adjacently Attached	→ Hierarchically Attached
→ single Level	→ Multiple Level
→ Easy	→ Difficult
→ Single Run	→ Multiple Runs
→ Memory is not Utilized in efficient way	→ In efficient way
→ Array, stack, LL	→ Tree Graph

3 Array

→ Store
→ Same type
→ Contiguous Memory Locations
→ Index Accessing



CLASS A

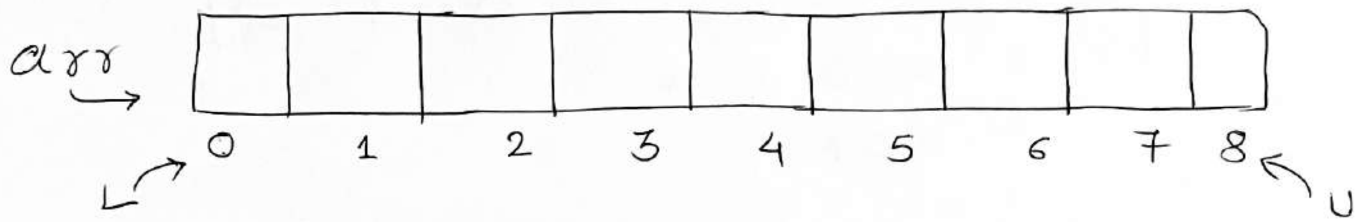


→ Datatype ArrayName [A_size]

↓ int ↓ Arr ↓ [10]

→ Random Accessing
→ Easy Retrieval
→ Easy to Use & understand
→ Fixed nature
→ Insert / Delete Issues

→ 1D Array



$$\text{Size}(arr) = U - L + 1 = 8 - 0 + 1 = 9$$

→ $BA = 1000$

$U = 8$

$L = 0$

$S = 1$

$$\text{Addr}(arr[i]) = BA + S[i - L]$$

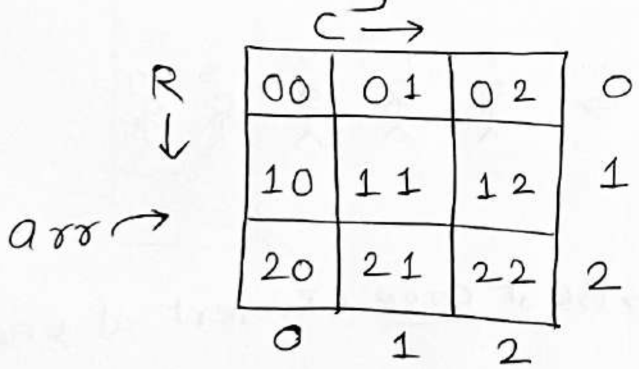
$i = 0$ $= 1000 + 1[0 - 0]$

$= 1000$

$i = 1$ $= 1000 + 1[1 - 0]$

$= 1001$

→ 2D Array



$BA = 1000$

$S = 1$

$L_R = 0$

$U_R = 2$

$L_C = 0$

$U_C = 2$

$$\text{Addr}(arr[i][j]) = BA + S[(i - L_R)(U_C - L_C + 1) + (j - L_C)]$$

$i = 1$, $j = 2$

$= 1000 + 1[(1-0)(3) + (2-0)]$

$= 1000 + 5$

$= 1005$

$$Addr(arr[i][j]) = BA + S[(j-L_C)(U_R-L_R+1)+(i-L_R)]$$

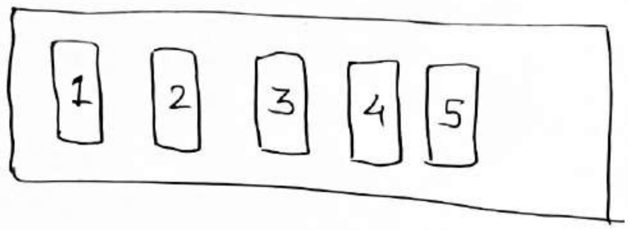
$i \to 1$, $j \to 2$

$$= 1000 + 1[(2-0)(3)+(1-0)]$$

$$= 1000 + 7$$

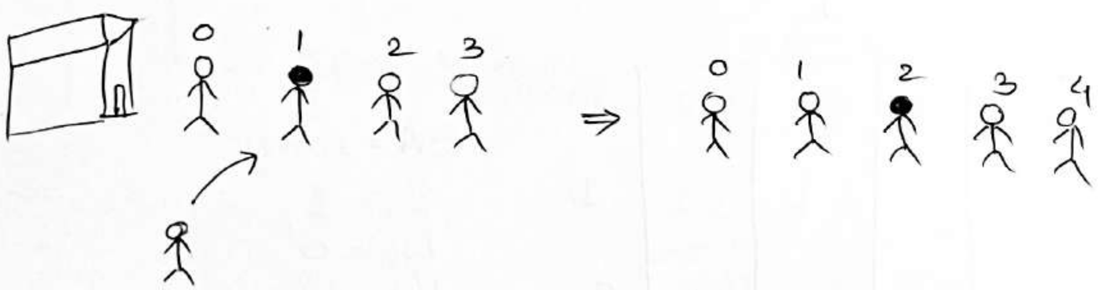
$$= 1007$$

→ Traversal operation :-

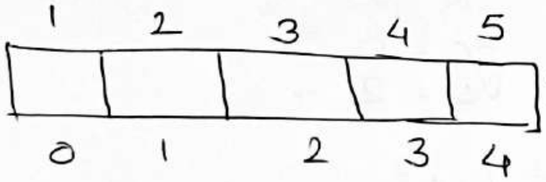



```
for (i=0; i<n; i++)
{
    printf(arr[i]);
}
```

→ Insertion operation :-



P →



I →

→ Best case (Insert at end)

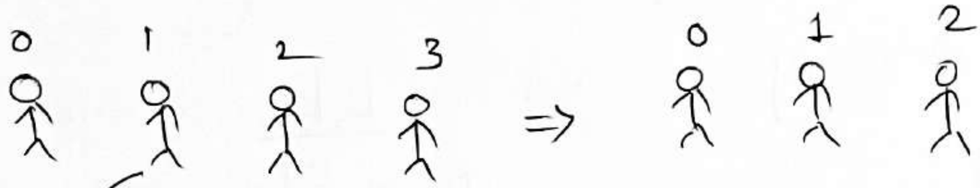
→ Worst case (Insert at (I=0))

$$P = I + 1$$

or

$$I = P - 1$$

→ Deletion Operation



10	20	30	40	50
0	1	2	3	4

↓ delete (I=1)

10		30	40	50

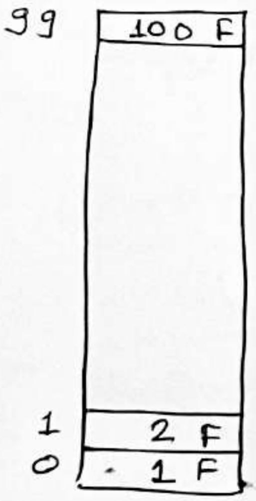
↓

10	30	40	50	

→ Best case (Last element)

→ Worst case (I=0)

→ Searching operation



→ Best case (1^{st} floor)

→ Worst case (100^{th} floor)

Array Vs LL

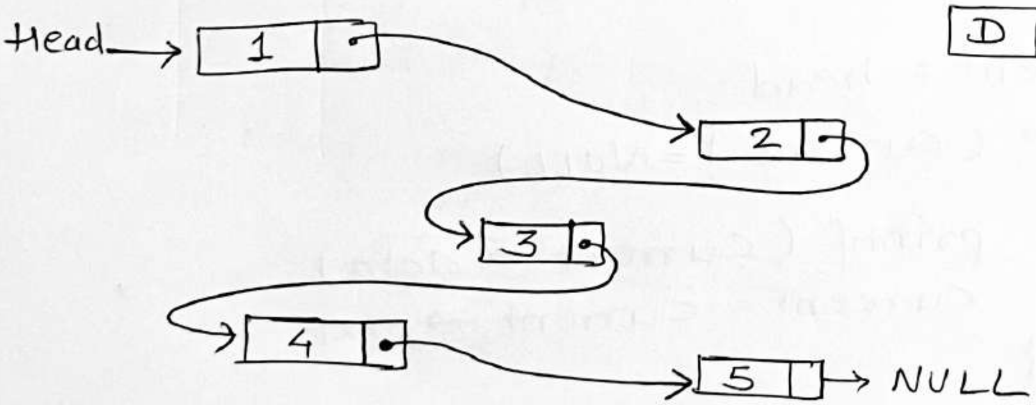
Array	LL
① Contiguous ML	① Not
② Random access	② Sequential Access
③ I & D takes More time	③ I & D → fast
④ Fixed, static Nature	④ Dynamic, changes are accepted.
⑤ 1D, 2D, --- MD	⑤ SLL, DLL, CLL
⑥ Sequential Representation	⑥ Linked Representation

	D	L
1	10	3
2		
3	20	5
4		
5	30	10

④ Linked List:

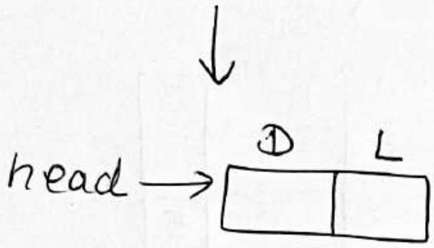
'node'

D	L



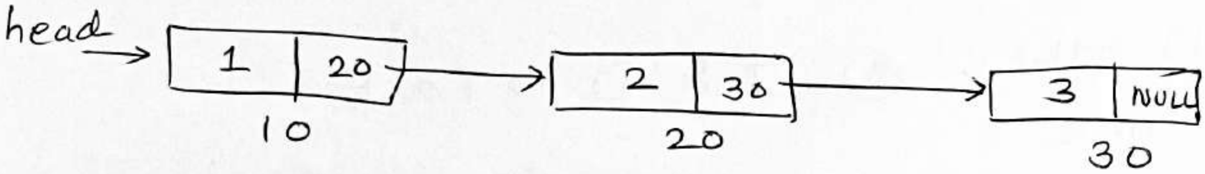

```
Struct node
{
    int data;
    struct node *link;
}
```

node* head = malloc (sizeof (node))



head → data = 5

head → link = NULL



head → data = 1

head → link = 20

head → link → data = 2

head → link → link = 30

head → link → link → data = 3

head → link → link → link = NULL

Traversal

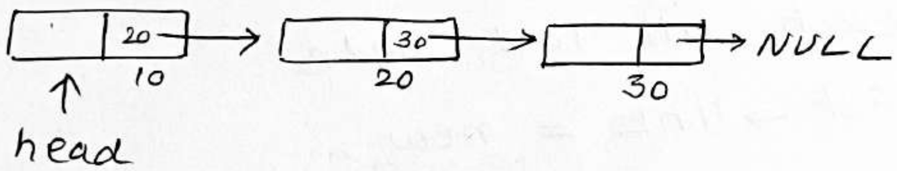
⇒

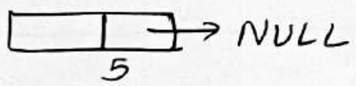
```
current = head
while (current != NULL)
  {
     printf (current → data)
     current = current → next
  }
```

Searching

```
⇒ current = head
  while (current != NULL)
  {
      if (current → data == key)
      {  return current
      }
      current = current → link
  }
```

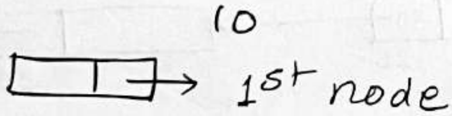
Insert → At Beginning.



⟹ 

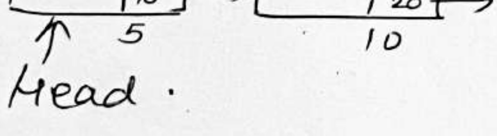
① new → next = head

10

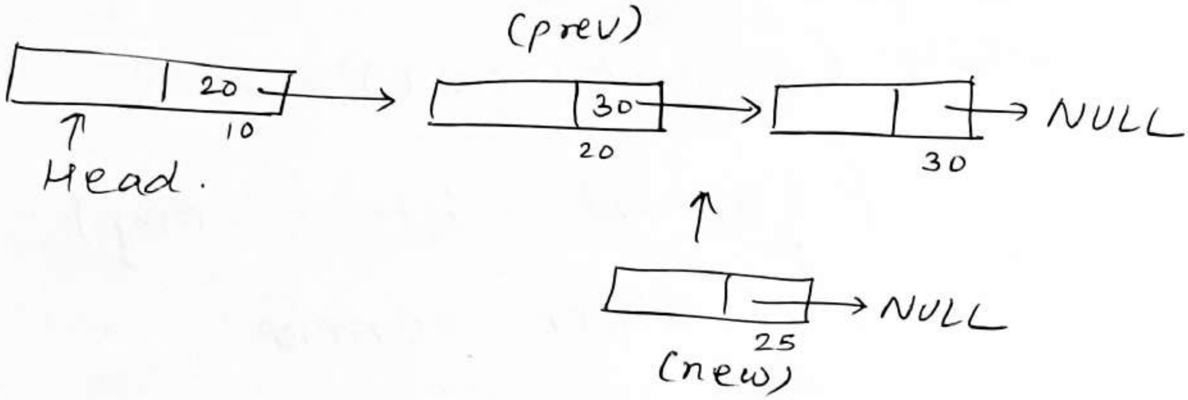


② head = new.

5



Insert → after a node.



① new → next = prev → next

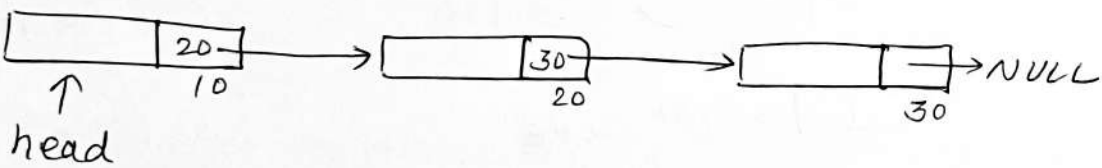
② prev → next = new.

Insert → at End

① Reach till last node

② last → = new

Delete → At Beginning.

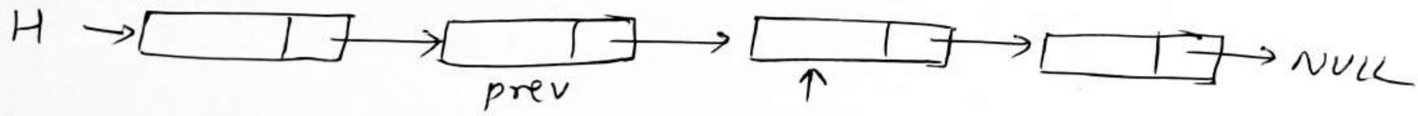


① del = head

② head = del → link

③ free (del)

Delete → after a node.



① del = prev → link

② prev → link = del → link

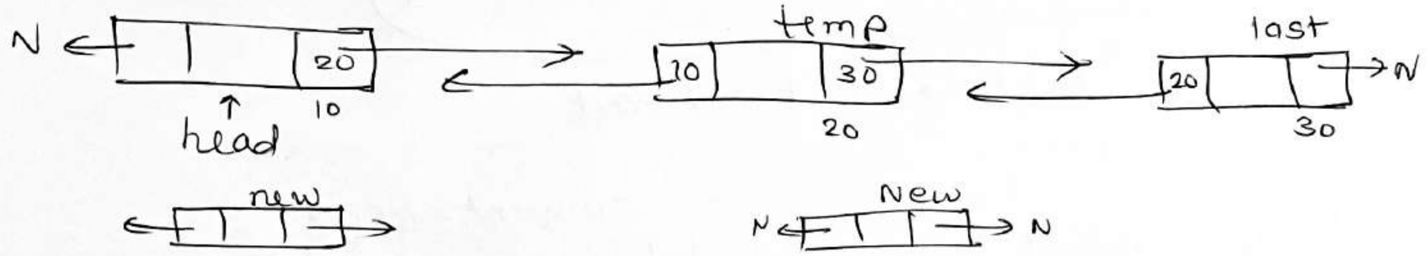
③ free (del)

Insert

At Beginning

After a node

At End



At Beginning

- new → next = head
- head → prev = new
- head = new

After a node

- new → next = temp → next
- temp → next → prev = new
- temp → next = new
- new → prev = temp

At End

- last → next = new
- new → next = last

Delete

At Beginning

- temp = head
- head = head → next
- head → prev = NULL
- free (temp)

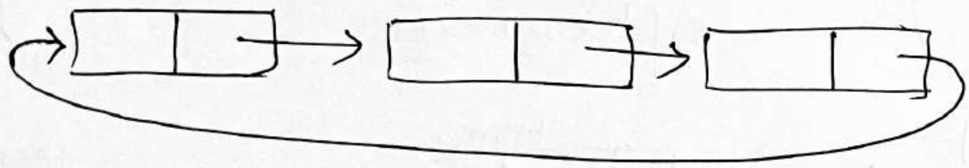
After a node

- p → next = p → prev → next
- p → next → prev = p → prev
- free (p)

At End.

- temp = p → next
- p → next = NULL
- free (temp.

→ Circular Linked List



$last \rightarrow next = head$

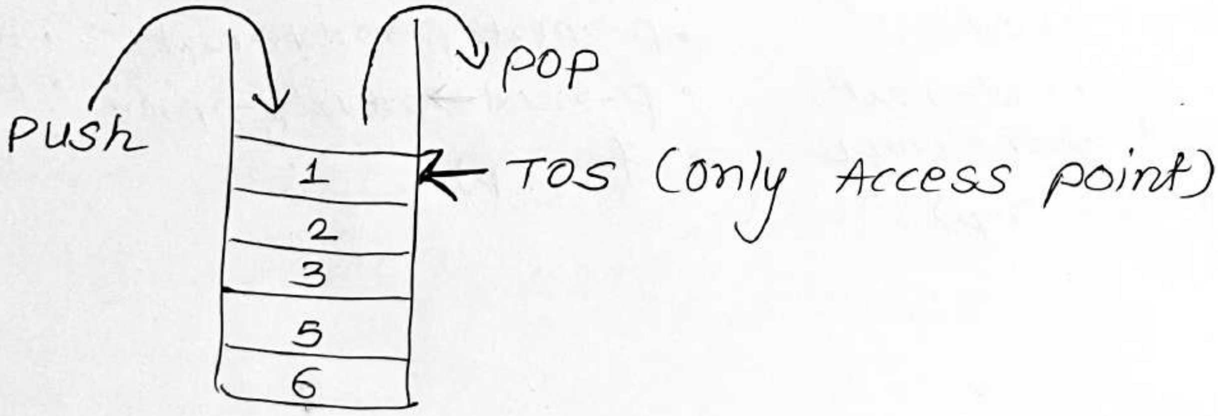
② . temp = head
③ . head = head → next
⑤ . free(temp)

```
current = head
while (current→next != head)
{
    current = current→next
};
```
①

④ current → next = head

⑤ Stack

→ LDS
→ I/D → from only one End
→ FILO / LIFO
→ Element at Top (TOS)



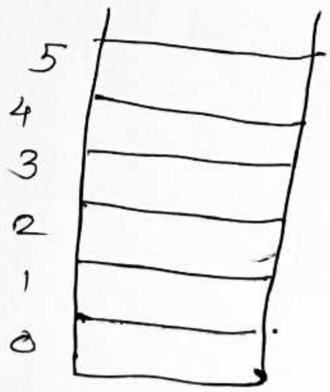
→ Static Imp : Arrays
→ Dynamic Imp : Linked List

} I/D from "Only One End"

```
→ Push (arr, n, TOS, x)
  {
      If (TOS == n-1)
        { printf(" stack is full")
        }
      TOS = TOS+1
      arr [TOS] = x
  }
```

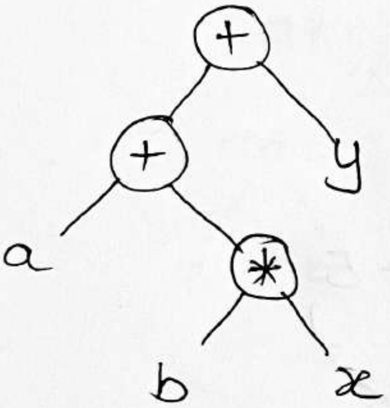
```
→ pop (arr, n, TOS)
   {
      If (TOS == -1)
        { printf(" stack is empty")
        }
      x = arr [TOS]
      TOS = TOS -1
      return (x)
   }
```

Q→ push(1), push(3), pop(), push(5), push(10)
push(10), pop(), pol(), poq(), pop()



Infix	Prefix	Postfix
$a+b*x+y$	$++a*bxy$	$abx*+y+$
$(l-R-r)$	$(R-l-r)$	$(l-r-R)$

(Tree)



	Stack	Postfix
a	-	a
+	+	a
b	+	ab
*	+*	ab
x	+*	abx
+	+	abx*+
y	+	abx*+y

↓

abx*+y+

$\underline{a+}\ \underline{b*x}\ +y$

↓ ↓ ↓

$\underline{a+\ bx*}\ \underline{+y}$

↓ ↓

$\underline{abx*+}\ +y$

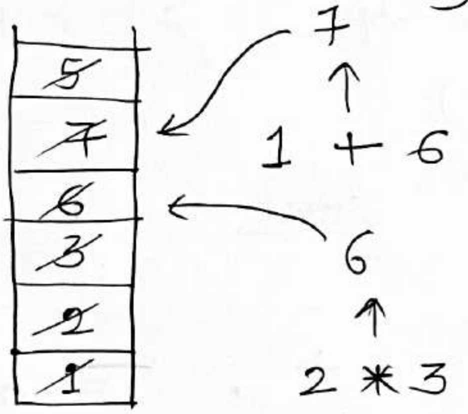
↓

→ $abx*+y+$ ←

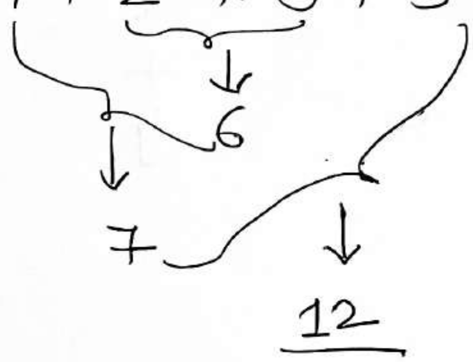
^ (R→L)
* / (L→R)
+ - (L→R)

$\Rightarrow$ 1 2 3 * + 5 + (a b x * + y +)

5 + 7 = $\underline{12}$

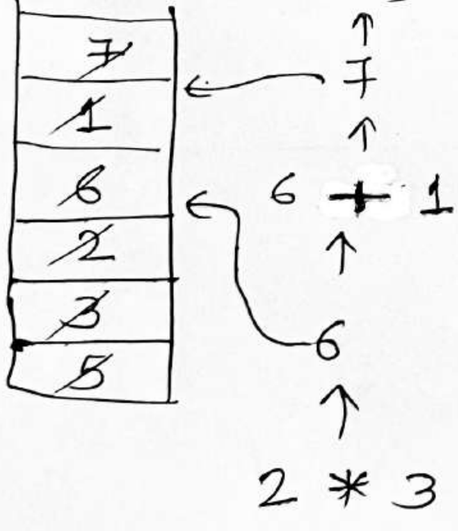


a + b * x + y = 1 + 2 * 3 + 5

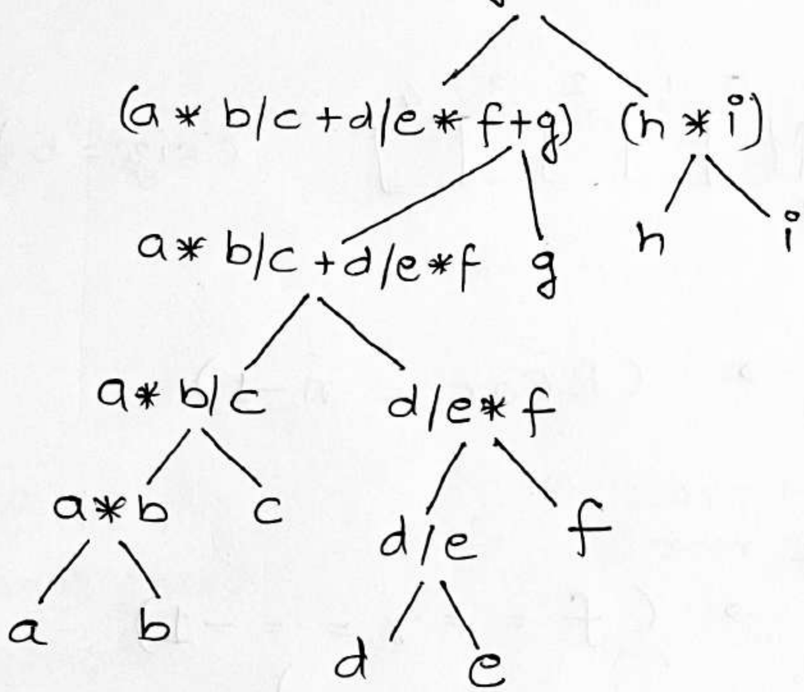


+ + a * b x y = + + 1 * 2 3 5

7 + 5 = $\underline{12}$

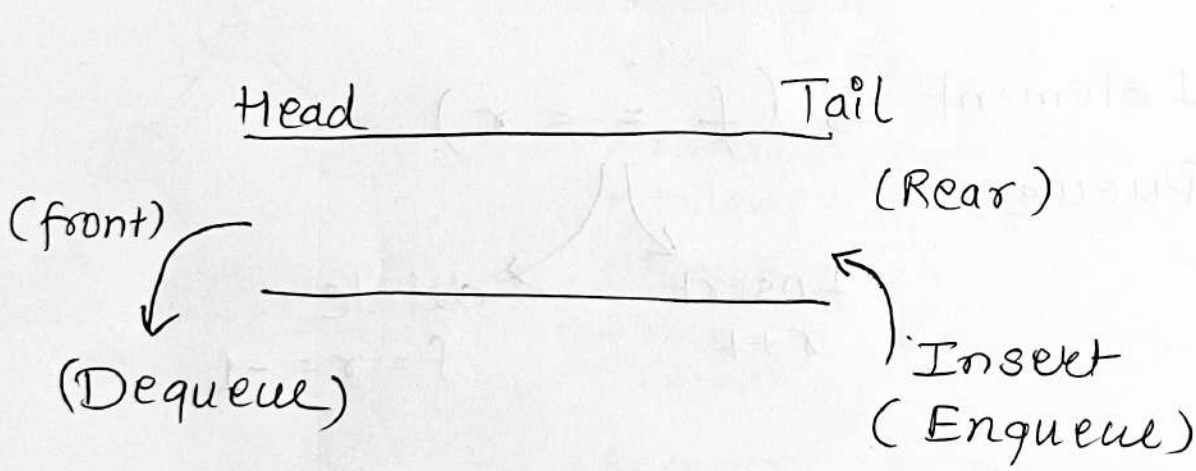


⇒ a * b | c + d | e * f + g − h * i



⇒ Queue

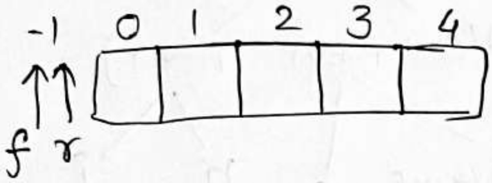
→ FIFO or LILO



Initially → front = rear = −1

→ Implementation using Array.

Initially →



(size = 5)

Overflow Condition → (Rear = n−1)

1st element Insertion Condition → (f = = r = = −1)

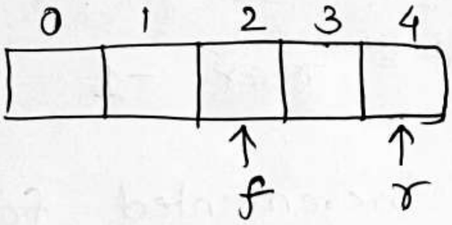
f = r = 0 (after insert)

Underflow Condition → (f = r = −1)

Only 1 element In Queue → (f = = r)

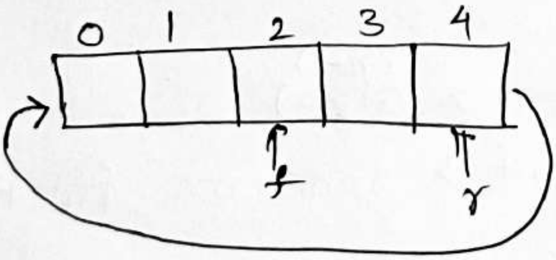
Insert: r++

delete: f = r = −1



Now insert won't be possible due to overflow.

So circular Queue.

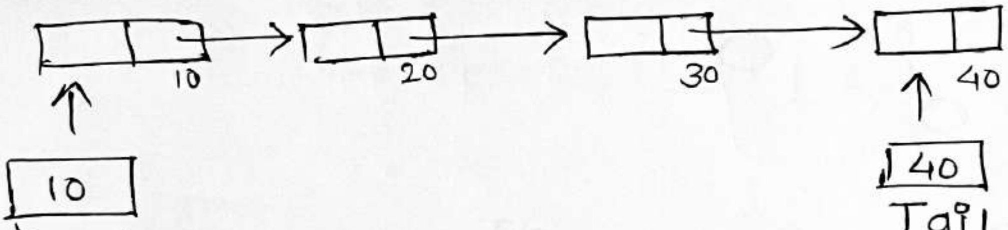


P++

(P+1) % n

here P → Rear
→ front

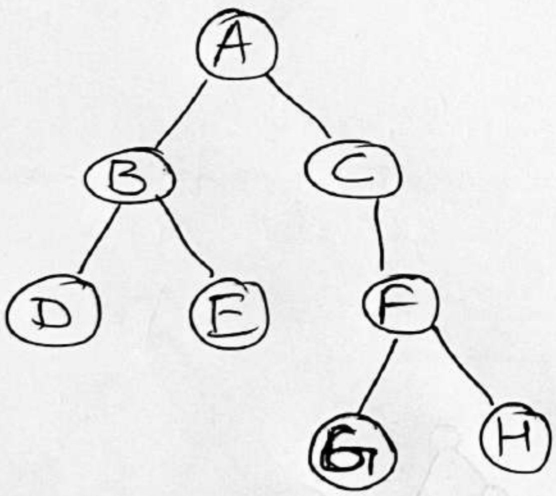
→ Implementation using LL



temp = front
front = front → next
free (temp)

rear → next = new
rear = new

⇒ Tree



- root = A
- leaf = D, E, G, H
- Parent = A, B, C, F
- children = B, C, D, E, E, G, H
- Non-LN = $\overline{LN}$
- Path (A→H) = A → C → F → H
- Ancestor (Before node) (A) & Decendant (After node) (F, H)

- Depth : Root → node
  - (A) = 0 (D) = 2
  - (B) = 1 (E) = 2
  - (G) = 3 (H) = 3

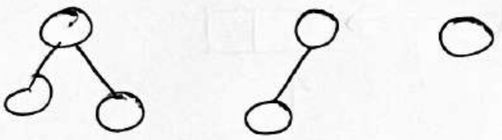
- Sibling → D, E ✓
  - B, C ✓
  - E, F ✗

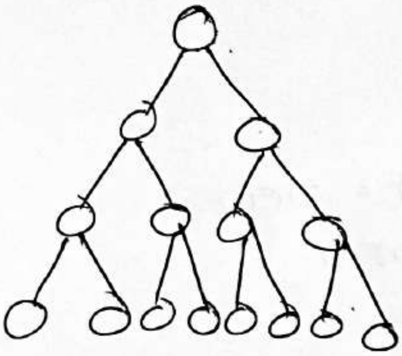
- Height : node → leaf*
  - (A) = 3 (C) = 2
  - (F) = 1 (E) = 0

- Degree of node → A = 2
  - B = 2
  - D = 0

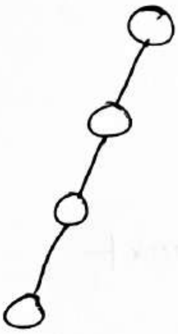
→ Binary Tree

↳ can have atmost 2 children





$(2^{h+1}-1)$ no. of nodes (Max)

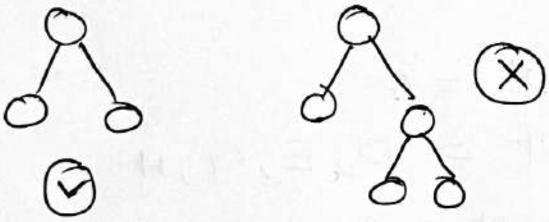


$(h+1)$ no. of nodes (min)

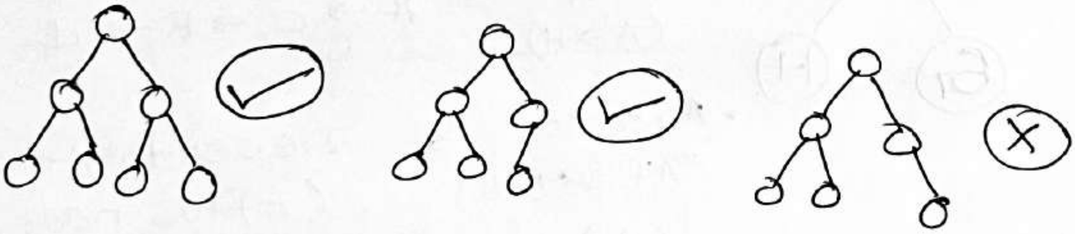
for $h = 3$, $2^{3+1}-1 = \underline{15}$

for $h=3$, $3+1 = \underline{4}$

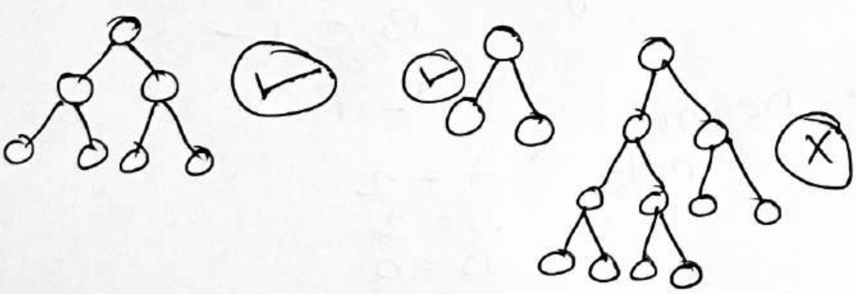
① full BT (0 or 2)



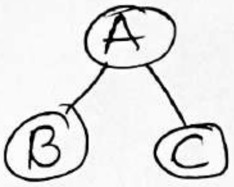
② Complete BT



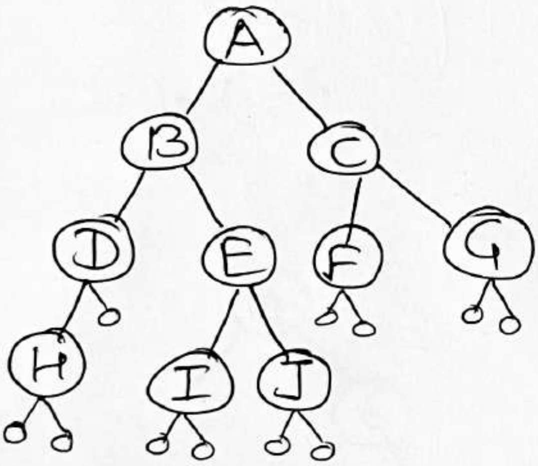
③ Perfect BT



⇒ Tree Traversal
- → preorder (R → l → r)
- → Inorder (l → R → r)
- → Post order (l → r → R)

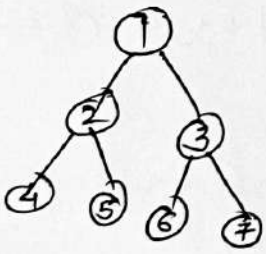


pre	In	Post
ABC	BAC	BCA



①	②	③
In	Pre	Post

→ Binary Tree (using Arrays)



1	2	3	4	5	6	7

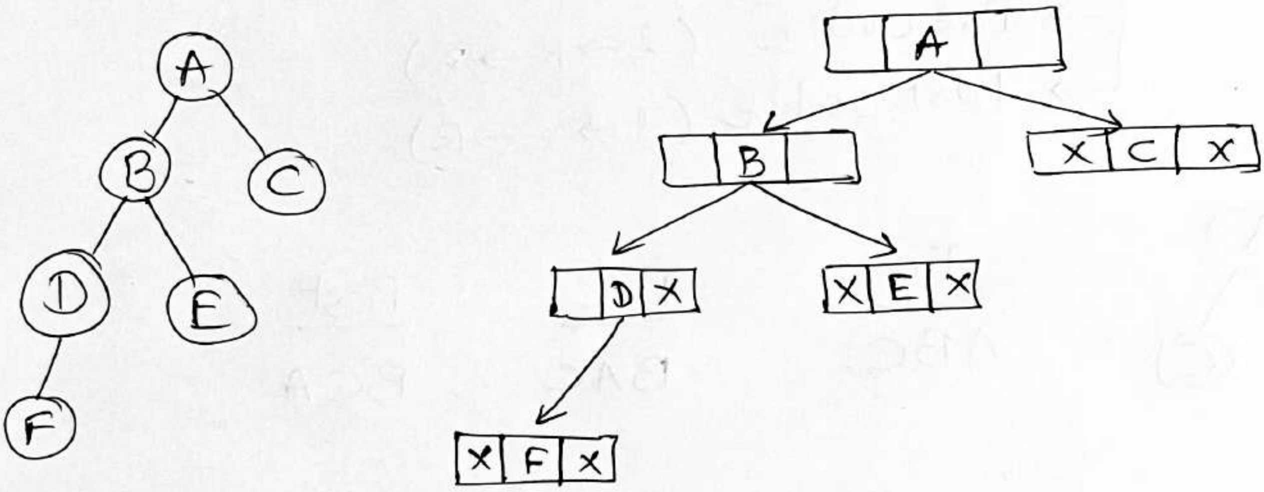
Root at → 1

Left child → $2 * i$

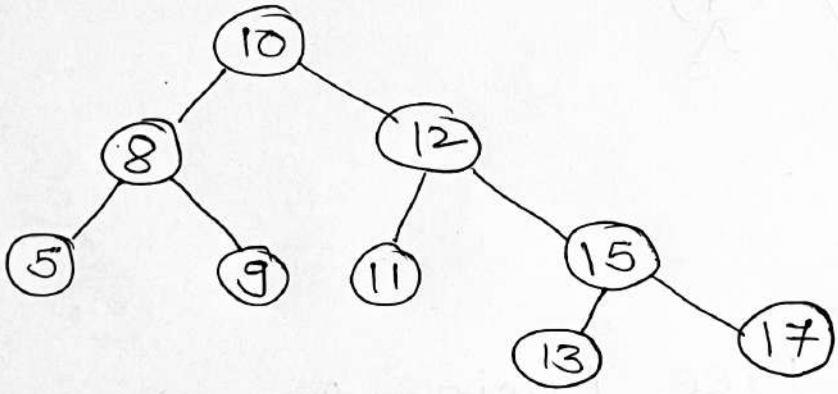
Right child → $2 * i + 1$

for eg:- $i = 3$
- → $L = 2 \times 3 = 6$
- → $R = 2 \times 3 + 1 = 7$

→ Binary Tree (LL)

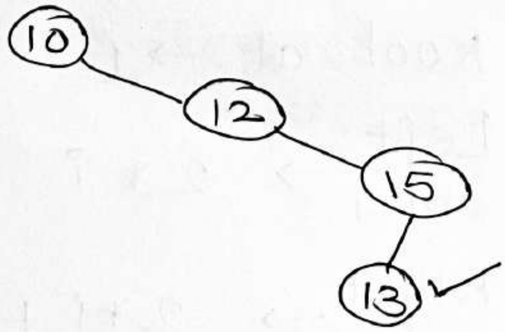


⇒ BST

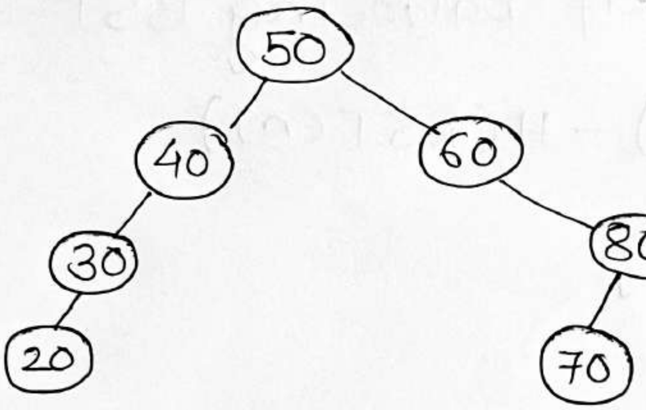


Inorder ⇒ 5, 8, 9, 10, 11, 12, 13, 15, 17

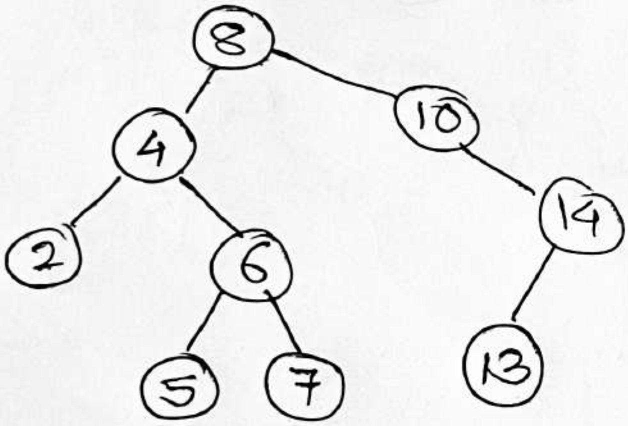
• Searching becomes easy (13)



• Inserting (50, 40, 30, 60, 80, 20, 70)



• Deletion



→ leaf node (Easy) direct (NO Impact)

→ One child node (14) → Replace it with that child (13)

→ 2 child node (4) → Replace it with inorder predecessor. (2).

2, 4, 5, 6, 7, 8, 10, 14, 13

for (8) → its 7.

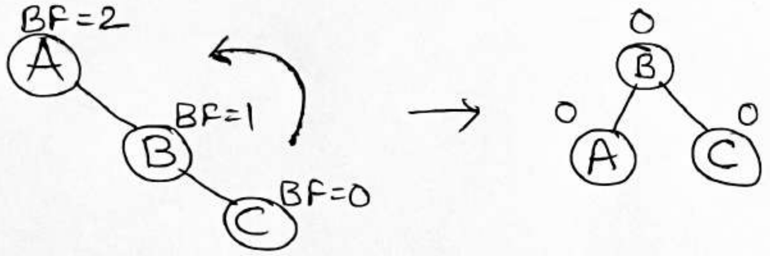
AVL Tree

↳ Its a self-balancing BST

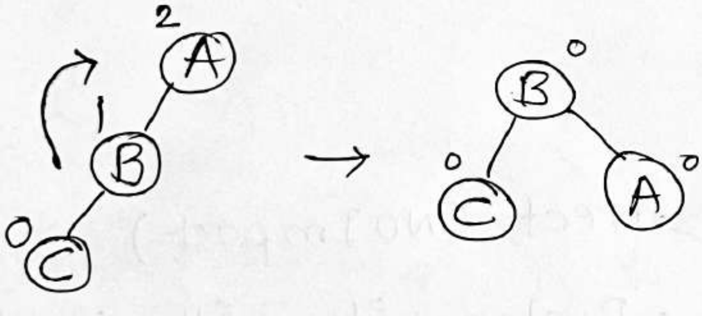
$Bf = H(LST(n)) - H(RST(n))$

↳ $\{-1, 0, +1\}$

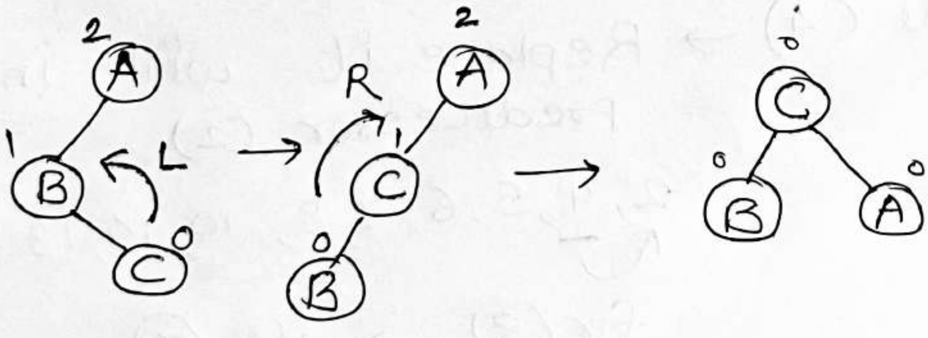
① Left Rotate



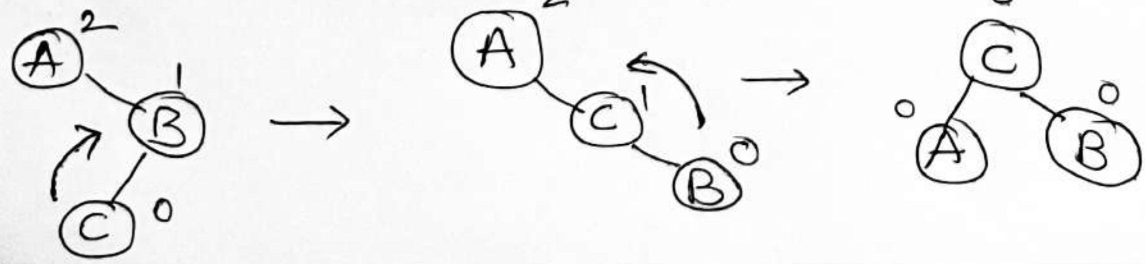
② Right Rotate



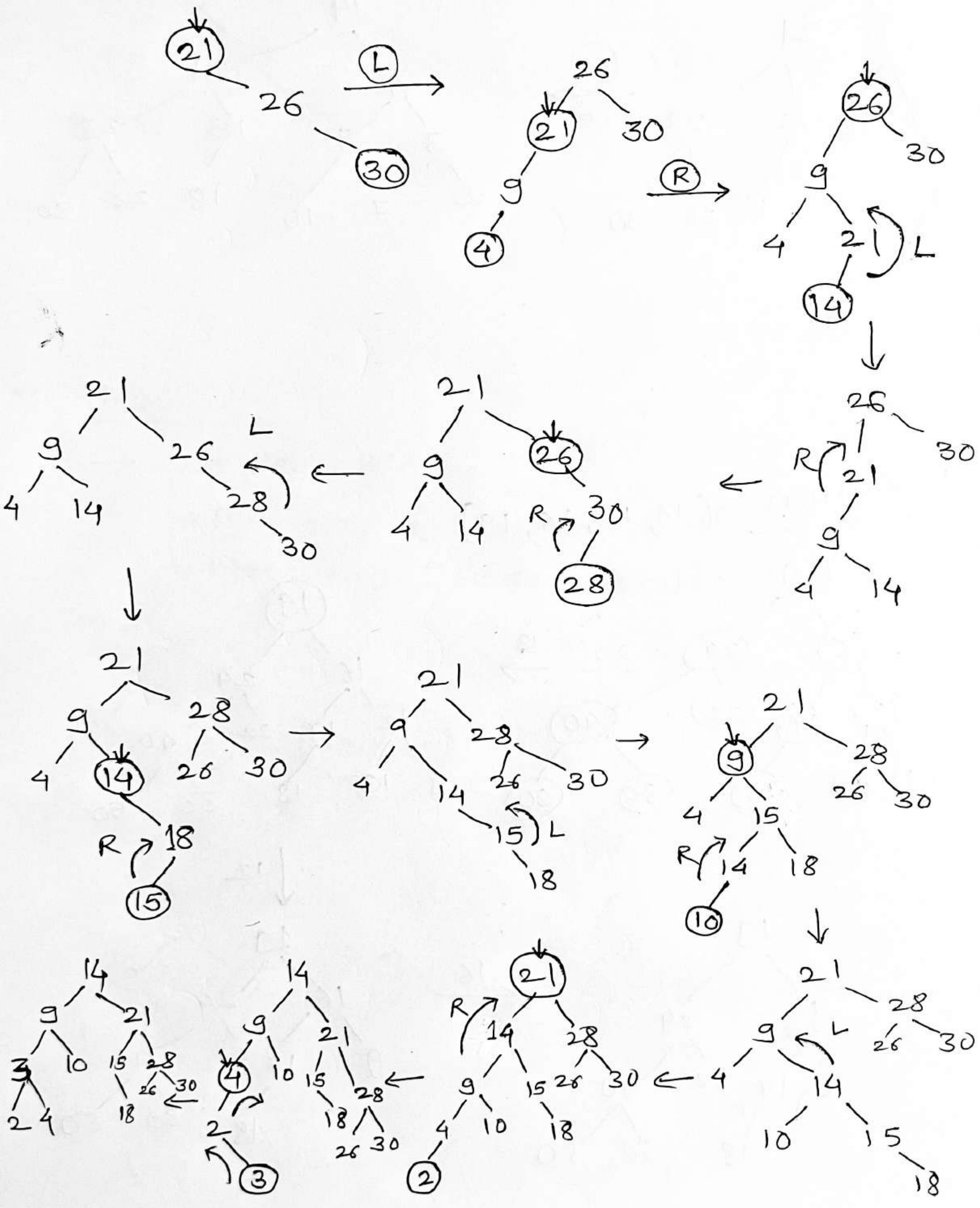
③ LR rotate

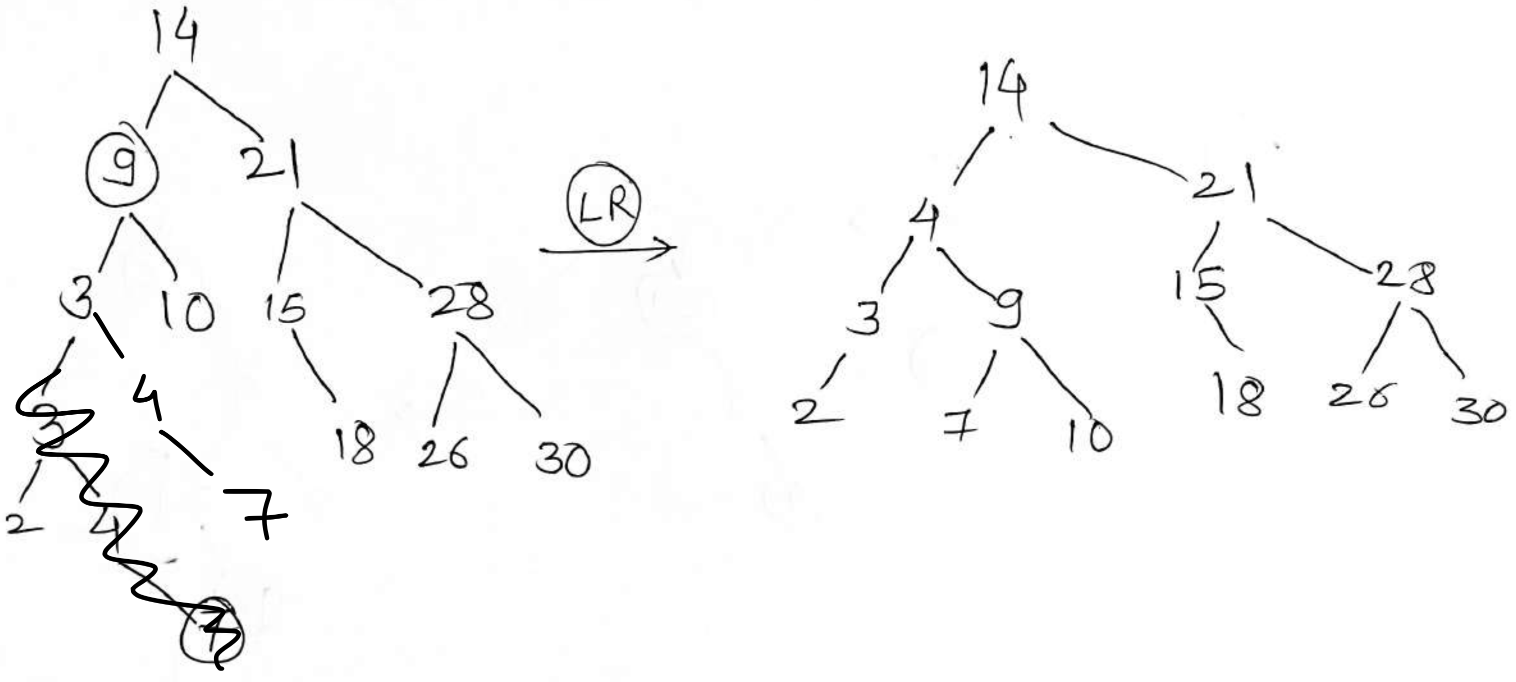


④ RL rotate

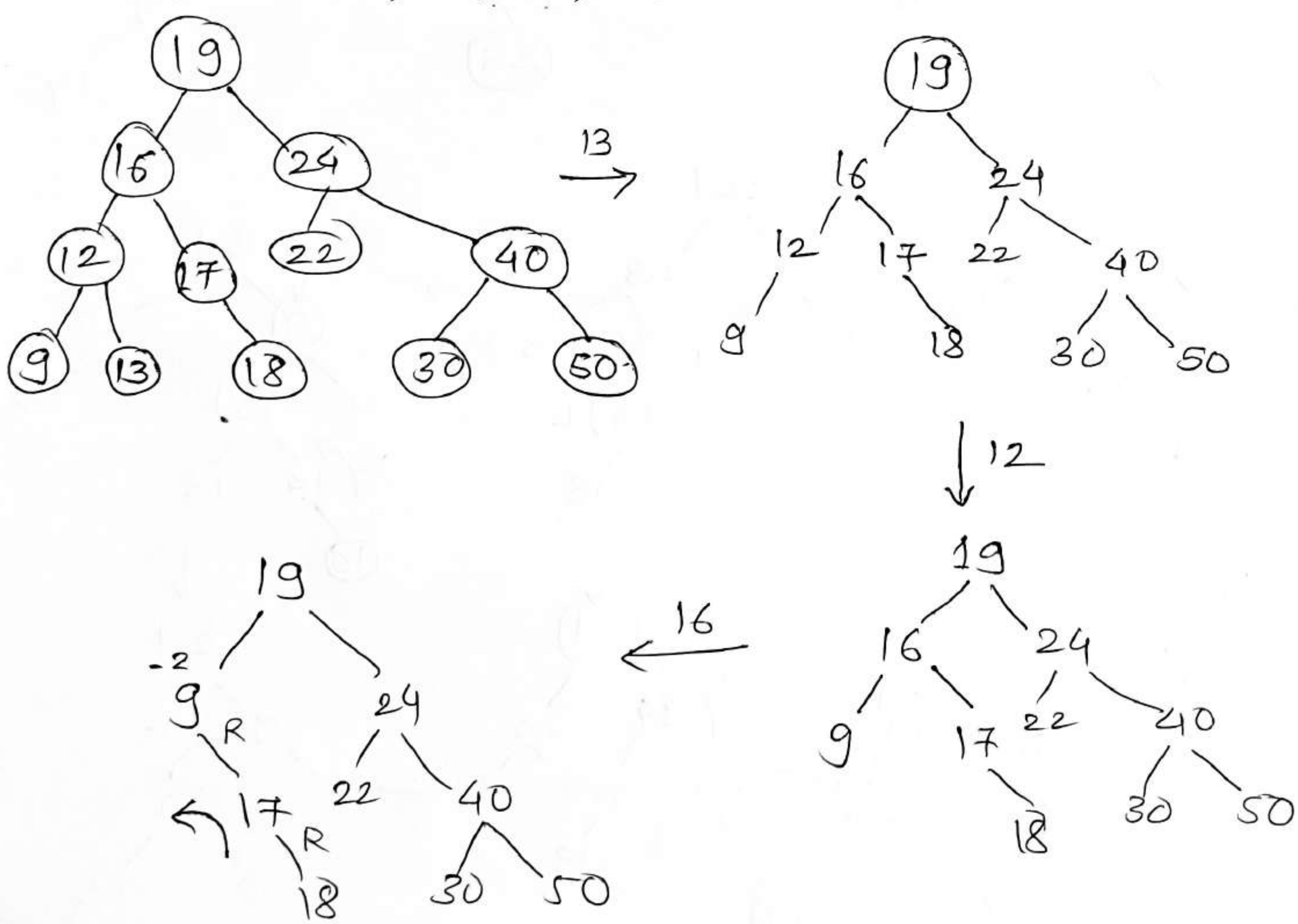


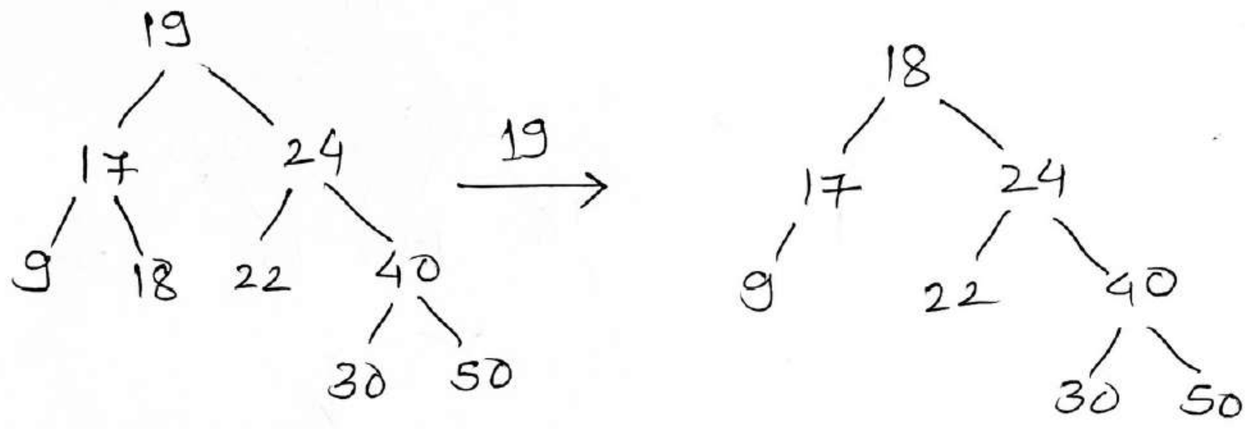
eg:- 21, 26, 30, 9, 4, 14, 28, 18, 15, 10, 2, 3, 7





Deletion ⇒ (13, 12, 16, 19)

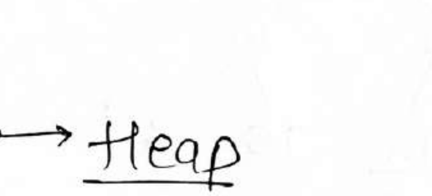




Heap

→ Complete Binary Tree
- → Min heap (Parent < child)
- → Max heap (Parent > child)

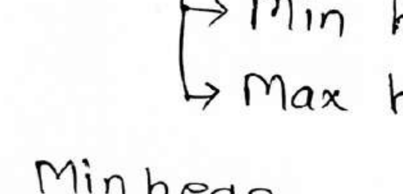
Min heap



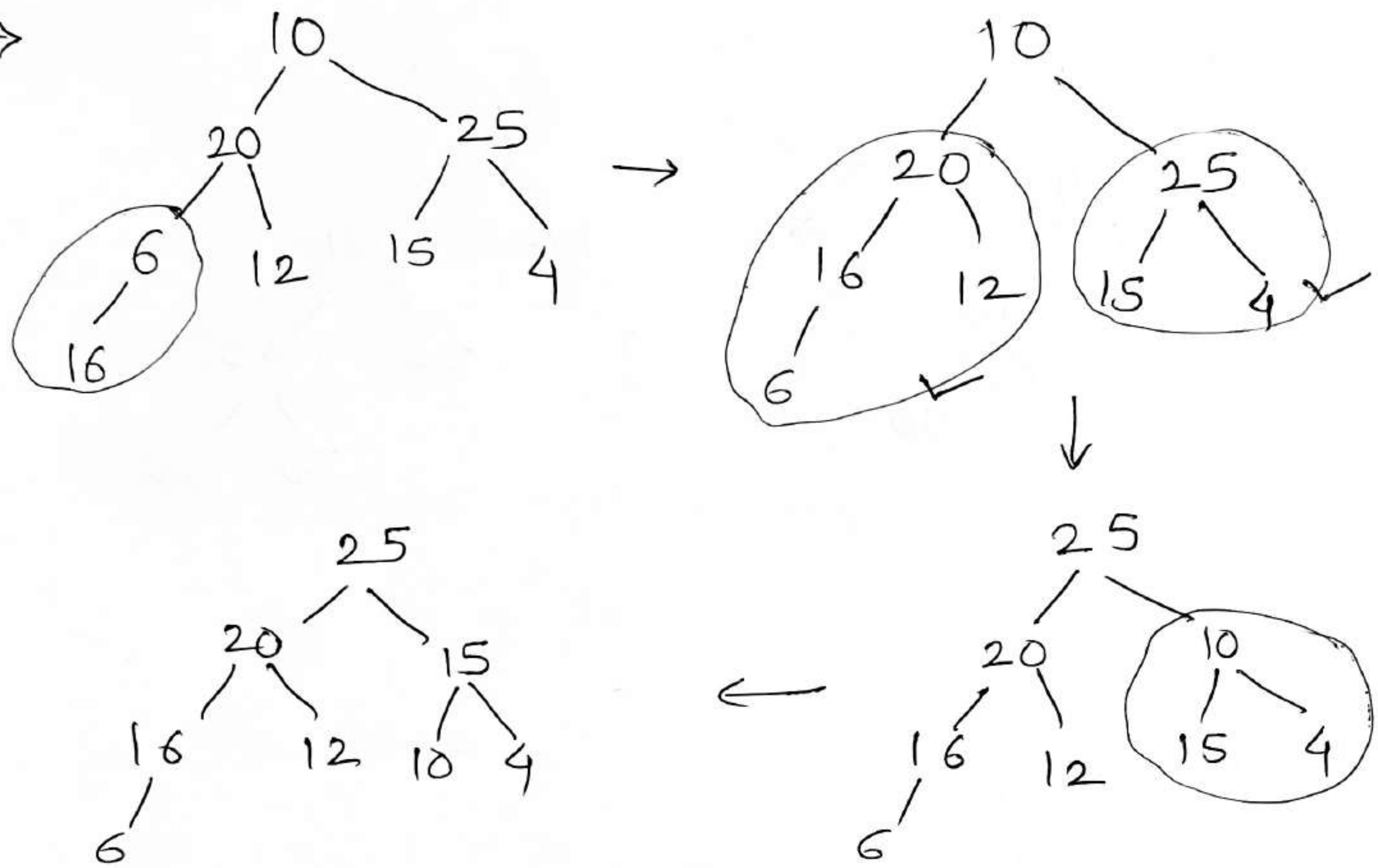
Heapify

Max heap

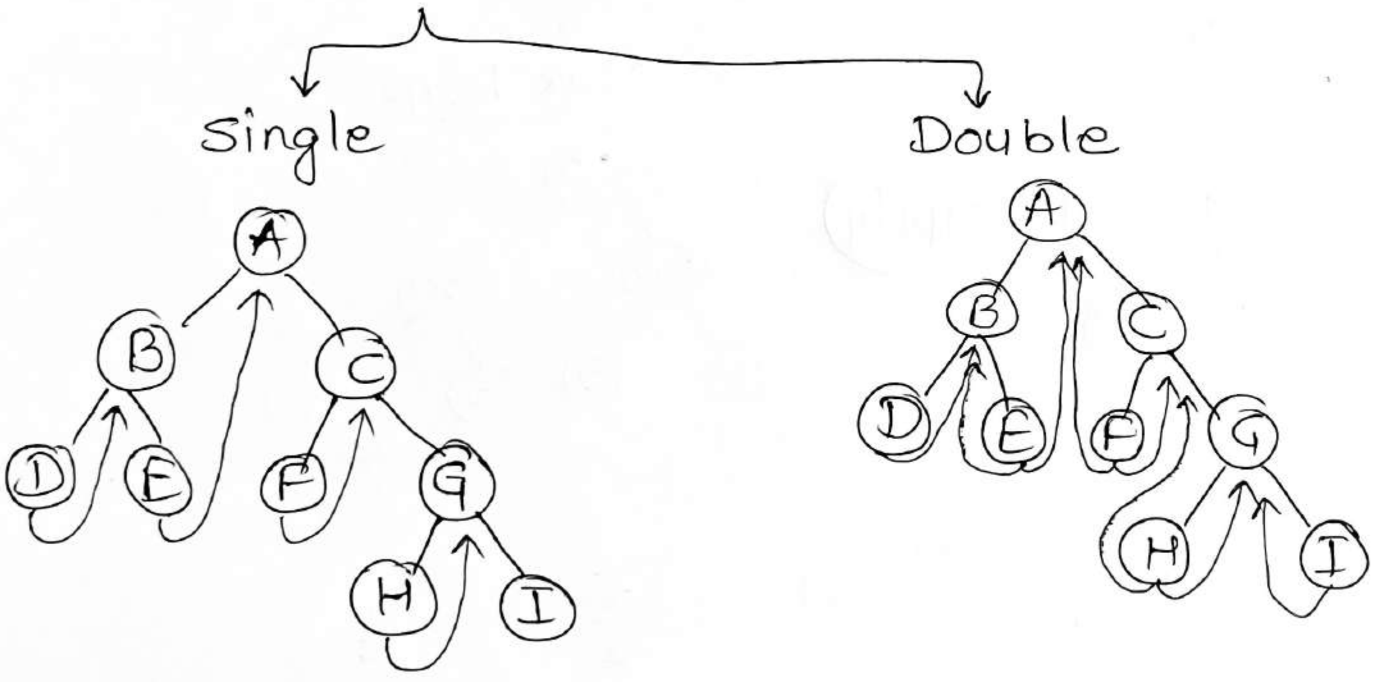
⇒



→

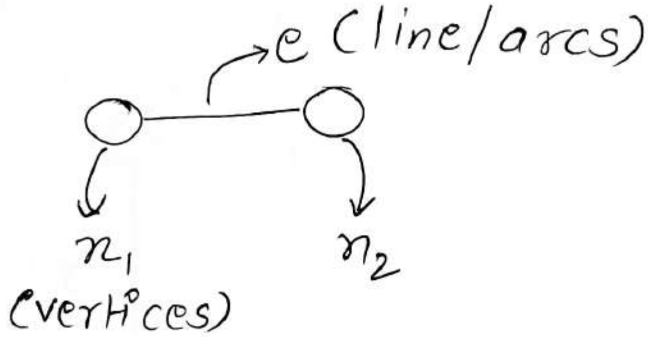


→ Threaded BT



Graph

→ NLDS
- → Nodes
- → Edge



① Directed Graph

$1 \to 2$ (1,2)

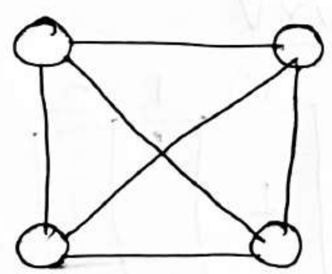
② Undirected Graph

(1,2) (2,1)

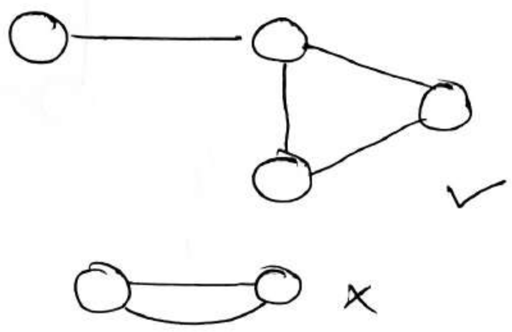
③ weighted Graph

④ Unweighted Graph

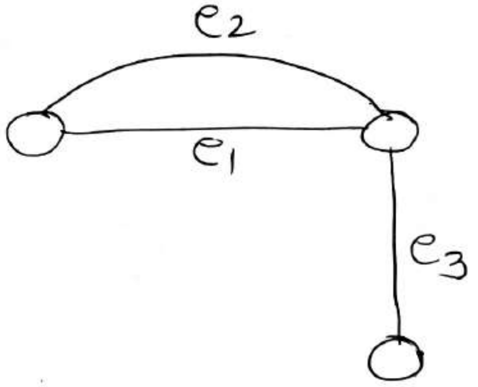
⑤ Complete Graph



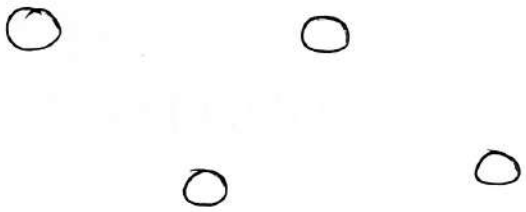
⑥ simple Graph



⑥ Multi Graph



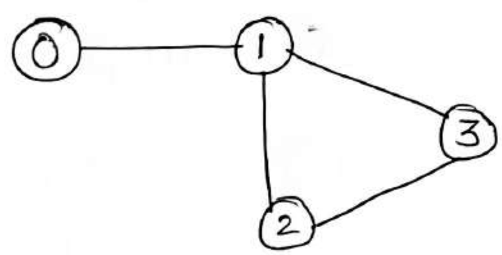
⑦ NULL Graph



⇒ Representation of graph:

- → Adjacency Matrix
- → Adjacency List

Eg:



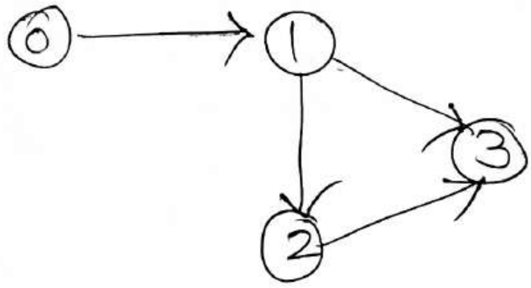
$V = 4$
$E = 4$

$1 \rightarrow$ ✓
$0 \rightarrow$ ×

V×V

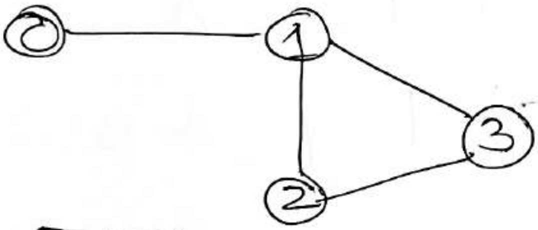
	0	1	2	3
0		1		
1	1		1	1
2		1		1
3		1	1	

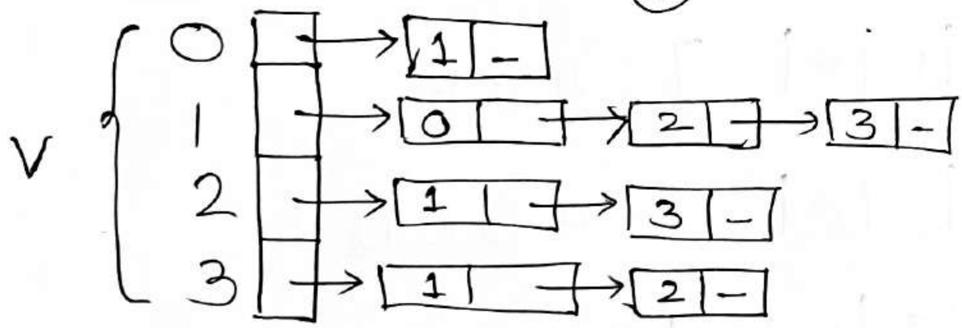
Eg



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

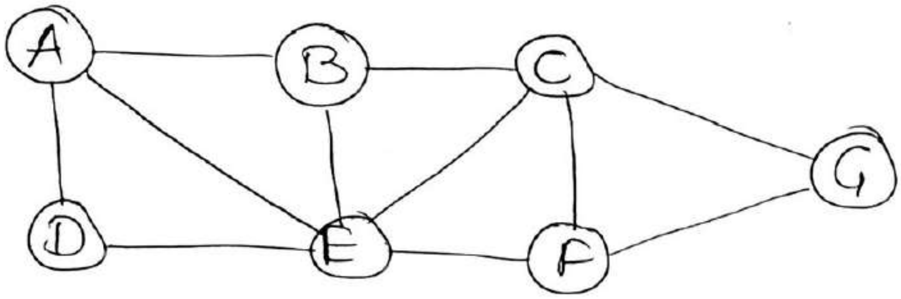
→ Adjacency List





→ Graph Traversal
- → BFS
- → DFS

BFS →



Start with (A)

⇒

A							

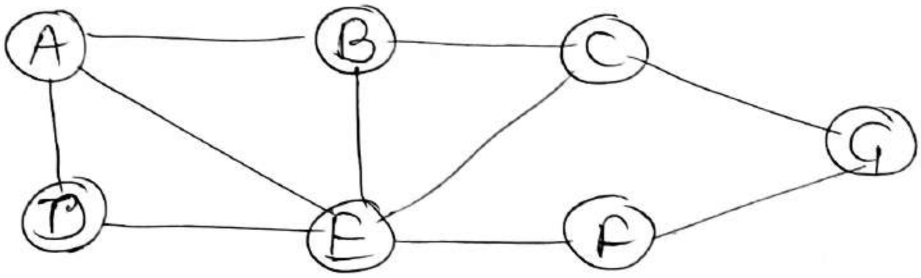
⇒

	B	E	D				: A
		E	D	C			: A B
			D	C	F		: A B E
				C	F		: A B E D
					F	G	: A B E D C
						G	: A B E D C F

↓

A B E D C F G

DFS



A → B, D, E

B → A, C, E

C → B, E, F, G

D → A, E

E → A, B, C, D, F

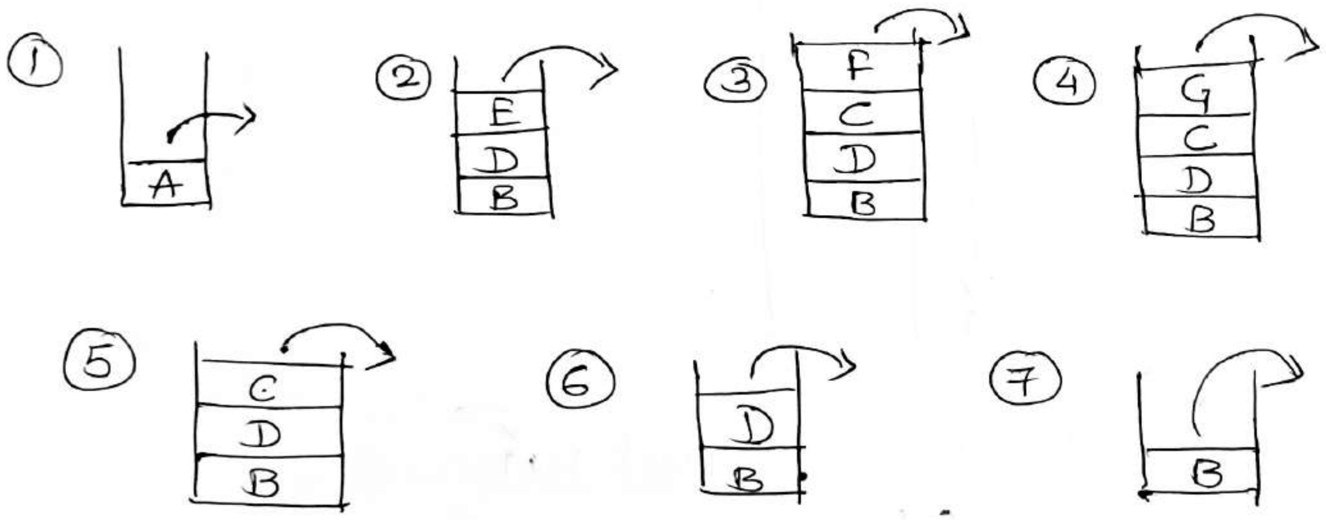
F → C, E, G

G → C, F

V

"A B C D E F G"

Ans: A E F G C D B



Hashing

(Time ↓ Space ↑)

→ Key

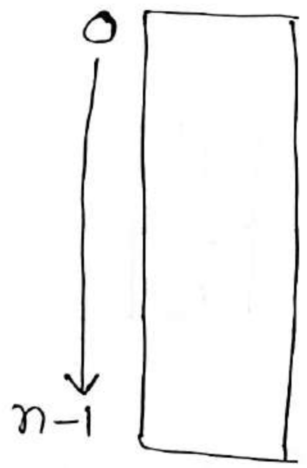
→ Location

→ Hash f^n

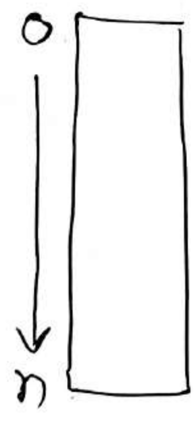
- → Easy
- → Fast
- → low

→ Hash table.

eg: $f^n(H(k)) = k \bmod n$



$f^n(H(k)) = \underline{k \bmod n+1}$



keys → (10, 11, 12, 13, 14, 15, 16, 17, 18, 19)

f^n : K mod n

n = 10

HT	I
10	0
11	1
12	2
13	3
14	4
15	5
16	6
17	7
18	8
19	9

- Mid Square

⇒ 12 ⟶ square → 144

↓

I=4 (store 12)

⇒ 11 ⟶ square → 121

↓

I=2 (store 11)

- k = 123456 (folding method)

123 + 456

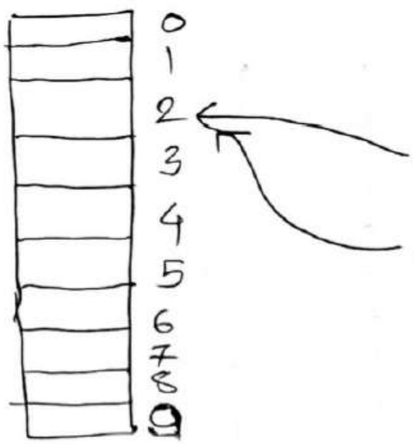
↓

$$\begin{array}{r} 123 \\ +456 \\ \hline 579 \end{array} \text{ mod } n$$

∴ n = 10, so 579 mod 10

⇒ 9 (store 123456)

Collision



(12, 42)

12 mod 10 = 2

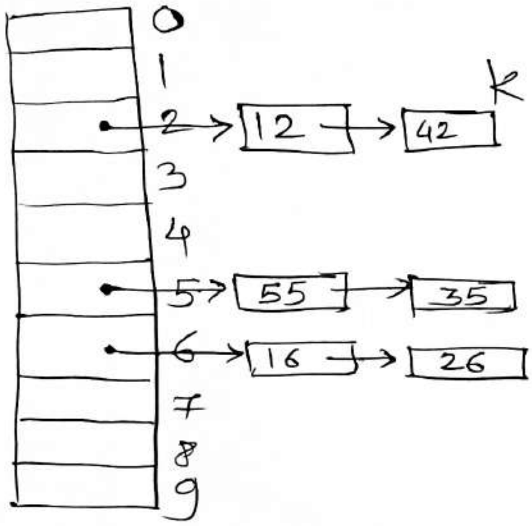
42 mod 10 = 2

CRT

- (Open H) chaining
- (Closed H)
  - Linear Probing
  - Quadratic Probing
  - Double H ~~Probing~~.

Chaining

$k \rightarrow (12, 42, 55, 35, 16, 26)$



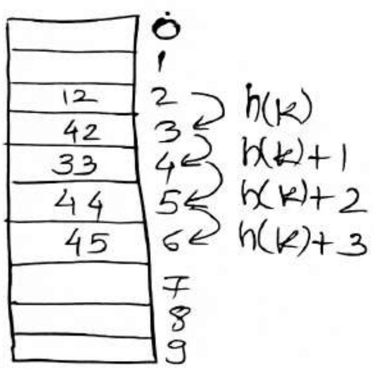
k mod 10

Linear Probing

k mod 10

$k \rightarrow (12, 42, 33, 44, 45)$

$h(k) \rightarrow \quad 2 \quad 2 \quad 3 \quad 4 \quad 5$



$k = 42$

$h(k) = 2$ (collision)

$i = 1$

$h(k) + i = 2 + 1 = \underline{3}$

Problems

↳ Primary clustering

Search ↑
Time

Quadratic Probing

$h(k) = k \bmod 10$

46	0
31	1
22	2
43	3
	4
	5
26	6
37	7
28	8
	9

$k \rightarrow 22, 26, 31, 43, 28, 37, 46, 52$

$\Rightarrow (h(k) + i^2) \bmod 10$

$46 \bmod 10 = 6$ [Collision]

$i = 1$

$(6 + (1)^2) \bmod 10 = 7$

$i = 2$

$(6 + (2)^2) \bmod 10 = 0$

for 52

$52 \bmod 10 = 2$ [Collision]

$i = 1$

$(2 + (1)^2) \bmod 10 = 3$

$i = 2$

$(2 + (2)^2) \bmod 10 = 6$

$i = 3$

$(2 + (3)^2) \bmod 10 = 1$

$i = 4$

$(2 + (4)^2) \bmod 10 = 8$

$i = 5 \; (2 + (5)^2) \bmod 10 = 7$

$i = 6 \; (2 + (6)^2) \bmod 10 = 8$

$i = 7 \; (2 + (7)^2) \bmod 10 = 1$

$i = 8 \; (2 + (8)^2) \bmod 10 = 6$

$i = 9 \; (2 + (9)^2) \bmod 10 = 3$

k_1	k_2	k_3
2	2	2
3	3	3
6	6	6
1	1	1
8	8	8
7	7	7

(Secondary Clustering)

Double Hashing

$$(h1(k) + i\,h2(k)) \% n$$

$h1(k) = k \bmod 13$

$h2(k) = 1 + (k \bmod 11)$

	0
79	1
	2
	3
69	4
	5
	6
98	7
72	8
	9
	10
	11
	12

$k \rightarrow 79, 69, 98, 72$

$h1(79) = 79 \% 13 = 1$

$h1(69) = 69 \% 13 = 4$

$h1(98) = 98 \% 13 = 7$

$h1(72) = 72 \% 13 = 7$ [Collision]

$\Rightarrow i = 1$

$[7 + 1 * \underbrace{(1 + 72 \% 11)]\% 13}_{\rightarrow 1}$ [collision

$\Rightarrow i = 2$

$[7 + 2 * \underbrace{(1 + 72 \% 11)] \% 13}_{\rightarrow 8}$ ✓