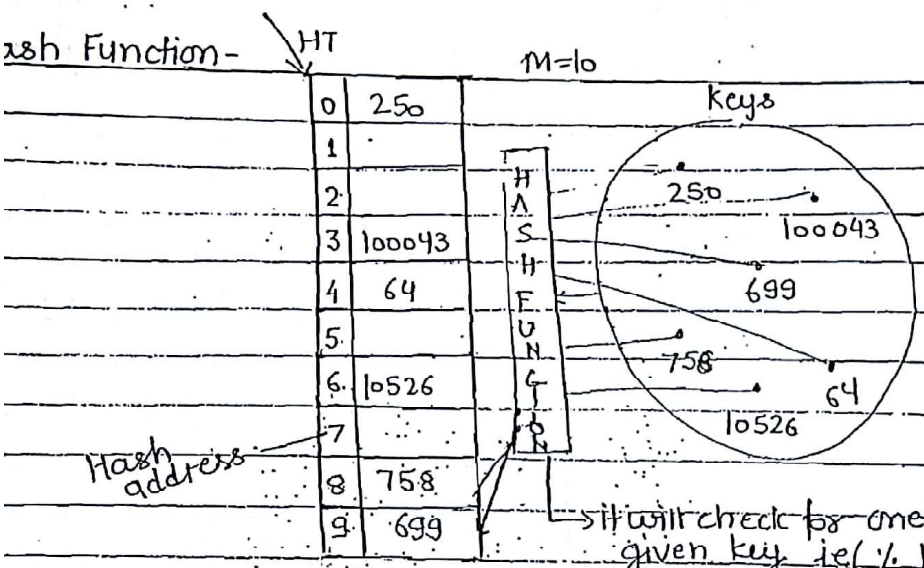
(If -ive keys were there)?

sh Function- HT M=10



it will check for one's place of the given key ie (% 10) we get the (0-9) key just store it as 699 → 699 % 10 ⇓ 9

to retrieve 758 again % 10 = 8 (758) is stored at 8.

∴ Again time complexity = O(1)

Hash function take more time compared to Hash table due to function calculation.

Hash function is better as it also save the space.

∴ if $n \leq 10$ → slot = 0 to 9

$n < 20$ slot = 0 to 19

Collision - If two keys mapped to same hash address by hash function then it is called collision.

ie Ex- 699 759

both get collided at 9 posn

122545

% if (is decided by us)

Hash function is better if no. of collision is as min. as pos.

Types of Hash function-

1. Division Modulo Method-
2. Digit Extraction Method
3. Mid Square Method
4. Folding Method -
   (i) Fold Boundary Method.
   (ii) Fold Shifting Method.

1. Division Modulo Method-

ex1- size of table m = 1000 (0 to 999)
key = 1 2 3 4 5 6 7 8 9
∴ Acc. to Division Modulo Method
Hash function (key) = key Modulo m
= 123456789 % 1000
= 789

0	
:	
789	123456789

ex2 - size of table m = 8 (2^3) (take LSB 3 bit here)
key = 10100101011100101
∴ Hf(key) = 10100101011100101 mod 2^3
= 101

∴ if $m = 2^k$
then Hf(key) ⇓ (k bits) of LSB

this Method donot bother about the whole data to how to store just take last k^{th} bits-

Ex 1010101111111111111 mod 2^4 = 1111

Ex 3 $m = 2^k$

key = 1010100101011111011110 mod 2^k = LSB k bits

if k = 8

∴ Hf(key) = 11011110

Hash function of

- if M is in power of 2, key will be LSB only that lead to more collision.
- So donot choose M as a power of 2.

Ex 1010100101011111011110 k=7

10101011111111111011110 LSB

Hf(key1) = 1011110

Hf(key2) = 1011110

1. So, do not pick M as exact power of 2 because if $M = 2^k$ then Hash function of key = LSB K bits always.
but if M is not power of 2 then less chances of collision

2. Pick the M value which is a prime no but it cannot be close t power of 2

Ques- Which M value can be choosen for better result

(a) 61 (c) 729

(b) 523 (d) 1024

729 is choosen as it is not power of 2 & not close of to power o

Steps - 1) Assume all are prime no
2) choose one which is not close to power of 2.

[encoding - decoding
store - retrieve

2. Digit Extraction Method- M = 1000

key = 789123456

hash function(key) = extract some digits

	7	8	9	1	2	3	4	5	6
	1	2	3	4	5	6	7	8	9

= 715. extract digit - (1, 4, 8)

0	
1	
715	789123456

the digits to be extracted are define in question. (you cannot extract 4 digi as size of stack is from 0-999

: Here no consideration is done to storage time.

- When you are extracting 3 digit, may lead to one digit or two digit address (if one of them become zero)

• Collision may also occur here as if

	7	7	7	1	2	3	4	5	9
	1	2	3	4	5	6	7	8	9

but it is not producing that much less collision i.e no of collision is more here.

∴ Digit Extraction Method produces more collision as compa to Division Modulo Method (as for Division modulo, you req M = 2^5) but here only some bits have to be changed.

• We extract 3 digit address as 3 digit addresses >> 2 digit ad

3. Mid-Square Method- M = 1000

key = 84925

Step 1-

1. Square the given key
2. check Middle of obtained key (take 3 bit from mid as it will have majority of 3-bit addresses.

Making ~~conter~~ counter here will be bit difficult, so it'll lead to less counter & less collision because itself key a larger no produces a more larging no.

Hash function = $(84925)^2$

= 7212255625

225 255 (as no exact mid possible)

225	7184925

store at any one address

To Retrieve- (1) Square the key

(2) take the mid, go to mid & extract the key.

Counter is not easy because of large each & every no (digit) participate in the calculation of square

Folding Method- M = 1000 (0-999)

key = 123456789

(i) Fold Boundary Method

- fold the boundary (take k bit from the key from boundary)
  k ≥ no of digit which have more address
  for 3 bits - more address

(123)(456)(789)

123
789
912

If it lead to

(912)

912 → 1 of 913

(191)

191
2
193

- folding boundary again & again

Key stored | 912 | 123456789

(123)(45)

123
45
168

Counter example = (123)(789)(789)

(912)

↓ again collision

counter is bit tougher than bit extraction as 6 digit participate

(ii) Fold Shifting Method

- Fold it according to fold boundary but fold every bit

(123)(456)(789)

123
456
789
(1368)
136
8
144

144 - 123456789

∴ fold shift is better than fold boundary as it require boundary 9 bit ie all the bits.

- Counter is also possible.

⇓ Ex 789 456 123

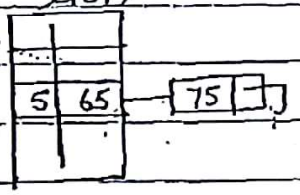
↓ since add^n satisfies commutative prop

ollision Resolution Technique-

1: chaining
2: open addressing

chaining

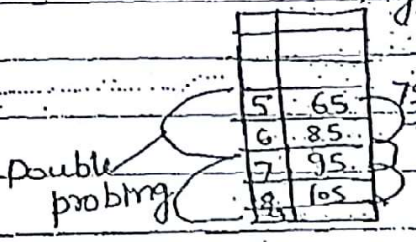
- outside (add linked list)



(If more than m keys are to be kept then chaining is used)

Open Addressing

- when only m keys are to kept
- inside (go to other slots which are empty
- Linear probing if 75 check for 5 fill 6→ fill and continous checking is done when no empty space



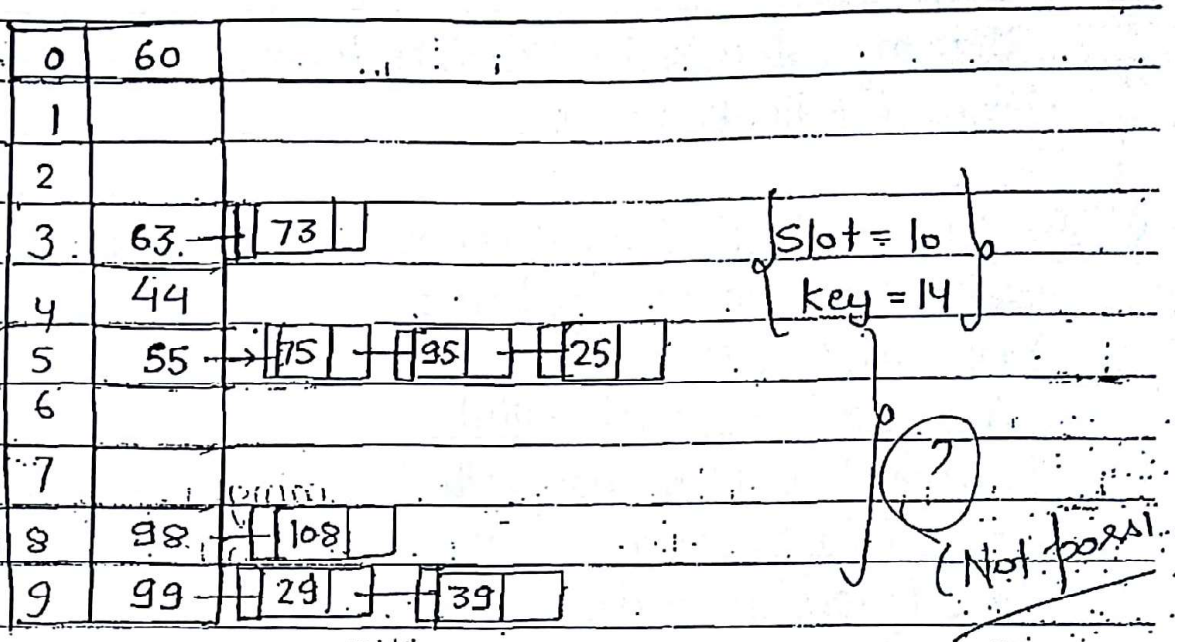
- Quadratic probing whe random jumps are mad known as quadratic probing
- Double hashing when two values are directly jump

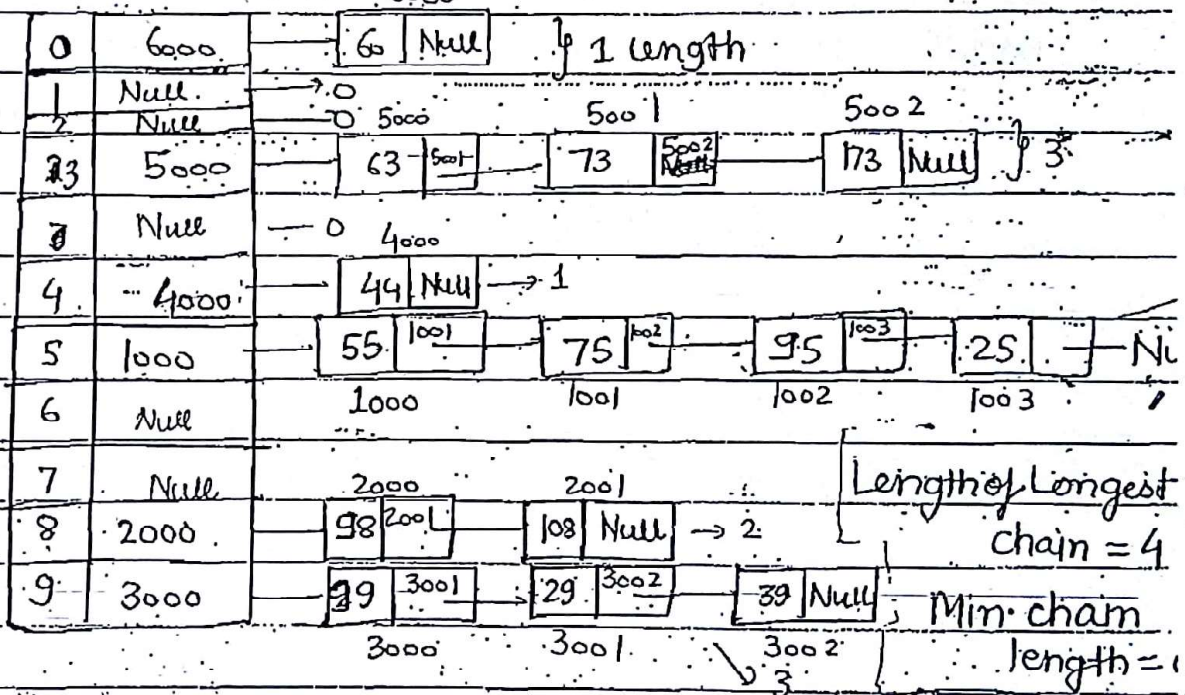
Chaining Process - m=10 (0-9)

key={55, 98, 63, 75, 99, 73, 60, 95, 44, 29, 3
73, 25, 108}

hf(key) = key mod m

Collision Resolution Technique = chaining





Here searching time increases.

∴ in Worst case, TC = O(n) as ~~same~~ if all element occur in 1 slot.

but if you be using better hashing function then it can be reduced as O(1).

~~It is also~~

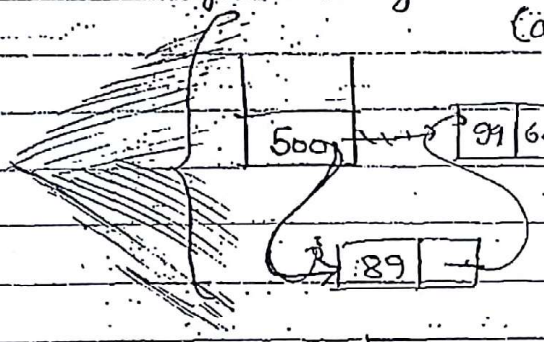
drawbacks

1. In chaining, space is wasted in the form of linked list even the space available inside.

2. The length of the longest chain possible is n. that lead to
Worst case searching time = O(n).
Best Case = O(1)
Avg. Case = O(n/2) ≈ O(n)

3. the greatest advantage with the chaining is infinite no. of collision can be handled by it. i.e infinite no of keys can be stored because of linked list.

4. Insertion of one key will take O(1) time (BC, WC, AC)
(as insertion is done in linked list only)



n elements
insertion will take O(1) time.

5. Deletion time will ~~take~~ be - Best case = O(1)
Worst case = O(n) (as it may be at last so you have to visit each node)

If address of node which has to be deleted is given then
time = O(1) (BC)
O(n) - (WC)
[since you cannot go back. so you have traversed by start]

· Solve More (k)

is to be deleted & its address is provided with do
t then time to delete = O(1)
= O(1)

~~done~~ in existence as in 10 slot you can store 100
ell.

ddressing- &

probing- M = 10 (0-9)

Hashing) Keys = (55, 99, 60, 75, 89, 42, 58, 69, 25)
hash function (key) = k mod m
C.R.T = Linear probing
bing (key, i) = (hf(key) + i) Mod m → attempt no
∀ i = {0, 1, 2, ... m-1}

0	60
1	89
2	42
3	69
4	
5	55
6	75
7	25
8	58
9	99

LP(55, 0) = (hf(55) + 0) mod 10 here sig
= 5 mod 10 1st atten
= 5 → (0) ex
LP(99, 0) = 9 — (0) N a
LP(60, 0) = 0 — (0) in
LP(75, 0) = 5 (fail collision C
LP(75, 1) = 6 (pass) ⇒ (2)
LP(89, 0) = 9 (fail)
LP(89, 1) = 0 (fail) ⇒ 2
LP(89, 2) = (pass)

5, 0) = 5 (fail)
5, 1) = 6 (fail) (2)
5, 2) = 7 (pass)

LP(42, 0) = 2 — (0)
LP(58, 0) = 8 — (0)
LP(69, 0) = 9 (fail)
LP(69, 1) = 0 (fail) LP(69, 4) = 3 (p
LP(69, 2) = 1 (fail) (3) (4)
LP(69, 3) = 2 (fail) (fail)

Total collision = 9

You can store only M elements in M-slots.

To Retreive - same for 75 → goto 5 if there Yes
else (+1)

~~Quadratic~~
Double Hashing - two hash functions - pri

Quadratic hashing (probing)

Quadratic Probing: M = 10
Key (25, 39, 46, 55, 89, 23, 68, 70, 94, 56)
Hf (key) = key mod m) $c_1 = c_2 = 1$ 78)
— CRT = QP

$QP(key, i) = (Hf(key) + c_1 i + c_2 i^2)$ Mod m
(quadratic pattern)

$\forall i = \{0, \dots M-1\}$

0	70
1	89
2	~~23~~ ~~78~~
3	23
4	94
5	25
6	46
7	55
8	68
9	39

QP(25,0) = 5 (0) collision.
QP(39,0) = 9 (0) Total collision = 2
QP(46,0) = 6 (0)
QP(55,0) = 5 fail
QP(55,1) = 7 (pass) (1)
QP(89,0) = 9 fail (1)
QP(89,1) = 1 Pass
QP(23,0) = 3 (0)
QP(68,0) = 8 (0)
QP(70,0) = 0 (0)
QP(94,0) = 4 (0)

If we choose li
probe = 4 colli
i.e collision de

QP(56,0) = 6 (
Q(56, 1) = 6 + 2 = 8
Q(56, 2) = 6 + 6 = 1
~~Q(56, 3) =~~

$\varphi P(78,0) = 8$ (fail) $\varphi P(78,3) =$ fail 0

$\varphi P(78,1) = 0$ (fail) $\varphi P(78,4) = 8$ fail

$\varphi P(78,2) = 14$ (fail) $\varphi P(78,5) = 8$ fail

$\varphi(78,6) = 0$ (fail) $\varphi(78,7) = 4$ (fail) } 10 collis

$\varphi(78,8) =$ ~~2 pass~~ fail ~~8+~~ $\varphi(78,9) =$ fail

∴ Total collision = 12

In Worst case, M-1 to 0 is covered ∴ O(m) you have to check.

∴ Worst case = O(m)

• Quadratic probing is faster than linear probing but it will generate inaccurate result (as gap may be there but you are not able to keep the element).

If Linear Probing is used, if anempty slot is present, elemen will surely get stored.

In Linear Probing, Worst case searching time = O(m)

Best case = O(1)

Average case = O(m)

Double Hashing:- M = 10

keys = (25, 39, 46, 55, 89, 23, 68, 70, 94, 78)

$hf_1(key) = key \bmod m$

$hf_2(key) = 1 + (key \bmod (m-2))$

CRT = Double hashing.

$DH(key, i) = (hf_1(key) + i\,hf_2(key))$

$\forall\ i = (0 \text{ to } M-1)$

0	70
1	89
2	78
3	55
4	94
5	25
6	46
7	23
8	68
9	39

DH(25,0) = 5

DH(39,0) = 9 + 0(6)) = 9

DH(46,0) = 6 + 0() = 6

DH(55,0) = 5 + 0 = 5 fail

(1) DH(55,1) = 5 + 1.hf2 55 = 5 + (1 + 55 mod 8

= 5 + 8 = 13 mod 10 = 3

D(89,0) = 9 (fail)

(1) D(89,1) = 9 + (1 + 89 mod 8 = 11 mod 10

= 1

D(23,0) = 3 (fail)

D(23,1) = 3 + (1 + 23 mod 8

(3) = 11 mod 10 = 1 (fail)

D(23,2) = 3 + 2(8) = 19 = (9)

D(23,3) = 7

Total collision = 7

D(68,0) = 8 (pass (0)

D(70,0) = 0 (pass) (0)

D(94,0) = 4 (pass) (0)

D(78,0) = 8 (fail)

(2) D(78,1) = 8 + 1(1 + 6) = 15 mod 10 =

D(78,2) = 8 + 2(7) = 22 mod 10

= 2 (pass)

Problem 1 Apply all 3 open addressing strategies-

$m = 10$

key = 25, 15, 90, 75, 69, 59, 44, 58, 85

0	90
1	59
2	85
3	
4	44
5	25
6	15
7	75
8	58
9	69

(Linear probing)

Total collision = 1+2+2
= 5

(In linear probing, order of occurence in sequence matters.)

If 25 came first it occupy the first pos as 5.

- If you want to find any element find if gap occur then element is not present in table.

Quadratic probing

0	90
1	75
2	
3	85
4	44
5	25
6	
7	15
8	58
9	69

Tcollision = 1+2+1
+1
= 23

3+1

1. We are not wasting space outside in the form of linked
2. Searching time = O(1) for Best case
O(m) for worst case
3. Insertion time = O(1) for Best case
O(m) for worst case
4. Deletion time = O(1) for Best case
O(m) for Worst case
5. Whenever delete a particular element, place $ otherwise at a time of searching gap occurs & it may lead to mis-searching.

~~if your table~~

(5)- If you delete one element, it will create trouble to other elements but we can manage with help of $ symbol if more dollar symbol than reHash again.

Quadratic Probing:-

1. No space is wasted outside in form of linked list.
2. Search time ⇒ O(1) = BC
   O(m) = WC
3) insertion time ⇒ O(1) = BC
   O(m) = WC
3) deletion time ⇒ O(1) = BC
   O(m) = WC
4. deletion of one element will trouble to other element but can manage with $, if more deletion, than rehash again.

Double Hashing:-

0	90
1	69
2	~~16~~
3	15
4	~~44~~
5	25
6	
7	59
8	~~75~~ 58
9	75 ~~16~~ ~~69~~

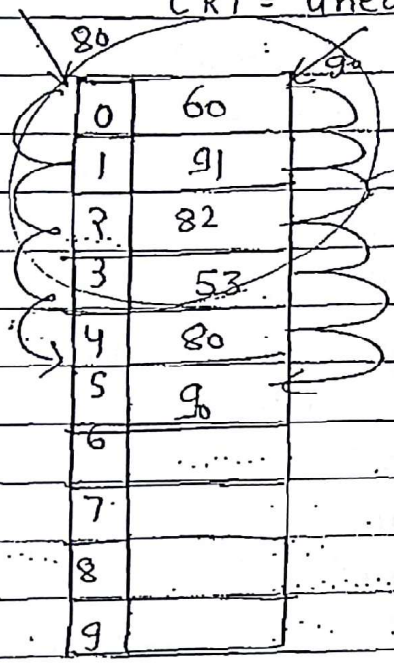
DH(25,0) = 5
DH(15,0) = 5 fail
DH(15,1) = 5+8 = 13 = 3
DH(90,0) = 90
DH(75,0) = 5 fail
DH(75,1) = 5+11

EX3 – m=10

keys = 53, 60, 80, 82, 91, 80, 90

hf(k) = k mod m

CRT = linear probing



primary clustering

LP(80, 0) = 0+0 = 0
0+1 = 1
0+2 = 2
0+3 = 3
0+4 = 4

LP(90, 0) = 0+0
0+1
0+2
0+3
0+4
0+5

Here both start with same addr follow same path unnecessarily.

Avg = $\frac{1+2+3+\cdots+m}{m} = \frac{m(m+1)/2}{m} = \frac{m+1}{2}$

1 person, 2 person, mth person

Primary Clustering: If two keys same initial hash address they both will follow same path unneccessarily in linear fashion because of this avg. time increases, this problem is known as primary Clustering.

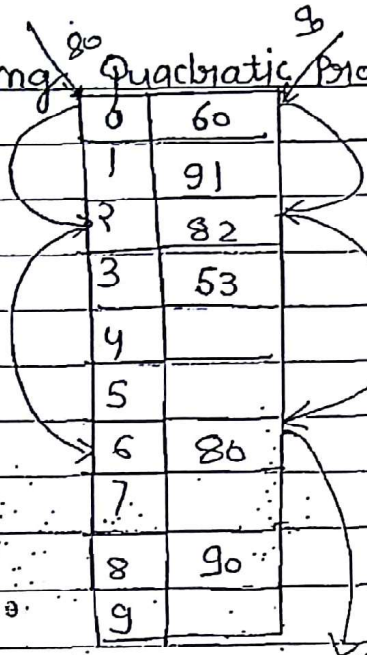
* Linear probing is suffering with primary clustering.

* Avg case = $1+2+3+\cdots+m$

$= \frac{m(m+1)}{2/m} = \frac{m+1}{2}$ as it suffers with the problem primary Clustering

as 2 will suffer with problem of 1.

y using Quadratic Probing



QP(80,0) = 0 (fail)
QP(80,1) = 0+1+1 (fail)
QP(80,2) = 0+2+2² = 6 (true)

QP(90,0) = 0 (fail)
QP(90,1) = 0+1+1 fail)
QP(90,2) = 0+2+2² = 6 (fail)
QP(90,3) = 0+3+3² = 12 = 2 (fail)
QP(90,31) = 0+20 = 0 (fail)
QP(90,5) = 0 (fail)
QP(90,6) = 2 (fail)
QP(90,7) = 8 (true)

and so on

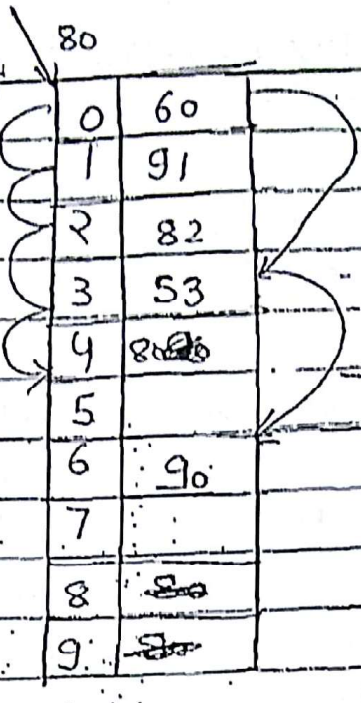
Here ~~primary~~ clustering occurs as what path is followed by 1 element will definitely followed by 2 element but here Avg. case deg decrease due to large jump Here clustering is known as secondary clustering.

Secondary Clustering:- If two key contain same starting hash address, they both will follow same path unneccessarily in quadratic manner, because of this reason avg. searching time increases (it is less than linear search probing time), this problem is known as secondary clustering

Quadratic probing is suffering with secondary clustering

Avg case = O(m) but actually it is less than $\left(\frac{m+1}{2}\right)$
(Asymptotically same but mathematically less)

Double Hashing



Here path is diff with initially address (same).

Here diff path is carried out with same initial address. no path will be same.

DH(100,0)=0

DH(100,0)=0+5=5 (True)

$$Avg = \frac{3+5+7+\cdots+2}{m} = \frac{DH}{m} = O(1)$$

(as a particular slot is covered by single element only)

(It might be possible that there must be some cases which lead to redundancy there in avg case, we have to consider for all the given case) so on an avg it is said that it is repeating one time).

In Double Hashing:- Eventhough two key contain same starting hash address, they both will follow diff path because second level hash fn will give diff value.

because of this reason 99% of redundancy is eliminated.

• Avg case = 3 + 5 + 7 + ... + 2
(slot covered by I element)
(slot covered by II element)

∴ on an avg

$= \frac{m}{m}$ ⇒ $\frac{cm}{m} = O(1)$

(as only few key will be repeating only)

Let 4 key repeated

total = $\frac{4m}{m}$

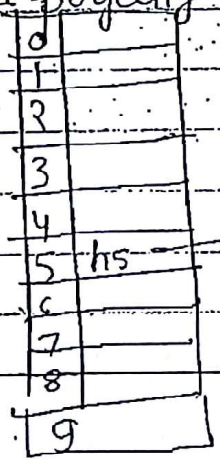
$= O(4)$

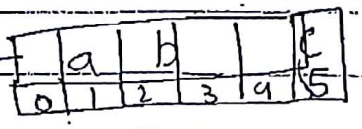
Avg. case = O(1)

∴ In double hashing, secondary clustering problem is present littlebit (1%)

Note - Using Perfect Hashing, you will get Worst case Searching time = O(1).

in hashing if collision occur to a, b, c at slot 5 they will go to 5 which have another his which is best hash fn and a hash table to store those three element then collision is removed perfectly.





∴ Total table = m+1

Total fn = M+1

∴ Worst case = O(1)

space = $O(m^2_{fm})$

m ✓

You cannot decide of size so use m size else use linked list so space increases but time decrease

m-slots n-keys

m slots – will store n keys

1-slot will store $\frac{n}{m}$ keys

⇓

Load factor – no of keys getting stored in 1 slot

Load factor (α) = $\frac{n}{m}$ keys per slot

Note 1 – the expected no of probes (attempt) in an unsuccessful search of an open addressing technique is

$$\left\lceil \frac{1}{1-\alpha} \right\rceil$$

Note 2 – the expected no of probes in successful search of an open addressing technique is $= \left\lceil \frac{1}{\alpha} \log_e \frac{1}{1-\alpha} \right\rceil$

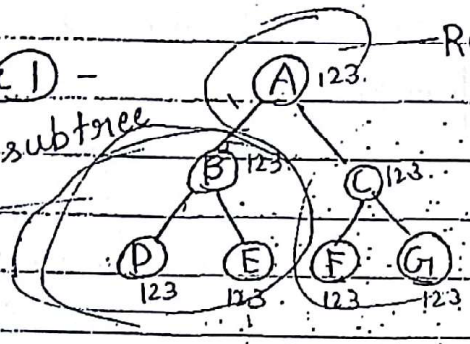
(CoreMan)

TREE AND GRAPH TRAVERSALS (2 Marks)

Tree Traversals -

1. Preorder (Root LST RST)
2. Postorder (LSTRST Root)
3. Inorder (LST Root RST)

Ex 1 -



tree is best solved by recursion as of having almost sam quality;

traversal - visiting each node once in given tree.

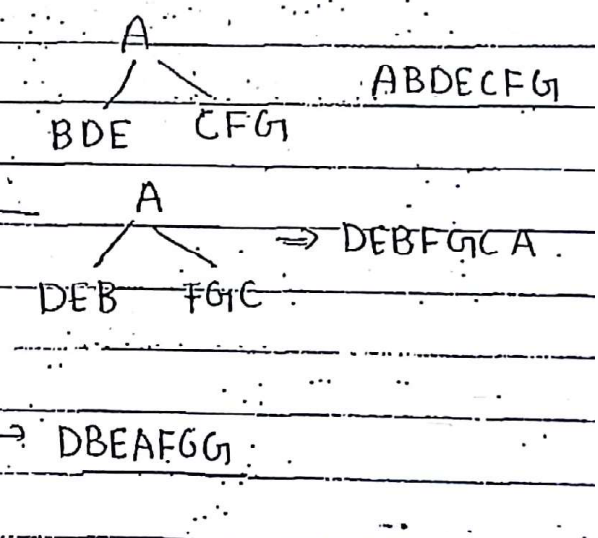
Left & Right tree cannot changed i.e left will always come before Right subtree

if changed → 3!

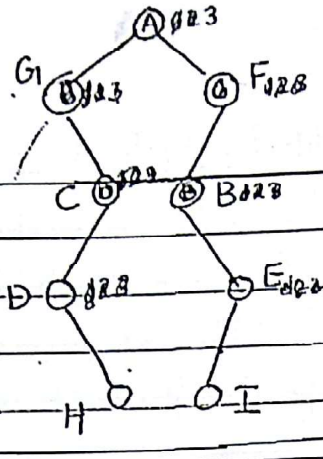
Preorder - ABDECFG

Postorder - DEBFGCA

Inorder - DBEAFCG



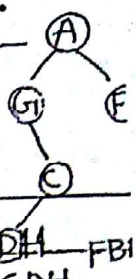
Ex2 -



Preorder - A G C D H F B E I

Inorder - G D H C A B I E F

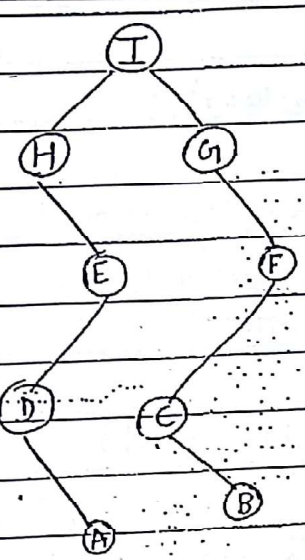
Postorder ~~H D C G I E B F A~~



G C D H

G D H C A B I E F

ex3 -



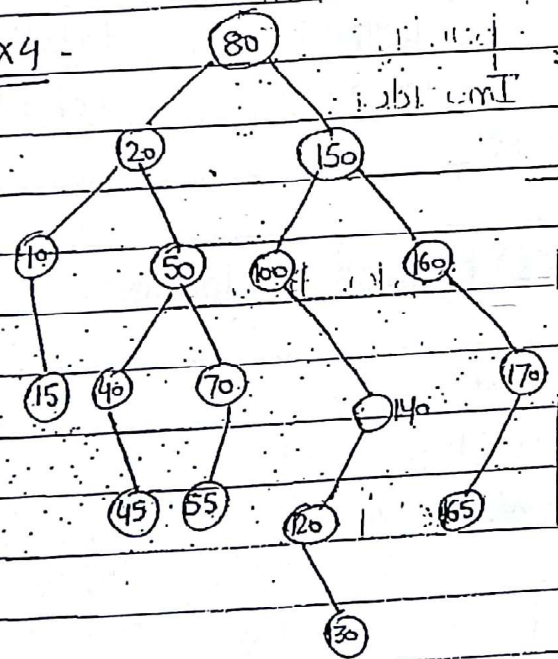
Preorder - I H E D A G F C B

Inorder - H D A E I G C B F

Postorder - A D E H B C F G I

To sort an array
- Create BST
- do inorder traversal

Ex4 -



Inorder - 10 15 20 40 45 50 55 70 80 100 120 130 140 150 160 165 170

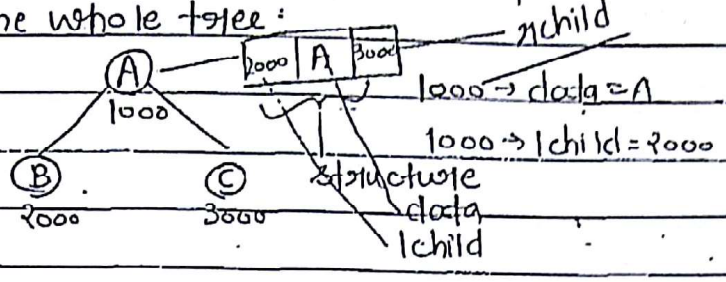
Preorder - 80 20 10 15 50 40 45 70 55 150 100 140 120 130 160 170 165

Postorder - 15 10 45 40 55 70 50 20 130 120 100 165 170 160 150 80

Note -

BST after inorder traversal will generate Ascending order

- Whenever a tree is given, a root (Address) is provided which can be used to traverse the whole tree:




```
Preorder(root)
{
    printf("root->data);      → O(1)
    preorder(root->lchild);   → T(n/2)
    preorder(root->rchild);   → T(n/2)
}
```

root = 1000
preorder(1000)
A
preorder(1000->lchild)
preorder(2000)
and so on.

```
postorder(root)
{
    postorder(root->lchild);
    postorder(root->rchild);
    printf("root->data);
}
```

```
Inorder(root)
{
    Inorder(root->lchild);
    printf(root->data);
    Inorder(root->rchild);
}
```

For preorder of a binary tree

$T(n) = 2T(n/2) + O(1)$ (by master theorem)

$= O(n)$ (Best case)

Worst partition - $T(n) = T(n-1) + T(0) + O(1)$

$= O(n)$ (Worst case)

for preorder, postorder, Inorder

Avg case $= O(n)$

WC, BC, AC same as each node has to visit once

Reccurence relation can also tell about stack sp
if $T(n/2) \to \log n$
$T(n-1) = n$

Note –

* Preorder Inorder Postorder will take O(n) time on n-node binary tree (WC, AC, BC), because each node has to be visited once.

Stack Space.
~~Space complexity~~ = O(logn) for balanced tree (Best case)
O(n) for unbalanced tree (Worst case)

Ques – if a BST is given, time to get sorted order – O(n)

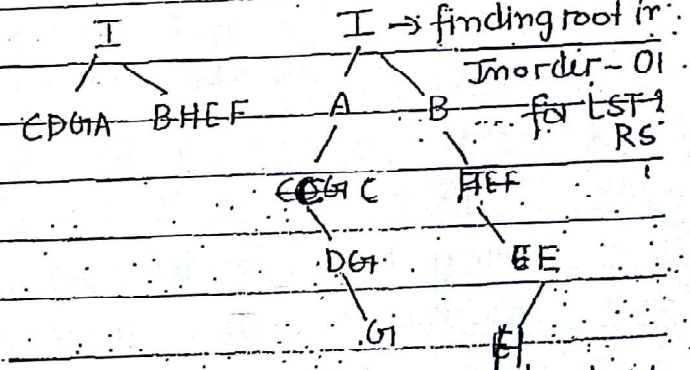
Ques – if a BST is given time to sum element 20 to 50
→ O(n) – Worst case
O(1) – Best case (start from 20 when 20 came & add
50)

Ques – Consider the following binary tree data–

Preorder: IACDGBFEH

Inorder: CDGAIBHEF

Postorder– GDCAHEFBI



Inorder traversal cannot judge for proot because it cannot trees are not balanced always

Preorder can give root as well as postorde can give it

Inorder is used to give Left subtree & right subtr

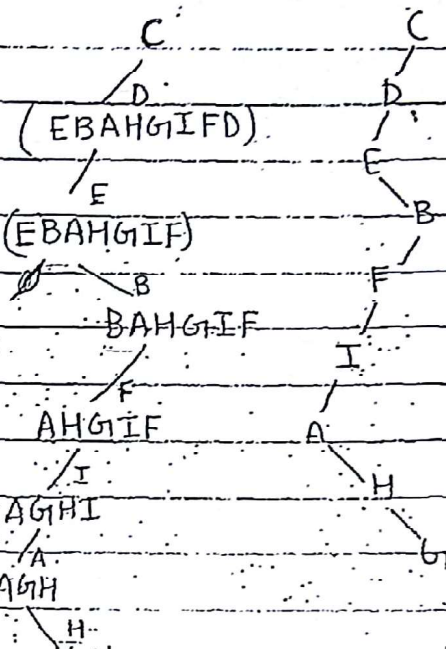
∴ Total complexity = n × O(n) [at 1 lvl (for LST & RST)]
= $O(n^2)$

Ques- Consider the following binary Tree data-

Postorder - GHAIFBEDC

Inorder EBAHGIFDC

preorder - CDEBFIAHG



(X = sometime possible)

To find out directly any order

- find out root
- find its pos^n in inorder case
- the digit or no of element in inorder

try to find them in postorder just reverse the order and vice versa.

a shortcut Not applicable everywhere

Ex- Here postorder & Inorder given, C its possition in inorder rightmost so C has empty right ST.

then go to postorder get the element in LST of C in Inorder take them & reverse them to obtain post order.

Note - To construct Binary tree for the given preorder inorder or postorder inorder will take $O(n^2)$ time (n times linear search to find LST & RST in given morder)

(n^2+n+c)

to find LST & RST

to find root n time

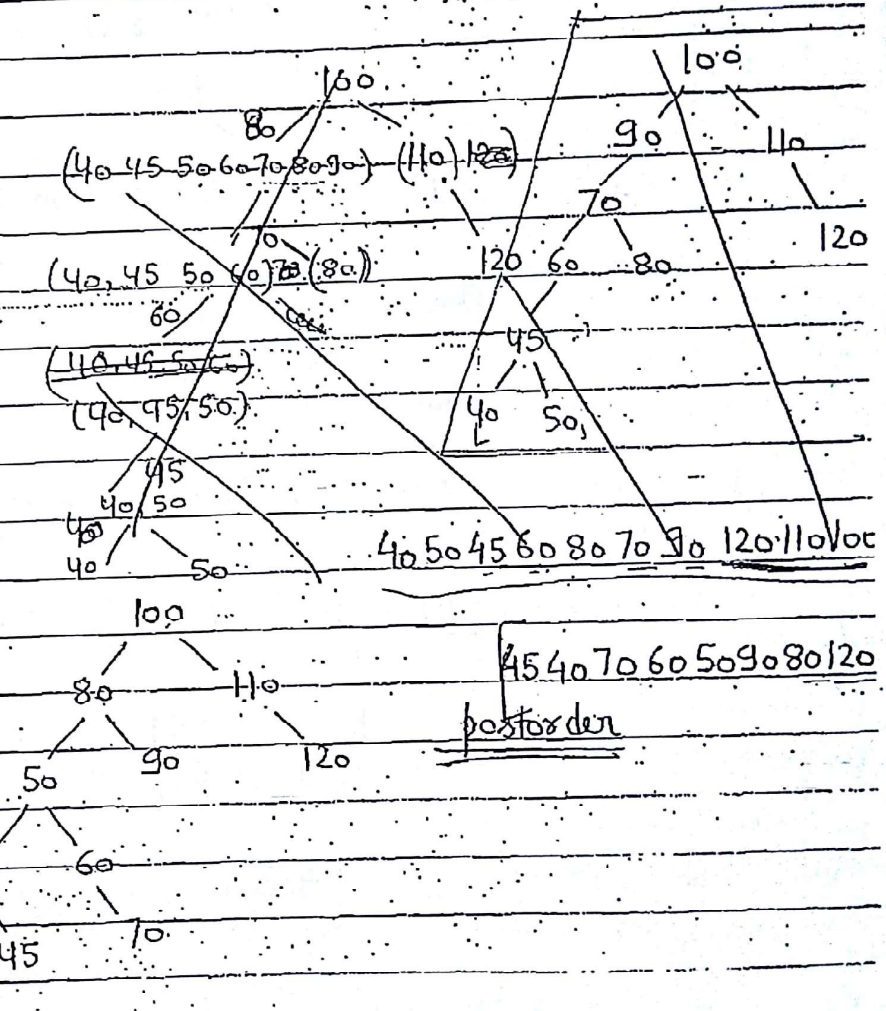
We cannot apply binary search as given sequence is not sorted but if BST it will take nlogn time

Ques - Consider the following BST data-

Pre: 100 80 50 40 45 60 70 90 110 120

Post: ~~90 70 60 45 40 50 80 120 110 100~~

In- 40 45 50 60 70 80 90 100 110 120 (A.O)



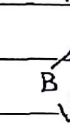
Note - for the given preorder inorder for postorder inorder to construct equivalent BT require (nlogn) time if inorder is already sorted

preorder: A B C
N L R

postorder: C B A
R L N

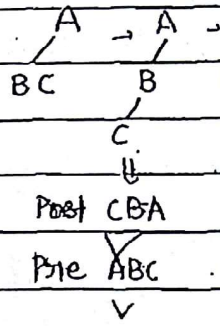
root = A

- Let both RST & LST present

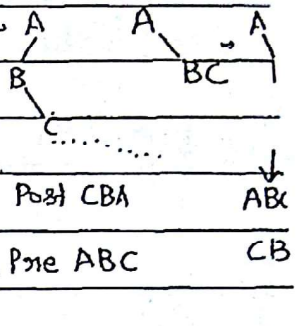


Not possible as postorder = BCA ✗

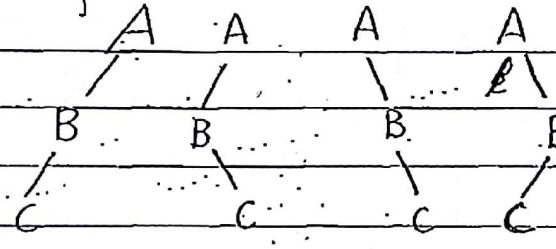
- if 1 absent(R)



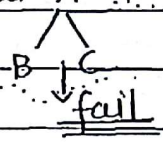
- if 1 present



So possible trees are



but



Note

If Preorder Inorder given - unique binary tree ~~bst~~ / Binary tree / Unique BT

postorder Inorder given - Unique Binary tree

if preorder postorder given - more than one binary tree
↳ Binary tree posh but not

To construct unique binary tree, Inorder is required (compulsor

When pre, post is given, manual checking is done To each no two possibilities either going to left or right so total possib for n node = $O(2^n)$

Upper bound as root will have only one possibility.

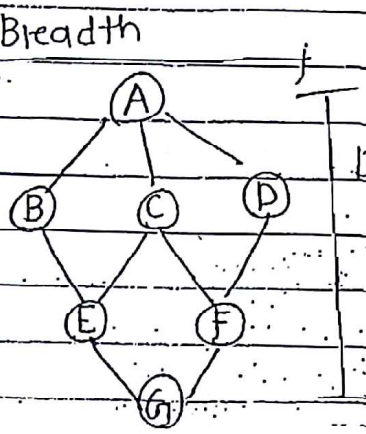
To find out cycle initially flag=0 then if visited flag=1 if again counter flag 1 then it is a cycle.

Graph Traversal

1. BFT (Breadth First Traversal)
2. DFT (Depth First Traversal)

Total Graph Traversal time = O(V+E)

⇓ visiting each vertex & each edge



We donot consider edge in tree & edge is less than vertices

Tree = (V+E)
V+V-1
= 2V-1 ≈ O(V)

Breadth first traversal - A B C D E F G

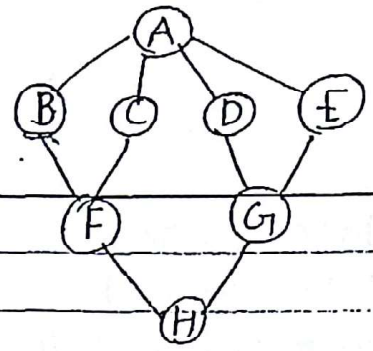
Depth " " - A B E G C F D

Breadth first Traversal:-

- Tree traversal are unique but graph traversal not.
- Visited is required as graph contains cycle and there is no mean of visiting a vertex again & again.
- Queue is used in BFT as we need FIFO structure

while loop is covering vertex & for loop is caring for edges.

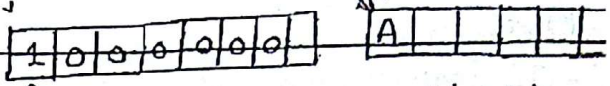
Ex



Initially Visited = 0 0 0 0 0 0 0 0
A B C D E F G H

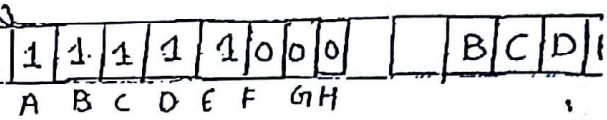
Starting with A

Queue empty



x = A (delete)

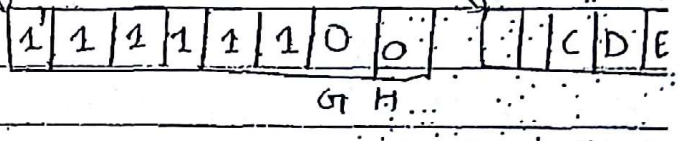
w = B C D E




```
BFT(V)
{
Visited[V] = 1
add(V, Q);
while (Q is not empty)
{
x = delete(Q)
print(Q)
for all w adjacent to x
{
if( visited[w] = 0)
visited[w] = 1
add(w, Q)
}
}
}
```

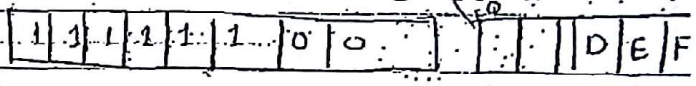
B deleted

w = A F

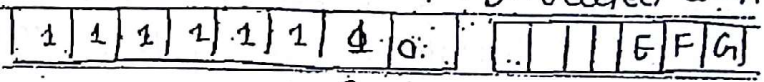


not added again

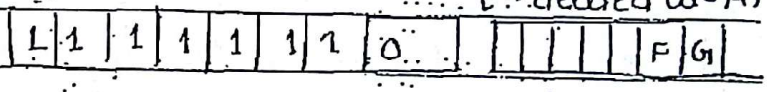
C → deleted w = A.



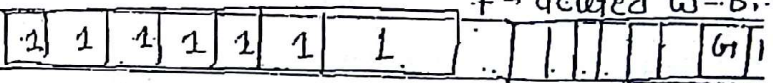
D → deleted w = A



E → deleted w = A,



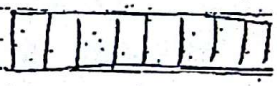
F → deleted w = B.



1

O/P → A B C D E F G H

(Order of deletion of element)



empty

loop end

Note -

- To implement BFT, we use queue data structure.
- Total complexity = O(V+E) (time) (BC, WC, AC)

If adj matrix is used TC = $O(V^2)$

Space → i/P + extra

If graph is adjacency list

(V+E) (V+V)

queue, visited array

$= (V+E+2V)$

$= 3V+E$

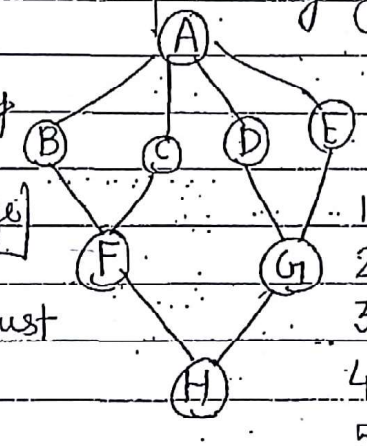
$= O(V+E)$

$= O(V^2)$ if adj. matrix is used

- BFT is also known as Level order traversal i.e level by level printing of nodes. (means adjacency list)

A → next level (adj of A)

Problem 2 - Consider the following graph-

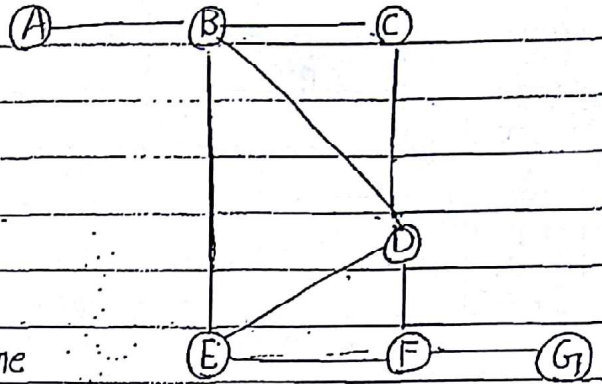


Adj of any vertex may come in any order in which you arrange all adj of a vertex must come altogether.

Find correct BFTs from th following.

1. ABCDEFGH (correct)
2. CAFBDEHG (correct)
3. ADCBEGFH (Correct)
4. EAGCDFBH (false)
5. ABCDEGHF (Not correct)

Ques - Consider the following graph.



Whether these are correct BFTs or not

(a) ABDECFG (correct)
(b) GFCEDBA (incorrect)
(c) CBDAEFG (correct)
(d) DBCEFAG (Correct)

Application of BFT :-

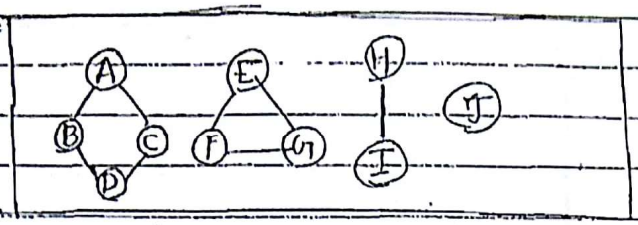
Ques - if a graph is given, how to check whether it is connect or not?

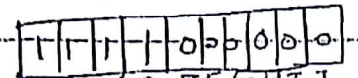
- ~~Draw~~ Apply BFT
- Check visited array
- if any 0 in visited array → to check for ar
- then graph disconnected. O(V+E)+V

if a linked list is given, to check whether it is connected

a linked list is also a graph but directed so apply the same procedure.

· We can verify given graph is connected or not



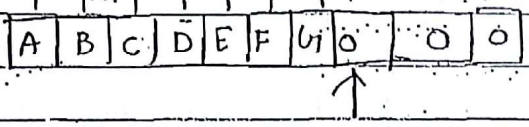


starting from A

∴ count = 1 (initially zero) → no of connected component

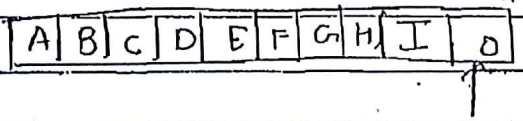
· When you get I zero, just stop & again apply the DFT again and so on, you can find connected connected components can be find out

again



Count = 2

again



Count = 3

Count = 4

∴ No of connected component = No of time BFT applied

∴ TC to find connected comp = O(V+E)

· Using BFT we can find out connected components in the given graph.

· if a null graph G(V, E) - no of connected component = (V)

3. to check for cycle in a given graph
- Apply BFT
→ If visited[i] = 1 & it encounter again then there is a cycle.

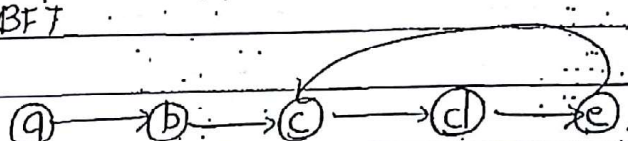
Time complexity = O(V+E) (as BFT work)

4. Whenever kruskal is going on edges are added to MST we have to check for occurence of cycle too as no cycle must occur, then by side BFT also working to check for visited[i] → it take constant time (for 1 edge)

$T(n) = E \log E + (V+E)$
↓ for BFT cycle check

3. Using BFT, we can check given graph contain cycle or not

If a linked list contain cycle, it can be checked easily by applying BFT

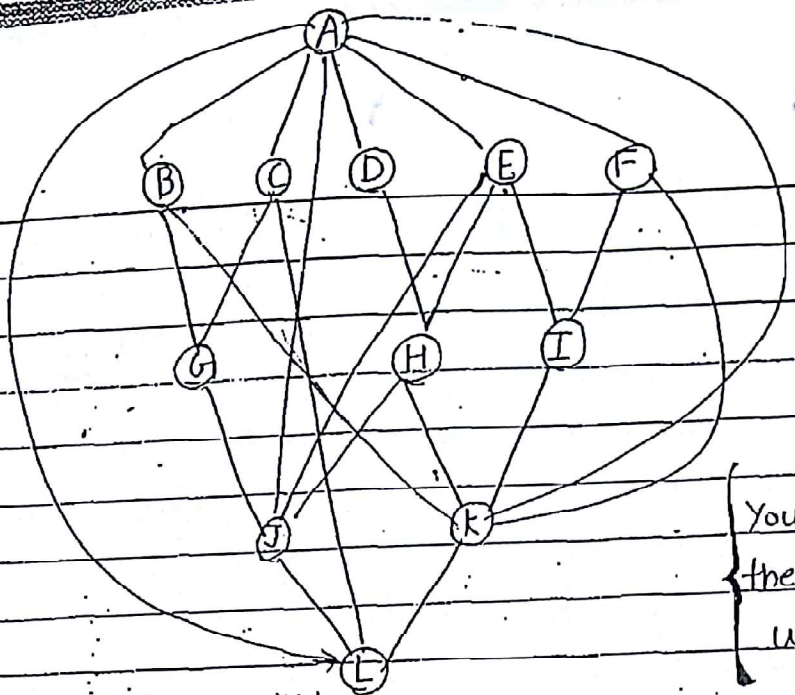


A B C D E (c)

again occur ∴ cycle exists.

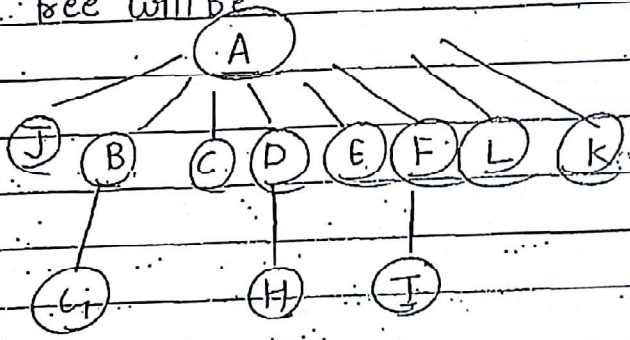
4. If an unweighted graph is given & single source shortest source path is not to be finded, then BFT is the efficient one algo as it will find the sh

∴ Using BFT, we can find out shortest path from given source to every vertex in given unweighted graph or the graph having equal edge weight (+ive)



You can easily find out the shortest path using O(V+E) time.

the BFT tree will be



unweighted graph - default weight = 1

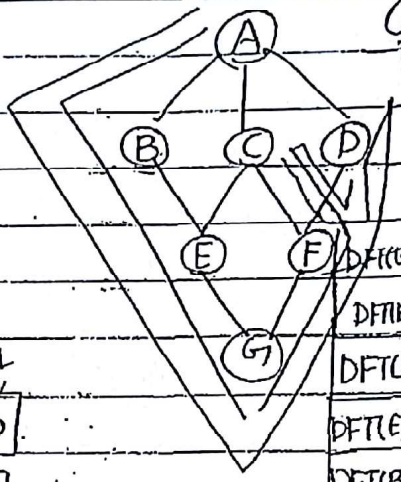
Ques- if a unweighted graph is given; the shortest path to be calculated from given source which data structure is used?

Queue

5. Using BFT we can verify a given graph is Bipartite graph?

Depth First Traversal

- It uses stack as recursion occur here.
- it will also maintain a visited array to check for cycle size V.



O/P → ABEGFCD

Start for A
Visited [A] = 1
pf(A)
DFT(G) DFT(D)
DFT(F) W = GD
DFT(C) W = FA
DFT(E) W = BCG
DFT(B) V[B] = 1 pf B W = AE
DFT(A) Visited [A] = 1 (visited)
pf A
W = BCD
↓
not visited
call DFT(B)

Visited
1 1 1 1 1 1 1
A B G D E F G

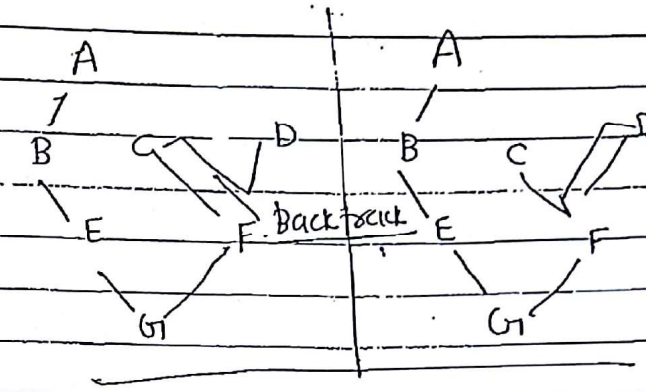
and soon stack size = O(n)

DFT(G) DFT(D)
DFT(F)
DFT(C)
DFT(E)
DFT(B)
DFT(A)

Order of adjacent vertex can change the column traversal.

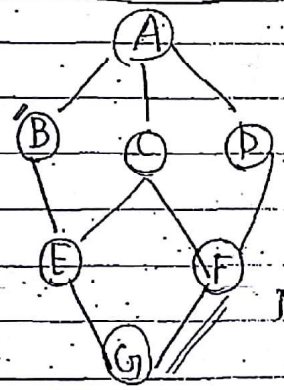
1. To implement DFD we are using stack.
2. Time Complexity = no of functional calls * work done at each func call
   = V + E (as if work is summed up)
   = O(V+E)
3. Space Complexity = i/p + extra
   = V+2E ↓ stack, Visit = O(V+E)
   V+2E V V
   ↓ for adjacency list

```
DFT(V)
{
1. Visited[V] = 1
2. pf(V);
3. for all w adj to V
   {
   1. if (w is not visited)
      2. DFT(w);
   }
}
```



In case of Adjacency Matrix = $O(V^2)$
(space as well as time complexity)

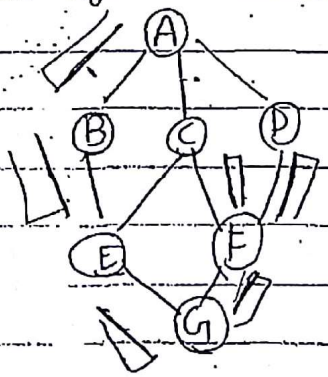
Problem:- Consider the following graph -



Find Correct DFT's

(a) ABEGFCD

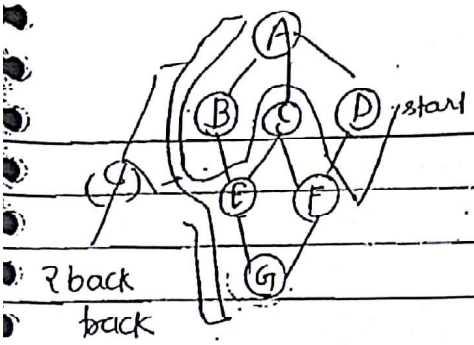
No of back track



Total Backtrack = 6

(b) ABECFDG
↓
backtrack occurs here

You can take any of the adjacent of a particular element.



DFCEBAG (correct)

(d) CFDABEG (No Back-back) (correct)
(Stack Size = n)
max. stack size = O(n)
↓ When no backTrack occurs

(e) GIECFABD (Incorrect) correct - GIECFDAB

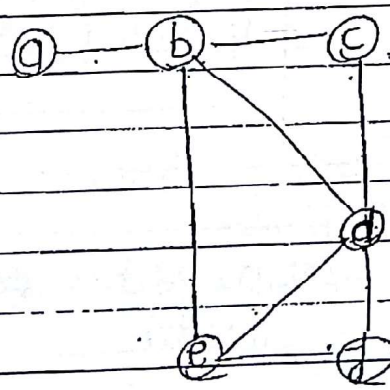
(f) ACFGEBD (correct)

(h) BACFDEG → (fail) Incorrect) correct - BACFDGE
because at D when possibilities ended we back track to F & F has G to be done but it is first completing G.

Br Back Tracking is done when all possibilities ended
Backtracking is nothing but poping

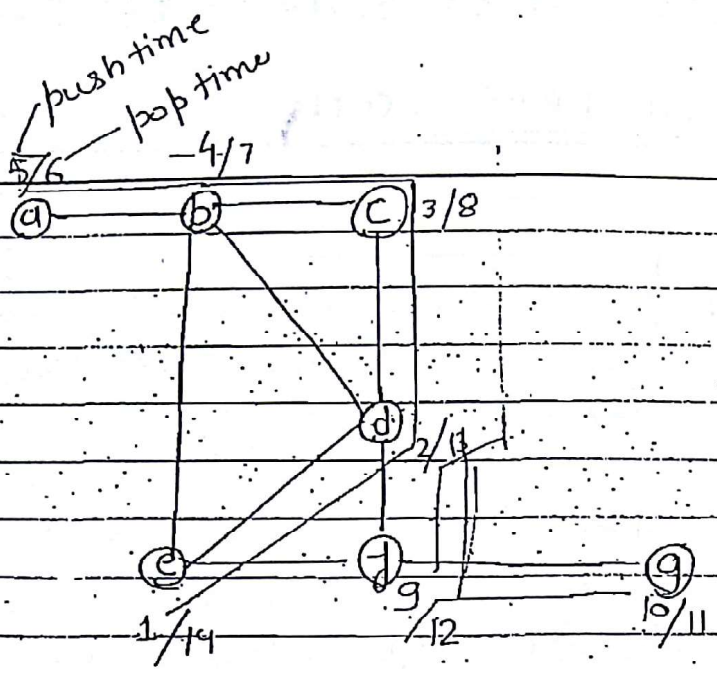
In DFT, if I print D after B, what is the relation b/w then
No relation because of backtracking any thing possible in DFT but BFT have adjacency.

Ques - Consider the following graph -



Check whether they are DFT or ~~BFT~~ or not.

1) edcbafg (DFT)
2) fdebagc (incorrect)
3 abdfgce (incorrect)
4) dcbefgga (correct)
5) befgdca (DFT)



edcbafg

how many element where the diff b/w push & pop time is 1 (Immediate back track)

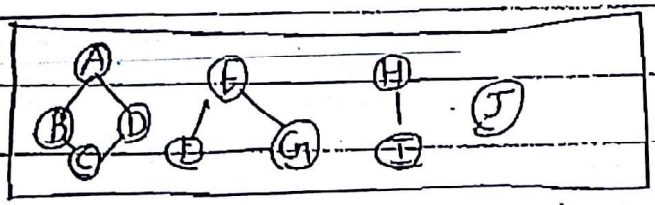
∴ Total element = 2 (a, g)

1/14 2/13 3/12 4/9 5/8 6/7 10/11
d c b e f g a

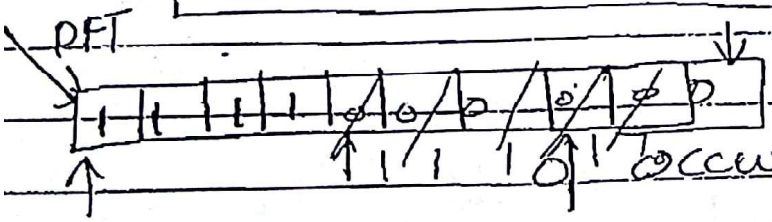
1/14 2/11 3/10 4/5 6/9 7/8 12/13
b e f g d c a

Applications of DFT-

- will check where graph is connected or not



if start for A

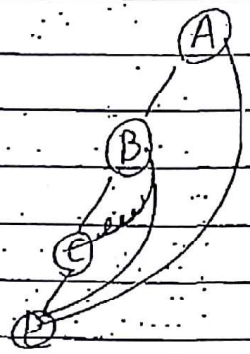


occur in visited array.

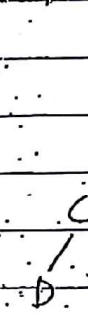
$\gamma(V+E)$

2. We can verify given graph contain cycle or not
O(V+E)

3. We can find out no of connected components
count = no of time DFT applied.

4. 

Here shortest path = ~~(1)~~ (1)
but if we take



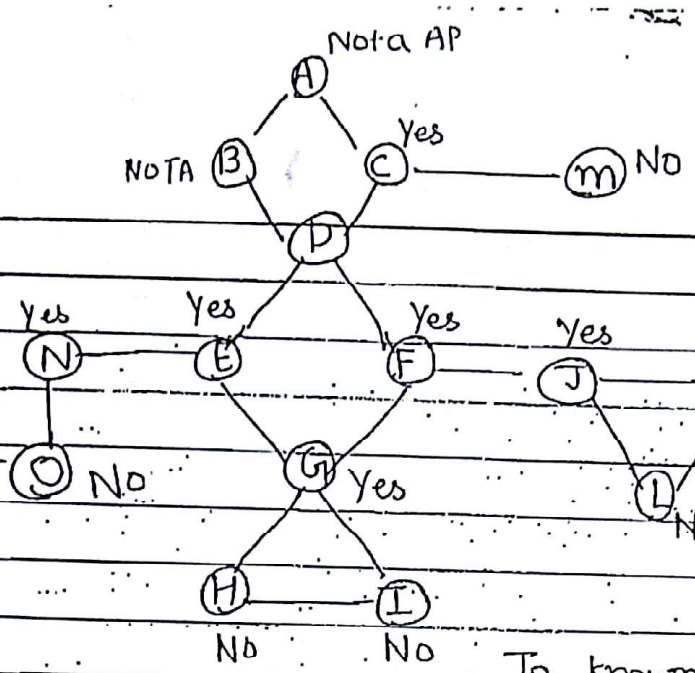
= 3 length path

So, DFT cannot (may or may not) work finding single source shortest path for given unweighted graph.

5. Using DFT, We can check given directed graph is strongly connected or not.?

6. Using DFT we can verify a vertex is articulation point or not.

Articulation point - if the deletion of an ~~edge~~ ~~lead~~ vertex ~~als~~ along with its edge lead to discon tion of graph known as articulation point.



To known whether a ~~Graph has~~ vertex is any articulation point-

1) Apply DFT on given graph
2) Delete that vertex & edge.
3) Again apply DFT
4) If Visited contain 1 for all except that delete vertex then that is an articulation point

Total Complexity = $O(V+E) + O(V+E)$
$= O(V+E)$

Bipartite Graph using BFT

first time visited in one set

second time another set

(level by level storing of elements

trongly Connected using DFT

n finding strongly connected component

you can use the concept of ~~strongly connected~~ graph

rticulation point

No of articulation point = No of strongly connected component + 1

Total Complexity = $E(V+E+V+E)$

↳ for articulation point

$= EV + E^2$

$= O(E^2)$

Programming-1

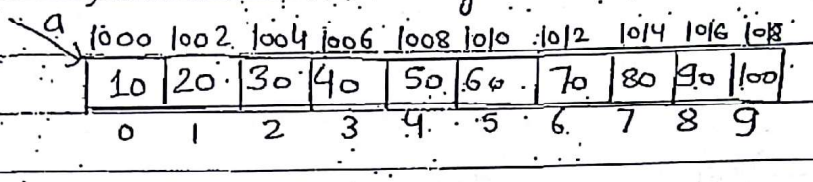
Array- 1-D Array

before 5 ele ~~be~~ from 0 = (5-0) = 5

Ex-1

int a[10] = {10, 20, 30, 40, ..., 100} a will store base address.

declaration (memory creation)



1 to 7 → how many elements = 7-1+1 = 7

-5 -4 -3 -2 -1 0 1 2 3 4 4-(-5)+1 = 10 elements

2-(-2)+1 = 5 elements

5 element occupy - 1010 & 101

print a = 1000 (base address)

Loc[a[5]] = base address + (size of data type)*(5-0)

= 1010

* 1010 - to access that particular M/M location)

Loc[a[9]] = base address + size of int * (9-0)

= 1000 + 2×9 = 1018

(only 9-0 bcz you dont wc ~~to~~ cross 9th element)

Ex2-

a[55 .... 550] Total element = 550-55+1 = 496

Base address = 990

Size of an element = 10 byte (C)

before 450 from 55.

Loc[a[450]] = Base address + C * [450-55]

= 990 + 10 * 395

= 3950 + 990 = 4940

• array must be continous no matter whether indices are (+)ve or (-)ve.

Ques a[-55 to 55] BA = 1000 C = 5

$$Loc[A[5]] = BA + [5-(-55)] \times 5$$
$$= 1000 + 60 * 5 = 1000 + 300$$
$$= 41300$$

ex4 = a[lb .. ub] BA = Base address

lower bound, upper bound, size = C

total element = ub - lb + 1

$$Loc[a[i]] = BA + C * [i - lb]$$

array index when started from 0, no need to do subtract at time to calculate location but when it start with 1, a subtract has to be done. So less time is required to calculate the value when starting from 0.

Loc of a[1 .. 10] $Loc[a[5]] = BA + (5-1) * C$ → offset calculation

a[0, 10] $Loc[a[5]] = BA + (5-0) * C$

• Array index is, by default, will start from 0 only because no need to calculate offset value

2-D Arrays- int a[4][5] (row, column)

(0=3) (0=4) (5-1)+1 = 5 column

int a[1..4][1..5] = total row (4-1)+1 = 4 Row

	1	2	3	4	5
1	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}
2	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}
3	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}
4	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}

Total element = 20 element

In m/m 40 bytes for continous m/m (no separate row & colu is present)

1000	02	04	06	08	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	1000 to 1039
a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	

row 1 row 2 row 3 row 4

Row Major order:- When elements are getting stored row by ro

Ex-1

a. C follows Row Major Order

Loc[a[4][3]] = 1000 + [(4-1)*5]*2 [5*(4-1) + (3-1)]

(visit row, visit co)

17 + 2 21

= BA + C [Column*(x - lb1) + (y - lb2)]

= BA + C [(ub2 - lb2 + 1)(x - lb1) + (y - lb2)]

Loc a[2][5] = BA + C [5*[2-0] + (5-1)]

= 1000 + 2 [5+4]

= 1018

Loc a[i][j] = BA + C [(ub2 - lb2 + 1)(i - lb1) + (j - lb2)]

lb1 ub1 lb2 ub2

(i - lb1): visit correct row.

(j - lb2): visiting column

Ex-2

$a[25 \ldots 750][80 \ldots 150]$ ↗ 726 rows ↗ 71 column   c = 10 byte

Row Major order   BA = 1000

1) $Loc(a[550][140]) = BA + c[(150-80+1) * (550-25) + (140-80)]$

$= 1000 + 10[71(525) + 60]$

$= 1000 + 10[37335]$

$= 373350 + 1000$

$= 374350$

525
× 71

Ex 3: $a[-25 \ldots +25][-50 \ldots 50]$ ↗ 51 ↗ 101, BA = 0   c = 1 Byte   RMO

$Loc\ a[20][30] = BA + c[(50+50+1)(20+25) + (30+50)]$

$= 0 + 1(101 * 45 + 80)$

$= 4545 + 80$

$= 4625$

Ex 4 – $a[lb_1 \ldots ub_1, lb_2 \ldots ub_2]$ a[4][3]

$ub_1 - lb_1 + 1$ $ub_2 - lb_2 + 1$

BA, C

Row Major order $a[i][j] = BA + c[(ub_2 - lb_2 + 1)(i - lb_1) + (j - lb_2)]$ — nc (no of column)

Column Major order $a[i][j] = BA + c[(ub_1 - lb_1 + 1)(j - lb_2) + (i - lb_1)]$ — (no of rows)

26-Mar

Column Major Order a[1...4][1...5]

a	1	2	3	4	5
1	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}
2	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}
3	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}
4	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}

BA = 1000 C = 10

a_{100} 02 04 06	08 10 12 14	16 18 20 22	24 26 28 30	32 34 36 38
a_{11} a_{21} a_{31} a_{41}	a_{12} a_{22} a_{32} a_{42}	a_{13} a_{23} a_{33} a_{43}	a_{14} a_{24} a_{34} a_{44}	a_{15} a_{25} a_{35} a_{45}
0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15	16 17 18 19
Column 1	Column 2	Column 3	Column 4	Column 5

Loc[a[4][3]] = BA + C[(3-1)*(no. of Rows + (4-1)]

= 1000 + 1[2(2*4+3)]

= 1022

Loc a[2][5] = 1000 + 1[(5-1)*no of row + (2-1)]

= 1000 + 2[4*4+1]

= 1034

both are same (Row Major, Column Major)

if no order is mentioned, go for Row Major (by default)

Ex2- a[-75...125][80...150] BA=0 C=1 byte

CMO

Loc[a[15][130]] = 0 + 1[(130-80)*(125+75+1) + (15+75)]

= 1(50*201+90)

= 1(10050+90) = 10040

= 101400

$\Rightarrow nr = ub_1 - lb_1 + 1$

Ex3 - $a[lb_1 \ldots ub_1][lb_2 \ldots ub_2]$ BA, C, CMo

$\Downarrow$

$nc = ub_2 - lb_2 + 1$

$Loc[a[i][j]] = BA + c[(j - lb_2) * nr + (i - lb_1)]$

3-D Arrays- collection of 2-D arrays

$a[3 \ldots 9][15 \ldots 35][8 \ldots 50]$

$9-3+1 = 7$ $\quad$ $35-15+1 = 21$ $\quad$ $50-8+1 = 43$

$\Rightarrow$ 7 table of size 21×43

$= 7$ [2-D array of size 21×43]

7 $\quad$ 21 no of rows $\quad$ 43 no of column

BA, Base Address. = 1000 $\quad$ C = 10 , RMO

$Loc[a[7][30][40]] = BA + C[(7-3)(nc * nr) + (30-15) * nc + (40-8)]$

$= 1000 + 10(4 * 21 * 43 + 15 * 43 + 32)$

$= 43890$

CMo

$Loc[a[7][30][40]] = BA + 10[(7-3) * nc * nr * (40-8) * nr + (30-15)]$

$= BA + 10$

$= 1000 + 10(4 * 21 * 43 + 8 * 21 * 15)$

$= 1000 + 10(3612 + 168 + 15)$

$= 1000 + 10(3795$

$= 38950$

~~Loc~~

Ex a[lb1 ~~ub2~~ l a[lb1 . . ub1, lb2 ... ub2, lb3 .... ub3]

BA, c

nr = ub2 - lb2 + 1

nc = ub3 - lb3 + 1

no of 2D = ub1 - lb1 + 1

(R, M, O)

loc [a[i][j][k] = BA + c [(i - lb1) * nc * nr + (j - lb2) * nc * (k - l

CMO

loc[a[i][j][k] = BA + c [(i - lb1 * nc * nr + (k - lb3) * nr + (j - lb

Lower Triangular Matrix -

	1	2	3	4
1	a11	a12	a13	a14
2	a21	a22	a23	a24
3	a31	a32	a33	a34
4	a41	a42	a43	a44

=

a11	0	0	0
a21	a22	0	0
a31	a32	a33	0
a41	a42	a43	a44

⇓ 16 element

6 = zero

(n/2) approx - zero

⇓ to save spa

Why we should store zero

aij belong to upper part if {j > i}

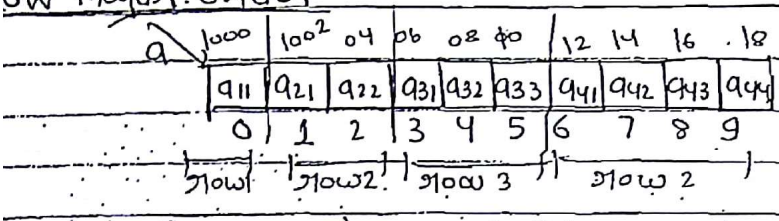
) return 0 at that time

Here store in row Major order -

row - 1 will have 1 element.

row - 2 will have 2 element.

ow Major Order-



visit row visit colm

$= Loc(a[4][3]) = BA + C[(4+3+2+1) - (4-1) + (3+2+1) + (3-1)]$

(sum of 3 natural no.) (4-1) nat no

$= BA + C[\text{sum of 3 natural no} + (3-1)]$

$= 1000 + 2[6+2] = 1016$

[All triangular Matrix are square Matrix]

$a[25 \to 85, 25 \to 85]$ (starting row no & colum no is also same)

BA = 1000

C = 1 Byte RMO LTM (Lower Triangular Matrix)

$Loc[a[60][55]] = BA + C[\text{sum of } (60-25) \text{ natural no} + (55-25)]$

$= 1000 + [(60-25)(60-25+1)] + 30$

$= BA + C[\text{sum of } (60-25) \text{ natural no} + (55-25)]$

$= 1000 + C\left[\frac{(60-25)(60-25+1)}{2} + 30\right]$

$= 7600$

formula

$Loc[a[lb_1 \dots ub_1, lb_2 \dots ub_2]] = BA + C$ RMO, LTM

$$Loc[a[i][j]] = BA + C\left[\frac{(i-lb_1)(i-lb_1+1)}{2} + (j-lb_2)\right]$$

a[4][3] = BA + c [sum of 3 natural no + (total rows - (3-1)]

= 1000 + 2[6 + 2]

= 1016.

a[25...85, 25, 85] BA = 1000 c = 10 Byte

CMO LTM

Rows = 61 column =

Loc a[60, 55] = BA + c [sum of (55-25) natural no + [no of rows - (55-1)

= 1000 + 10[35×18 + 61 - [55-25-1)]

= 1000 + 10[630 ... + 27

= 7570.

CMO a[i][j] = BA + c [sum of (j-lb) natural no + (no of rows - (j-lb

~~extra~~

~~fibonacci heap~~

$$Loc[a[4][3]) = 1000 + \left[\frac{4\times5}{2} - \frac{2\times3}{2} + (4-3)\right] * 2$$

BA

$\frac{4\times5}{2}$ ↓ crossing all column

$\frac{2\times3}{2}$ ↓ crossing unnecessary column → 3 row and 3 column

$(4-3)$ → Visiting 4th row

$= 1000 + 16 = 1016$

$$Loc(a[4][1]) = BA + c\left[\text{sum of } 4 \text{ nat. no} - \text{sum of } (4+1+1) \text{ no} + (4-1)\right]$$

sum of 4 nat. no ↓ crossing all column

sum of (4+1+1) no ↓ crossing unnecessary crossed column

(4-1) ↓ Visiting 1st row

it is used to cross all column

$= 1000 + 2[10 - 10 + 3]$

$= 1006$

ex2 - A[25....100, 25....100] BA = 1000 C = 10B LTM CMO

76 76

$$Loc(A[80][45]) = BA + c\left[\text{sum of } 76 \text{ natural no} - \text{sum of } (100-45+1) + (80-45)\right]$$

$$= 1000 + 10\left[\frac{76\times77}{2} + \frac{31\times32}{2} + 10\right]$$ ↓ Visiting 80th row

5

38

77

266

266 x

2926

31

15

46

$= 1000 + 10[2926 +$

$= 1000 + 10\left[\frac{76\times77}{2} + \frac{56\times57}{2} + 35\right]$

$= 151469$

When you are at 15 row col
you are at 15 co row.

Loc [A[5]

A[-50 .... 50, -50 ... +50] BA = 0 C = 1 Byte LTM, CM

$$Loc(A[25][15]) = 0 + 1\left[\underset{\text{no}}{\text{sum of 101 nat}} - \underset{\text{nat no}}{\text{sum of [50-15+}} + (25-15)\right]$$

↑ since you at 15 row

$$= \frac{101 \times 51}{2} + 10 - \frac{36 \times 37}{2}$$

$$= 5151 - 666$$

$$= 4995$$

(as 15 column will start from 15 row at ... element before 15 are: 2×10

Ex: A[lb1 ... ub1][lb2 ... ub2] BA, C, LTM, CMD

Loc

Loc[A[i][j]] = BA + C[sum of $(ub_2 - lb_2 + 1)$ nat no − sum of $(ub_2$ nat no $+ (i-j)]$

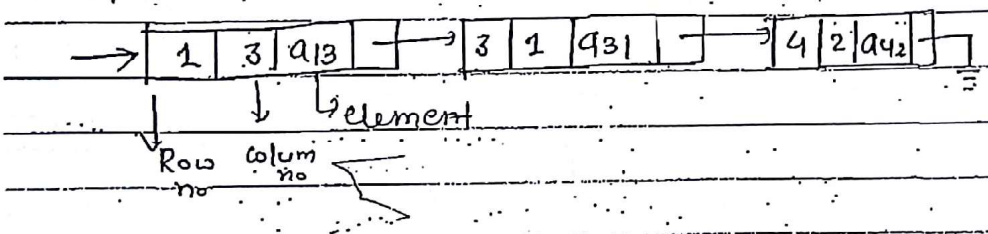
sum of all column

Sparse Matrix - A very less element in array are 1, and other are zero & there is no relation in them

$$\begin{bmatrix} 0 & 0 & a_{13} & 0 \\ 0 & 0 & 0 & 0 \\ a_{31} & 0 & 0 & 0 \\ 0 & a_{42} & 0 & 0 \end{bmatrix}$$

⇒ so need to store in array.

So we used linked list for its storage because if you use array lot of space is required.



Upper triangular Matrix

Z Matrix - all matrix except Z are zero

$$\begin{bmatrix} Z \end{bmatrix}$$

to exe... | ... | one o

to

Programming

Scope of a variable

(i) Static Scoping

(ii) Dynamic Scoping

(data type followed by name of variab... – declarat...)

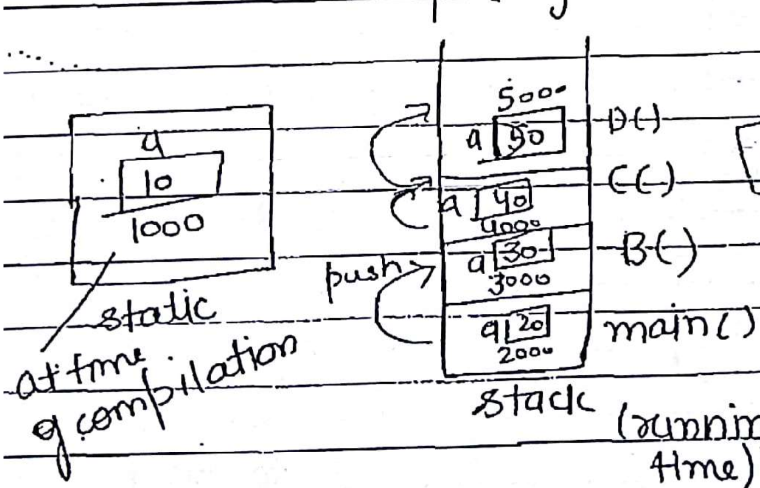
Ex 1 -

```
int a = 10;
main()
{
    int a = 20;
    B();
}
B()
{
int a = 30;
D();
}
C()
{
int a = 40;
D();
}
D()
{
int a = 50;
pf(a);
}
```

for all f^n call, a single stack is u...

(both static & dynamic as no scope problem) 50

M/M:
- stack (for local f^n variable)
- static (at time of compilation)
- heap (dynamic m/m)



O/P = 50

as stack will call top most value

Whenever a function is ... memory to local vari... is created & its runn... completed, m/m is deactivated but ... global variable, m... created at time of compilation. the m/m is created is static area).

the space taken by an any f^n in stack is equal to local variable

static by default - C

if both local & global data are not there, no mean (Garbage)

free variable - if a fn is using a variable which is not declared in it.

as if D()
{
p(a);
}

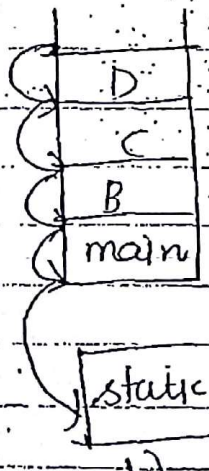
no a is declared but used

(A variable whi
is not initiali
cannot be a
Free variable

then
O/P = 10 (static)
40 (dynamic)

Whenever there is a free variable, compiler will identify it at time of compilation so, compiler will initialize it by global variable & this problem is known as scope problem & this problem if resolved at time of compilation, known as static scoping because at that time only global variable was initiali
i.e. compiler can't solve problem at co
but if compiler has restricted to solve scope problem at the time of compilation that it is not initialized by global data it will be resolved at run time if 'a' in not in D then go to its calling function & use from there and so on. if no calling function has a, then use global variable 'a'.

- Dynamic Scope will generate closer result as selecting the value from the closer fn



- Dynamic is difficult to implement

easier
static scoping - problem solve at compile tim
dynamic scoping at run time
↓ difficult

because In dynamic scoping
Worst case - all fn
to be poped to the

static scoping - by default

C, C++, J

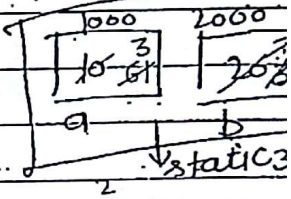
Static variable get m/m first & last deallocated at l
i.e after complete

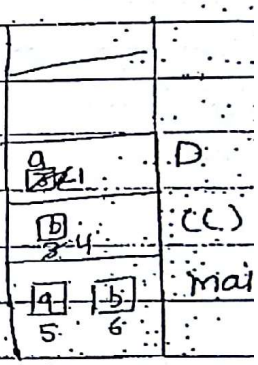
If a fn as D()
{ pf(a) and so on then static scoping - 10
dynamic - 40

Change done at compile time - static change
Change done at run time - dynamic change (in dynamic change are m
to previous

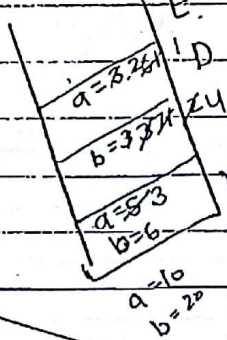
Ex2 int a=10, b=20;
main()
{
int a=5, b=6;
pf(a,b);
C();
pf(a,b);
}
C()
{ int b=3;
pf(a,b);
D(b);
pf(a,b);
a=3, b=4;
}

D(int a)
{
pf(a,b);
a=2;
b=3;
E();
pf(a,b);
a=1;
b=2;
}
E()
{
pf(a,b);
a=61;
b=71;
}

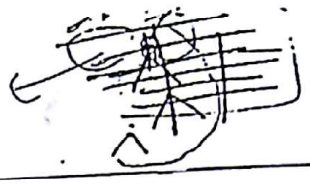




Static - 5,6 M
10,3 C
3,20 D
10,3 E
2,71 D
61,3 C
5,6 M



Dynamic - 5,6
5,3 5,6
3,3 5,3
3 3 3,3
3 3 2,3
5 3 61,71
5 6 3,6



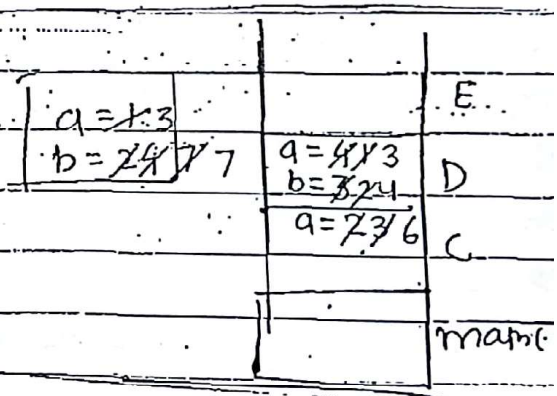
Q-3

```
int a=1, b=2;
main()
{
  pf(a,b);
  C(b);
  pf(a,b);
}
C(int a)
{
  a=3, b=4;
  pf(a,b);
  D(b,a)
  pf(a,b);
  a=6;
  b=7;
}
```

```
D(int a, int b)
{
  pf(a,b)
  a=1, b=2
  E();
  pf(a,b);
  a=3 ; b=4;
}
E()
{
  pf(a,b);
  a=3 ; b=7;
  pf(a,b);
```

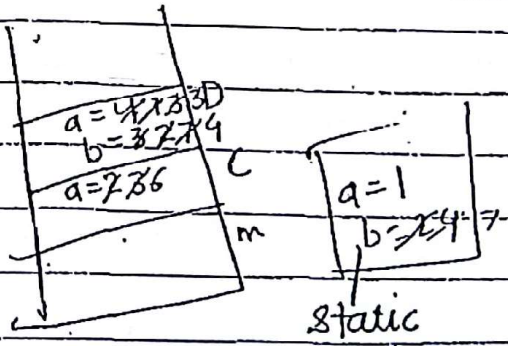
Static Scope -

1,2
3,4
4,3
1,4
3,7
1,2
3,7
3,7



Dynamic

1,2
3,4
4,3
1,2
3,7
3,7
3,4
1,7



local varia...
dynamic m/m → heap area

in char - '\0'
~~int '0'~~
float '0.0'
pointer 'Null'

Static Variable-

ex1 main( )

```
{
    static int var = 5;
    printf ("%d", var--);
    if (var--)
    {
        pf ("%d", var)
        main();
    }
}
```

var = 5

without static	with static
5 4 5 4 5 4 5 ∞ [infinite loop] → stack overflow	~~None o/p~~ 4 3 2 1 0

- When local variable are declared with static; M/M will be created at Compile time.

With static

main( )

1. M/M already created
2. if (5) ↓ print(4)

and so on
no M/M created
if (4)

var: [~~5~~ ~~4~~ 3], ~~Too~~

- by default, global are static as m/m created at compile time.

o/p - 4 3 2 1 0

as M/M is created only once.

at end of program [var = -1]

- M/M created i.e static is only one time as compilation is done one time only.

a = 3

b = a--	b = --a
pf(a, b)	pf(a, b
(2, 3)	(2, 2)

first assign and decrease afterwards

if (-10)
{ pf (hi) ⇒ hi
else
pf (bye

if non zero it will print hi

if ('\0' or Null o...
↓ fa...