GRAPH

Handwritten Notes of Striver(TUF) Playlist

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1. Introduction to graph | Types | Convention used.
2. Graph representation | Two ways
3. What are connected components.
4. BFS (Bredth first search)
5. DFS (Depth first search)
6. Number of Provinces | connected components
7. Number of islands | Number of connected components in graph
8. Flood fill Algorithm
9. Rotten oranges
10. Detect cycle in an undirected graph using BFS
11. Detect cycle in an undirected graph using DFS
12. Distance of nearest cell having 1 0/1 matrix.
13. Surrounded Regions | Replace O's with X's.
14. Number of enclaves | Multisourc BFS.
15. Number of distinct island | constructive Thinking + DFS
16. Bipertite Graph | BFS
17. Bipertite Graph | DFS
18. Detect cycle in a directed graph using DFS
19. Find Eventual safe states - DFS
20. Topological sort Algorithm | DFS
21. Kahn's Algorithm | Topological sort Algorithm | BFS
22. Detect a cycle in a directed graph | Topological sort | Kahn's Algorithm | BFS
23. Course schedule I and II | Pre-requisite Task | Topological sort
24. Find Eventual safe states | BFS | Topological sort
25. Alien Dictionary | Topological sort
26. Shortest path in Directed Acyclic graph Topological sort.
27. shortest path in undirected graph with unit weights
28. Word Ladder - I | shortest paths
29. Word Ladder - II | shortest paths
30. Dijkstra's Algorithm - using priority queue
31. Dijkstra's Algorithm - using Set
32. Dijkstra's Algorithm why Pq and not Q, intuition Time complexity Analys
33. Print shortest path - Dijkstra's Algo
34. Shortest distance in a Binary maze.
35. Path with minimum Effort
36. cheapest flight with K stops
37. Minimum multiplication to reach End
38. No. of ways to arrive at destination
39. Bellman ford Algorithm
40. Floyd warshall Algorithm
41. Find the city with smallest no. of neighbours at a threshold distance
42. Minimum spanning Tree - Theory
43. Prim's Algorithm - minimum spanning Tree
44. Disjoint set | union by rank | union by size | path compression
45. Kruskal's Algorithm - minimum spanning Tree
46. Number of provinces - Disjoint set
47. Number of operations to make Network connected | DSU
48. Accounts Merge | DSU
49. Number of Island - II - Online queries - DSU
50. Making a large Island - DSU
51. Most stones Removed with same row or column - DSU
52. strongly connected components - Kosaraju's Algorithm
53. Bridges in graph - using Tarjan's Algorithm of time in and low time
54. Articulation point in graph

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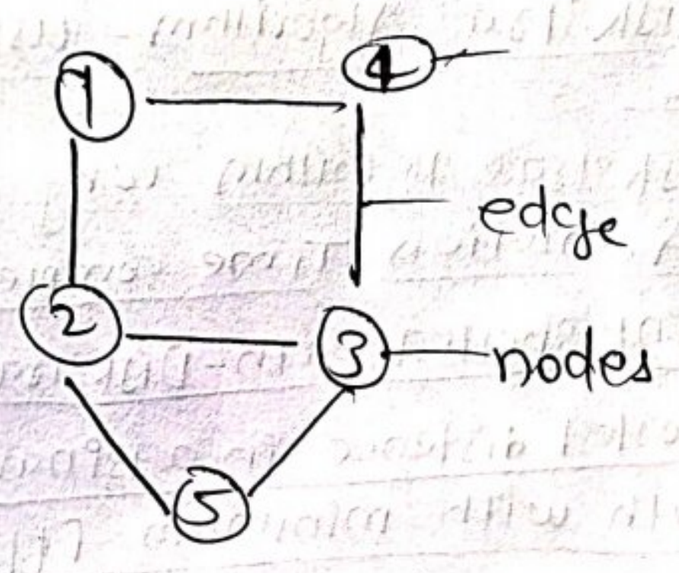
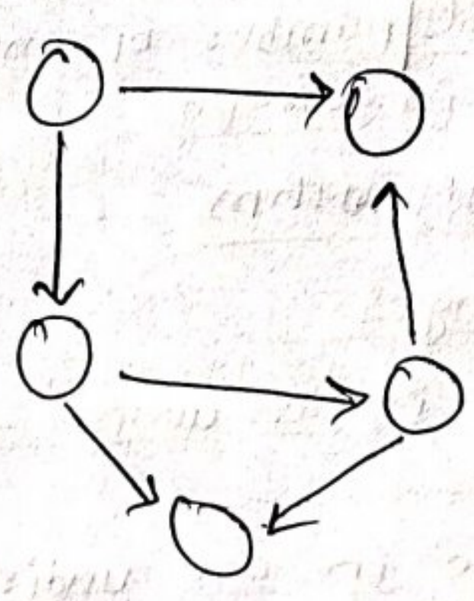
Vec 1

IN GRAPH

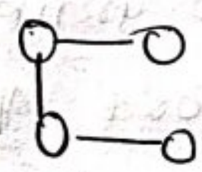
01-/04/2023

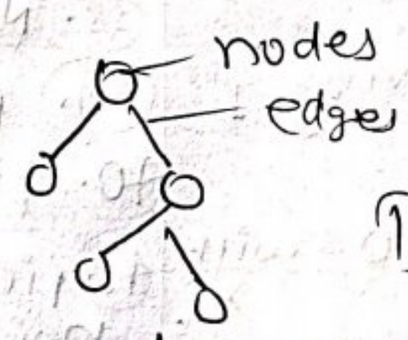
There are two types of graph
(1) undirected graph & (11) directed graph





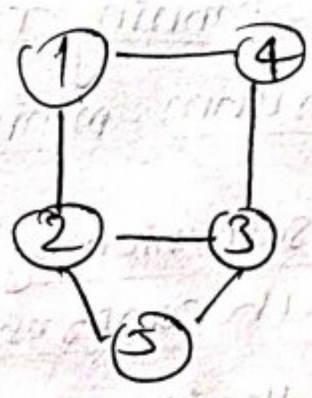
cycle in a graph



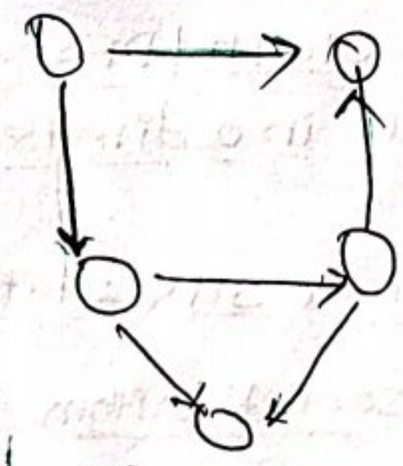


This is also graph

Defn: Start from a node and end at that node is called cycle.

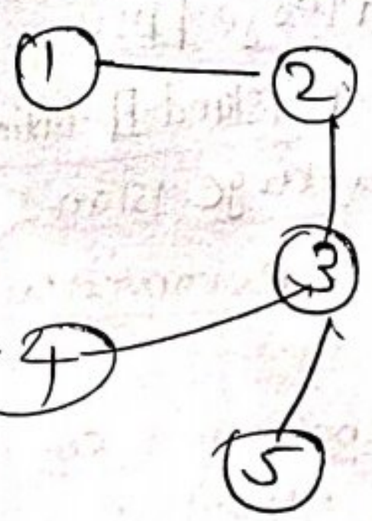


cyclic graph



Directed Acyclic graph (DAG)

Path: Contain a lot of nodes and each of them are reachable.



1 2 3 5 — path

1 2 ~~3~~ 2 1 — Not a path

A node can't appear twice in a path.

1 3 5 ✗ Not a path

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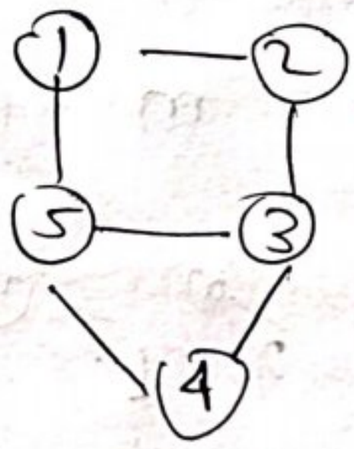
Degrees on Graph :-



D(3) → 3 for an ~~un~~ un

D(4) → 2

D(5) → 3

D(2) → 2

D(1) → 2

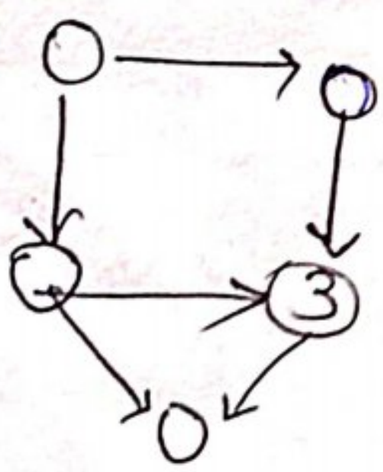
for an undirected graph the no. of edges that are attached to it is called degree.

Total Degree of a graph = 2x no. of edges

For directed graph :-

Indegree(node)

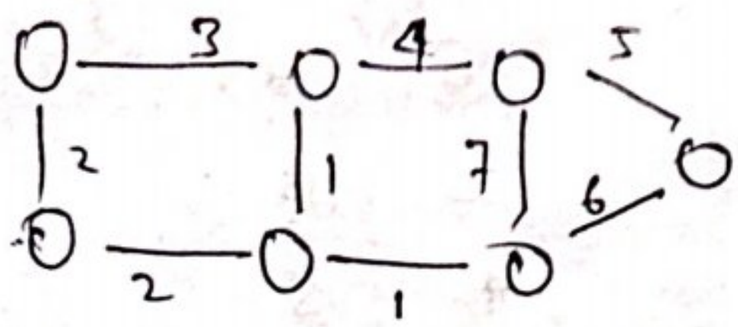
Outdegree(node)



Indegree(3) = 2

Outdegree(3) = 1

edge weights :-



if weight is not assign unit weight

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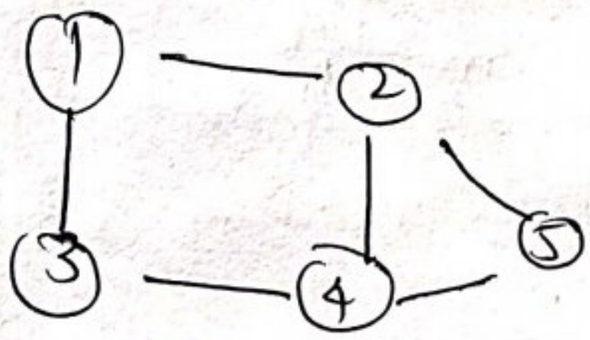
Lec

Lec 2

input



n-nodes, m-edges
5 6

m lines → Represent edges

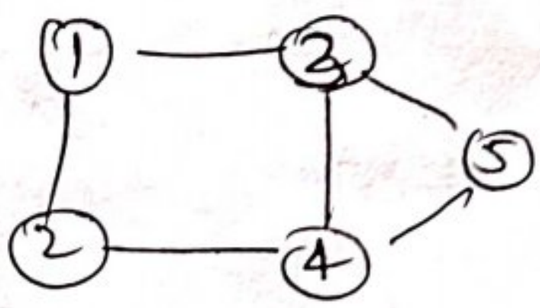
2 1
1 3
2 4
3 4
2 5
4 5

5 6

m lines
1 3
2 1
2 4
3 4
2 5
4 5

Two way for store

(1) matrix (2) List



1 2
1 3
2 4
3 4
3 5
4 5

(1) matrix

	0	1	2	3	4	5
0	0	0	0	0	0	0
1	0	0	1	1	0	0
2	0	1	0	0	1	0
3	0	1	0	0	1	0
4	0	0	1	1	0	1
5	0	0	0	1	1	0

Space $n \times n$

costly

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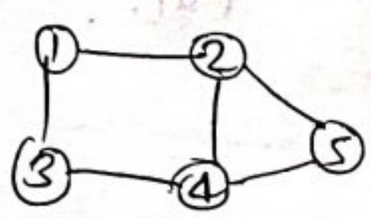
Code :-

```
int main()
{ int n, m;
  cin>>n>>m;
  int adj[n+1][m+1];
  for( int i=0; i<m; i++)
    { int u, v;
      cin>> u>>v;
      adj[u][v] = 1;
      adj[v][u] = 1;
    }
  return 0;
}
```

(ii) List :-



1 → {2, 3}
2 → {1, 4, 5}
3 → {1, 4}
4 → {2, 3, 5}
5 → {2, 4}

Code :-

```
int main()
{ int n, m;
  cin >>n>>m;
  int ~~adj~~ vector<int> adj[n+1];
  for(int i=0; i<m; i++)
    { int u,v;
      cin>>u>>v;
      adj[u].push_back(v);
      adj[v]. push_back(u);
    }
  return 0;
```

for directed graph

adj[u]. push_back(v);

S.C. = O(Edges)

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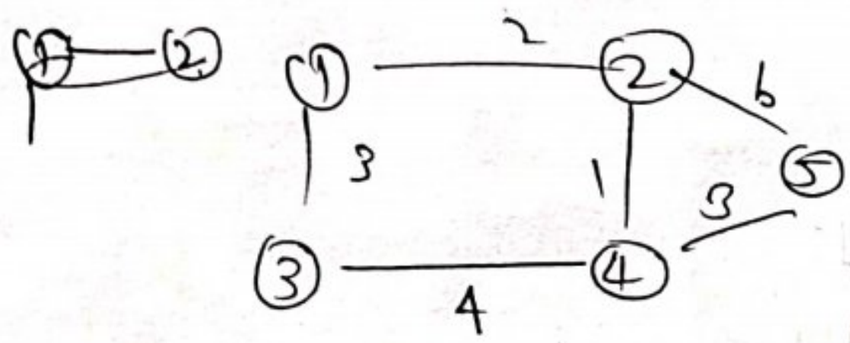
weighted graph :-



Matrix

	0	1	2	3
0				
1			2	
2		2		
3				

adj[u][v] = weight;

list

0 we will store pair.

1

2

3

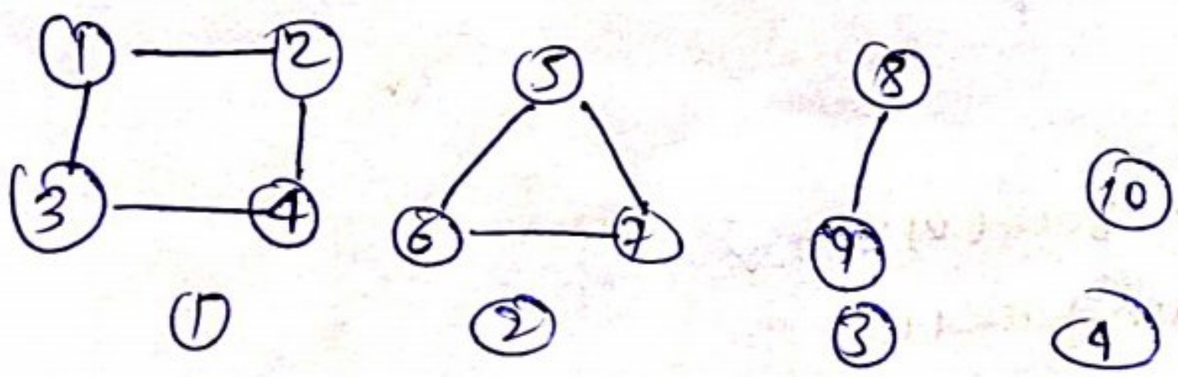
4 → {2, 3, 5} → instead of this store this

{ (2,1), (3,4), (5,3) }
weight

3. Lec 4.

Connected components :-

N = 10, M = 8



1 2
1 3
2 4
3 4
5 6
6 7

4 different components of a single graph
it can be also 4 different graph.
But according to input / question it is a single graph.

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vis [| | | | | |]

If we start from 1st component then we will never reach to the 2nd component so for that we will use something ~~called~~ like visited array.

vis [| | | | | | | | | |]
0 1 2 3 4 5 6 7 8 9 10

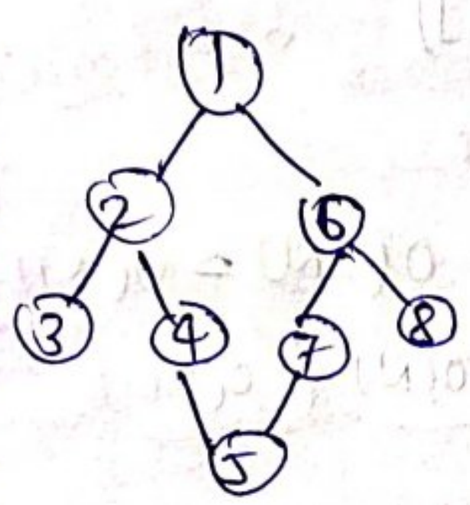
N = 11

```
for (i = 1 → 10)
    if(!vis[i])
        traversal(i);
```

for any traversal if node is not visited. // then call traversal also from this node.

A. Lecs.

BFS (Breadth First Search)

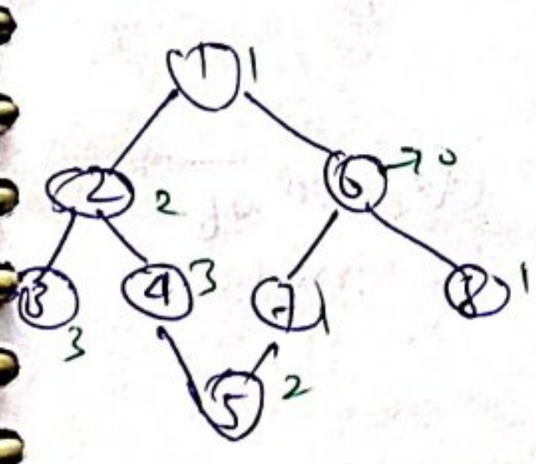


level
0
1
2
3

Breadth → levelwise

1 | 2 6 | 3 4 7 8 5 | :
0 | 1 | 2 | 3 | 4

let say 6 is starting node



6 | 1 7 8 | 2 5 | 3 4
0 | 1 | 2 | 3

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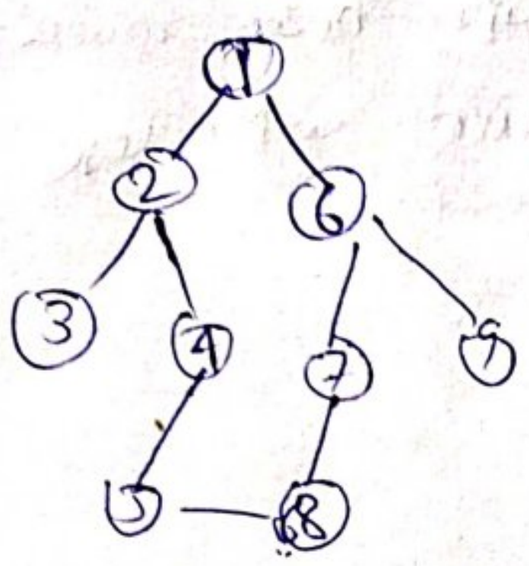
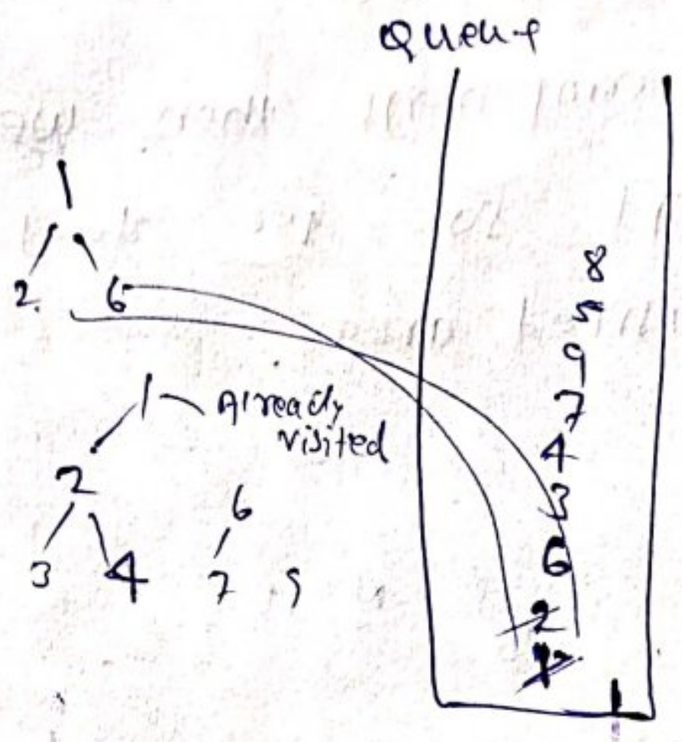
It is same as like level order traversal





Adjacency list

0 — {1}
1 — {2, 6}
2 — {1, 3, 4}
3 — {2}
4 — {2, 5}
5 — {4, 8}
6 — {1, 7, 9}
7 —

vis

0	1	2	3	4	5	6	7	8	9
0	1	1	1	1	1	1	1	1	1

Output: 1 | 2 6 | 3 4 7 9 | 5 8

0 1 2 3

Code :-

```
vector<int> bfsOfGraph(int V, vector<int> adj[])
{
    int vis[n] = {0};
    vis[0] = 1;
    queue<int> q;
    q.push(0);
    vector<int> bfs;
    while(!q.empty())
    {
        int node = q.front();
        q.pop();
        ~~bfs.push_back~~
        bfs.push_back(node);

        for(auto it : adj[node])
        {
            if(!vis[it])
            {
                vis[it] = 1;
                q.push(it);
            }
        }
    }
    return bfs;
}
```

run for degree of node

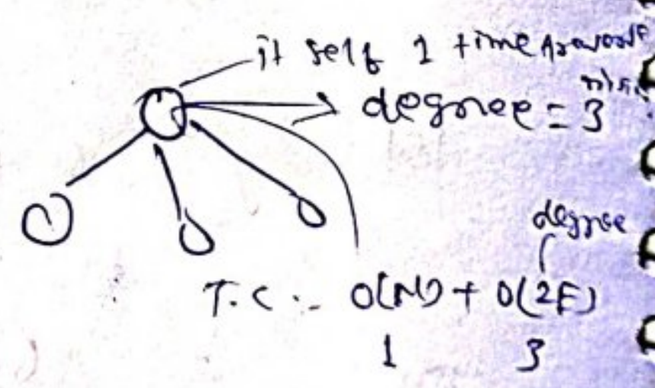
$O(N) \times O(2E)$

$1 + (2E)$

S.C. — $O(3N) \simeq O(N)$

T.C. — $O(N) + O(2E)$

2E = Total degree



T.C. — $O(N) + O(2E)$ (degree)

1 3

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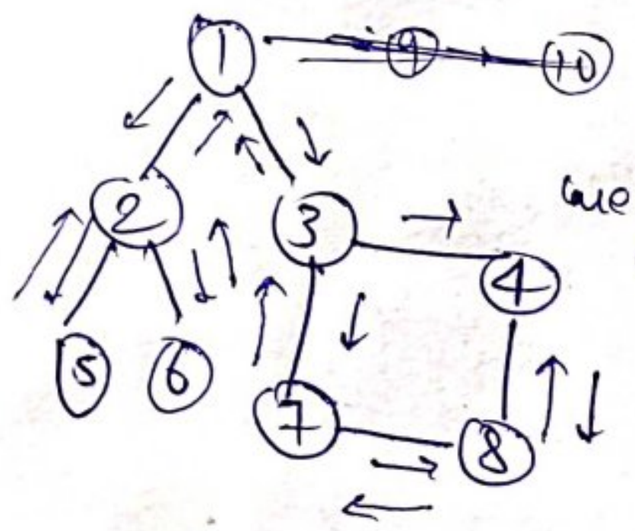
5: Lec 6

DFS (Depth First Search) : Recursion



Starting node = 1

we can choose any path

1 2 5 6 3 7 8 4

Main thing is, ~~traversing~~ in depth

if Starting node = 3

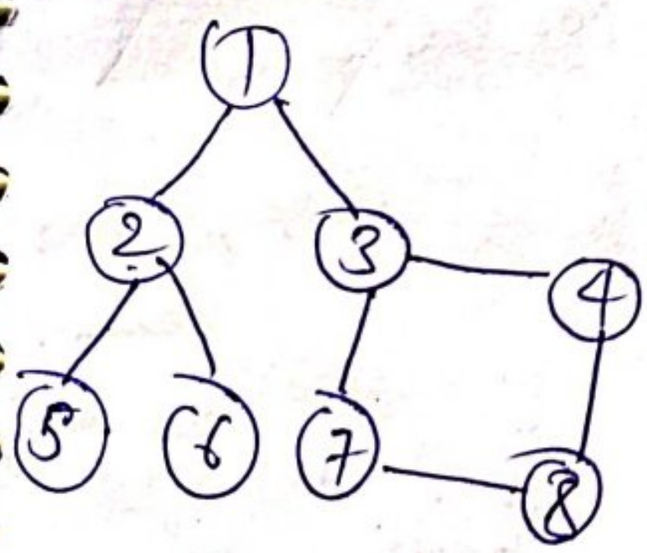
3 4 8 7 1 2 5 6

Recursion is an algo which goes till depth calculate and returns back.

So we use Recursion in DFS.

vis _ [ ]

Adjacency list :-



dfs(1)

dfs(2) dfs(3)

1 - {2,3}
2 - {1,5,6}
3 - {1,4,7}
4 - {3,8}
5 - {2}
6 - {2}
7 - {3,8}
8 - {4,7}

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```
vector<int> dfsOfGraph(int V, vector<int> adj[])
{
    int vis[V] = {0};
    int start = 0;
    vector<int> ls;
    dfs(start, adj, vis, ls);
    return ls;
}

void dfs(int node, vector<int> adj[], int vis[], vector<int> &ls)
{
    vis[node] = 1;
    ls.push_back(node);
    for(auto it : adj[node])
    {
        if(!vis[it])
        {
            dfs(it, adj, vis, ls);
        }
    }
}
```

S.C. → $\underset{dfs}{O(N)} + \underset{visited}{O(N)} + \underset{Recursion}{O(N)}$

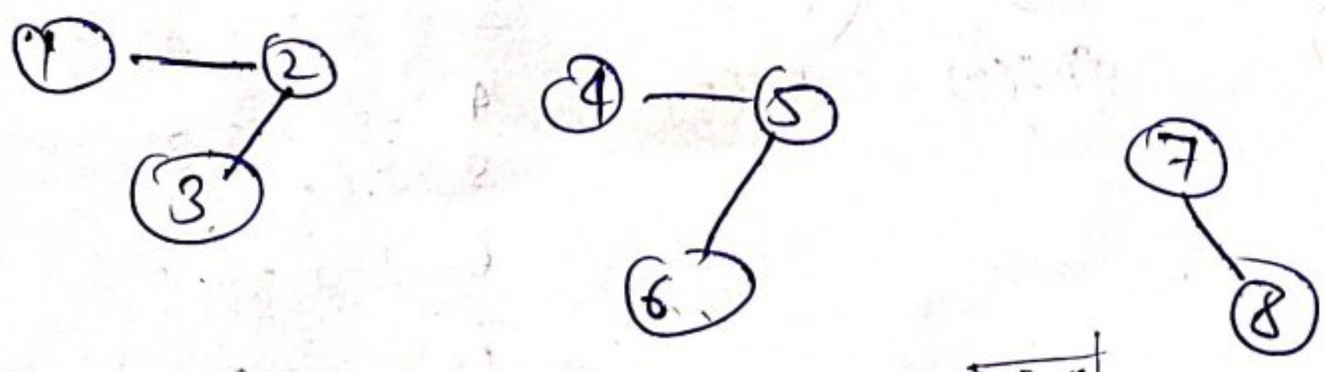
$\approx O(N)$

T.C. - $O(N) + \underset{degree}{O(2E)}$

↓ For directed graph

T.C. - $O(E)$

Lec 7. Q: Number of Provinces :-



1 - 2
2 - 1, 3
3 - 2
4 - 5
5 - 4, 6
6 - 5
7 - 8
8 - 7

No. of provinces = 3

3	x
2	x
1	✓

0	1	2	3	4	5	6	7	8
	1	1	1					

From node 1 we can go 2, 3 or, from ② → 1, 3, from ③ → ①, ② so ① — ② — ③ this is 1 province.

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we will have multiple starting point

start = 1/2/3
start = 4/5/6
start = 7/8

~~Clear~~

```
void dfs(int node, vector<int> adjLs[], int vis[])
{
    vis[node] = 1;
    for(auto it : adjLs[node])
    {
        if(!vis[it])
        {
            dfs(it, adjLs, vis);
        }
    }
}
```

T.C. $O(N) + O(V+2E)$ — for all dfs node
$\approx O(N)$

S.C. — $O(N) + O(N)$ — Recursion stack space.

```
int numProvinces(vector<vector<int>> adj, int v)
{
    vector<int> adjLs[v];
    for(int i=0; i<v; i++)
    {
        for(int j=0; j<v; j++)
        {
            if(adj[i][j]==1 && i != j)
            {
                adjLs[i].push_back(j);
                adjLs[j].push_back(i);
            }
        }
    }
    int vis[v] = {0};
    int cnt = 0;
    for(int i=0; i<v; i++)
    {
        if(!vis[i])
        {
            cnt++;
            dfs(i, adjLs, vis);
        }
    }
    return cnt;
}
```

1 2 3
1 1 1 1

1 — 2
2 — 1,3
3 — 2

adjLs[i].push_back(j);

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~~No. of component~~

Number of Islands

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

no. of Island

3. Starting Nodes

3 Island

Using BFS

Starting — {0,1}

Visited array

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

~~{0,2}~~

~~{2,1}~~
~~{1,1}~~
~~{1,2}~~
~~{0,2}~~
~~{0,1}~~

{0,1} Q.

adjacency list

They can be neighbour so we will go in all 8-direction.

Then after traversal the queue will be empty

Now starting point will change and process will be same.

so we will use three starting points.

for finding starting points we will traverse from (0,0) to (m-1, n-1) and if we find 0 then ignor while

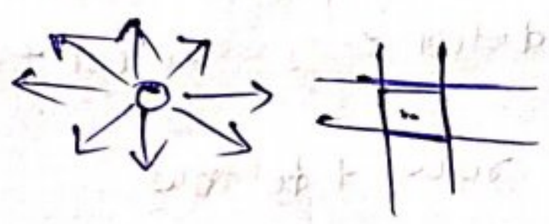
if we find 1 then call traversal algo.

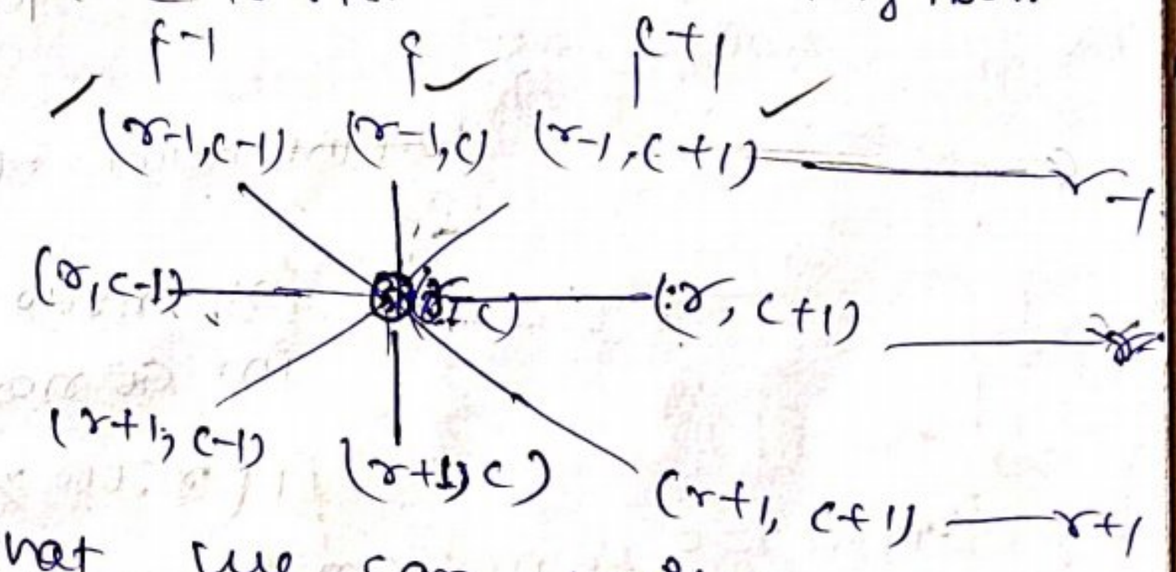
pseudo code :-

```
for(row -> (0-n))
{
    for (col -> (0-m))
    { if(!vis[row][col]
      {
        bfs(row, col);
        cnt++;
      }
    }
}
```

for BFS traversal

we have to visit all the neighbour nodes.





for that we can write a code

```
for(delrow -1 to 1)
{
  for(delcol -1 to 1)
  {
    new_row = row + delrow;
    new_col = col + delcol;
  }
}
```

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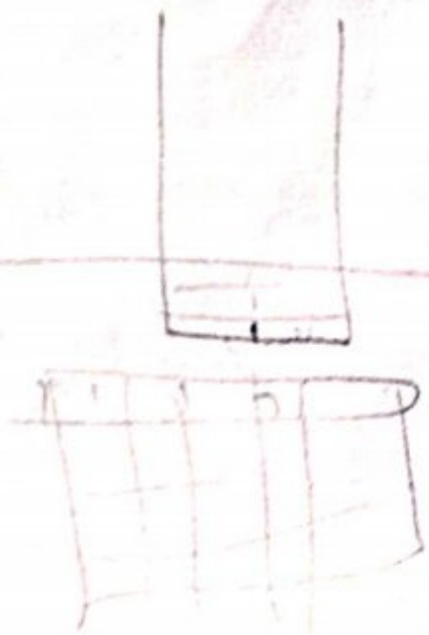
```
void bfs( int row, int col, vector<vector<int>> &vis,
vector<vector<char>> &grid)
{
        vis[row][col] = 1;
        queue<pair<int,int>> q;
        q.push({row, col});   int n = grid.size();
        while(!q.empty())     int m = grid[0].size();
        {
            int row = q.front().first;
            int col = q.front().second;
            q.pop();
        // traverse in the neighbours & mark them visited
        for( int delrow = -1; delrow <= 1 ; delrow++)
        {
            for( int delcol = -1; delcol <= 1; delcol ++)
            {
                int nrow = row + delrow;
                int ncol = col + delcol;
                if( nrow >= 0 && nrow < n &&
        ncol >= 0 && ncol < m && grid[nrow][ncol] == '1' &&
            !vis[nrow][ncol] )
            {
                vis[nrow][ncol] = 1;
                q.push({nrow, ncol});
            }
        }
    }
}
```



@Aashish Kumar Nayak

```
int numIslands(vector<vector<char>> &grid)
{
    int n=grid.size();
    int m = grid[0].size;
    vector<vector<int>> vis(n, vector<int>(m,0));
    int cnt=0;

    for(int row=0; row<n; row++)
    {
        for(int col=0; col<m; col++)
        {
            if(!vis[row][col] && grid[row][col] == '1')
            {
                cnt++;
                bfs(row, col, vis, grid);
            }
        }
    }

    return cnt;
}
```

S.C. :- $O(N^2)$ + $O(N^2)$
matrix queue

$\approx O(N^2)$

T.C :- ~~$N^2 \times 9$~~

$N^2 + N^2 \times 9$
matrix check for 1 | BFS

$\approx O(N^2)$

In matrix use BFS

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Lec 9

Flood Fill Algorithm

Ex

by DFS

sr, sc — starting coordinate

initial = 2

new color = 3

	0	1	2
0	1	1	1
1	2	2	0
2	2	2	0

DFS(2,0)

DFS(1,0)

DFS(2,1)

DFS(1,1)

DFS(2,1)

$\begin{bmatrix} 1 & 1 & 1 \\ 3 & 3 & 0 \\ 3 & 3 & 0 \end{bmatrix}$

We can choose BFS / DFS any of them

But we choose DFS here for no reason

Initial color will be image[sr][sc]

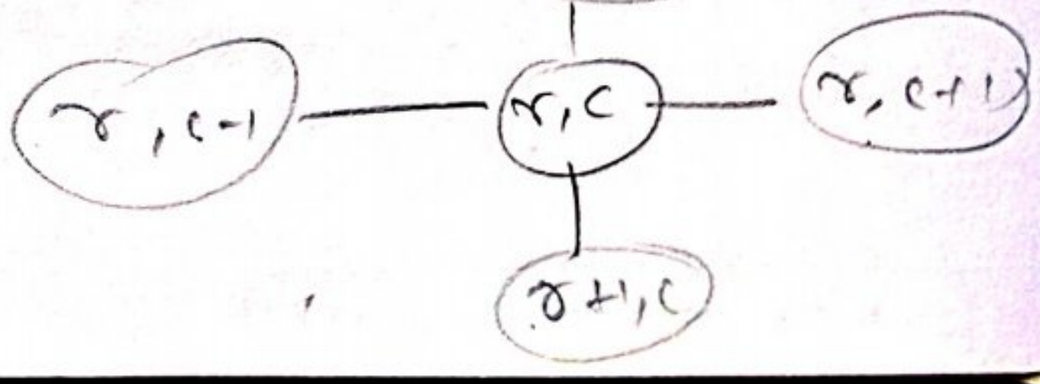
Code:

```
vector<vector<int>> floodFill (vector<vector<int>> &image,
int sr, int sc, int newcolor)

{ int inicolor = image[sr][sc];   //2
    vector<vector<int>> ans = image;
    int delRow[] = {-1, 0, +1, 0};
    int delCol[] = {0, 1, 0, -1};
    dfs(sr, sc, ans, image, newcolor, delRow, delCol, iniColor)

    return ans;
}
```

	0		
2	2	2	2



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```
void dfs(int row, int col, vector<vector<int>> &ans, vec
vector<vector<int>> &image, int delrow[], int delcol[]
{
    ans[row][col] = newColor;
    int n = image.size();  int m = image[0].size();
    for (int i = 0; i < 4; i++)
    {
        int nrow = row + delrow[i];
        int ncol = col + delcol[i];
        if(nrow >= 0 && nrow < n && ncol >= 0 &&
        nrow < m && image[nrow][ncol]
        == iniColor && ans[nrow][ncol] != newcolor)
        {
            dfs(nrow, ncol, ans, image, newcolor, delrow,
            delcol);
        }
    }
}
```

T.C. $(N \times M) \times 4$ — matrix for every 4 neighbour node

$= \underbrace{(N \times M)}_{\text{call dfs}} + (N \times M) \times 4$ — dfs

$\approx O(N \times M)$

S.C. $O(N \times M) + delrow + delcol$

$\approx O(N \times M)$

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Rotten oranges :-

we have to find the minimum time to rotten all the oranges.

0	1	2
0	1	1
2	1	1

0 — Empty box
1 — Fresh orange
2 — rotten orange

* in 1 unit of time it can rott 4 oranges if avilable.

* if you can't rotten all orages than return -1.

Sol: we have to visit same level nodes at same time & BFS is the only traversal algo which traverse Level wise

if we use DFS

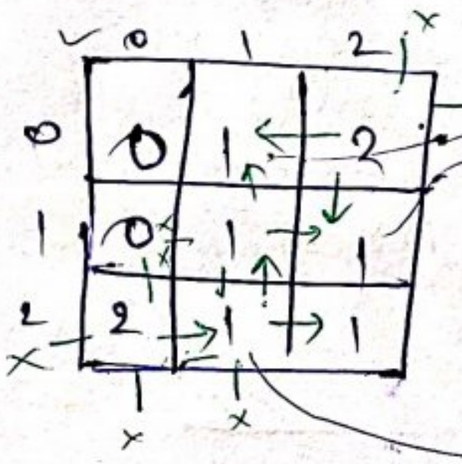
0	2	2
0	2	2
2	2	2

it will take 5 sec

But we have to do it in min time and that is only possible if we move in the neighbouring direction with equal peace.

BFS simultaneously rotten.

BFS



with time +1

(2,0) + = 0

(0,2) + = 0

with time +1

(2,1) + = 1

Queue (q)

~~(2,2),2~~
~~(1,1),2~~
(0,1),1
~~(1,2),1~~
(2,1),1
~~(0,2),0~~
~~(2,0),0~~

time

rotten

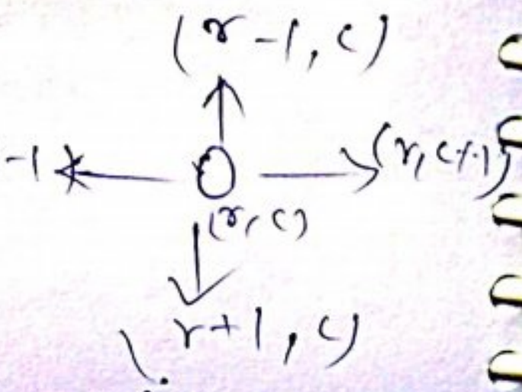
max time = ~~0~~ 1 2

visited

0	2	2
0	2	2
0	2	2

Max time = 2 sec

return max time,



neighbour nodes

@ Aashish Kumar Nayak

```
int orangesrotting(vector<vector<int>> &grid)
{
    int n = grid.size();
    int m = grid[0].size();

    queue< pair< pair<int,int>, int>> q;
    int vis[n][m];
    int cntfresh = 0;
    for(int i=0; i<n; i++)
    {for(int j=0; j<m; j++)
        { if(grid[i][j] == 2)
          {
            q.push({{i, j}, 0});
            vis[i][j] = 2;
          }
        else {
            vis[i][j] = 0;
        if( grid[i][j] == 1)
            { cntfresh ++;
            }
        }
    }

    int tm = 0;
    int drow[] = {-1, 0, +1, 0};
    int dcol[] = {0, 1, 0, -1};
    int cnt=0;
    while(!q.empty())
    { int r = q.front().first.first;
      int c = q.front().first.second;
      int t = q.front().second;
      tm = max(tm, t);
      q.pop();
    for(int i=0; i<4; i++)
      { int nrow = r + drow[i];
        int ncol = c + dcol[i];
    if(nrow >=0 && nrow<n && ncol>=0 && ncol<m && vis[nrow][ncol]==0
    && grid[nrow][ncol] == 1) { q.push({{nrow, ncol}, t+1});
                                vis[nrow][ncol] = 2; cnt ++; }}}
```

time

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T.C. $O(N\times M)_{vis} + O(N\times M)_{oranges}$

$\approx O(N\times M)$

T.C. $O(N\times M)_{loop} + O(N\times M)\times 4$ (every node, neighbour)

$\approx O(N\times M)$

Scanned with OKEN Scanner

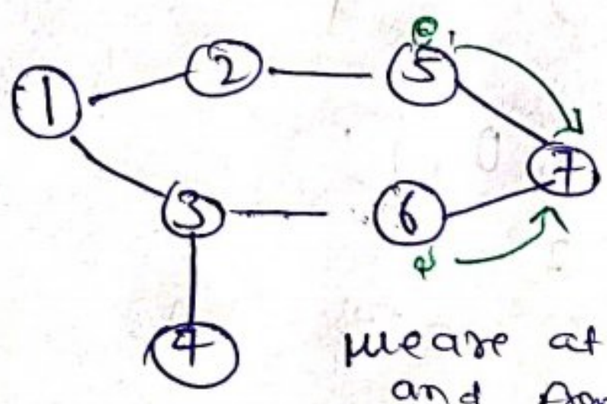
```
if(cnt != cntFresh)
    return -1;

return tm;
}
```

Detect a cycle in an undirected graph :-

Using BFS

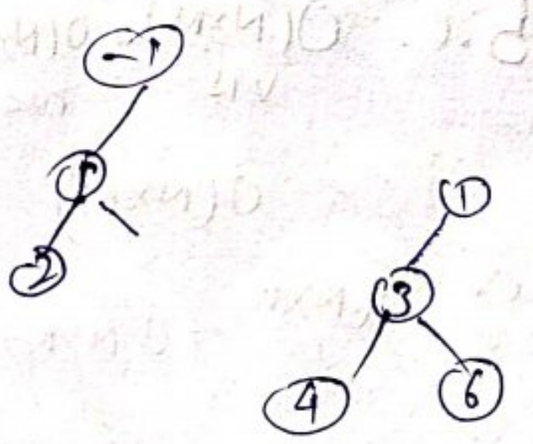
if you are starting traverse and you are able to come back at that particular node then there will be cycle in the graph.



adj list

1 - {2, 3}
2 - {1, 5}
3 - {1, 4, 6}
4 - {3}
5 - {2, 7}
6 - {3, 7}
7 - {5, 6}

we are at level 2 ⇒ 5, 6 and from both side if we touched 7 it means there is cycle



~~(6,3)~~
~~(4,3)~~
~~(5,2)~~
~~(3,1)~~
~~(2,1)~~
~~(1,-1)~~

q

vis

1	2	3	4	5	6	7
1	1	1	1	1	1	1

for component graph

```
for( i = 1; i<=n; i++)
{   if( !vis[i] )
    {   if( detectCycle(i) == true)
            return true;
    }
}
return false;
```

T.C. - $O(N + 2E) + O(N)$ (component thing)

S.C. - $O(N) + O(N)$ (queue, visit)

$\approx O(N)$

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```
bool detect(int src, vector<int> adj[], int vis[])
{
    vis[src] = 1;
    queue<pair<int,int>> q;
    q.push({src, -1});
    while(!q.empty())
    {
        int node = q.front().first;
        int parent = q.front().second;
        q.pop();
        for(auto adjacentNode : adj[node])
        {
            if(!vis[adjacentNode])
            {
                vis[adjacentNode] = 1;
                q.push({adjacentNode, node});
            }
            else if(parent != adjacentNode)
            {
                return true;
            }
        }
        return false;
    }
```

node parent

```
bool isCyclic(int v, vector<int> adj[])
{
    int vis[v] = {0};
    for(int i=0; i<v; i++)
    {
        if(!vis[i])
        {
            if(detect(i, adj, vis))
                return true;
        }
    }
    return false;
}
```

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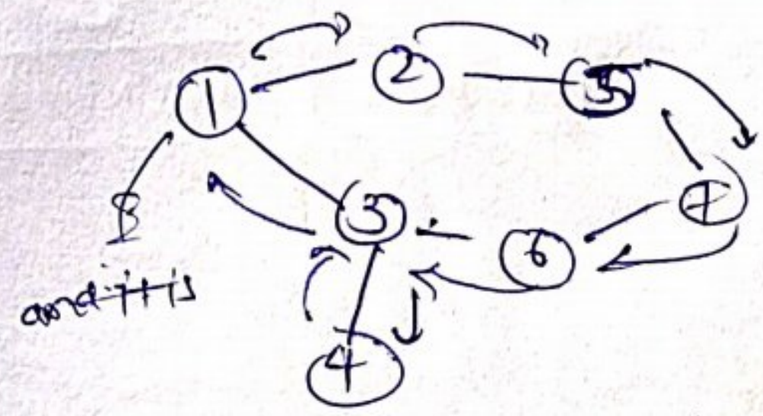
Cycle detection in undirected graph → using DFS



Start from somewhere and if we got a node which is previously visited, then we can there is cycle.

and it is

and it should ~~and its parent is different~~ not be parent of that node.

Adj List

1 - 2,3
2 - 1,5
3 - 1,4,6
4 - 3
5 - 2,7
6 - 3,7
7 - 5,6

vis

1	2	3	4	5	6	7
1	1	1	1	1	1	1

normal node

parent node

DFS(1 , -1)

T

T

no need for further call

because we got True

1 — 2, 5

DFS(2, 1)

DFS(3, 1)

we will go this call after completing the DFS(2,1) call

T

T

DFS(1, already visited but parent is same as node

DFS(5, 2)

T

so, it is not cycle.

DFS (7, 5)

T

DFS (6, 7)

for (7 there will be no call because it is parent)

DFS (3, 6)

T

DFS(4, 3)

DFS(1, 3)

return true,

3 is marked visited and also it is not parent, so we got the cycle.

∴ return true.

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```
bool dfs(int node, int parent, vector<int> vis[], vector<int>
  adj[])
{ vis[node] = 1;
    for (auto adjacentNode : adj[Node])
    {
        if( !vis [adjacentNode])
        {
            if(dfs (adjacentNode, Node, vis, adj) == true)
                return true;
        }
        else if (adjacentNode != parent )
            return true; }
    }
    return false;
}
```

```
bool isCyclic(int v, vector<int> adj[])
{ int vis[v]={0};
  for (int i=0; i<v; i++)
  { if(!vis[i])
      {
        if( dfs (i, -1, vis, adj ==true)
          {
            return true;
          }
      }
  }
  return false;
}
```

S.C. – $\underbrace{O(N)}_{\text{Recursion}} + \underbrace{O(N)}_{\text{Vis}} \approx O(N)$

T.C. – DFS Traversal
$O(N+2E) + O(N)$
$\approx O(N+2E)$ for loop

Not $O(N)$ — But it will depends on components

Ex. $O(3)$

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Distance of nearest cell having 1 :

for this one 1 cell

1	0	1
1	1	0
1	0	0

× no diagonal distance

$$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix}$$

return Ans

∵ This is something related to graph, and also we have to find min steps or min distance, it means it is a graph problem.

which algo – BFS comes in my mind.

Because it will simultaneously travels in all direction and always minimum count.

1	0	1
1	1	0
1	0	0

instead of

1	0	1
1	1	0
1	0	0

✓ ×

	0	1	2
0	2	1	2
1	1	0	1
2	0	1	0

vis

1	1	1
1	1	1
1	1	

Q
(0,0),2
(1,0),1
(2,1),1
(1,2),1
(0,1),1
(2,2),0
(2,0),0
(1,1),0

T.C. – $O(n \times m) \times 4 \approx O(n \times m)$

S.C. – $O(n \times m)$

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```
vector<vector<int>> nearest (vector<vector<int>> grid)
{   int n = grid.size();
    int m = grid[0].size();
  vector<vector<int>> vis(n, vector<int>(m,0));
  vector<vector<int>> dist(n, vector<int>(m,0));
  queue<pair<pair<int,int>,int>> q;
     for(int i=0; i<n; i++)
     {  for(int j=0; j<m; j++)
        {  if(grid[i][j] == 1)
           {  q.push({{i,j}, 0});
              vis[i][j] = 1;
           }
           else
           {  vis[i][j] = 0;
           }
        }
     }
     int delrow[] = {-1, 0, +1, 0};
     int delcol[] = { 0, +1, 0, -1};
  while(!q.empty())
  {  int row = q.front().first.first;
     int col = q.front().first.second;
     int steps = q.front().second;
       q.pop();
     dist[row][col] = steps;
  for(int i=0; i<4; i++)
{ int nrow = row + delrow;
  int ncol = col + delcol;
  if(nrow >=0 && nrow <n && ncol >=0 && ncol <m && vis[nrow][ncol]
                                                    == 0)
{   vis[nrow][ncol] = 1;
      q.push({{nrow, ncol}, steps+1});
  }
}}
}  return dist;
```

@Aashish Kumar Nayak

Replace O's with X's

X	X	X	X	
X	O	X	X	
X	O	O	X	
X	O	X	X	
X	X	O	O	

only those ~~ze~~ O's which are surrounded by X in top, down, left, right that can be converted into X. rest ~~are~~ will not converted.

Observation : ~~if someone is on the boundary they.~~
~~Can~~ A set of X connected to a boundary 'O' cannot be converted.

DFS

① go to the boundary and find if there is zero if we got zero ~~cw~~ then call the dfs ~~for~~ from that index

	0	1	2	3	4
0	X	X	X	X	X
1	X	O	O	X	O
2	X	X	O	X	O
3	X	O	X	O	X
4	O	O	X	X	X

VIS

O	O	O	O	O
O	X	X	O	1
O	O	X	O	1
O	1	O	X	O
1	1	O	O	O

dfs(4,0)

dfs(4,1)

dfs(3,1)

X

It is already visited no need to traverse again

dfs(1,4)

dfs(2,4)

X

Some visited from Boundary so can't convert.

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Algo:-

→ from boundary, find 'O's & traverse & mall all O's connected to it.

then → Rest of zero can be converted into X.

Code:-

```
void dfs(int row, int col, vector<vector<int>> &vis, ~~vector<~~
    vector<vector<char>> &mat, int delrow[], int delcol[])
{   vis[row][col] = 1;
    int n = mat.size();
    ~~int m = mat.size();~~ int m = mat[0].size;

    for( int i = 0; i<4; i++)
      {  int nrow = row + delrow[i];
         int ncol = col + delcol[i];
      if(nrow >=0 && nrow <n && ncol >=0 && ncol < m
      && !vis[nrow][ncol] && mat[nrow][ncol] == 'O')
      {
        dfs(nrow, ncol, vis, mat, delrow, delcol);
      }
    }
}

vector<vector<char>> fill( int n , int m, vector<vector<char>> mat)
{   int delrow = {-1, 0, 1, 0};
    int delcol = {0, 1, 0, -1};
    vector<vector<int>> vis(n, vector<int>(m,0));
      for //traverse first & last row,
      for(int j=0; j<m; j++)
        {  if(! vis[0][j] && mat[0][j] == 'O')
           {  dfs(0, j, vis, mat, delrow, delcol);
           }
           if(! vis[n-1][j] && mat[n-1][j] == 'O')
           { dfs(n-1, j, vis, mat, delrow, delcol);
           }
        }
~~for(int~~ // ~~traver~~

//traverse for 1st col & last col
```

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```
for(int i=0; i<n; i++)
{
    if(!vis[i][0] && mat[i][0] == '0')
    {
        dfs(i, 0, vis, mat, delrow, delcol);
    }

    if(!vis[i][m-1] && mat[i][m-1] == '0')
    {
        dfs(i, m-1, vis, mat, delrow, delcol);
    }
}

for(int i=0; i<n; i++)
{
    for(int j=0; j<m; j++)
    {
        if(!vis[i][j] && mat[i][j] == '0')
        {
            mat[i][j] = 'X';
        }
    }
}

return mat;
}
```

dfs 4 neighbors loop Boundary

T.C. $O(N \times M) \times 4 + O(N) + O(N)$

$\approx \underline{\underline{O(N \times m)}}$

S.C.

$\underline{\underline{O(N \times m)}}$

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Number of Enclaves | Multi-source BFS

count the no. of 1's or land from where you can not go outside the matrix. (inside 1's)
(B means B. you can't count 1's which is on boundary and also the 1's which is connected to the boundary 1's)

so then the remaining 1's will be our answer.

lets try BFS for no reason just to get clarity

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

put all boundary's 1

~~1,2~~
~~0,4~~
~~1,3~~
~~4,4~~
~~4,3~~
~~0,4~~
~~0,3~~

vis

0	0	0	1	1
0	0	1	1	0
0	0	0	0	0
0	0	0	0	0
0	0	0	1	1

← b →
↓

Once the queue is empty
now count the unvisited 1's and return ans.

ans = 3

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Code :

@Aashish Kumar Nayak

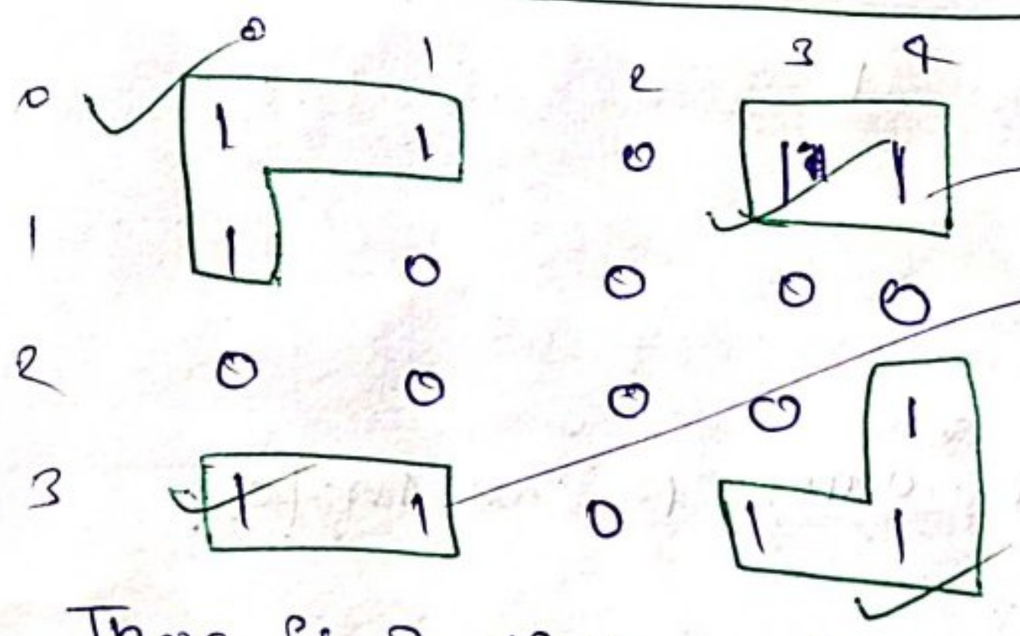
```
int numberofEnclaves(vector<vector<int>> &grid)
{ queue<pair<int,int>> q;
  int n= grid.size();
  int m = grid.size();
  int vis[n][m] = {0};
  For(int i=0; i<n; i++)
   { for(int j=0; j<m; j++)
     { if(i==0 || j==0 || i=n-1 || j==m-1)
       { if(grid[i][j] == 1)
         { q.push({i,j});
           vis[i][j] = 1;
         }
       }
     }
  int delrow[] = {-1, 0, +1, 0};
  int delcol[]= { 0, +1, +0, -1};
  while( !q.empty())
   { int row = q.front().first;
     int col = q.front().second;
     q.pop();
     for(int i=0; i<4; i++)
      { int nrow = row + delrow[i];
        int ncol = col + delcol[i];
        if(nrow >=0 && nrow <n && ncol >=0 && ncol<m && 
          vis[nrow][ncol] == 0 && grid[nrow][ncol] ==1)
          { q.push({nrow, ncol});
            vis[nrow][ncol] = 1;
          }
      }
   }
  int cnt=0;
   for(int i=0; i<n; i++)
    { for(int j=0; j<m ; j++)
      { if(grid[i][j] == 1 & vis[i][j] == 0) cnt++;
      }
  return cnt;
}
```

T.C. - $O(N \times M) \times 4$
$\approx O(N \times M)$

S.C. - $\approx O(N \times M)$

Number of distinct Islands

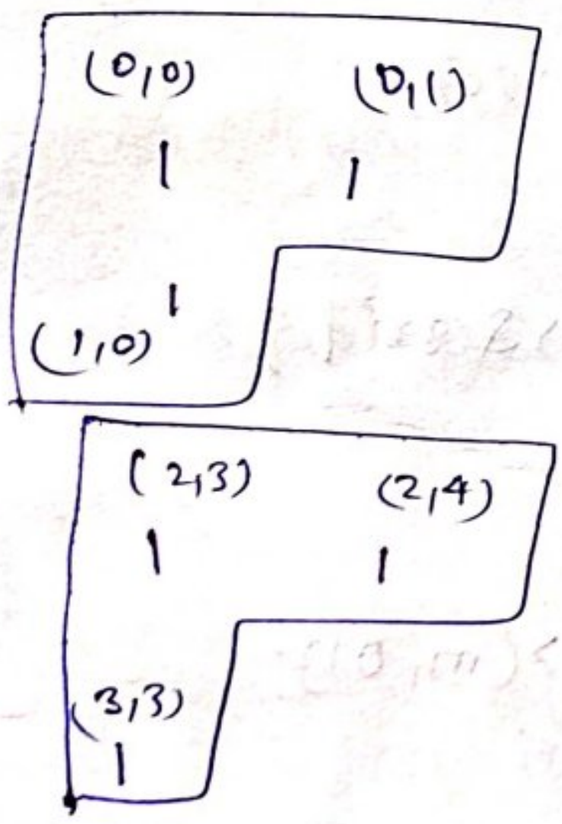
@Ashish Kumar Mayak



These are identicle so it will be count as 1.

There is 8 distinct island.

1 way is we can store the shapes in a set so that it will store only unique shapes.



How to store these shapes ~~so that~~ ~~we~~ such that these two come out to be identical

{(0,0) (0,1) (1,0)}
{(2,3) (2,4) (3,3)} } These are not identicle

so make starting point as base origin

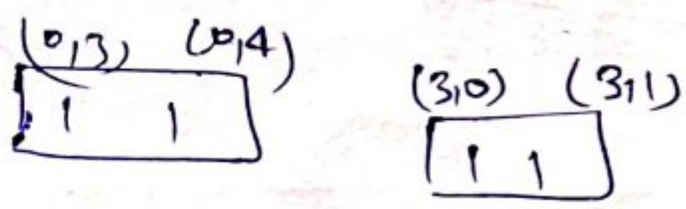
(0,0) − (0,0) = (0,0)
(0,1) − (0,0) = (0,1)
(1,0) − (0,0) = (1,0)

= {(0,0) (0,1) (1,0)}

(2,3) − (2,3) = (0,0)
(2,4) − (2,3) = (0,1)
(3,3) − (2,3) = (1,0)

= {(0,0) (0,1) (1,0)}

} Now there are identicle



(0,3) − (0,3) = (0,0)
(0,4) − (0,3) = (0,1)
(3,0) − (3,0) = (0,0)
(3,1) − (3,0) = (0,1)

{(0,0) (0,1)}
{(0,0) (0,1)} } T

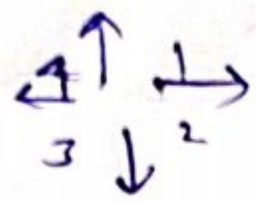
but what if

1 1 1 1

1 1 1

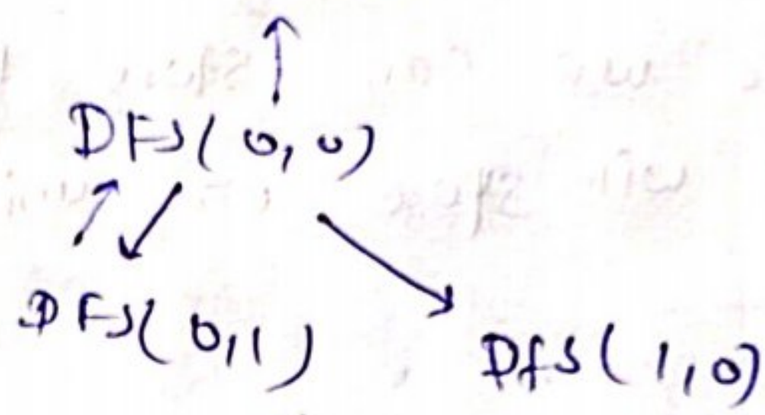
1

So must follow the same order for all shapes.



1 1 0

1 0 0



Code :-

```
int CountDistinctIslands( vector<vector<int>> & grid )
{ int n = grid.size();
  int m = grid[0].size();
  vector<vector<int>> vis(n, vector<int>(m, 0));
  set<vector<pair<int, int>>> st;
  for(int i=0; i<n; i++)
  {
    for(int j=0; j<m; j++)
    {
      if(!vis[i][j] && grid == 1)
      {
        vector<pair<int, int>> vec;
        dfs(i, j, vis, grid, vec, i, j);
        st.insert(vec);
      }
    }
  }
  return st.size();
}
```

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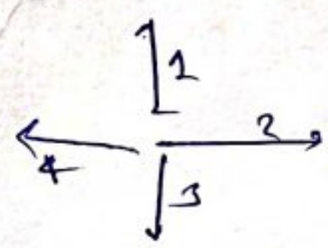
```
void dfs(int row, int col, vector<vector<int>> & vis,
vector<vector<int>> &grid, vector<pair<int,int>> &vec, int
row0, int col0)
{
    vis[row][col] = 1; ~~vec.push_back({row-row0, col-col0});~~
    int n = grid.size();
    int m = grid[0].size();
    vec.push_back({row-row0, col-col0});
    int delrow[] = {-1, 0, 1, 0};
    int delcol[] = {0, -1, 0, 1};
    for(int i=0; i<4; i++)
    {
        int nrow = row + delrow;
        int ncol = col + delcol;
        if(nrow >=0 && nrow < n && ncol >=0 && ncol < m
        && !vis[nrow][ncol] && grid[nrow][ncol] == 1)
        {
            dfs(nrow, ncol, vis, grid, vec, row0, col0);
        }
    }
}
```



for loop dfs x neighbour

T.C. $\cancel{O(N\times M)} + O(N\times M)\times 4$

$O(N\times M \times \log(n\times m))$

$\approx \cancel{O(N\times M)} = O(N\times M \log(N\times M) + (N\times M)\times 4$

S.C. $\approx O(N\times M)$

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Bipartite graph

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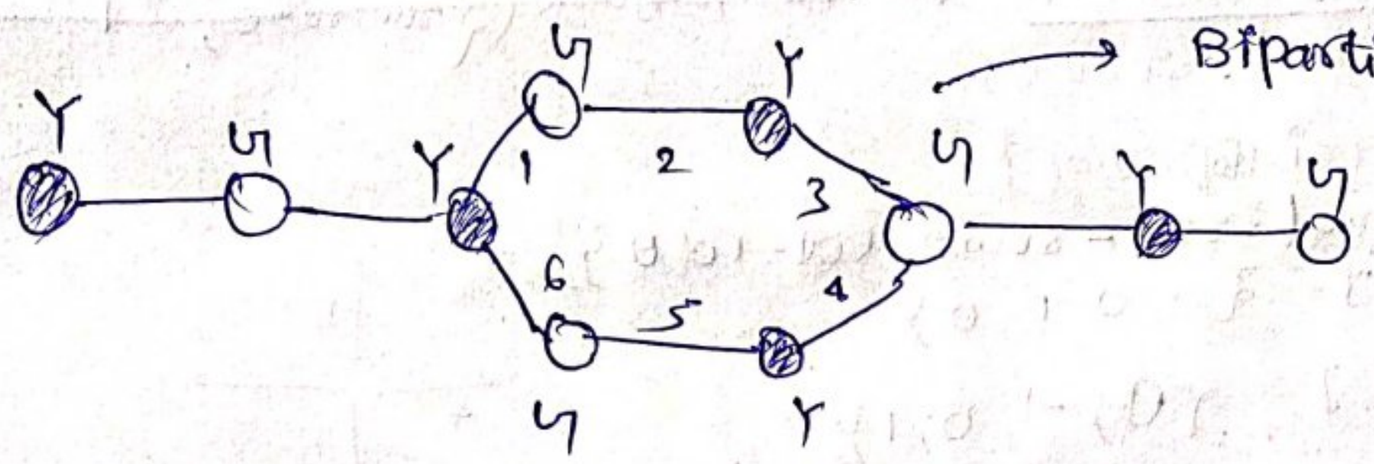
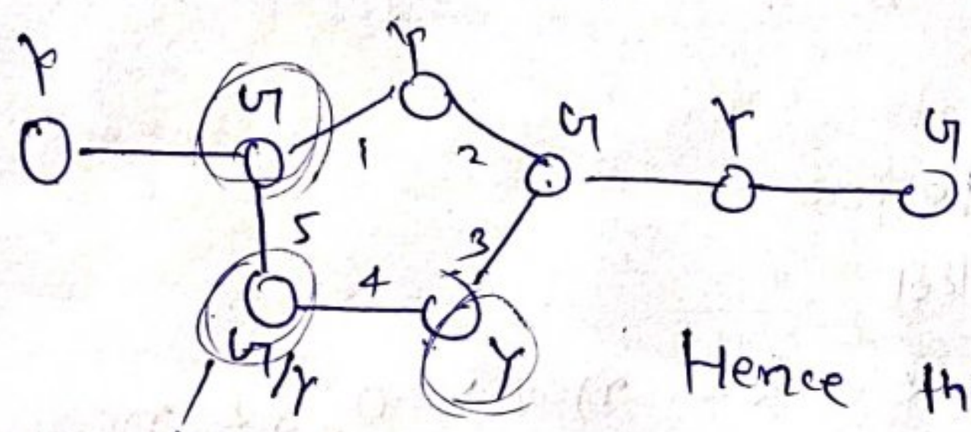
Colour the graph with 2 colours such that no adjacent nodes have same colour.





We can't colour this node with any of the two colours

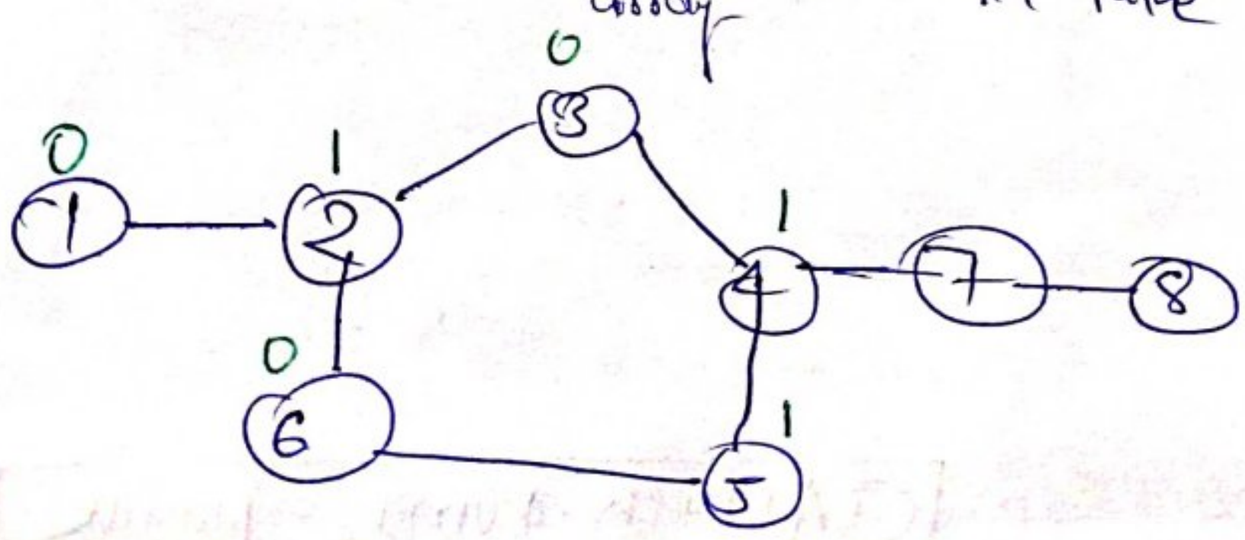
Hence this is not a Bipartite graph.

* Linear graphs with no cycles are always Bipartite graph.

* Any graph with even length cycle can also be Bipartite.
* Any graph with odd length cycle can never be a Bipartite.

We will solve this problem using BFS

& instead of visited array we will take colour array.



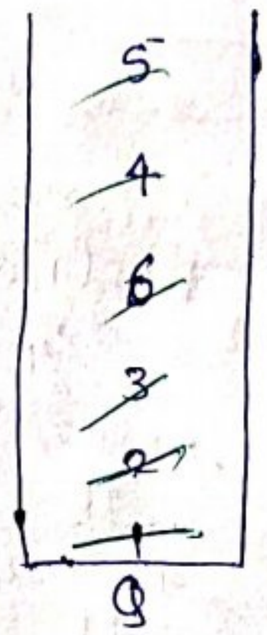
adj. list

1 - {2}
2 - {3, 1}
3 - {2, 4}
4 - {2, 5, 7}
5 - {4, 6}
6 - {2, 5}
7 - {4, 8}
8 - {7}

colour

0	1	2	3	4	5	6	7	8
0	1	-1	-1	-1	-1	-1	-1	-1

node = 4



code :

```
bool cheak( int start , int v , ~~vector<int>~~
vector<int> adj[] , int color[] )
{ queue <int> q;
  q.push (start);
  color[start] = 0;
  while ( !q.empty ())
  {
     int node = q.front();
     q.pop();
     for (auto it : adj[node])
     {  if( color [it] == -1)
        { color[it] = !color [node];
          q.push (it);
        }
     else if( color [it] == color [node])
        { return false;
        }
     }
  }
  return true;
}
bool isBipartite (int v, vector<int> adj[])
{ int color[v];
    for( int i = 0; i<v ; i++)
        color [i] = -1;
  for(int i = 0; i<v; i++)
     { if(color[i] == -1)
       { if( cheak (i, v, adj , color) == false)
         { return false;
         }
       }
     }
  return true;
```

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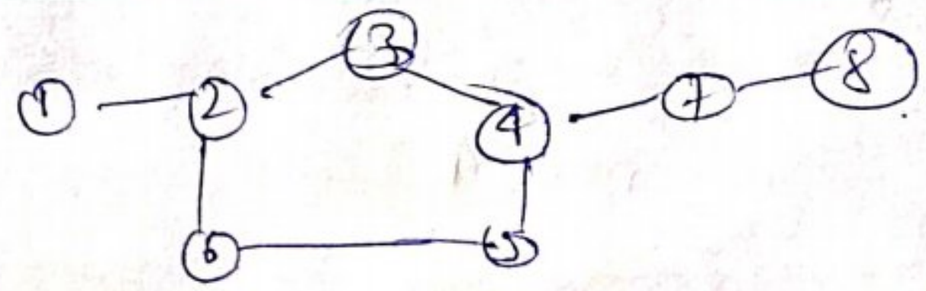
Bipertite Graph using DFS :



node color

DFS (1, 0) → F

↑F

DFS (2, 1)

↑F

DFS (3, 0)

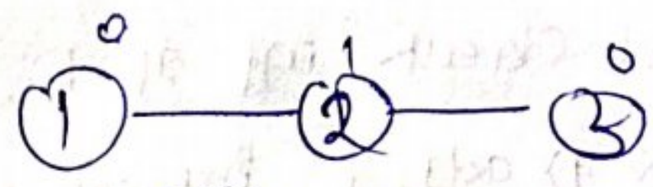
F ↑ ↑F

F ↑ DFS (4, 1) ↑F

F ↑ DFS (7, 0) DFS (5, 0) ↑ False

DFS (6, 1)

DFS (8, 1)



↑ True

DFS (1, 0)

True ↑ ↓

DFS (2, 1)

True ↑ ↓

DFS (3, 0)

DFS Algo

T.C. - O(V+2E)

S.C. - O(V)

color

code :

```
bool dfs(int node, int col, int color[], vector<int> adj[])
{ color[node] = col;
  for(auto it : adj[node])
  {  if(colour[it] == -1)
     {  if(dfs(it, !col, color, adj) == false)
          return false;
     }  else if( color [it] == col)
          {  return false;
          }
  }  return true;
}

bool isBipertite(int V, vector<int> adj[])
{  int color[V];
   for(int i=0; i<V; i++)
      {  color[i]=-1;
   for( int i=0; i<V; i++)
    {  if(color[i] == -1)
         {  if(dfs(i, 0, color, adj) == false)
            {return false;}
         }
    }  return true;
}
```

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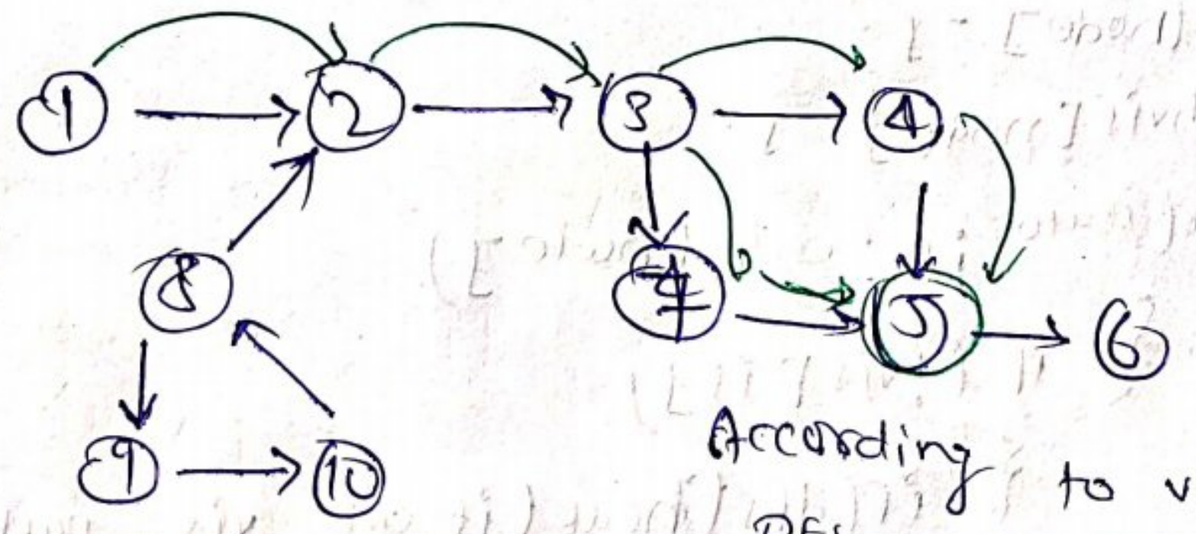
Detect cycle in a directed graph

visited algorithm using the DFS will not work here
this algo will work only in undirected graph

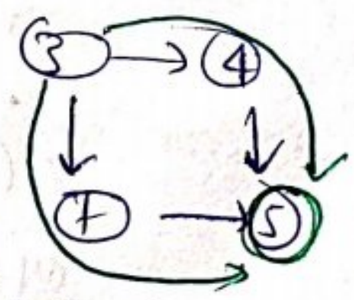
for ex:-



dfs(1)
↓
dfs(2)
↓
dfs(3) → dfs(7)
↓
dfs(4)
↓
dfs(5)

According to visited algo using DFS

This is a cycle but this is not true.



So [on the same path, node has to be visited again]

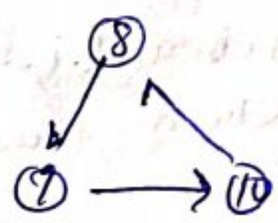
	0	1	2	3	4	5	6	7	8	9	10
vis —	0	1	1	1	1	1	1	1	1	1	1
path vis —		1	1	1	1	1	1	1	1	1	1

when we are returning then make path unvisited visited array.

dfs(1)
↑
dfs(2)
↑
dfs(3)
↑
dfs(4)
↑
dfs(5)
↑
dfs(6)
↑
false

dfs(8)
↓
dfs(9)
↓
dfs(10)
↓
dfs(8)

T T T



1 – 2
2 – 3
3 – 4, 7
4 – 5
5 – 6
6 –
7 – 5
8 – 2, 7
9 – 10
10 – 8

we got 8 which is visited & path visited
return true.

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Code :-

```
bool dfscheak( int node, vector<int> adj[], int vis[], int
pathvis[])
{   vis[node] = 1;
    pathvis[node] = 1;
    for( auto it : adj[node])
    {  if (!vis[it])
        {  if(dfscheak(it, adj, vis, pathvis) == true)
                return true;
        }
        else if (pathvis[it])
        {   return true;
        }
    }
    pathvis[node] = 0;
    return false;
}

bool iscyclic(int v, vector<int> adj[])
{   int vis[v] = {0};
    int pathvis[v] = {0};
    for(int i=0; i<v; i++)
    {   if(!vis[i])
        {  if(dfscheak(i, adj, vis, pathvis) == true)
                return true;
        }
    }
    return false;
}
```

T.C. - $O(V+E)$

S.C. - $O(2N)$
$\approx O(N)$

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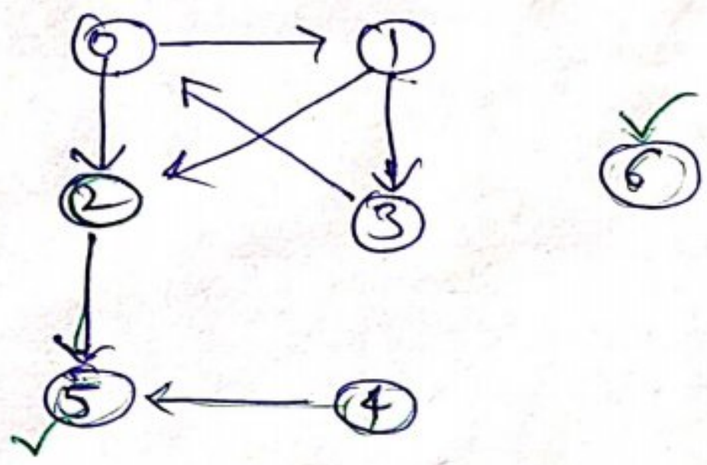
Find Eventual safe states :-



we have to find which are the safe node :-

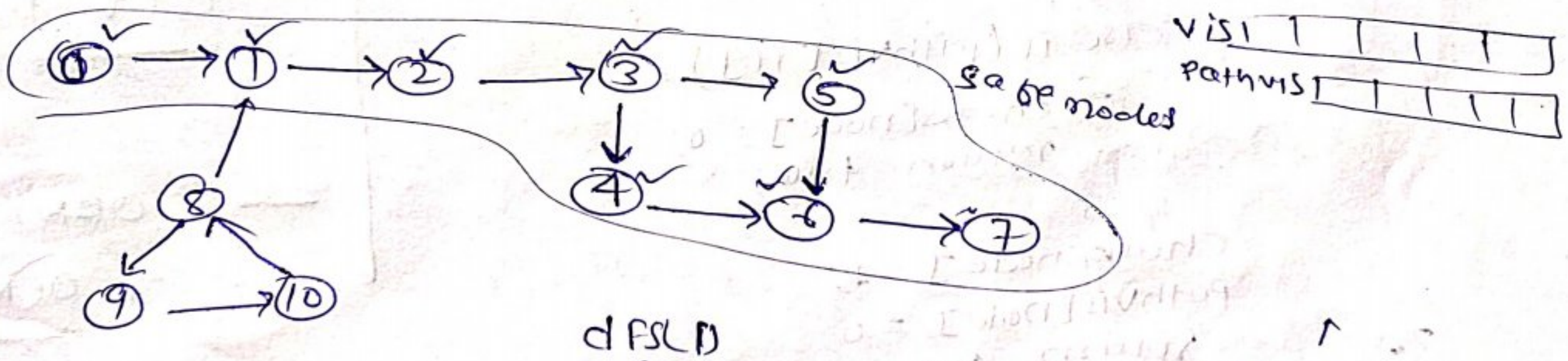
terminal nodes
↳ outdegree ⇒ 0

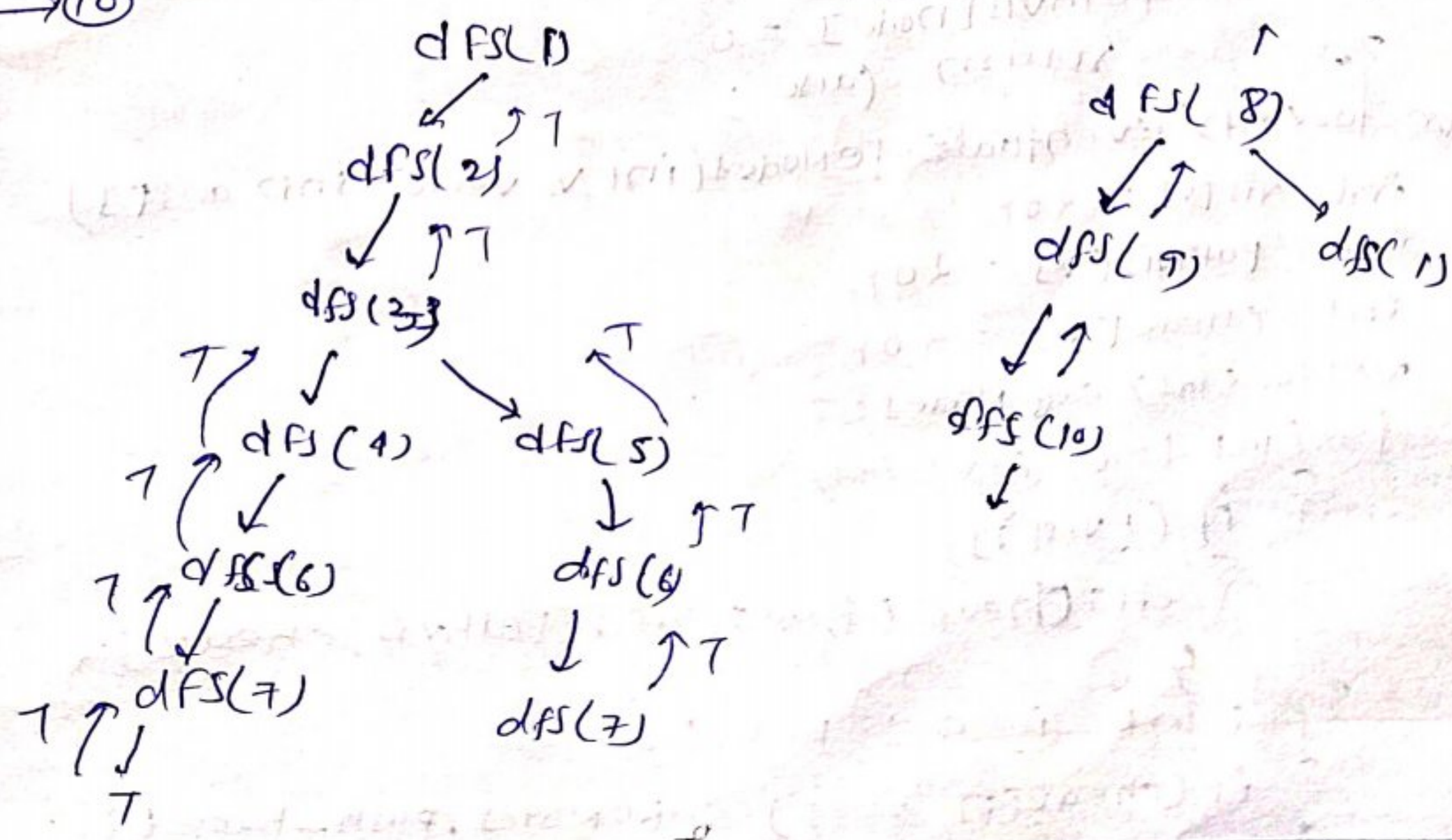
Nodes which are ending at terminal node.

Safe Node arr → [2, 4, 5, 6]

→ Any one who is a part of cycle can not be safe node
→ Any one that leads to a cycle can not be safe node
→ Rest of all are safe nodes

we will solve by cycle detection technique.





@ Aashish Kumar Nayak

Code :

```
bool dfscheak( int node, vector<int> adj[] ,int vis[],
int pathvis[] , int cheak[])
{
    vis[node] = 1;
    pathvis [node] = 1;
    cheak[node] = 0;
    for( auto it : adj[node])
    {
        if(! vis [it])
        {
            if(dfsCheak(it,adj , vis , pathvis ,cheak)
              == true)
            {
                cheak[node] = 0;
                return true;
            }
        }
        else if(pathvis[it])
        {
            cheak[node] = 0;
            return true;
        }
    }
    cheak[node] = 1;
    pathvis[node] = 0;
    return false;
}
vector<int> eventualSafeNodes(int v, vector<int> adj[])
{ int vis[v] = {0};
  int pathvis[v] = {0};
  int cheak[v] = {0};
  vector<int> safeNodes;
  for( int i = 0; i<v; i++)
    { if (! vis[i])
      { dfs(cheak(i,adj, vis , pathvis, cheak);
      }
  }for( int i = 0 ; i<v ; i++)
  { if (cheak[i] == 1) safeNodes.push_back(i);
  }
  return safeNodes;
}
```

T.C. – $O(V+E)$

S.C. – $O(2N)$

$\approx O(N)$

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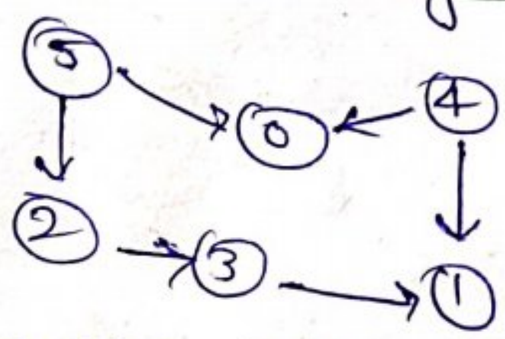
Topological Sort (DFS) :-

(DAG)

↳ linear ordering of vertices such that if there is an edge between u & v, u appears before v in that ordering.



5 4 2 3 1 0

4 5 2 3 1 0

Only possible in (DAG) Directed Acyclic graph

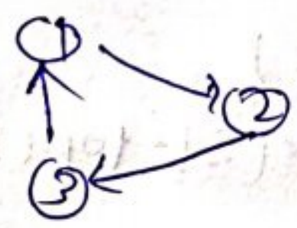
(i) should be directed

(ii) should be no cycle.

① — ②

1 2

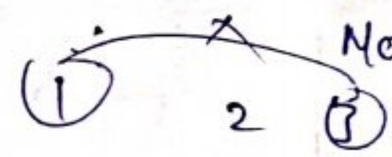
2 1 ✗ not possible



1 — 2

2 — 3

3 — 1

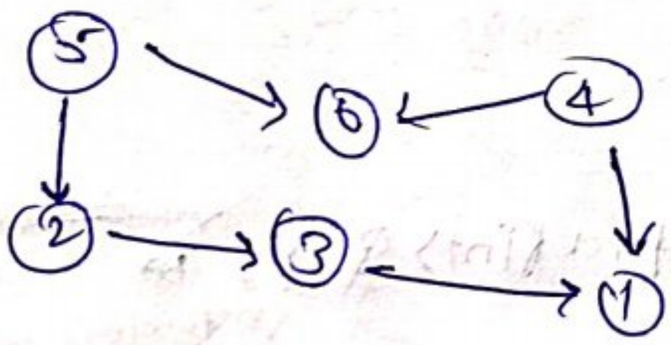


Not possible

1 should be before 3

3 should be before 1

✗ not possible both at same time.



Adjacency list

0 — { }

1 — { }

2 — {3}

3 — {1}

4 — {0, 1}

5 — {0, 2}

VIS | 1 | 1 | 1 | 1 | 1 |

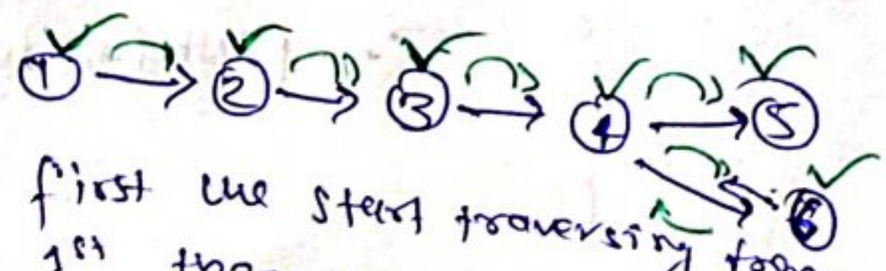
5
4
2
3
1
0

STACK

st.top().

{ 5 4 2 3 1 0 } — Ans

Institution :-



first we start traversing from 1st then we will go till end & when we are returning back at that time we will store it on stack.

2
3
4
5
0

Who's dfs is completed just store it on stack.

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Code :-

```
vector<int> toposort( int V, vector<int> adj[])
{
    int vis[V] = {0};
    stack<int> st;
    for( int i=0; i<V; i++)
    {
        if( !vis[i])
        {
            dfs( i, vis, st, adj);
        }
    }
    vector<int> ans;
    while( !st.empty())
    {
        ans.push_back(st.top());
        st.pop();
    }
    return ans;
}

void dfs( int node, int vis[], stack<int> &st, vector<int> adj[])
{
    vis[node] = 1;
    for (auto it : adj[node]).
        {if(!vis[it]) .
            {dfs(it, vis, st, adj);
            }
        }
    st.push(node);
}
```

S.C. . $\underset{vis}{O(N)} + \underset{stack}{O(N)}$

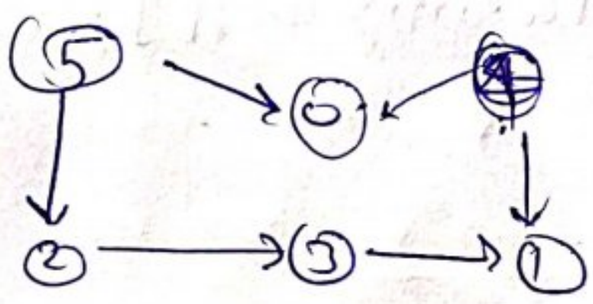
$\approx O(N)$

T.C. - $O(V + E)$

directed graph

@Aashish Kumar Nayak

Kahn's Algorithm (Topological sort) :-

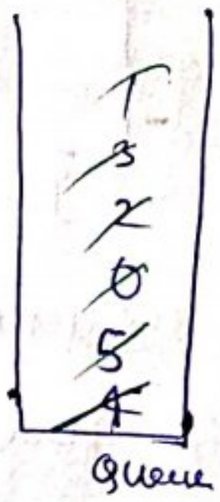


we will use queue & indegree array

Indegree

0	1	2	3	4	5
~~2~~ 1	~~2~~ 1	~~1~~ 0	~~0~~ 1	0	0

There is no element which comes to 4 & 5 Indegree = 0
so we can place 4, 5 in starting



Step 1 :- Insert all nodes with Indegree 0

Step 2 :- take them out of the queue.

Step 3 :- Remove the degree of adjacent nodes.

How we find indegree
we can do that from adj list.

2 → 3 it means indegree of 3 is 1
so we will increase ++ indegree.

0 → { }
1 → { }
2 → {3}
3 → {1}
4 → {0,1}
5 → {0,2}

@Aashish Kumar Nayak

Code :

```
vector<int> toposort(int v, vector<int> adj[])
{ int degree[v] = {0};
  for(int i=0; i<v; i++)
    {
      for(auto it: adj[i])
        {
          indegree[it]++;
        }
    }

  queue<int> q;
  for(int i=0; i<v; i++)
      {if(indegree[i] == 0)
          { q.push(i);
          }
      }
  vector<int> topo;
  while(!q.empty())
  {
    int node = q.front();
    q.pop();
    topo.push_back(node);

    for(auto it: adj[node])
    {
      indegree[it]--;
      if(indegree[it] == 0)
          q.push(it);
    }
  }
  return topo;
}
```

T.C. $O(V+E)$

S.C. $\underbrace{O(N)}_{\text{indegree}} + \underbrace{O(N)}_{\text{queue}}$

$\approx O(N)$

@Aashish Kumar Nayak

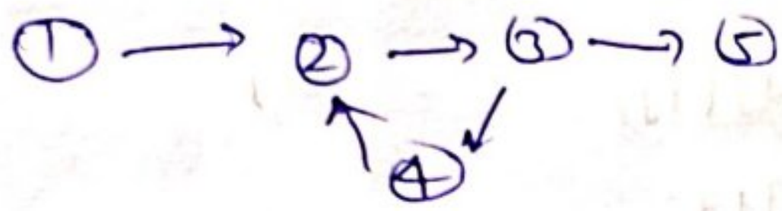
Detect a cycle in directed graph using topological sort → BFS

in previous com we used vis, pathvisited and when we were returning then we reseting the pathvisitid array.

But in BFS we can't do that like backtracking

So we use Kahn's Algo

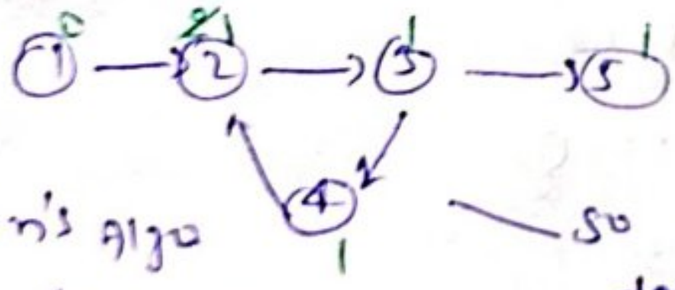
This is a direct cyclic graph



1 — 2
2 — 3
3 — 4, 5
4 — 2
5 — 4

Toposort is only applicable for DAG

lets try to find out the topological sort for this Direct cyclic graph



Kahn's Algo
indegree queue
reduce indegree

so for this toposort will be

$\boxed{1}$

So if Toposort has N elements then it must be DAG

& if Toposort has less than N element than it must have cycle.

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Code:- Code is same as Kahn's Algo

we will just ~~take~~ check size of toposort array in last if size of toposort == N then there is no cycle ~~or~~ and if size is less than V then there is cycle.

```
bool isCycle(int V, vector<int> adj[])
{ int indegree[V] = {0};
  for(int i=0; i<V; i++)
    {  for(auto it: adj[i])
        {  indegree[it]++;
        }
    }
  Queue<int> q;
  for(int i=0; i<V; i++)
      {  if(indegree[i] == 0)
           q.push(i);
      }
  }
  int cnt=0;
while( !q.empty())
  {  int node = q.front();
     q.pop();
     cnt++;
  for( auto it: adj[node])
     {  indegree[it]--;
     if( indegree[it] ==0)
          q.push(it);
     }
  }
  if( cnt == V)
     return false;
return true;
}
```

T.C. - O(V+E)

S.C. - O(N)

@Aashish Kumar Nayak

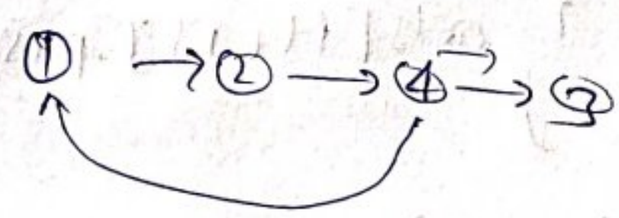
Course schedule - I & II

pre requisite task

[1, 0]
[2, 1]
[3, 2]

3 2 1 0 Yes

[1, 2]
[4, 3]
[3, 4]
[4, 1]



No

This is happing ~~Bea~~ because cycle is present.

We can use topological sort.

$u \rightarrow v$ (u, v)

u must have before v

Topo sort

Direct & Acyclic

Code

```
bool isPossible(int v, vector<pair<int,int>> &prerequisites)
{
    vector<int> adj[v];
    for(auto it: prerequisites)
    {   adj[it.first].push_back(it.second);
    }
    int indegree[v]={0};
    for(int i=0; i<v; i++){ for (auto it: adj[i])
                            { indegree[it]++;
                            }
                           }
    queue<int> q;
    for(int i=0; i<v; i++)
    { if(indegree[i] == 0)
      { q.push(i);
    } }
    vector<int> topo;
    while(!q.empty())
    { int node = q.front();
      q.pop();
      topo.push_back(node);
      for(auto it: adj[node])
      { indegree[it]--;
          if(indegree[it] ==0)
          q.push(it);
    } }
    if(topo.size() == v) return true;
    return false;
}
```

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Course schedule :-

Code

```
vector<int> findOrder(int V, int m, vector<vector<int>> & prerequisites)
{ ~~for(~~ vector<int> adj[V];
    for( auto it : prerequisites)
    {
      adj[it[1]].push_back(it[0]);
    }

  ~~for(~~ int indegree[V] = {0};
    for(int i=0; i<V; i++)
    {
      for(auto it : adj[V])
      {
        indegree[it] ++;
      }
    }
  Queue<int> q;
    for( int i=0; i<V; i++)
    { if( indegree[i] == 0)
      { q.push(i);
    }}
    vector<int> topo;
  while( !q.empty())
    { int node = q.front();
      q.pop();
      topo.push_back(node);

      for(auto it : adj[node])
        { indegree--;
          if(indegree[it] == 0) q.push(it);
      }}
      if(topo.size() == V) return topo;
      ~~ret~~
      return {};
}
```

***
Something is before something
use topo sort in these kind of problem.

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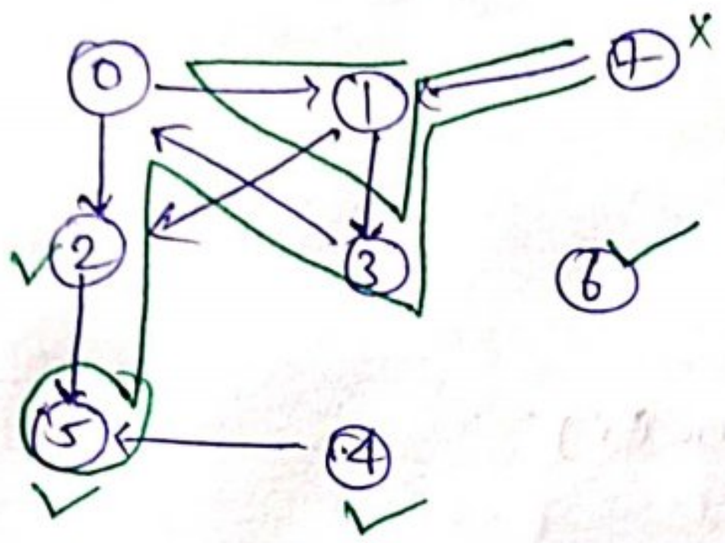
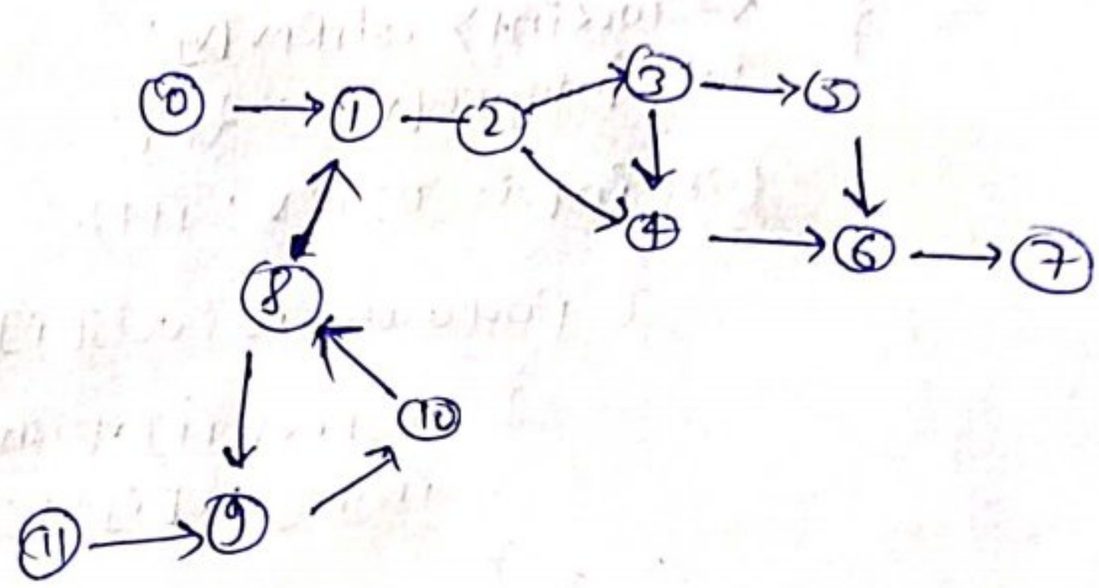
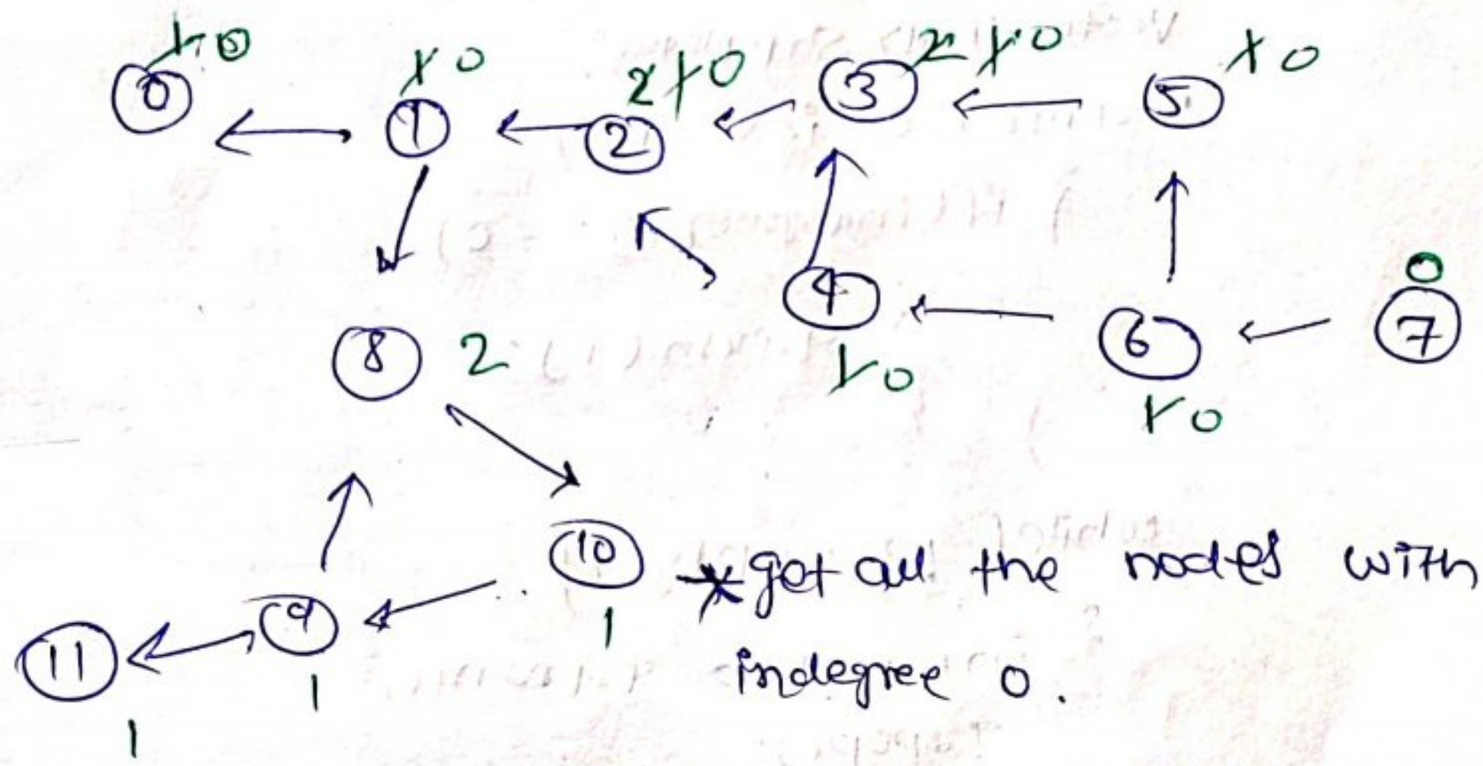
Eventual safe states using BFS Topo sort





→ Reverse all the edges



~~0~~
~~1~~
~~2~~
~~3~~
~~4~~
~~5~~
~~6~~
~~7~~

* get all the nodes with indegree 0.

* do a ~~traversal~~ removal of edges on adjacent nodes.

Safe Node :- 7 6 5 4 3 2 1 0

then we will sort the safe node array.

then return

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Code :-

```
vector<int> eventualSafeNodes(int V, vector<int> adj[])
{
    vector<int> adjRev[V];
    int indegree[V] = {0};
    for(int i = 0; i<V; i++)
        {  for(auto it : adj[i])
            {  adjRev[it].push_back(i);
               indegree[i]++;
            }  }
    queue<int> q;
    vector<int> SafeNodes;
    for(int i=0; i<V; i++)
        {  if(indegree[i] == 0)
                {  q.push(i);
        }  }
    while( !q.empty())
        {  int node = q.front();
           q.pop();
           SafeNodes.push_back(node);
           for(auto it : adjRev[node])
               {  indegree[it]--;
                  if(indegree[it] == 0)
                      q.push(it);
               }
        }
    sort(SafeNodes.begin(), SafeNodes.end());
    return SafeNodes;
}
```

T.C. - $O(V+E)$ + $O(V\log V)$ sorting

S.C. - $\sim O(V)$

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Alien Dictionary | Topological sort

Alien

baa
abcd
abca
cab
cad

Normal a b c d e f g h - - -

abca
a comes before b: abcd, baa
b comes before c: cab, cad

~~find the order~~ find out the alien order?

~~b a c~~ [b d a c] Alien order

*** This question says something before something so use Topological sort.

i = 0

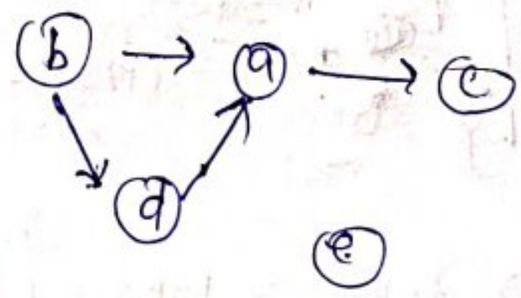
baa
abcd
abca
cab
cad

figure out where char is not equal and then make DG according to that

K = 5

a	b	c	d	c
0	1	2	3	4

[b d a c] — Toposort return ans



i =

s_1 = arr[i];

s_2 = arr[i+1];

compare s_1 & s_2

if we got unequal char then make Directed graph

then after completing the graph. We will do toposort then return the toposort.

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* what if order is not possible. like abcd $-s_1$
abc $-s_2$

if the largest string is before smallest string and every character of small string is matches then its wrong dictionary.

* And also when there is cyclic dependency

ex:-

wrong dictionary $a \rightarrow b$

$a < b$ — a b c
b a f
a d e

$\times$ $b < a$
not possible

```
String findOrder( string dict[], int N, int K)
{   vector<int> adj[K];
    for( int i=0; i<N-1; i++)
    {   string s1 = dict[i];
        string s2 = dict[i+1];
        ~~for~~ int len = min(s1.size(), s2.size());
        for( int ptr=0; ptr<len; ptr++)
        {   if( s1[ptr] != s2[ptr] )
            {   ~~adj[s1[ptr]].push_back(s2[ptr]);~~
                ~~break;~~
                adj[s1[ptr]-'a'].push_back(s2[ptr]-'a');
                break;
            }
        }
    }
    vector<int> topo = toposort( K, adj);
    string ans = "";
    for( auto it : topo)
    {   ans = ans + char( it + 'a');
    }
    return ans;
}
```

(n = no. of string, K = total char.)

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```
vector<int> topo sort( int v, vector <int> adj [])
{   int indegree [v] ={0};
    for( int i=0; i<v; i++)
    { for(auto it : adj[i])
        {   indegree [it] ++;
        }
    }

    queue< int > q;
    for(int i=0; i<v; i++)
      } if(indegree [i] == 0)
          { q.push(i);
      } }
    vector<int> topo;
    while(!q.empty())
      { int node = q.front();
        q.pop();
        topo.push_back( node);

        for(auto it : adj[node] )
        { indegree[it]--;
          if( indegree [it] == 0)
              q.push(it);
        }
    }

    return topo;
}
```

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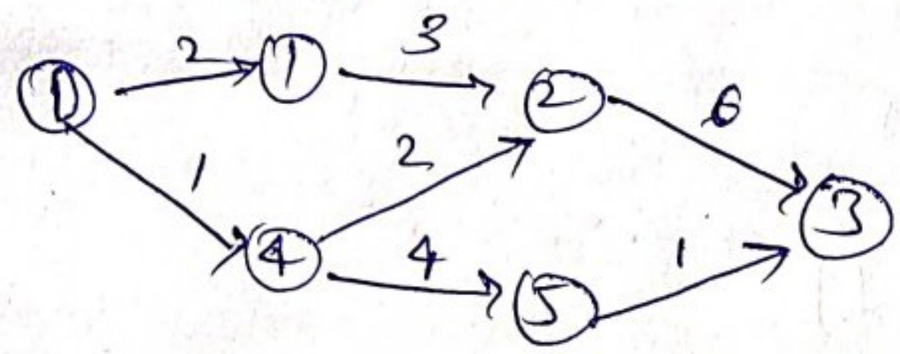
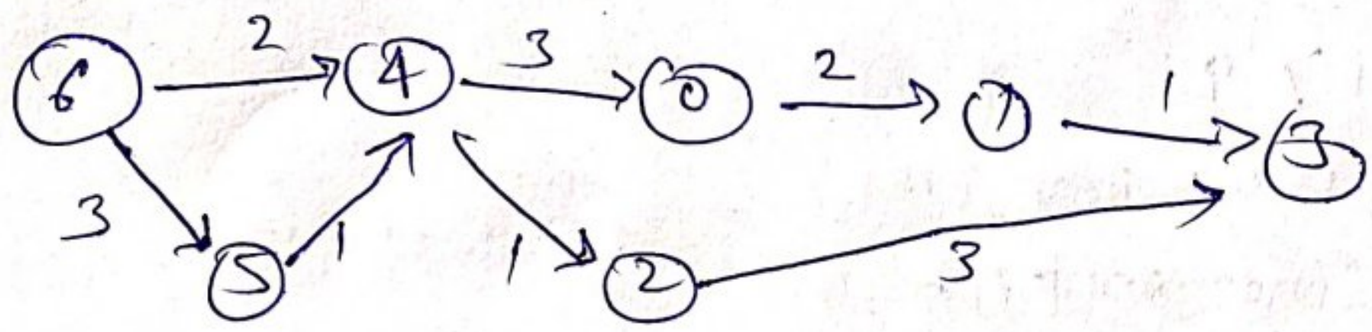
~~Sor~~ Shortest path in Directed Acyclic Graph:-

Topological sort:-



We have to print the shortest distance for all nodes from 0 node in an array. ~~and ret.~~



adj list:-

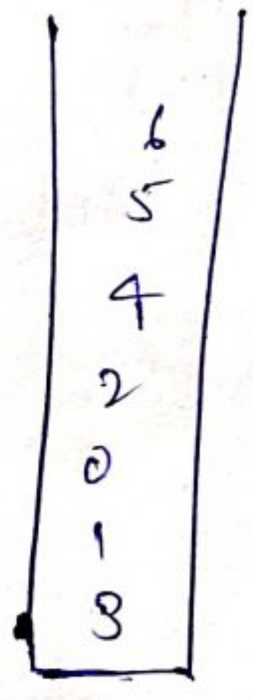
node
weight

0 - {1,2}
1 - {3,1}
2 - {3,3}
3 -
4 - {0,3}, {2,1}
5 - {4,1}
6 - {4,2} {5,3}

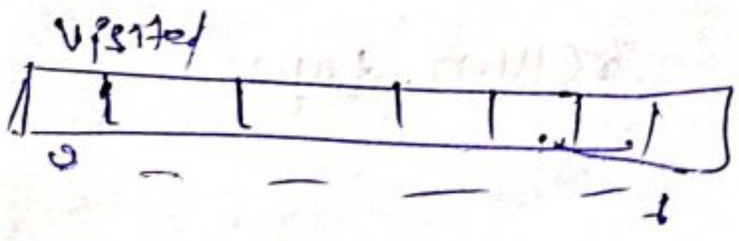
Step 1:- Do a toposort on the graph.

DFS ways
BFS ways

DFS Method



this stack will store the toposort



6 | 5 | 4 | 2 | 0 | 1 | 3

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Step 2:- take the nodes out of stack and relax the edges.

node = 6 , dist = 0

+3 ↓ node = 5, dist = 3

↓ node = 4

dist[] = | 5 | 7 | 3 | 6 | 2 | 3 | 0 |
0 1 2 3 4 5 6

node = 5 , dist = 3

+1 ↓ node = 4, dist = 4

5 → {4, 1}

Code:-

```
vector<int> shortestPath ( int N , int M, vector<int> edges[])
{ vector<pair<int, int>> adj[N];
  for( int i= 0; i<M; i++)
  {  int u = edges[i][0];
     int v= edges[i][1];
     int wt= edges[i][2];
     adj[u].push_back({v , wt});
  }
  int vis[N] = {0};
  stack<int> st;
  for(int i=0; i<N; i++)
    { dist[i] = Ieg; }
  dist[0] = 0;
  while( !st.empty())
    { int node = st.top();
      st.pop();
      for(auto it : adj[node])
      { int v = it.first;
        int wt = it.second;
        if(dist[node] + wt < dist[v])
        { dist[v] = dist[node] + wt;
        }
      }
    }
  return dist;
}
```

```
for(int i=0 ; i<N ; i++ )
  { if( !vis[i])
      { toposort(i,adj, vis,st);
      }
  }
```

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```
void toposort(int node, vector<pair<int,int>> adj[],
int vis[], stack<int> & st)
{
    vis[node] = 1;
    for(auto it: adj[node])
    {
        int v = it.first;
        if(!vis[v])
        {
            toposort(v, adj, vis, st);
        }
    }
    st.push(node);
}
```

T.C. $\approx O(N+M)$

S.C. $\approx O(N)$

intuition:

Finding the shortest path to a vertex is easy if you already know the shortest path of all the vertices that can precede it. Finding the longest path to a vertex in DAG is easy if you already know the longest path to all the vertices that can precede it.

Processing the vertices in topological order ensures that by the time you get to a vertex, you have already processed all the vertices that can precede it.

Dijkstra's algorithm is necessary for graphs that can contain cycles, because they can't be topological sorted.

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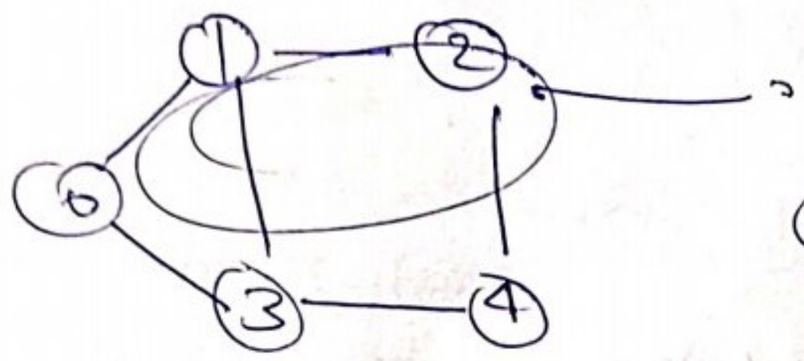
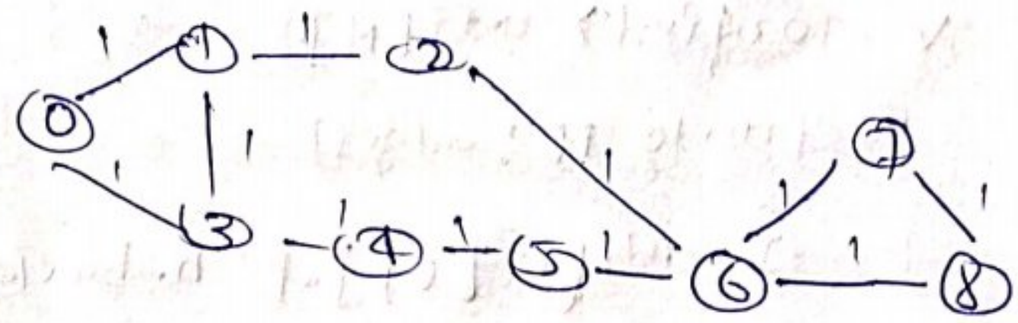
Shortest path in undirected graph having unit distance :-





	0	1	2	3	4	5	6	7	8
dist →	0	1	2	1	2	3	3	4	4

1 < 2 so no updation

0 — 1, 3
1 — 0, 2, 3
2 — 1, 6
3 — 0, 4
4 — 3, 5
5 — 4, 6
6 — 2, 5, 7, 8
7 — 6, 8
8 — 6, 7

node = 0 dist = 0

node = 1, dist = 1 (+1)
node = 3, dist = 1 (+1)

node = 1, dist = 1

node 0, dist = 2 (+1)
node 2, dist = 2 (+1)
node 3, dist = 2 (+1)

discarded

Queue {node, dist}

~~{8,4}~~
~~{7,4}~~
~~{5,3}~~
~~{6,3}~~
~~{4,2}~~
~~{2,2}~~
~~{3,1}~~
~~{1,1}~~
~~{0,0}~~

we are looking for shortest path

node = 3, dist = 1

node = 0, dist = 2 (+1)
node = 4, dist = 2 (+1)

node = 2, dist = 2

node = 1, dist = 3
node = 6, dist = 3

node = 4 dist = 3

node	3	5
dist	3	3

node = 6, dist = 3

node	2	5	7	8
dist	4	4	4	4

node = 5, dist = 3

node	4	6
dist	4	4

node = 7, dist = 4

node	6	8
dist	5	5

node = 8, dist = 4

node	6	7
dist	5	5

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Code :-

```
vector<int> shortestPath(vector<vector<int>> &edges, int N,
int M, int src)
{   vector<int> adj[N];
    for(auto it : edges)
        {  adj[it[0]].push_back(it[1]);
           adj[it[1]].push_back(it[0]);
        }
    int dist[N];
    for (int i=0; i<N; i++)
        {  dist[i] = 1e9;
        }
    dist[src] = 0;
    queue<int> q;
    q.push(src);
    while(!q.empty())
        {  int node = q.front();
           q.pop();
           for(auto it : adj[node])
           {  if(dist[node] + 1 < dist[it])
              {  dist[it] = 1 + dist[node];
                 q.push(it);
              }
           }
        }
    vector<int> ans (N, -1);
    for(int i = 0; i<N; i++)
        {  if( dist[i] != 1e9)
           {  ans[i] = dist[i];
           }
        }
    return ans;
}
```

T.C. - BFS algo
$\approx O(V+2E)$

S.C. $\approx O(N)$

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WORD Ladder - I

Hard problem

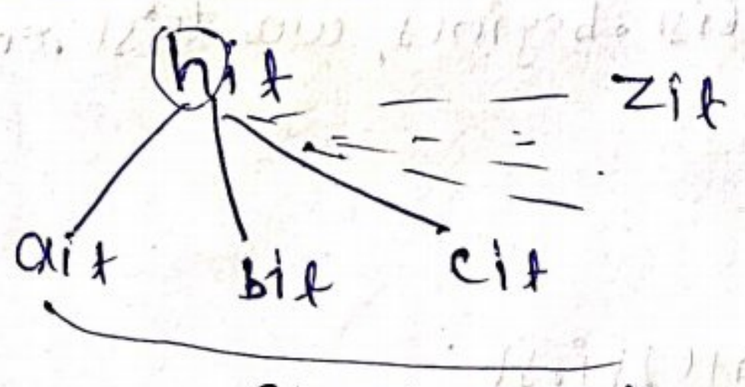
begin word = "hit" endword = "cog"

wordlist = [hot, dot, dog, lot, log, cog]

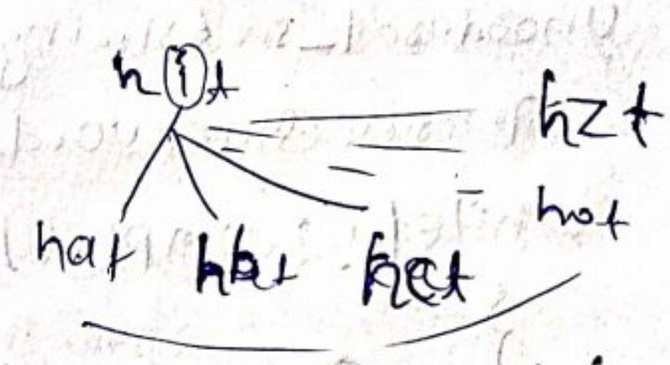
hit → hot → dot → dog → log

Minimum no. of transformation

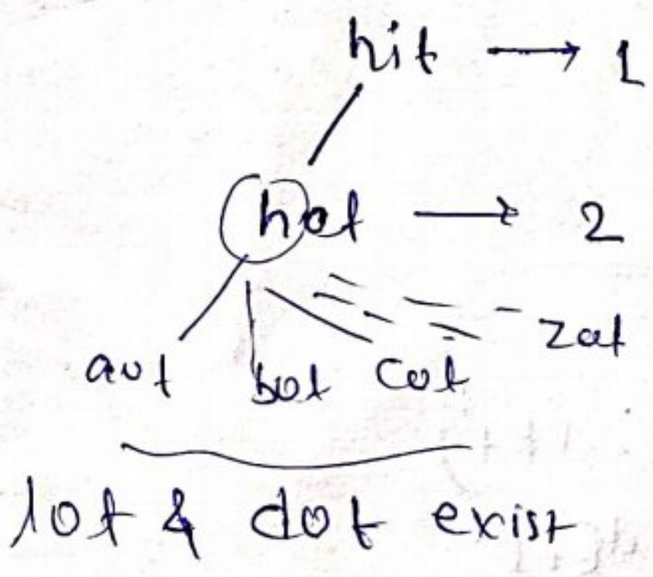
Brute Force

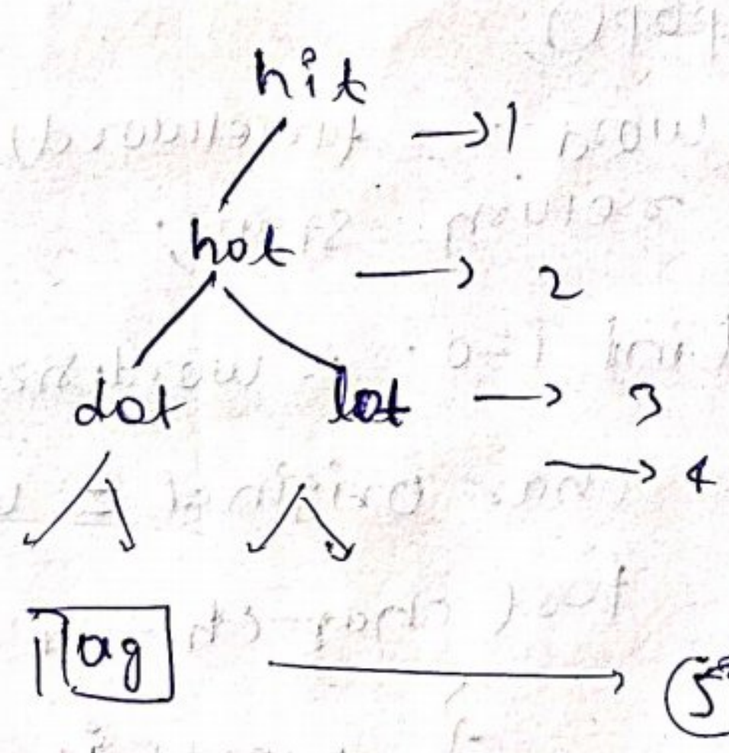


check all in word list



check all.
we got hot





BFS

hit, 1
ait
bit
zit
hit

hat
hbt
hct
⋮
hot — 2

hot, 2
bot
cot
dot, 3
lot, 3
zot

lot, 3

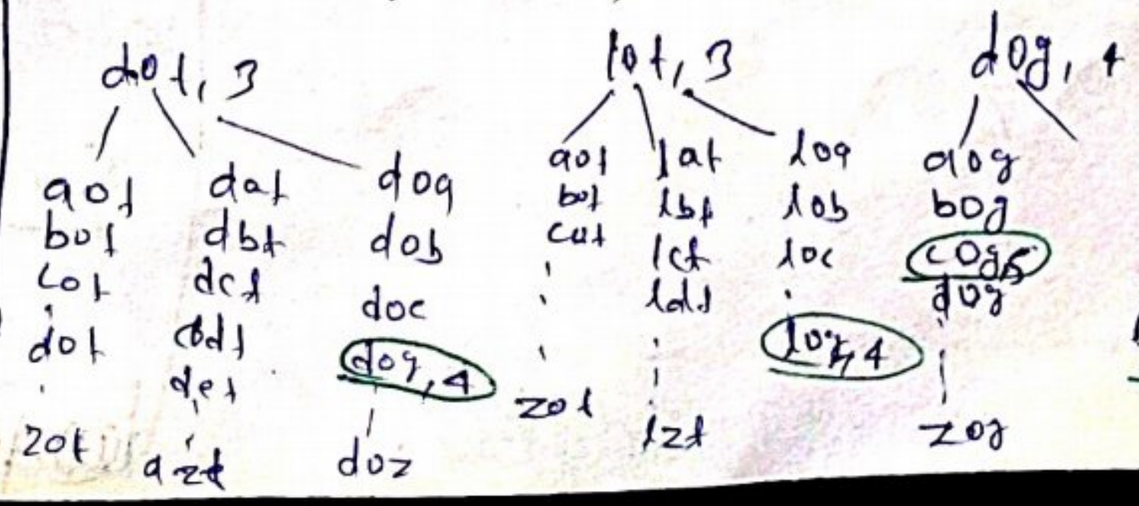
~~cog, 5~~
~~log, 4~~
~~dog, 4~~
~~lot, 3~~
~~dot, 3~~
~~hot, 2~~
~~hit, 1~~

Queue

we will remove words from wordlist when we will get word.

and ~~suppose~~ we got same word in next iteration we will not take it.

[~~hot~~, ~~dot~~, ~~dog~~, ~~lot~~, ~~log~~, cog] — now we can stop



Ans = 5

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Scanned with OKEN Scanner

Code :-

```
int wordLadderLength( string startword, string ~~end~~ targetword,
vector<string> & wordlist)
{ queue<pair<string, int>> q;
    q.push({ startword, 1 });
  unoodered_set<string> st(wordlist.begin(), wordlist.end());
    st.erase(startword);
  while(!q.empty())
  {
      string word = q.front().first;
      int steps = q.front().second;
       q.pop();
       if(word == targetword)
          return steps;
      for(int i=0; i< word.size(); i++)
      {
        char original = word[i];
        for( char ch = 'a'; ch <= 'z'; ch++)
        {
            word[i] = ch;
        if( st.find(word) != st.end())
        {
            st.erase(word);
            q.push({word, steps+1});
        }
        }
        word[i] = original;
  }
  return 0;
}
```

set

T.C. O(N * word.length * 26 * log N)

S.C O(N)

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Word Ladder II

Hard

begining word = bat end word = coz

wordlist = [~~pat~~, ~~bot~~, pot, poz, coz]

bat → pat → pot → poz → coz

bat → bot → pot → poz → coz

[~~pat~~, ~~bot~~, ~~pot~~, ~~poz~~, coz]

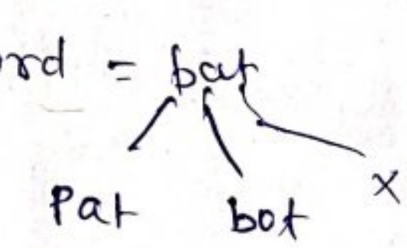
Erase only when entire level completed.

ans list

{bat, bot, pot, poz, coz}	5
~~{bat, pat, pot, poz, coz}~~	
~~{bat, bot, pot, poz}~~	4
~~{bat, pat, pot, poz}~~	
~~{bat, bot, pot}~~	3
~~{bat, pat, pot}~~	
~~{bat, bot}~~	2
~~{bat, pat}~~	
~~{bat}~~	1

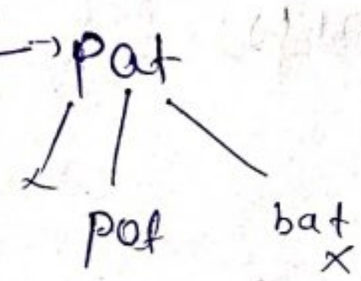
level

{bat} word = bat

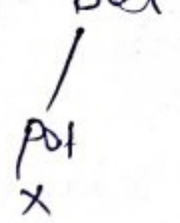


{bat, pat}

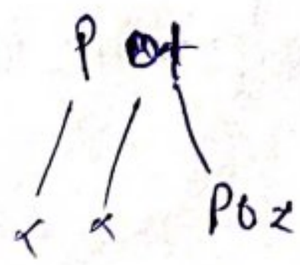
next word → pat



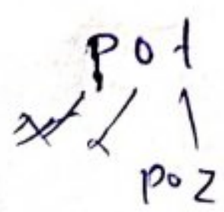
{bat, bot} —— bot



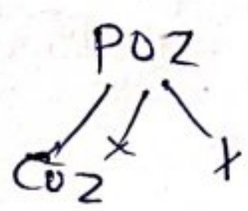
{bat, pat, pot}



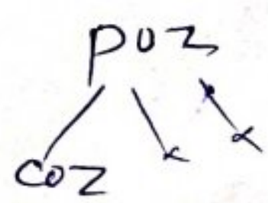
{bat, bot, pot}



{bat, pat, pot, poz} ——



{bat, bot, pot, poz}



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Scanned with OKEN Scanner

Code:-

```
vector<vector<string>> findSequence(string beginword, string endword
    vector<string>&wordlist)
{ unordered_set<string> st(wordlist.begin(), wordlist.end());
    queue<vector<string>> q;
      ~~vector<string> used~~
      q.push({beginword});
      vector<string> usedonlevel;
      usedonlevel.push_back(beginword);
      int level=0;
      vector<vector<strings>> ans;
      while(!q.empty())
        { vector<string> vec = q.front();
          q.pop();
          if(vec.size() > level)
            { level++;
              for(auto it : usedonlevel)
                { st.erase(it);
              usedonlevel.clear();
            }
          string word = vec.back();
          if(word == endword)
            { if(ans.size() == 0)
                { ans.push_back(vec);
              else if(ans[0].size() == vec.size())
                { ans.push_back(vec);
            }
```

(1)

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```
for(int i=0; i<word.size(); i++)
{ char original = word[i];
  for(char ch='a'; ch<='z'; ch++)
  {
    word[i] = ch;
    if(st.count(word) > 0)
    {
      vec.push_back(word);
      q.push(vec);
      usedOnLevel.push_back(word);
      vec.pop_back();
    }
    word[i] = original;
  }
}
return ans;
}
```

This soln will not work on leetcode (T.L.E) but it is fine and acceptable in interview.

T.C. It will vary with different examples. it is next to impossible to find T.C. of this code.

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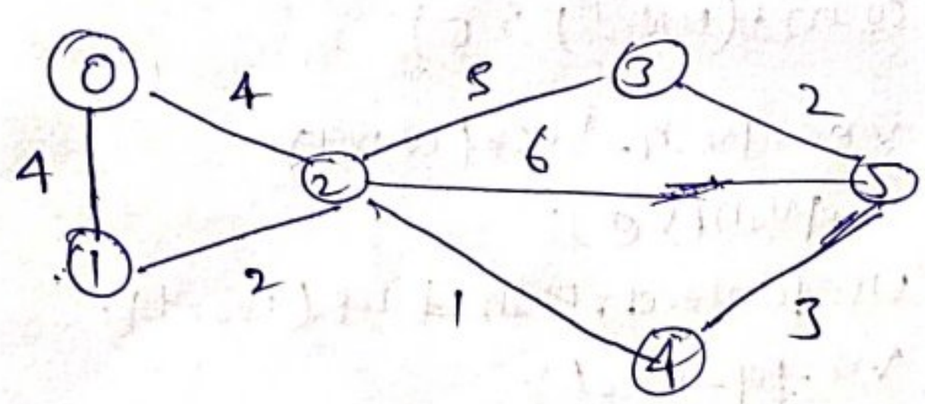
~~Word ladder~~ : II (optimised approach)
only for CP

DIJKSTRA'S ALGORITHM (using priority queue)

we always wanted minimum distance at 1st.

Reason for using Priority-queue

Dijkstra's Algorithm → shortest path



Adj list

node weight

0 → {1,4}, {2,4}
1 → {0,4} {2,2}
2 → {0,4}, {1,2}, {3,3}, {4,1} {5,6}
3 → {2,3}, {5,2}
4 → {2,1}, {5,3}
5 → {2,6}, {3,2}, {4,3}

0 → 0 d=0
→ 1 d=4
2 d=4
3

There is two methods in Dijkstra's Algo
① priority queue take less time
② Set — fastest
③ queue — ✗ take much time

min heap
{dist, nodes}

~~{8,5}~~
~~{10,5}~~
~~{5,4}~~
~~{7,3}~~
~~{4,2}~~
~~{4,1}~~
~~{0,0}~~

d=0 node = 0
node 1 2
distance = 0+4 0+4

d=4 node = 1
node 0 2 5
dist 4+4 =8 4+2 =6

dist=4 node = 2
node 5 0 1 3 4
dist 4+6 =10 4+4 =8 4+2 =6 3+4 =7 1+4 =5

dist 0 4 4 7 5 10
0 1 2 3 4 5

node = 4 dist = 5
node 2 5
dist = 5+4 =9 5+3 =8

dist = 7 node = 3
node 2 5
dist 7+3 =10 7+2 =9

dist = 8 node = 5
node 2 3 4
dist 14 10 17

dist = 10
node = 5
2 5 4
16 12 13

@Aashish Kumar Nayak return dist; Ans

Code :

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~~vector<int> dijkstra(int v, vector<vector<pair<int,int>>>~~

```
vector<int> dijkstra( int v , vector<vector<int>> adj[ ], int s)
{ priority_queue<pair<int, int>, vector<pair<int, int>>,
    greater<pair<int, int>> pq;

    vector<int> dist(v);
    for(int i=0; i<v; i++)
        dist[i]=1e9;
    dist[s] = 0;
    pq.push({0, s});
    while (!pq.empty())
    { int dis = pq.top().first;
      int node = pq.top().second;
      pq.pop();

      for(auto it : adj[node])
      { int edgeweight = it[1];
        int adjNode = it[0];
        if ( dis + edgeweight < dist[adjNode])
        {  dist [adjNode] = dis + edgeweight;
           pq.push({ dist[adjNode], adjNode});
        }
      }
    }
    return dist;
}
```

T.C. $E \log V$

edges, nodes

* Dijkstra does not works in → negative weight
→ negative cycle

(0) —(-2)— (1)

dist	0	~~-2~~
	0	1

-2
-4

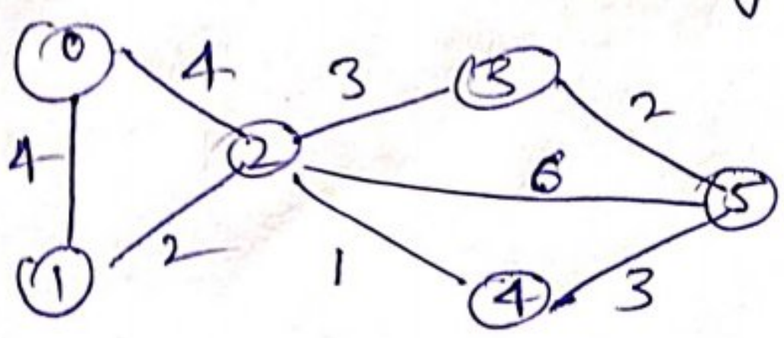
Infinite loop

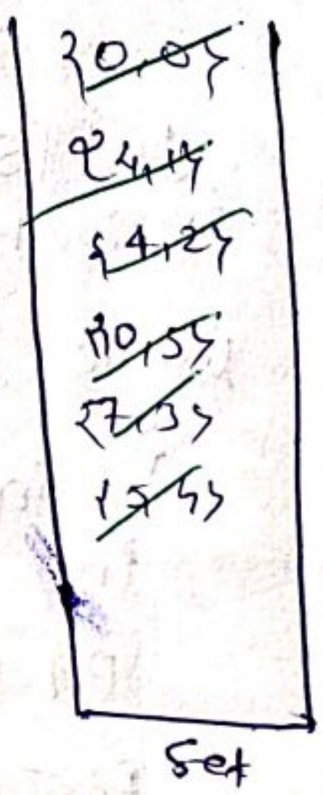
Dijkstra's is applicable for +ve weights.

Dijkstra's Algorithm (using set) :-

We always wanted minimum distance at first, so we used priority_queue in previous approach.

Set :- set stores unique value and smallest value at the top (ascending order)





node = 0 $\xrightarrow{+4}$ node = 1, d = 4

node = 0 $\xrightarrow{+4}$ node = 2, d = 4

node = 1, dist = 4 $\xrightarrow{+4}$ node = 0, d = 8

node = 1, dist = 4 $\xrightarrow{+2}$ node = 2, d = 6

node = 4, d = 5 $\xrightarrow{+1}$ node = 2, d = 6

node = 4, d = 5 $\xrightarrow{+3}$ node = 5, d = 8

{dist, node}

dist[] =

0	4	4	7	5	10
0	1	2	3	4	5

st.erase(); — Logn

But we are saving iterations

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Code :-

```
vector<int> dijkstra's (int v, vector<vector<int>> adj[], int s)
{ set<pair<int, int>> st;
  vector<int> dist (v, 1e9);
    st.insert({0, s});
    dist[s] = 0;

  while (!st.empty())
  {
    auto it = *(st.begin());
    int node = it.second;
    int dis = it.first;
    st.erase(it);

    for (auto it : adj[node])
    {
        int adjNode = it[0];
        int edgW = it[1];

        if(dis + edgW < dist[adjNode])
        {
            if (dist[adjNode] != 1e9)
              st.erase({dist[adjNode], adjNode});
            dist[adjNode] = dis + edgW;
            st.insert({dist[adjNode], adjNode});
        }
    }
  }
  return dist;
}
```

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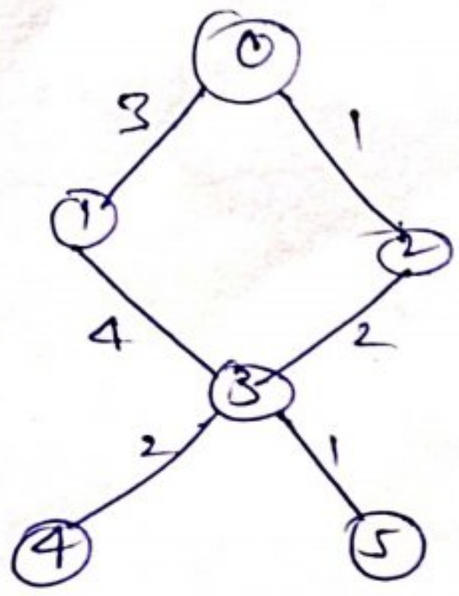
Dijkstra's Algorithm

Why PQ and not Q, intution, Time Complexity Derivation

TIME complexity $O(E \log V)$



dist[]

0	1	2	3	4	5
0	3	1	7	4	8

0 → {1,3} {2,1}
1 → {0,3} {3,4}
2 → {0,1} {3,2}
3 → {1,4} {2,2} {4,2} {5,1}
4 → {3,2}
5 → {3,1}

Queue.
{4,5} (+1) unnecessary occurance
{5,4}
{8,5}
{9,4}
~~{3,7}~~
~~{7,3}~~
{1,2}
~~{3,1}~~
~~{0,0}~~

{dist, node}

node = 0
d = 0
+3 → node = 1, d = 3
+1 → node = 2, d = 1

node = 1
d = 3
+0 → node = 0, d = 3 ×
+4 → node = 3, d = 7

node = 2
d = 1
1 → node = 0, d = 2
2 → node = 3, d = 3

node = 3
d = 7
4 → node 1, d = 11 ×
2 → 2, 9 ×
2 → 4, 9
1 → 5, 8

node = 3
d = 3

* if we are using Q it means we are doing Brute force we are traversing all the path.
* in set or priority queue its like we are using greedy algo.

Q will take lot mor time complexity.

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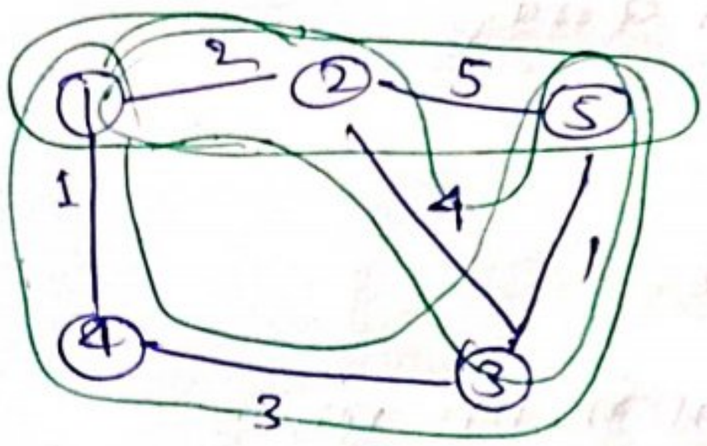
if we use priority-queue we explore minimal-minimal-minimal - - - - - -

T.C. $E \log V$

E → no. of edges, V → no. of nodes

Print shortest path - Dijkstra's Algorithm :-



src = 1
dst = 5

3 paths -

	sum
1 - 2 - 5	= 7
1 - 2 - 3 - 5	= 7
1 - 4 - 3 - 5	5 ✓ shortest path

we need to print path

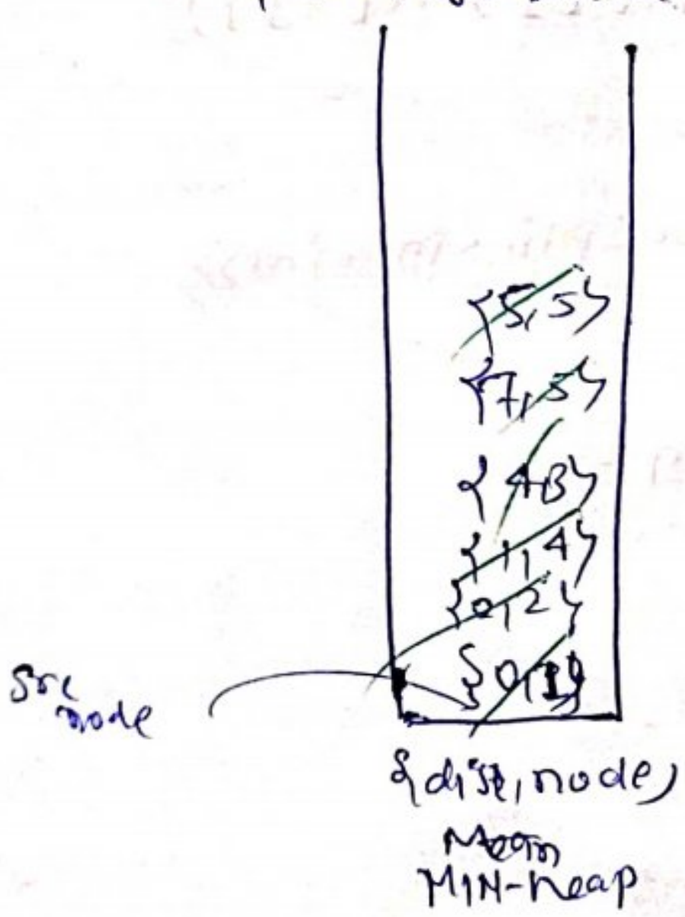
$\boxed{1 - 4 - 3 - 5}$

HINT

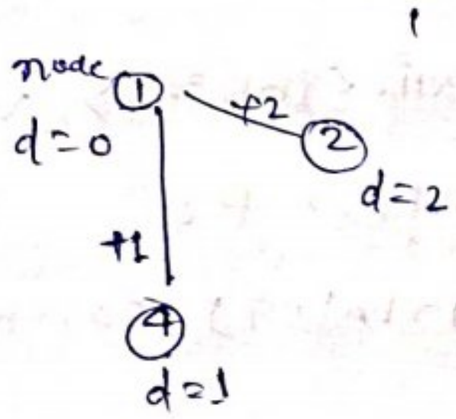
remember where I am coming from

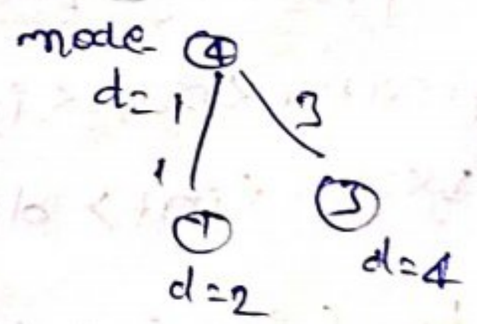
than backtrack the path

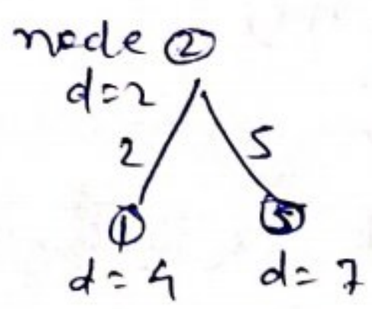
priority-queue

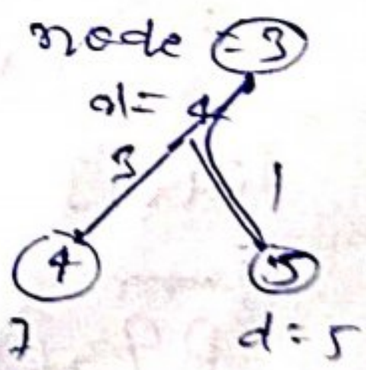


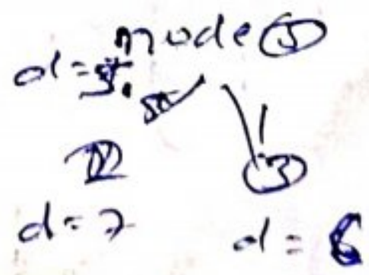
parent [1 | 1 | 4 | 1 | 3]
dis[] [0 | 2 | 4 | 1 | 5]
1 2 3 4 5

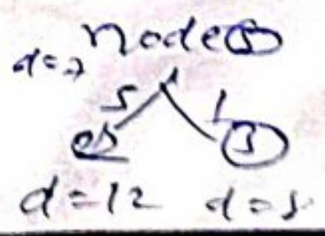












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dist = 5

1 → 4 → 3 → 5

5 come from 3

go to 3 and check where did 3 coming from

dist[1] = 0
then stop

or
if node equals to src.
then stop

→ then we will store it in array
→ Reverse the array
→ return the array

Code :-

```
vector<int> shortestPath(int n, int m,
vector<vector<int>> & edges)
{ vector<pair<int,int>> adj[n+1];
for (auto it : edges)
  { adj[it[0]].push_back({it[1], it[2]});
    adj[it[1]].push_back({it[0], it[2]});
  }

priority_queue<pair<int,int>, vector<pair<int,int>>,
greater<pair<int,int>>> pq;
vector<int> dist(n+1, 1e9), parent(n+1);
for(int i=1; i<=n; i++)
  { parent[i] = i;
dist[1] = 0;
pq.push({0,1});
```

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```
while(!pq.empty())
{
    auto it : pq.top();
    int node = it.second;
    int dis = ~~it.second~~ it.first;
    pq.pop();

    for(auto it : adj[node])
    {
        int adjNode = it.first;
        int edw = it.second;
        if(dis + edw < dist[adjNode])
        {
            dist[adjNode] = dis + edw;
            pq.push({dist + edw, adjNode});
            parent[adjNode] = node;
        }
    }
}

if(dist[n] == 1e9)
    return -1;
vector<int> path;
int node = n;
while (parent[node] != node)
{
    path.push_back(node);
    node = parent[node];
}
Path.push_back(1);
reverse(path.begin(), path.end());
return path;
}
```

T.C. - $O(N) + O(E \log V)$

$\approx O(E \log V$

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Shortest Distance in a Binary maze

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

src = {0,1}
dest = {2,2}

5 steps

3 steps

84918 30142

Dijkstra's Algo

dist[]

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

return dist = 3
Ans

3
3
3
3
2 ~~(3,1,1)~~
~~(2,1,0)~~
~~(2,2,1)~~
~~(2,0,3)~~
~~1 (0,0)~~
~~1, (0,1)~~
~~(1, (0,2))~~
~~0, (0,1)~~

PQ

d=0. (0,1)
+1, +1, +1
(0,0) d=1
(1,1) d=1
(0,2) d=1

we are using pq to take out minimal of the distance but here we will find no difference in Q or PQ so we will use Q here so save T.C. log(N)

Q{list, {row, col}}

(0,1) d=2
d=2 (1,0)
(1,1) d=1
(1,2) x
(2,1) d=2

(row+1, col)
(row, col-1) ← (row, col) → (row, col+1)
(row+1, col)

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Code :-

```
int shortestPath(vector<vector<int>> & grid , pair<int, int> source,
 pair<int, int> destination)
 {
 queue<pair<int, pair<int,int>>> q;
 int n= grid.size();
 int m= grid[0].size();
 vector<vector<int>> dist(n, vector<int> (m,1e9));
 dist[source.first][source.second] =0;
  q.push({0,{source.first, source.second}});
   int dr[] = {-1,0,1,0};
   int dc[] = {0,1,0,-1};
   auto it = q.front();
     q.pop();
   int dis = it.first;
   int r = it.second.first;
   int c = it.second.second;
  for(int i=0; i<4; i++)
     { int newr =r+dr[i];
       int newc =c+dc[i];
      if(newr>=0 && newr<n && newc >=0 && newc<m
 && grid[newr][newc] == 1 && dis+1 < dist[newr][newc])
 { dist[newr][newc] = 1+dis;
   if(newr == destination.first && newc == destination.second)
      return dis+1;
   q.push({1+dis,{newr, newc}});
   }
 }
 return -1;
}
```

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Path with Minimum Effort

1	2	2
3	8	2
5	3	5

1 2 2 2 5

1 0 0 3 = max → 3 effort

1 3 8 2 5

2 5 6 3 = max → 6 effort

1 3 5 3 5

2 2 2 2 = max → 2 effort

figure out ~~minimum~~ max effort from all the path and take the min ~~effort~~ of all max effort.

* Something related to path, minimum, shortest path kind of thing then apply **Dijkstra's Algorithm**

~~dist[][]~~

	0	1	3
0	1	2	2
1	3	8	2
2	5	3	5

dist[][]

	0	1	2
0	0	1	1
1	2	5	1
2	2	2	3

(2,2,2)	
(7,2,1)	
(7,2,0)	
(5,1,1)	
(3,2,2)	
(1,1,2)	
(6,1,1)	
~~(1,0,2)~~	
(2,1,0)	
~~(1,0,1)~~	
(0,0,0)	(dist, r, c)

p q

(0,0) diff = 0 {max of all the diff. on the path}

(1,0) diff = 2 (0,1) diff = 1

diff = 1 (0,1) — (0,2) diff = 0; (0,0); (1,1) diff = 6

new max(6,1) = 6

diff = 1 (0,2) — (1,2) d = 0

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```
int MinimumEffort (vector<vector<int>>& heights)
{
priority_queue<pair<int, pair<int, int>>, vector<pair<int, pair<int, int>>>,
  greater<pair<int, pair<int, int>>> > pq;      // {diff, {row, col}}

  int n = height.size();
  int m = height[0].size();

vector<vector<int>> dist(m, vector<int>(m, 1e9));
  dist[0][0] = 0;
  pq.push({0,{0,0}});
  int dr[] = {-1, 0, 1, 0};
  int dc[] = {0, 1, 0, -1};
  while(!pq.empty())
  {
    auto it = pq.top();
    pq.pop();
    int diff = it.first;
    int row = it.second.first;
    int col = it.second.second;
    if(row == n-1 && col == m-1)
      return diff;

    for(int i=0; i<4; i++)
    {
      int newr = row + dr[i];
      int newr = col + dc[i];
if(newr >=0 && newc >=0 && newr < n && newc < m)
  {
    int newEffort = max(abs(heights[row][col] -
                            heights[newr][newc]),
    diff);
    if(newEffort < dist[newr][newc])
      {
        dist[newr][newc] = newEffort;
        pq.push({newEffort, {newr, newc}});
    }}}
}
return 0; // unreachable.
```

T.C. $O(E \log V)$

edges nodes

$\Rightarrow \approx O(N \times M)$

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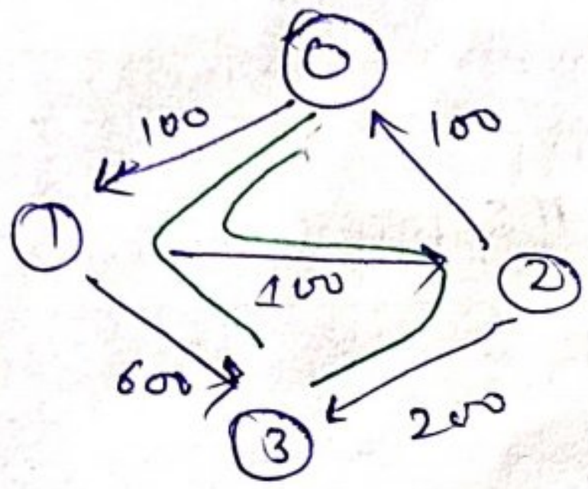
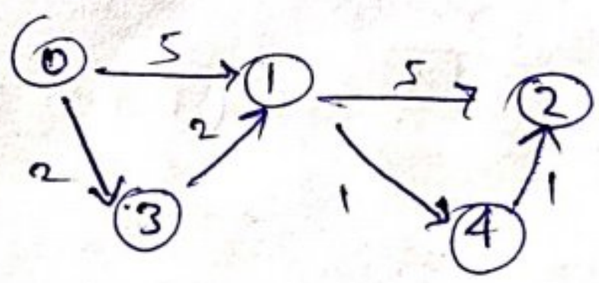
Cheapest Flights within K stops :-



src = 0, dest = 3, K = 1

at max we can take K stops

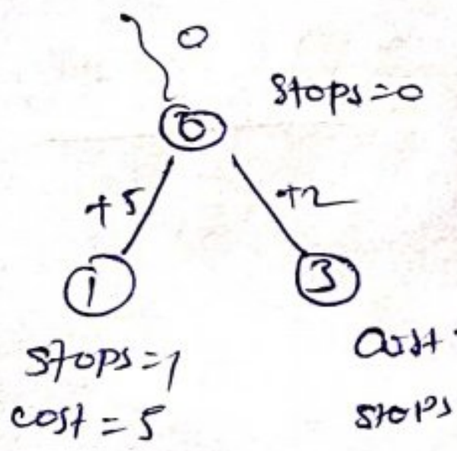
Let's see why simple Dijkstra's will fail

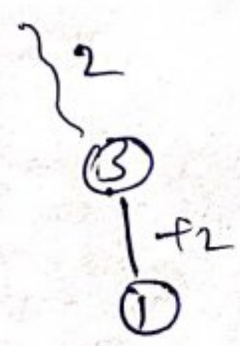


cost
dist[]

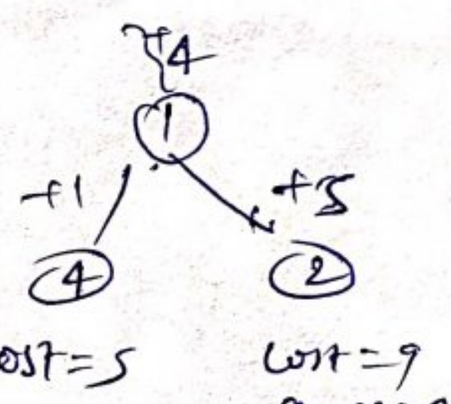
0	1	2	3	4
0	4	9	2	3

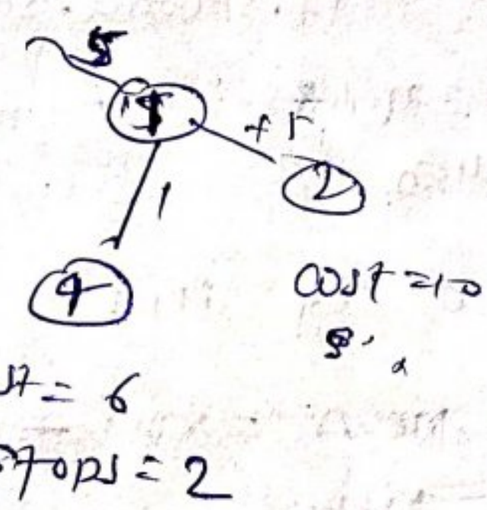
src = 0
dest = 2
K = 2

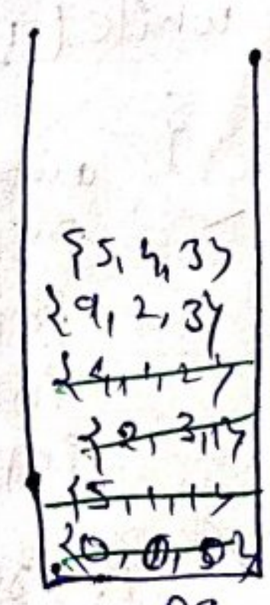




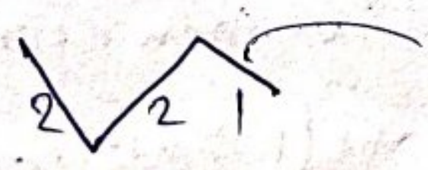
cost = 4
stops = 2







pq
{dist, node, stops}



This path has sortest distance but more stops so we can't choose this.

∴ Dijkstra's Algo store everything in terms of distance, but in this question we have to store in terms of stops.

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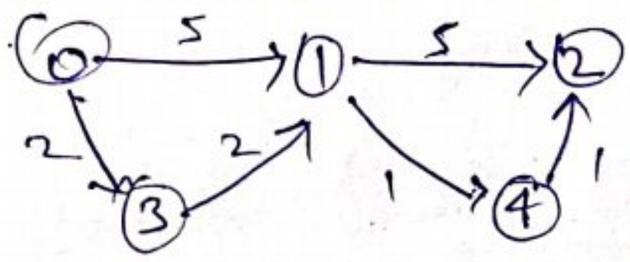
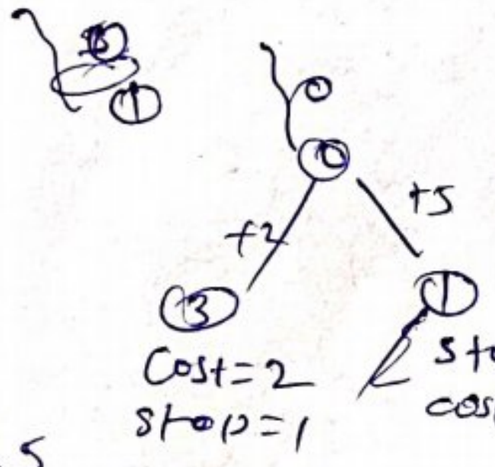


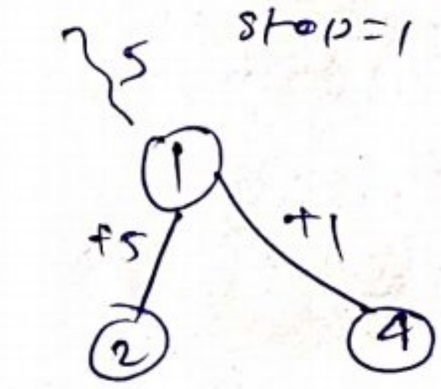


dist[] =

0	1	2	3	4
0	5	~~7~~ 6	2	6

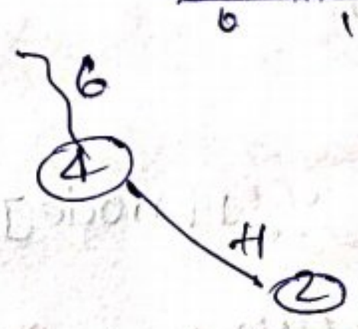
{3, 2, 7}
{2, 2, 10}
{2, 4, 6}
{7, 3, 2}
{1, 1, 5}
{0, 0, 0}

{stops, node, dist}



cost = 10
stops = 2

cost = 6
stops = 2



cost = 7
stop = 3

~~we~~ there no need of priority queue because ~~stops~~ stops are increasing constantly.
we can extra O(log N)

Code :

```
int CheapestFlights( int n , vector<vector<int>> & flights,
int src, int dst , int k)
{ vector<pair<int, int>> adj[n];
  for( auto it : flights)
    { adj[ it[0]].push_back( {it[1], it[2]} ).
  }
  queue< pair<int , pair< int, int >>> q;
  q.push({0, {src , 0}});
  vector<int> dist(n, 1e9);
  dist[src] = 0;
```

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```
while(!q.empty())
  {  auto it = q.front();
     q.pop();
  int stops = it.first;
  int node = it.second.first;
  int cost = it.second.second;

  if(stops > K)
     continue;
  for(auto iter : adj[node])
     {  int adjNode = iter.first;
        int edw = iter.second;

        if(cost + edw < dist[adjNode] &&
           stops <= K)
        {  dist[adjNode] = cost + edw;
           q.push({stops + 1, {adjNode, cost + edw}});
        }
     }
  }

  if(dist[dst] == 1e9)
        return -1;
  else
        return dist[dst];
}
```

T.C. $O(E \cancel{\log V})$

But we are not using PQ

so $O(E)$

Sol.

Flights size().

@Ashish Kumar Nayak

Minimum multiplication to reach End :

start = 3 end = 30

arr[] = {2, 5, 7}

start = 3 $\xrightarrow{\times 2}$ 6 $\xrightarrow{\times 5}$ 30

② Ans

start = 7 end = 66175

arr[] = {3, 4, 65}

7 × 3 = 21

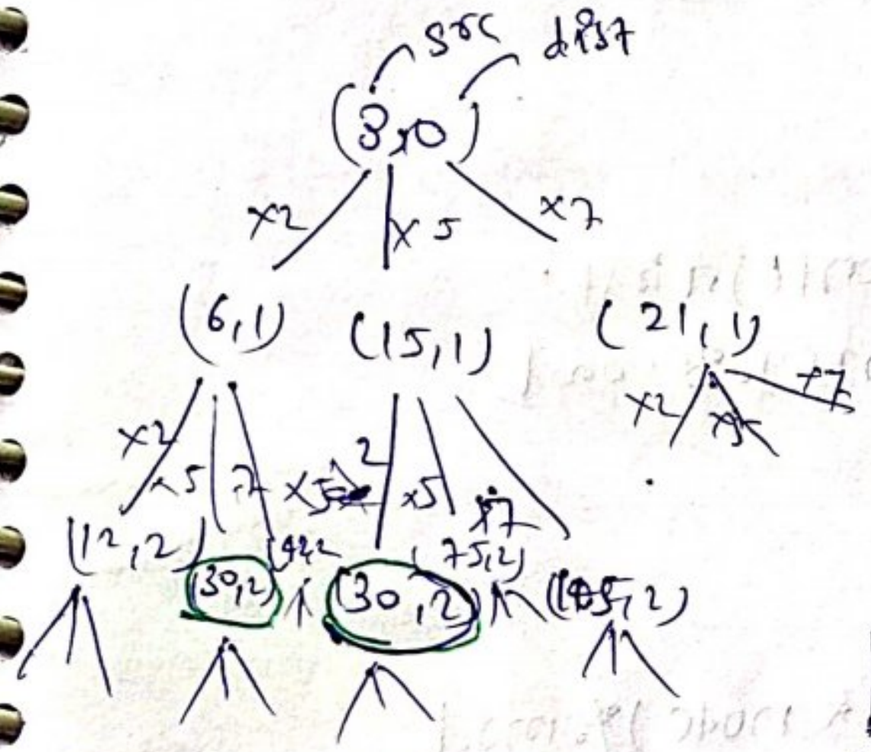
21 × 3 = 63

63 × 65 = 4095

4095 × 65 = 266175

266175 % 100000 = 66175 Ans

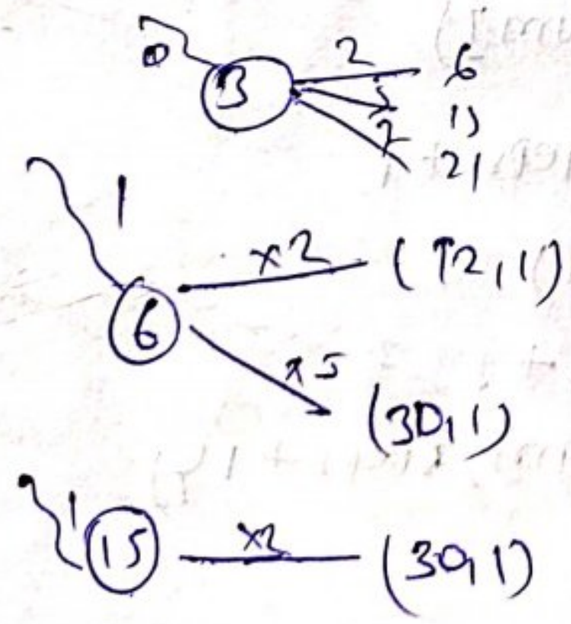
④ Ans



Dijkstra's Algo

dist[]

0	1	2	3		6		999
∞	∞	∞	0		1		∞



∵ no need to use pq we will use queue.

(12, 42)
(7, 30)
(7, 12)
(1, 21)
(1, 15)
(1, 6)
(0, 3)

Steps, using min-heap

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code :

```
int minimumMultiplication (vector<int> &arr, int start,
int end)
{ queue< pair<int, int>> q;
    q.push({ start, 0});
    vector<int> dist (100000, 1e9);
      dist[ start ] = 0;
      int mod = 100000;
  while( !q.empty())
      { int node = q.front().first;
        int steps = q.front().second;
          q.pop();
      for(auto it : arr)
        { int num =(it * node)% mod;
        if(steps +1 < dist[num])
          { dist[num] = steps + 1;
          if(num == end)
           { return steps + 1; }
             q.push({num, steps+1});
          }
        }
      }
      return -1;
}
```

T.C. $O(100000 * N)$

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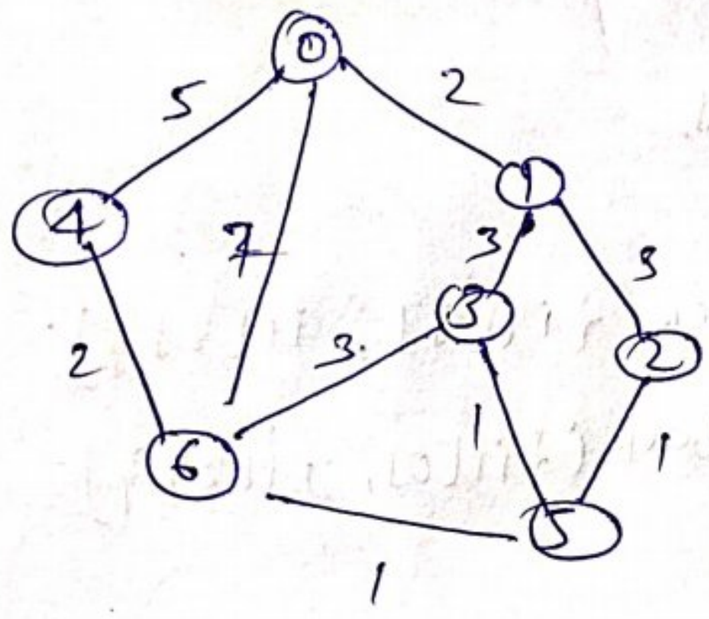
Number of ways to Arrive at Destination



$n = 7$, $src = 0$, $dest = 6$

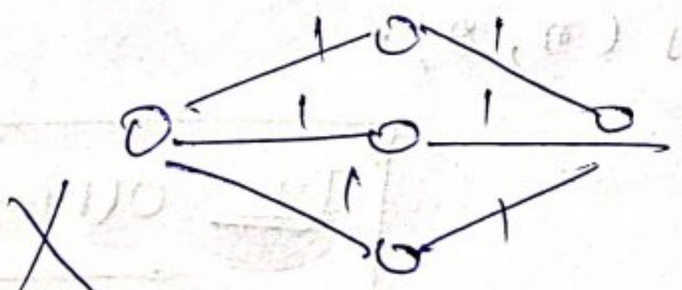
$0 \to 6$

$0 \to 4 \to 6$

$0 \to 1 \to 2 \to 5 \to 6$

$0 \to 1 \to 3 \to 5 \to 6$

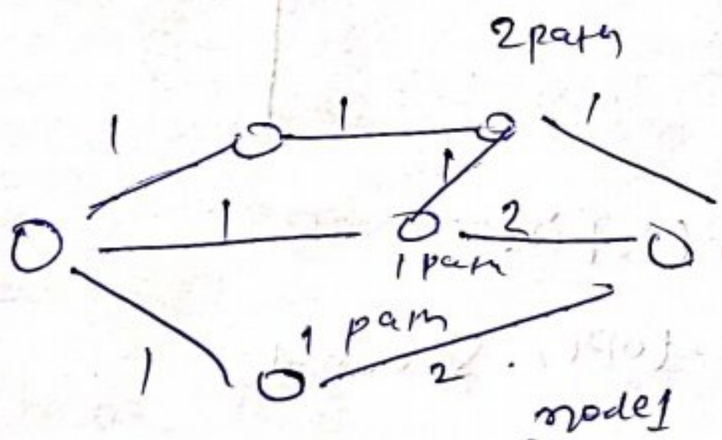
No. of paths which are shortest. (There will be multiple path with same distance shortest)



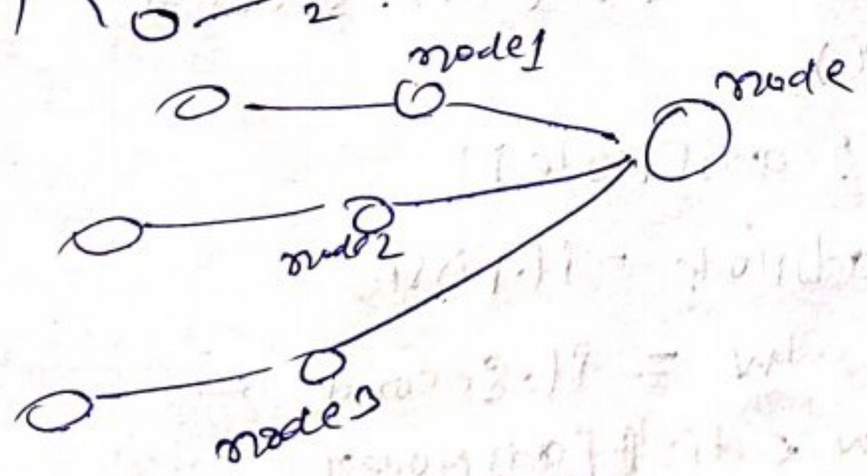
minimum distance

3 times we ends

Bcz this is wrong



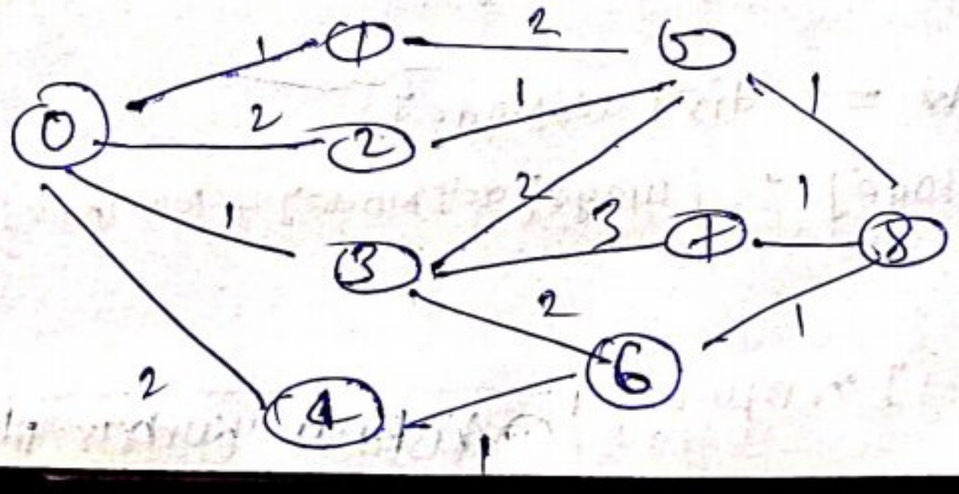
4 path



{3,6}
{4,7}
{3,5}
{2,4}
{1,3}
{2,2}
~~{1,1}~~
~~{0,0}~~

{dist, node}

ways[node] = ways[node 1] + ways[node2] + ways[node3]



ways

0	1	2	3	4	5	6	7	8
1	~~0~~	~~0~~	~~0~~	~~1~~ 2	~~1~~ 3	~~1~~	~~1~~ 2	~~1~~ 5

dis

0	1	2	3	4	5	6	7	8
~~0~~	~~1~~	~~2~~	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~

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Code :-

```
int countPaths(int n, vector<vector<int>> & roads)
{
vector<pair<int,int>> adj[n];
for(auto it : roads)
  {
    adj[it[0]].push_back({it[1], it[2]});
    adj[it[1]].push_back({it[0], it[2]});
  }
priority_queue<pair<int, int>
  vector<pair<int, int>>, greater<pair<int,int>>> pq;
vector<int> dist(n, 1e9) , ways (n, 0);
dist[0]=0;
ways[0] = 1;
pq.push({0,0});
int mod = (int)(1e9+7);
while(!pq.empty())
    { int dis = pq.top().first;
      int node = pq.top().second;
      pq.pop();
    for(auto it : adj[Node])
      { int adjNode = it.first;
        int edw = it.second;
    if(dis + edw < dist[adjNode])
      { dist[adjNode] = dis + edw;
        pq.push({dis + edw, adjNode});
        ways[adjNode] = ways[node];
      }
    else if(dis + edw == dist[adjNode])
      { ways[adjNode] = (ways[adjNode] + ways[node])%mod;
      }
    }}
return ways[n-1] % mod;
}
```

T.C. O(E log V)

S.C.

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Belman ford Algorith (~~Shor~~ Algorithm for finding shortest path)

Need of Belmom ford Algorithm :-

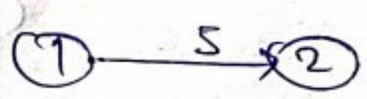
It Helps us to detect negative cycles.

In Dijkstra's we can not calculate distance with -ve weight or -ve cycle.

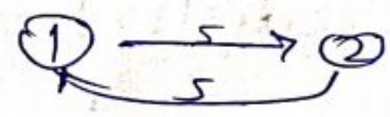
But in Belman ford Algo we can calculate path with -ve weight or -ve cycle.

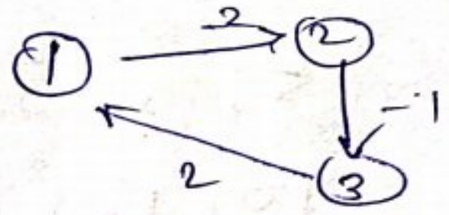
This Algo is Applicable for → DG

Ex:-

if we have 

then change it

to 



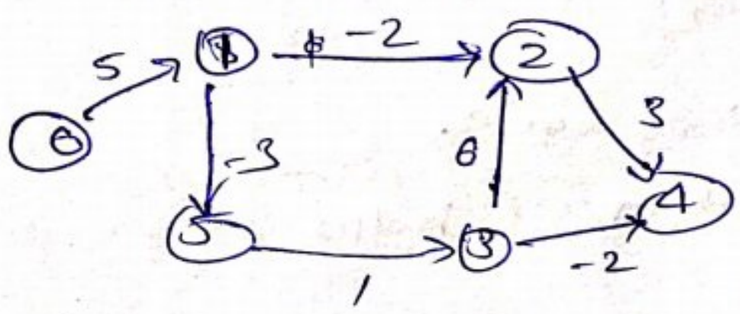
→ Diskstra will fall in TLE or infinite loop.

path weight = ~~2+~~ $-2-1+1$
$= -1$

if path weight < 0 it has negative cycle.

Belman ford Algo :-

src = 0



adj list

(u, v, wt)
(3, 2, 6)
(5, 3, 1)
(0, 1, 5)
(1, 5, -3)
(1, 2, -2)
(3, 4, -2)
(2, 4, 3)

This operation for all edges and it will call 1st iteration

⊛ This algo says Relax all the edges N-1 times sequentially

⊛⊛ This is called Relax

```
if( dist[u] + wt < dist[v] ).
    dist[v] = dist[u] + wt
```

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dist	0	5	3	~~x~~	6	2
	0	1	2	3	4	5

1st iteration

	(u, v, wt)
dist[3] + 6 < dist[2]	(3, 2, 6)
dist[5] + 1 < dist[5]	(5, 3, 1)
dist[0] + 5 < dist[1]	(0, 1, 5)
dist[1] + 3 < dist[5]	(1, 5, -3)
dist[1] − 2 < dist[2]	(1, 2, -2)
dist[3] −2 < dist[4]	(3, 4, -2)
dist[2] + 3 < dist[4]	(2, 4, -3)

dist	0	5	3	3	1	2
	0	1	2	3	4	5

2nd iteration

dist[3] + 6 < dist[2]	(3, 2, 6)
dist[5] + 1 < dist[3]	(5, 3, 1)
dist[0] + 5 < dist[1]	(0, 1, 5)
dist[1] −3 < dist[5]	(1, 5, -3)
dist[1] − 2 < dist[2]	(1, 2, -2)
dist[3] −2 < dist[4]	(3, 4, -2)
dist[2] + 3 < dist[4]	(2, 4, -3)

3rd iteration

① Why N-1 cycles

② How we detect negative cycle.

→ 0 helps to calculate 1, than 1 helps, 5 ---- so on

∴ there are N nodes

till (N-1) iteration

(N-1) edges

Hence (N-1) cycles

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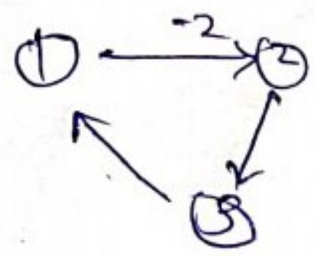
since, in a graph of N nodes, in worst case, you will take N-1 edges to reach from the first to the last, thereby we iterate for N-1 iteration.

Try drawing a graph which takes more than N-1 edges for any path, it is not possible.

Q. How to detect -ve cycle, becaus in every iteration we are decreasing path value



On Nth iteration the relaxation will be done and the distance array get reduced.

We should get our answer till $(N-1)^{th}$ iteration but if it is still reducing in Nth iteration it means there is a negative cycle.

Code:

```
vector<int> bellman_ford(int v, vector<vector<int>> &edges,
int s)
{ ~~dist[s] = 0;~~ vector<int> dist(v, 1e8); dist[s] = 0;
  for(int i = 0; i < v-1; i++)
  { for(auto it : edges)
      { int u = it[0];
        int v = it[1];
        int wt = it[2];
      if( dist[u] != 1e8 && dist[u] + wt < dist[v])
        { dist[v] = dist[u] + wt;
        }
      }
  }
  // Nth iteration to check negative cycle
  for(auto it : edges)
    { int u = it[0]; int v = it[1]; int wt = it[2];
      if(dist[u] != 1e8 && dist[u] + wt < dist[v])
      { return {-1};
      }
    }
  return dist;
}
```

T.C. ≈ O(V×E)
Nodes, edges

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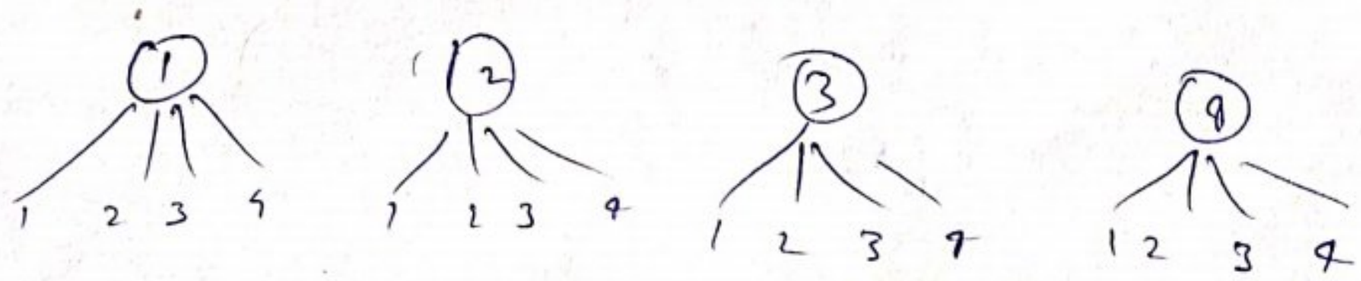
Floyd Warshall Algorithm (Algorithm for shortest path)

This is very-very different from Dijkstra & Bellman ford.

in these two previous Algo src same point is 1.

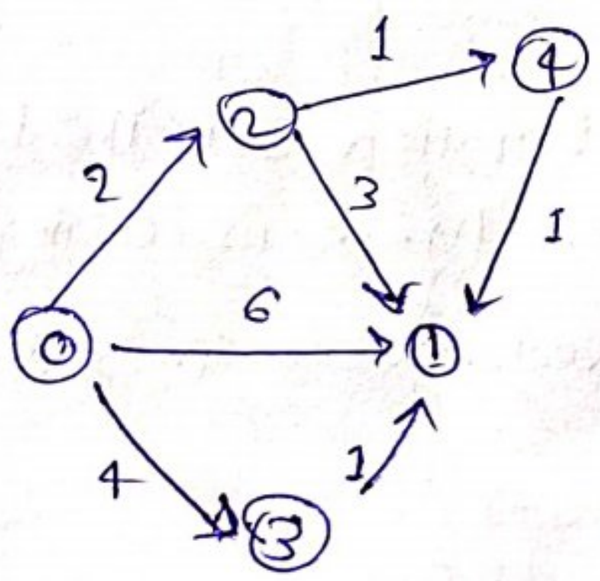
But in floyd warshall algo there is multiple source point.

we have to find shortest distance of all node from each node.



This is also known as multi source shortest path algorithm

Note: uto via every Nodes/vertex.



0 1

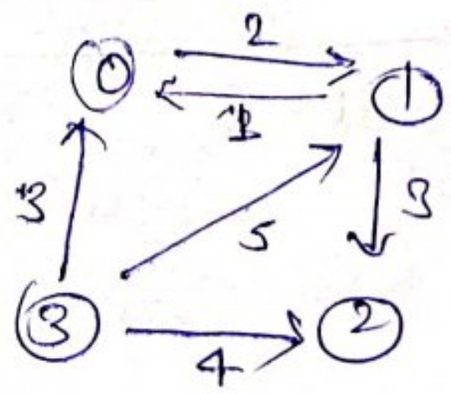
$0 \to 1 = 6$

$(0 \to 2) + (2 \to 1) = 5$
2 3

$(0 \to 3) + (3 \to 1) = 5$
4 1

$(0 \to 4) + (4 \to 1) = 4$
3 1

$min(d[i][k] + d[j][k])$



$$\begin{array}{c|cccc} & 0 & 1 & 2 & 3 \\ \hline 0 & 0 & 2 & \alpha & \alpha \\ 1 & 1 & 0 & 3 & \alpha \\ 2 & \alpha & \alpha & 0 & \alpha \\ 3 & 3 & 5 & 4 & 0 \end{array}$$

Un → Dn
$0 \xrightarrow{1} 5$ $\quad$ $0 \xrightarrow{1} 5$
$0 \xleftarrow{1} 5$

cost

$[0][1] = 0 \to 0 + 0 \to 1$

$[0][2] = [0][0] + [0][2]$

$[1][2] = [1][0] + [0][2]$
$1 + \alpha$

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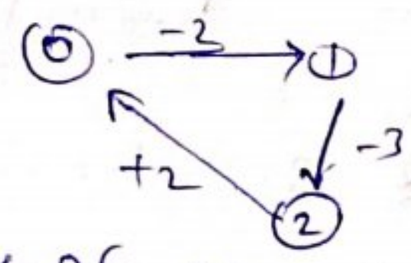
This algorithm is not much intutive as the other ones. It is more of a brute force, where all combination of paths have been tried to get the shortest paths.

Nothing to be panic much on the intution, it is a simple brute on all paths. Focus on the three for loops.

(*) How to detect -ve cycle.



$-2 + 2 - 3$

cost $= -3$

if the costing of any node cost[i][i] < 0 (node to node) it means there will have negative cycle.

Code :- void shortest_distance (vector<vector<int>> &matrix)

```
{ int n = matrix.size();
    for(int i = 0; i<n; i++)
      { for(int j=0; j<n; j++)
          {  if(matrix[i][j] == -1)
               { matrix[i][j] = 1e9;
               }
             if(i==j)
               { matrix[i][j] = 0;
               }
          }
      }

    for(int k = 0; k<n; k++)
      { for(int i=0; i<n; i++)
          { for(int j = 0; j<n; j++)
              { matrix[i][j] = min(matrix[i][j], matrix[i][j] +
                                                matrix[i][k] +
                                                matrix[k][j]);
```

T.C. - $O(N^3)$

S.C. $O(N^2)$ matrix

//for negative cycle

```
for(int i=0; i<n; i++)
    { if(matrix[i][i] < 0)
        { //we can return or print something.
        }
    }
for(int i=0; i<n; i++)
  { for (int j=0; j<n; j++)
      { if(matrix[i][j] == 1e9) { matrix[i][j] = -1; }
        ~~if(i==j) { matrix~~
      }
}
```

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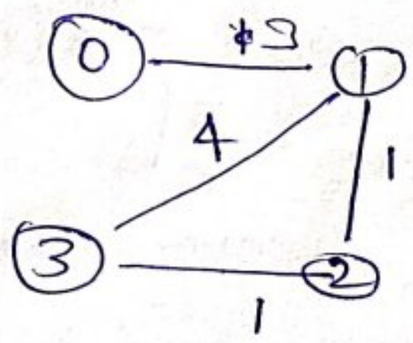
City with the smallest no. of Neighbours at a threshold distance



threshold = 4

city

0 → 1, 2 — lowest no. of neighbour

1 → 0, 2, 3

2 → 0, 1, 3

3 → 1, 2

	0	1	2	3
0	0	3	4	5
1	3	0	1	2
2	4	1	0	1
3	5	2	1	0

0, 3

largest one is 3

∴ Ans = 3

cnt = 0

cntmax = 5 ∴ we have 4 cities

city = -1

cnt max = 3

for 0 including itself

cnt = 1 + 2 + 3 , cnt = 3

for 1

cnt = 1 + 2 + 4

cntmax = min(cnt, cntmax)

for 2

cnt = 1 + 3 + 4 = cnt = 8

for 3

cnt = 1 + 2 = 3

cntmax = min(cnt, cntmax)

take largest one.

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```
int findCity( int n, int m, vector<vector<int>>& edges,
int distanceThreshold)
{ vector<vector<int>> dist(n, vector<int> (n, INT_MAX));
for (auto it: edges)
  {   dist[ it[0] ][ it[1] ] = it[2];
      dist[ it[1] ][ it[0] ] = it[2];
  }
for (int i=0; i<n; i++)
  { dist[i][i] = 0; }
for ( int k=0 ; k<n; k++)
  { for (int i=0; i<n; i++)
      { for ( int j=0; j<n; j++)
          { if(dist[i][k] == INT_MAX || dist[k][j] == INT_MAX)
              continue;
            dist[i][j] = min ( dist[i][j], dist[i][k] + dist [k][j]);
          }
      }
  }
int cntCity = n;
int cityNo = -1;
for( int city = 0; city<n ; city ++)
  {   int cnt =0;
      for(int adjCity = 0; adjCity <n ; adjCity ++)
        { if( dist[city][adjCity] <= distanceThreshold)
            cnt++;
        }
      if( cnt <= cntCity)
        {  cntCity = cnt;
           cityNo = city;
        }
  }
return cityNo;
}
```

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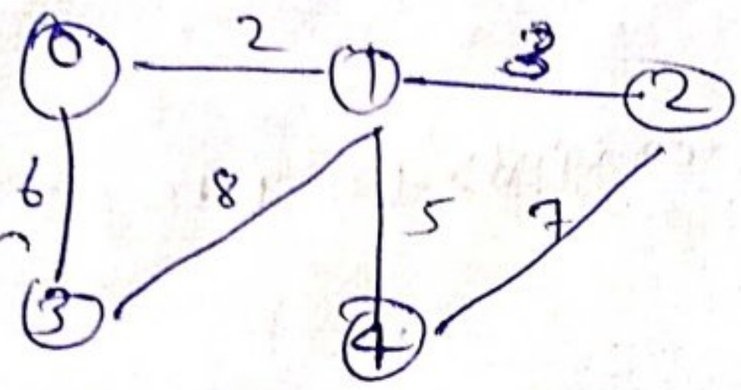
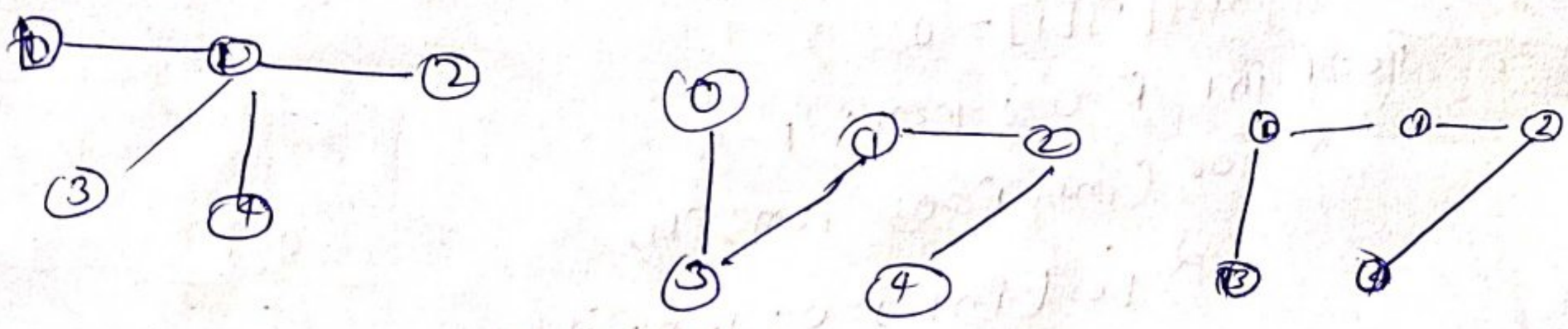
Minimum Spanning Tree (MST) :-

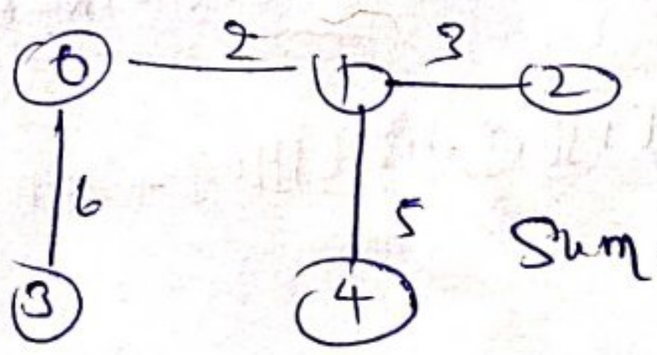


N-nodes (5)
M - Edges (6)

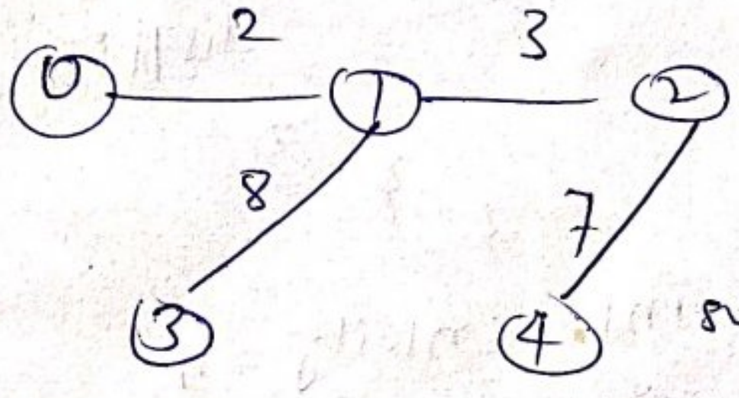
A tree in which ~~hesue~~ have N nodes & N-1 edges & all nodes are reachable from each other.



For this graph

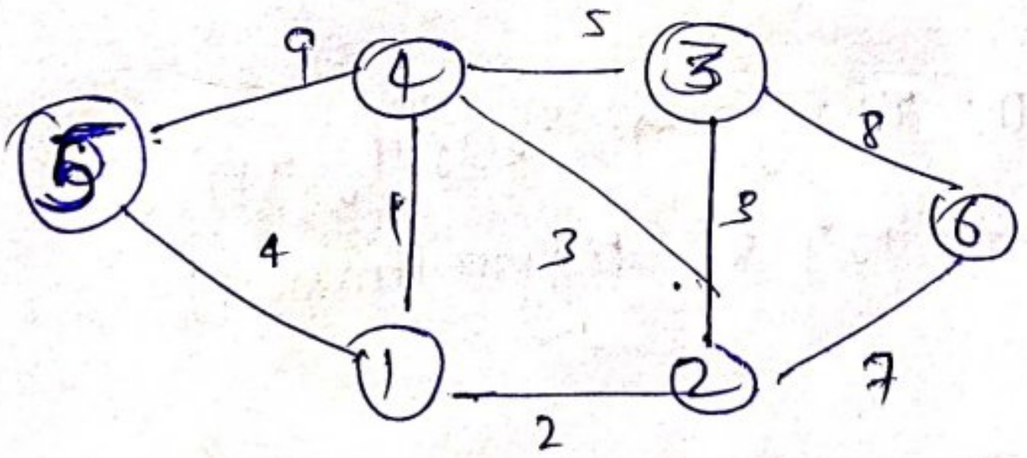


Sum = 16



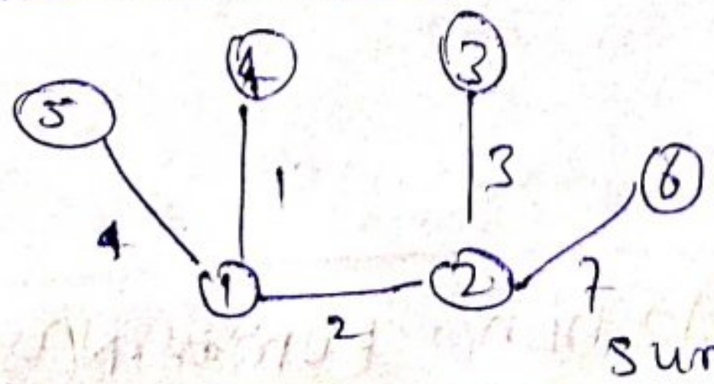
sum = 20

(MST) Both are spanning tree but 1st one is Minimum spaning tree.



for finding MST we have
(i) Prim's Algorith
(ii) Kruskal's Algorith
↳ Disjoint set

spanning Trees are :-



sum = 17

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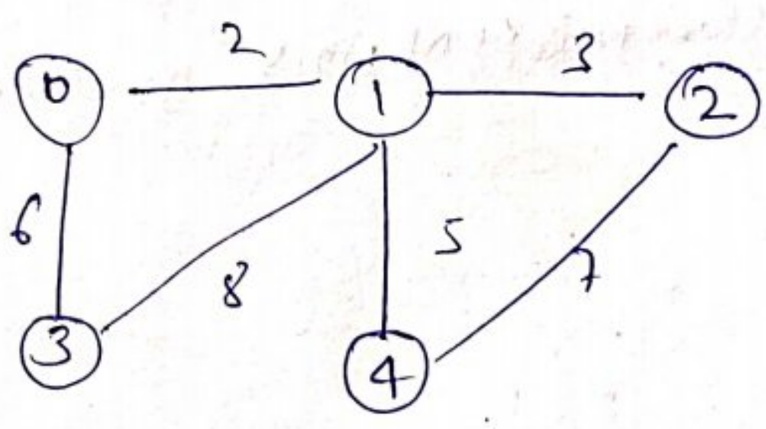
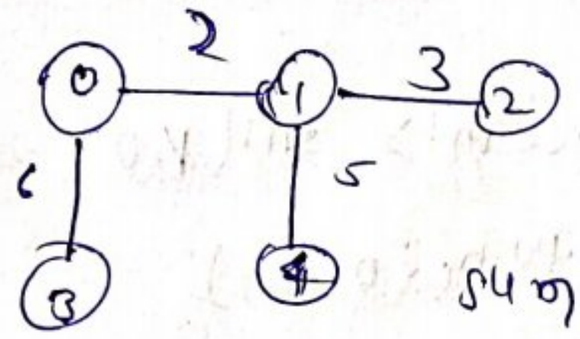
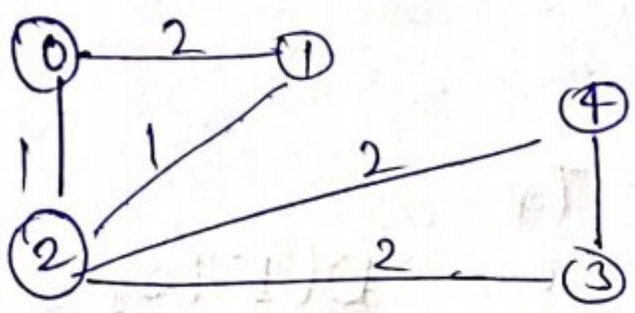
Prim's Algorithm :-

It helps to find MST (Minimum spanning Tree).





sum = 16



vis[]

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

node parent (-1) it means its a 1st node so dont add in MST

look at adjacent of node = 0

(2, 2, 3)
(1, 4, 3)
~~(2, 3, 2)~~
~~(2, 4, 2)~~
~~(1, 1, 2)~~
~~(1, 2, 0)~~
~~(2, 1, 0)~~
~~(0, 0, -1)~~

(wt, node, parent)
Min-heap

least wt always

1 , 2 , 0

0 1 3 4

sum = ~~0~~ + 2

1 1 2

0 1

2 1 0

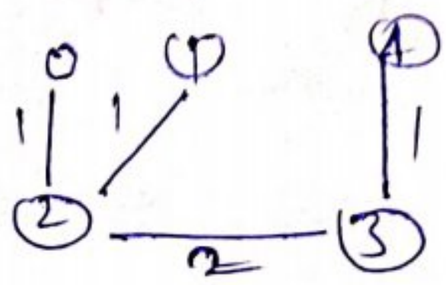
0 1

MST → [(0,2) (1,2) (2,3) (3,4)]

2 , 3 , 2

2 4

1 , 4 , 3



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Code :

```
int spanningTree( int V, vector<vector<int>> adj[])
{ priority_queue<pair<int,int>, vector<pair<int,int>>, greater<int,int>> pq;
vector<int> vis(V,0);
pq.push({0,0});
int sum=0;
while(!pq.empty())
{ auto it = pq.top();
  pq.pop();
int node = it.second;
int wt = it.first;
if(vis[node]==1)
  continue;
vis[node]=1;
sum += wt;
for(auto it : adj[node])
  { int adjNode= it[0];
    int edw = it[1];
    if(!vis[adjNode])
      {
        pq.push({edw, adjNode});
      }
  }
return sum;
}
```

T.C. $O(E \log E)$

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Disjoint Set Data structure :-

important for Online Assessments way.

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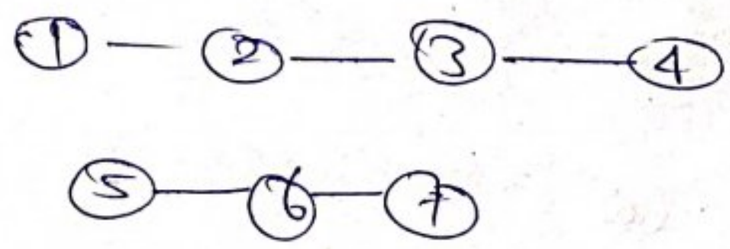


1 & 5 are connected or not?

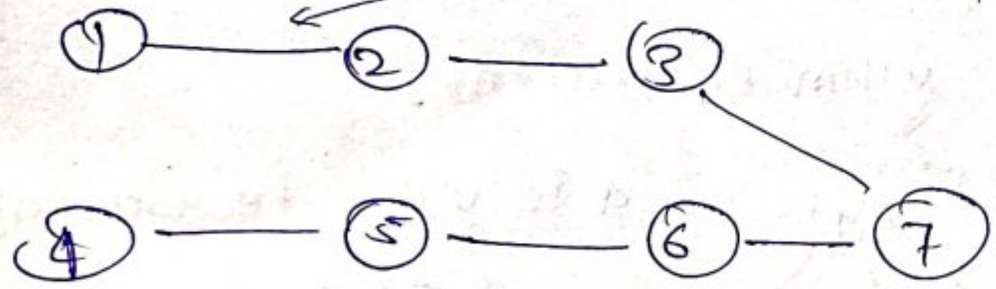
→ No (use BFS/DFS Traversal to find)
takes O(N+E)
i.e. Brute Force

But disjoint set. will do this same on constant time.
It gives

find parent()

union() → rank
→ size

(1,2) (1,2) this function will connect ① & ②
(2,3)
(4,5)
(6,7)
(5,6)
(3,7)



graph is changing and we can find parent or union as is two nodes are ~~cum-part~~ connected or
Dynamic not at any stage.

union() → rank
→ size

we can implement union in two ways rank and size.

① union() by rank

rank array

0	0	0	0	0	0	0
1	2	3	4	5	6	7

parent

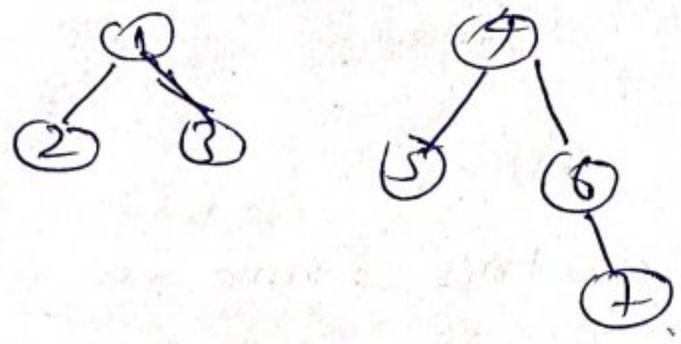
1	2	3	4	5	6	7
1	2	3	4	5	6	7

union(u,v)

1. find ultimate parent of u & v, pu, pv
2. find rank of ultimate parents
3. connect smaller rank to larger rank always.

Rank | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
1 2 3 4 5 6 7

Parents | 1 | 1 | 1 | 1 | 4 | 4 | 6 |
1 2 3 4 5 6 7



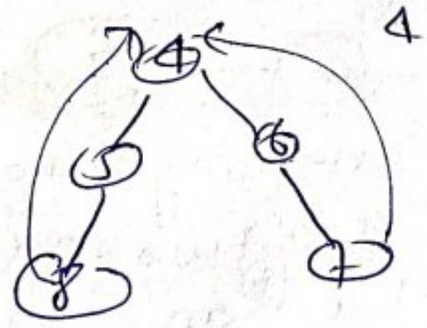
does 1 & 7 belong to same component.

Ans :- No., we will check parents of both 1 & 7

∵ they both are different

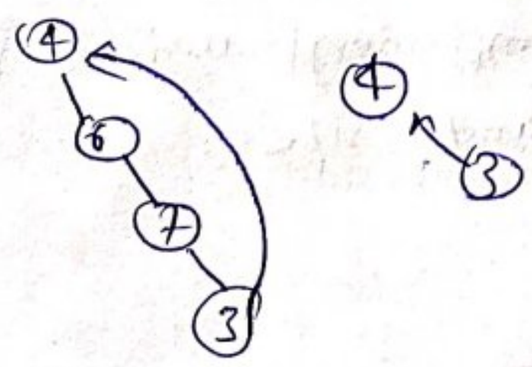
Both should have equal ultimate parent.

like

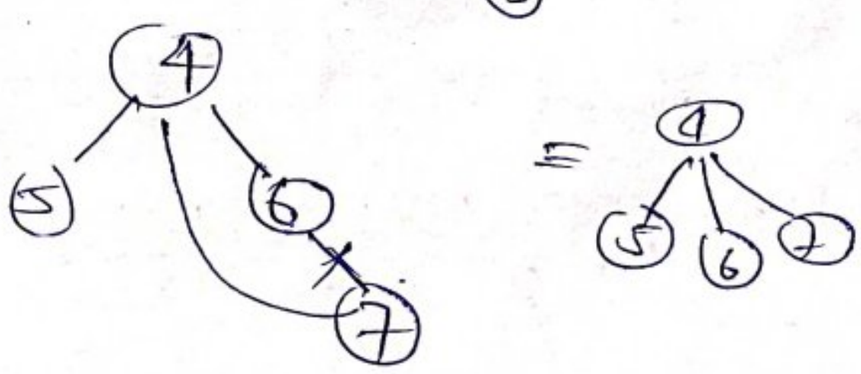


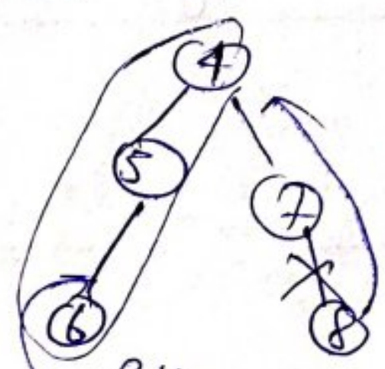
4 is ultimate parent of 8 & 7

Path compression



we will store ultimate parent of each node.





But this side is still same so it can't be reduced

* Hence why it is called rank.

n-1 height

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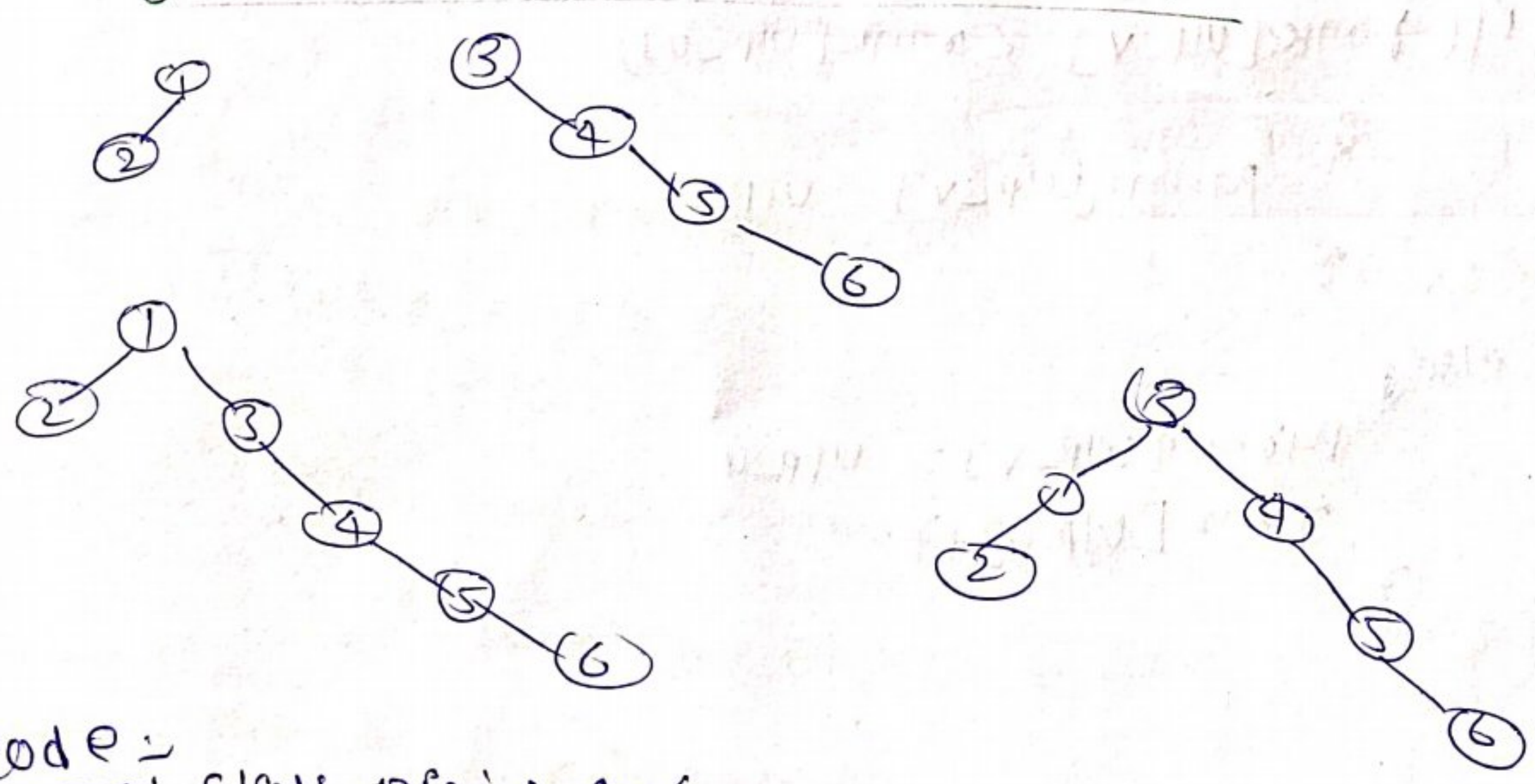
why connected ~~to~~ smaller to larger



Code:-

```
class DisjointSet.
{ vector<int> rank, parent, size;
public:
    DisjointSet(int n)
    {
      rank.resize(n+1, 0);
      parent.resize(n+1, 0); size.resize(n+1);
      for(int i=0; i<=n; i++)
        { parent[i] = i;
          size[i] = 1;
        }
    }
    int findUpar(int node)
    {  if(node == parent[node])
           return node;
       return parent[node] = findUpar(parent[node]);
    }
    void unionByRank(int u, int v)
    {  int ulp_u = findUpar(u);
       int ulp_v = findUpar(v);
       ~~if(rank[ulp_v~~
       if(ulp_u == ulp_v)
           return;
       if( rank[ulp_u] < rank[ulp_v])
         { parent[ulp_v] = ulp_v;
```

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```
else if( rank[ulp_v] < rank[ulp_u])
        {
            parent[ulp_v] = ulp_u;
        }
    else {
            parent[ulp_v] = ulp_u;
            rank[ulp_u]++;
        }
}
};

int main()
{
    DisjointSet ds1(7), ds2(8);
        ds.unionByRank(1,2);
        ds.unionByRank(2,3);
        //          (4,5);
        //          (6,7);
        //          (5,6);
    if(ds.findUpar(3) == ds.findUpar(7))
        {
            cout<<"same\n";
        }
    else    cout<<"Not same\n";
    // ds.unionByRank(3,7);
    // ds.unionBySize(3,7);  > dont use Both simultaneously.
    if(ds.findUpar(3) == ds.findUpar(7))
        {   cout<<"same\n";
        }
    else    cout<<"Not same\n";
    return 0;
}
```

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```
void unionBysize(int u, int v)
{
    int ulp_u = findupar(u);
    int ulp_v = findupar(v);
    if(ulp_u == ulp_v)
        return;

    if(rank[ulp_u] < rank[ulp_v])
        {
            parent[ulp_u] = ulp_v;
        }
    else if (rank[ulp_v] < rank[ulp_u])
        {
            parent[ulp_v] = ulp_u;
        }
    else {
            parent[ulp_v] = ulp_u;
            size[ulp_u] += size[ulp_v];
        }
}
```

T.C.: $O(4\alpha)$

$\approx$ constant

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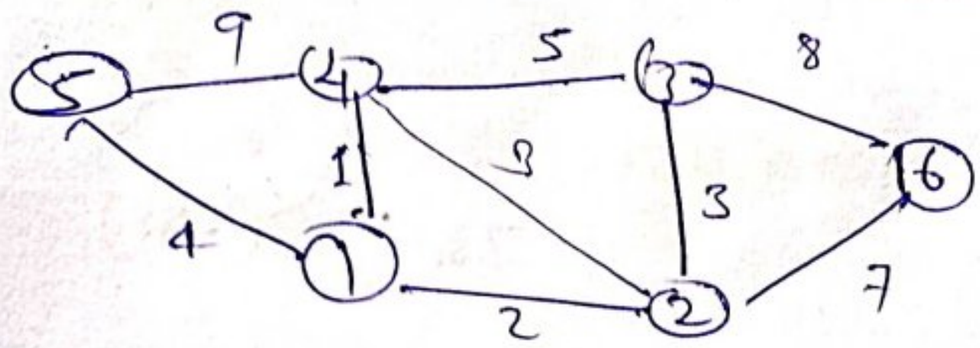
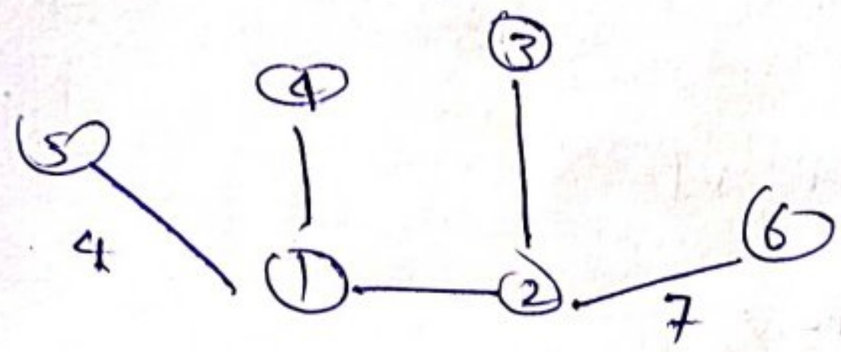
Kruskal's Algorithm





sort all the edges acc to wt.

(wt, u, v)

(1, 1, 4)
(2, 1, 2)
(3, 2, 3)
(3, 2, 4)
(4, 1, 5)
(5, 3, 4)
(7, 2, 6)
(8, 3, 6)
(9, 4, 5)

Code :-

```
int spanningtree(int v, vector<vector<int>> adj[])
{
    vector<pair<int, pair<int, int>>> edges;

    for(int i=0; i<v; i++)
      { for(auto it : adj[i])
          {  int adjNode = it[0];
             int wt = it[1];
             int node = i;
             edges.push_back({wt, {node, adjNode}});
          }
      }
    DisjointSet ds(v);

    sort(edges.begin(), edges.end());
    int mstWt = 0;
    for(auto it : edges)
      { int wt = it.first;
        int u = it.second.first;
        int v = it.second.second;
```

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Scanned with OKEN Scanner

```
if(ds.findUPar(u) != ds.findUPar(v))
    {
        mstWt += wt;
        ds.unionBySize(u,v);
    }
}
return mstWt;
}
```

T.C.

$\approx O(M \times 4 \times \alpha \times 2)$

$\approx O(M)$

```
class DisjointSet
    vector<int> rank, parent, size;
public :
    DisjointSet (int n)
    { rank.resize(n+1,0);
      parent.resize(n+1);
      size.resize(n+1);
      for(int i=0; i<=n ; i++)
      { parent[i] = i;
          size[i] = 1;
      }
    }
    int findUPar(int node)
    { if(node == parent[node])
          return node;
      return parent[node] = findUPar(parent[node]);
    }
    ~~void unionByRank~~ void unionBySize(int u, int v)
    { int ulp_u = findUPar(u);
      int ulp_v = findUPar(v);
      if(ulp_u == ulp_v) return;
      if(size[ulp_u] < size[ulp_v])
      { parent[ulp_u] = ulp_v;
        size[ulp_v] += size[ulp_u];
      }
      else { parent[ulp_v] = ulp_u;
             size[ulp_u] += size[ulp_v];
      }
    }
};
```

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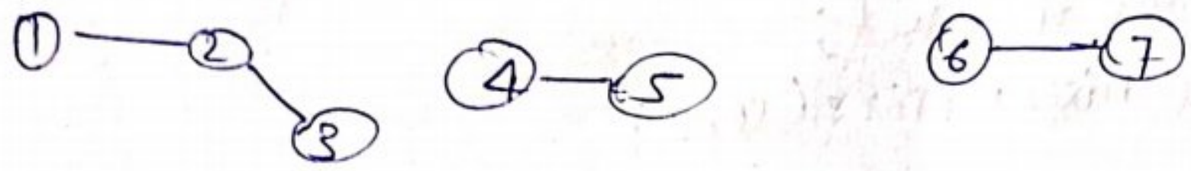
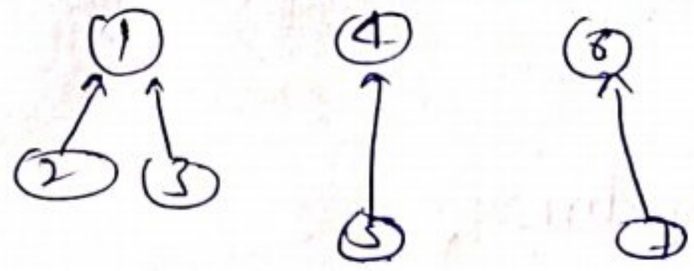
No. Number of provinces :-



	1	2	3	4	5	6	7
1	0	1	0	0	0	0	0
2	1	0	1	0	0	0	0
3	0	1	0	0	0	0	0
4	0	0	0	0	1	0	0
5	0	0	0	1	0	0	0
6	0	0	0	0	0	0	1
7	0	0	0	0	0	1	0



Count the no. of unique ultimate parent.

or if count findUp(u) == u then cnt++

<u>code</u> :- int numProvinces(vector<vector<int>> adj, int v)

```
{ DisJointSet ds(v);
  for (int i = 0; i<v; i++)
    { for (int j = 0; j<v; j++)
      { if (adj[i][j] == 1)
        { ds.unionBySize(i,j);
        }
      }
    }
    int cnt = 0;
    for (int i = 0; i<v; i++)
      { if (ds.parent[i] == i)
          cnt++;
      }
    return cnt;
}
```

```
class DisJointSet {
}
};
```

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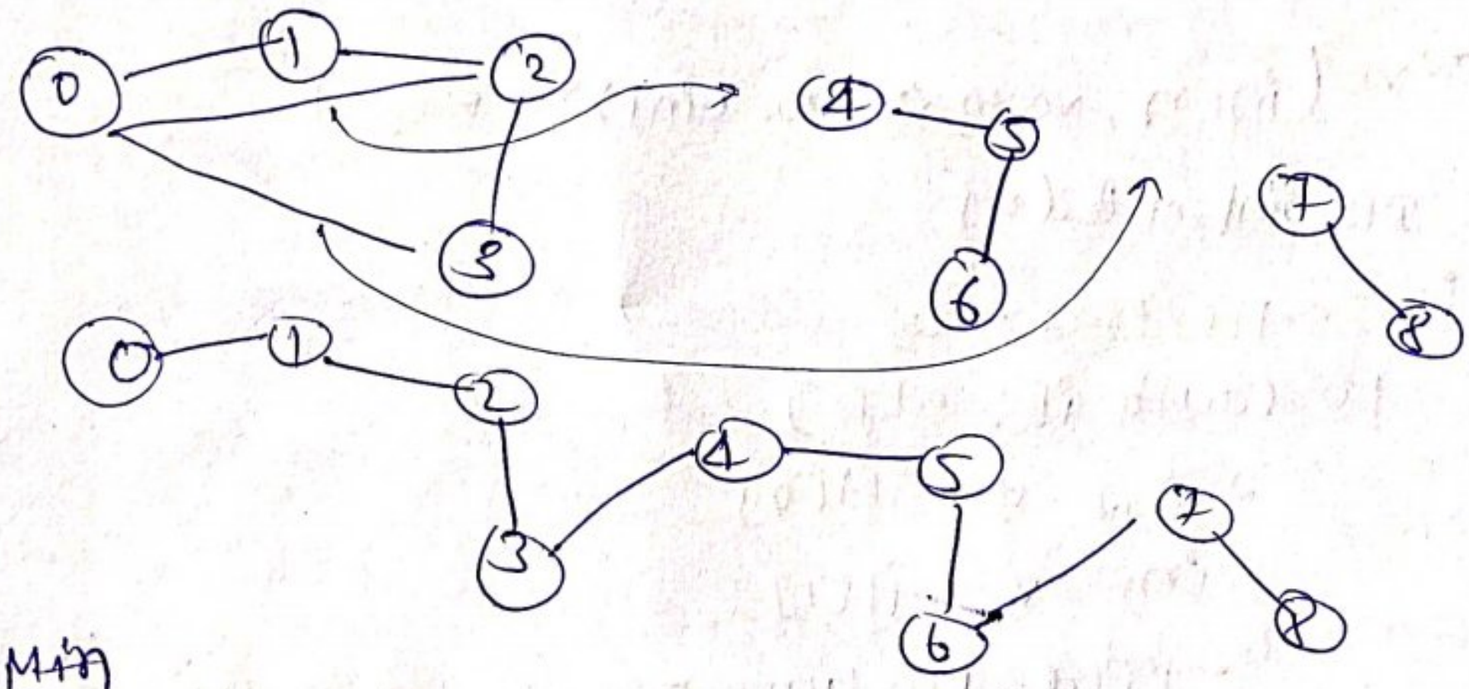
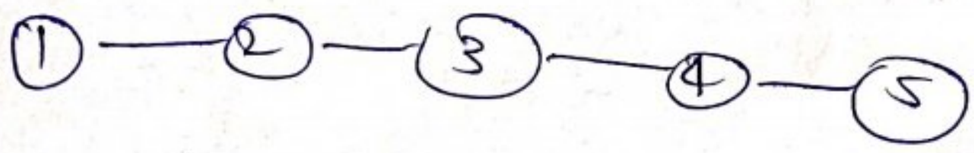
Min no. of operations to make a graph connected



Min for n components we require (n-1) edges



no. of connected components -> nc

then ans = nc-1 and it will be always minimum.

```
if(extraedges >= ans)

        return ans;

else

        return -1;
```

0 1

0 3

0 2

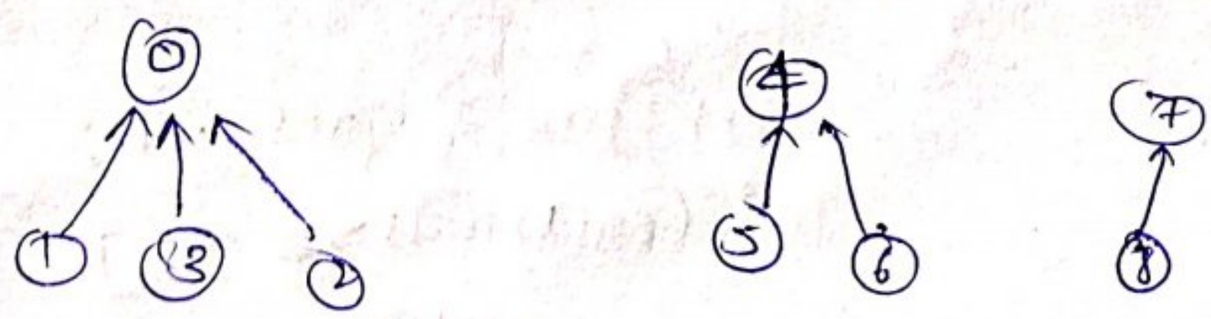
1 2

2 3

4 5

5 6

7 8



extra = 2

Anyone who is pointing itself is an ultimate parent or counted as component.

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```
class DisjointSet {
    ===
    }

int solve(int n, vector<vector<int>> & edges)
{
    DisjointSet ds(n);
    int cntExtras = 0;
    For(auto it: edge)
        { int u = it[0];
          int v = it[1];
          if(ds.findUpar(u) == ds.findUpar(v))
          {
            cntExtras++;
          }
        else
          {
            ds.unionBySize(u, v);
          }
    }

    int cntC = 0;
    for (int i=0; i<n; i++)
      { if(ds.parent[i] == i)
          cntC++;
      }
    int ans = cntC - 1;
    if(cntExtras >= ans)
        return ans;
    return -1;
}
```

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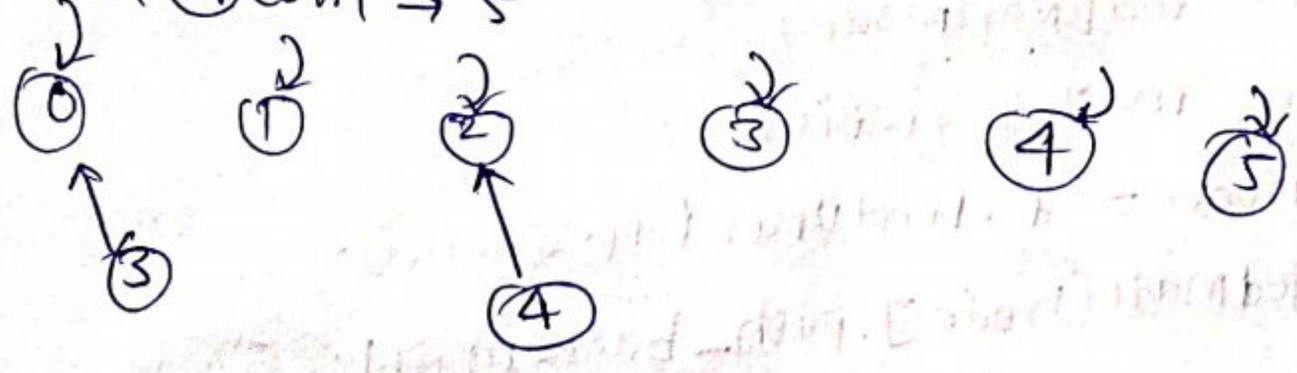
Account Merge - DSU

["John", "J1@gmail.com", "J2@com", "J3@com", "J5@com"] — 0
["John", "J4@com"] — 1
["raj", "r1@com", "r2@com", "r3@com"] — 2
["John", "J1@com", "J5@com"] — 3
["raj", "r2@com", "r3@com"] — 4
["many", "M1@com"] — 5

we are merging and disjoint data structure that helps us to merging

J1@com → 0
J2@com → 0
J3@com → 0
J4@com → 1
r1@com → 2
r2@com → 2
J5@com → 3
r3@com → 4
M1@com → 5

when we are traversing in 3 index we saw "J1@com" but it it already a part of Index 0 so all rest account of index 3 we will merge at index 0.
And so on.



0 → J1@com, J2@com, J3@com, J5@com
1 → J4@com
2 → r1@com, r2@com
3 →
4 →
5 → M1@com

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Code:

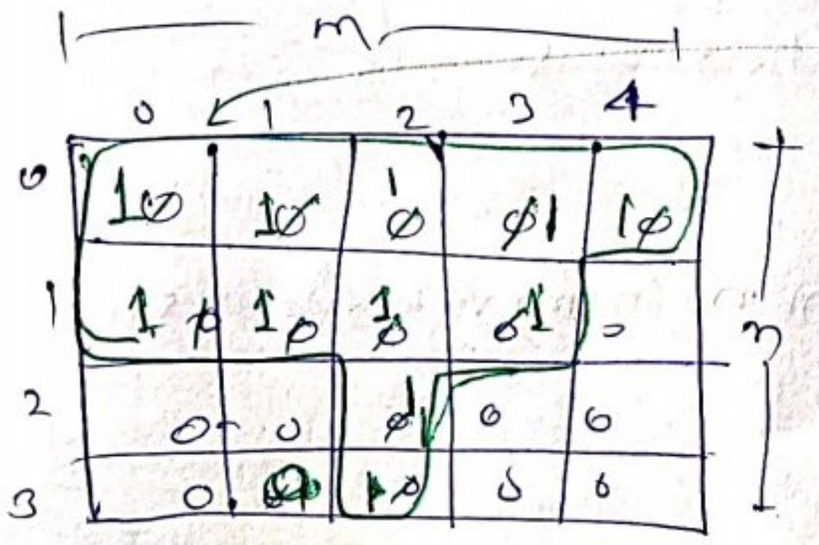
```
class DisjointSet
{
  ==
}

vector<vector<string>> mergeDetails(vector<vector<string>> & details)
{ int n = details.size();
  unordered_map<string, int> mapMailNode;
  for(int i=0; i<n; i++)
   { for(int j=1; j<details[i][j];
      if( mapMailNode.find(mail) == mapMailNode.end())
      {
        mapMailNode[mail] = i;
      }
      else
      {
        ds.unionBysize(i, mapMailNode[mail]);
      }
   }
}

vector<string> mergeMail[n];
for(auto it :mapMailNode)
  { string mail = it.first;
    int node = ds.findUPar(it.second);
    mergedMail[node].push_back(mail);
  }

vector<vector<string>> ans;
for(int i=0; i<n; i++)
  { if(mergedMail[i].size() ==0) continue;
    sort(mergedMail[i].begin(), mergedmail[i].end());
    vector<string> temp;
    temp.push_back(details[i][0]);
    for(auto it: mergedMail[i])
      { temp.push_back(it);
      }ans.push_back(temp);
} return ans; }
```

Number of Islands - II - online queries - DSU

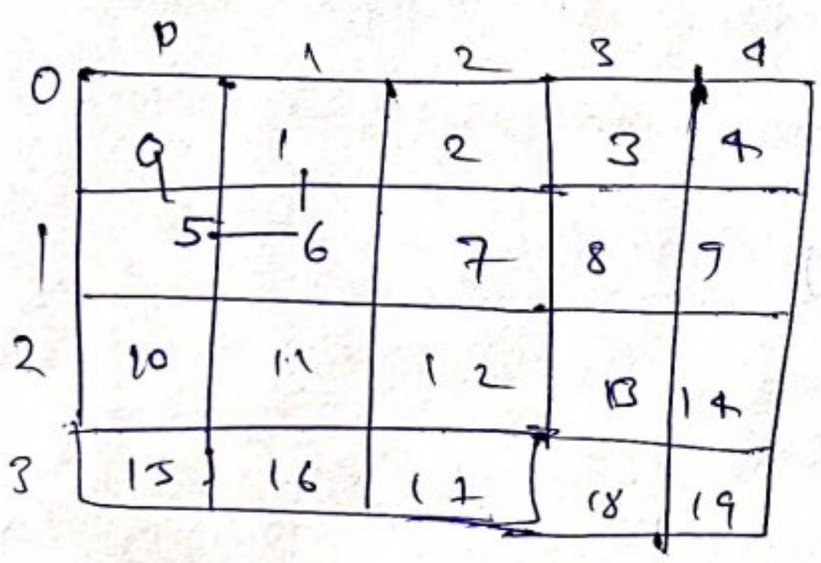


groups

(0,0) → 1
(0,0) → 1
(1,1) → 2
(1,0) → 1
(0,1) → 1
(0,3) → 2
(1,3) → 2
(0,4) → 2
(3,2) → 3
(2,2) → 3
(1,2) → 1
(0,2) → 1

[1 1 2 1 1 2 2 2 2 3 3 1 1]

⇒ formula (row, col) = $\underbrace{(row \times m) + col}_{node}$



Out: 1 1 2 2 2 3 3 3 4 4 2
3 1 2 2 3 3 1
2 2 1

class DisjointSet {

}

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```
bool isvalid(int adjr, int adjc, int n, int m)
{ return adjr >=0 && adjr < n && adjc >= 0 && adjc < m;
  }
Public: vector<int> numOfIslands(int n, int m, vector<vector<int>
&operators)
{ DisjointSet ds(n * m);
    int vis[n][m];
    memset(vis, 0, sizeof vis);
    int cnt = 0;
    vector<int> ans;
    for(auto it : operators)
    { int row = it[0];
      int col = it[1];
      if( vis[row][col] == 1)
          { ans.push_back(cnt);
            continue;
          }
      vis[row][col] = 1;
      cnt++;
int dr[] = {-1, 0, 1, 0};
int dc[] = {0, 1, 0, -1};
    for(int ind = 0; ind < 4; ind++)
        { int adjr = row + dr[ind];
          int adjc = col + dc[ind];
          if(isValid(adjr, adjc, n, m))
            {  if(vis[adjr][adjc] == 1)
                { int nodeNo = row * m + col;
                  if(~~ds.findUpar()~~
                    int adjNodeNo = adjr * m + adjc;
                  if(ds.findUpar(nodeNo) != ds.findUpar(adjNodeNo))
                    { cnt--;
                      ds.unionBySize(nodeNo, adjNodeNo);
                    }
                }
            }
        }
    }
    ans.push_back(cnt);
    return ans;
}
```

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Making ~~connect~~ a Large Island - DSU

	0	1	2	3	4
0	1	1	0	1	1
1	1	1	0	1	1
2	1	1	1	1	1
3	0	0	1	0	0
4	0	0	1	1	1
5	0	0	1	1	1

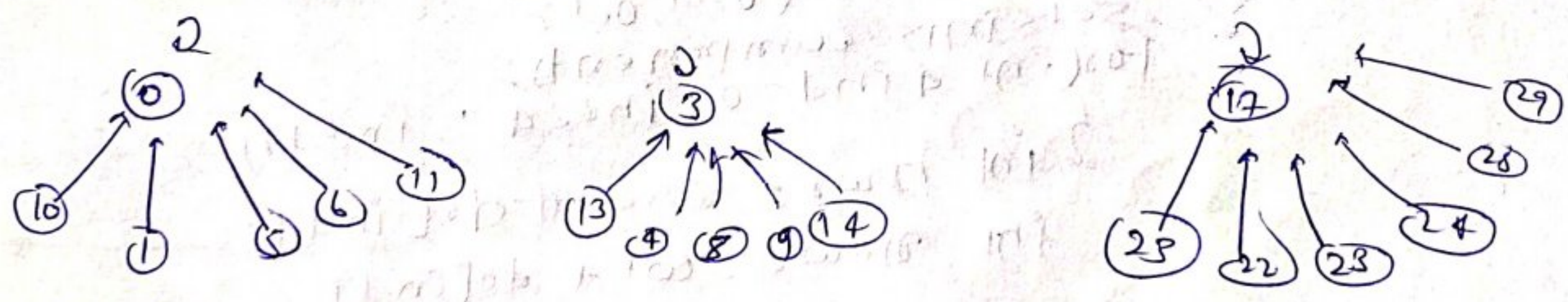
size = 6 + 6 + 7 + 1
= 20

	0	1	2	3	4
0	1	1	0	1	1
1	1	1	0	1	1
2	0	0	0	0	0
3	1	0	0	0	0
4	1	1	1	1	1
5	1	1	1	1	1

size = 10 + 1
= 11

we for using Disjoint set we have to convert an indexes into a single no. so that we can map it and use.

formula = (row * m) + col




```
class DisjointSet {
    ==
    ==
    ==
};

class solution {
public:
int maxConnection (vector<vector<int>> & grid)
{ int n=grid.size();
  DisjointSet ds(n*n);
  for(int row=0; row<n; row++)
   { for(int col=0; col<n; col++)
     { if(grid[i][j] == 0)
          continue;
       int dr[] = {-1, 0, 1, 0};
       int dc[] = {0, -1, 0, 1};
```

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Scanned with OKEN Scanner

```
for(int ind = 0; ind<4; ind++)
    { int newr = row + dr[ind];
      int newc = col + dc[ind];

if( isValid(newr, newc, n) && grid[newr][newc] ==1)
{ int nodeNo = row*n + col;
  int adjNodeNo = newr*n + newc;
  ds.unionBySize( nodeNo, adjNodeNo);
}
}
}
}
int max = 0;
for(int row =0; row<n; row++)
{ for(int col=0; col<n; col++)
  { if(grid [row][col] ==1
    { continue;
  int dr ={-1,0,1,0};
  int dc = {0,-1,0,1};
  set<int> components;
  for(int ind=0; ind<4; ind++)
  { int newr = row + dr[ind];
    int newc = col + dc[ind];
    if( isValid(newr, newc, n)) && grid[newr][newc] ==1)
    { int nodeNo = row * n + col;
      int adjNodeNo = newr*n + newc;
      ds.unionBySize(nodeNo, adjNodeNo);
if( isValid(newr, newc, n)){
  if(grid[newr][newc] ==1) {
    components.insert(ds.findupar(newr*n + newc));
}}
int sizetotal =0;
for(auto it: components)
  { sizetotal += ds.size[it];
  }
  Mx = max(Mx, sizetotal);
}}
```

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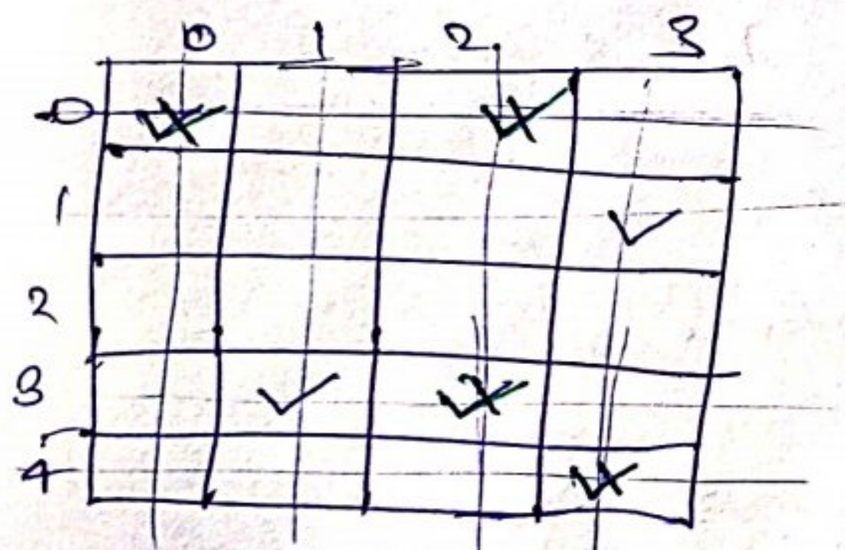
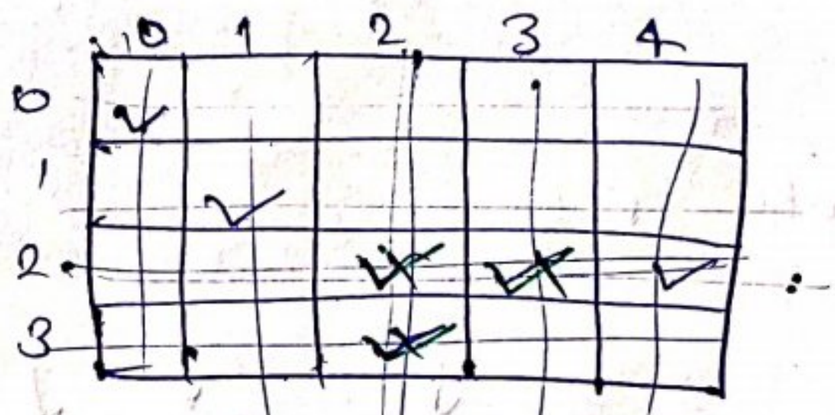
```
for( int cellNO=0; cellNo < n*n ; cellNO ++)
{
  Mx = Max(Mx, ds.size[ds.findupar(cellNo)]).
}
return mx;
}
```

$\boxed{T.C.\ O(N^2 * \alpha)}$

Most Stones Removed with same row or column

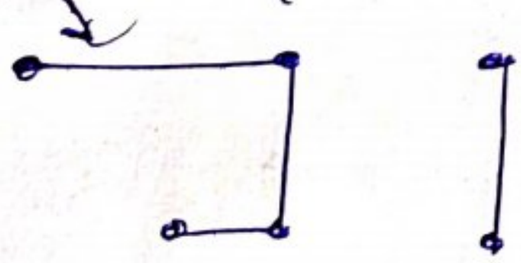


ans = 4



ans = 3

Components Remove 1 element in each component



$= (4-1) + (2-1)$

$= 3 + 1$

$= 4$

$= (1-1) + (1-1) + (4-1)$

$= 0 + 0 + 3$

$= 3$

if there are n stones.

C_1	C_2	C_3	C_4
x_1 stones	x_2 stones	x_3 stones	x_4 stones

$x_1 + x_2 + x_3 + \dots = n$ stones

Stones are removed $(x_1 - 1) + (x_2 - 1) + (x_3 - 1) + \dots =$

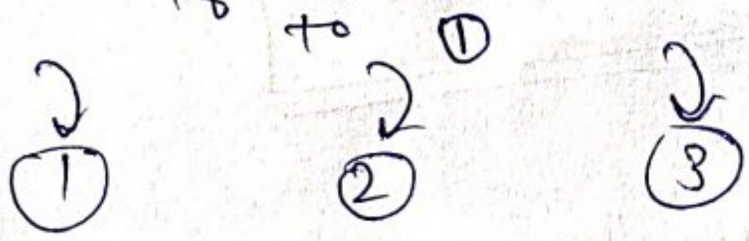
$(x_1 + x_2 + x_3 + \dots) - (1 + 1 + 1 \dots)$

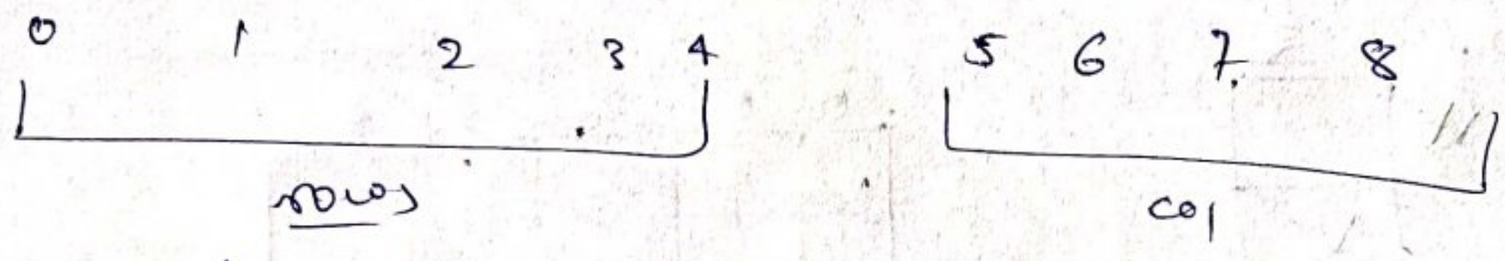
$\boxed{\text{ans} = n - \text{no. of components.}}$ n = no. of stones

Here we are connecting stones to make node.
so we use disjoint set data structure.

we will treat row as a node

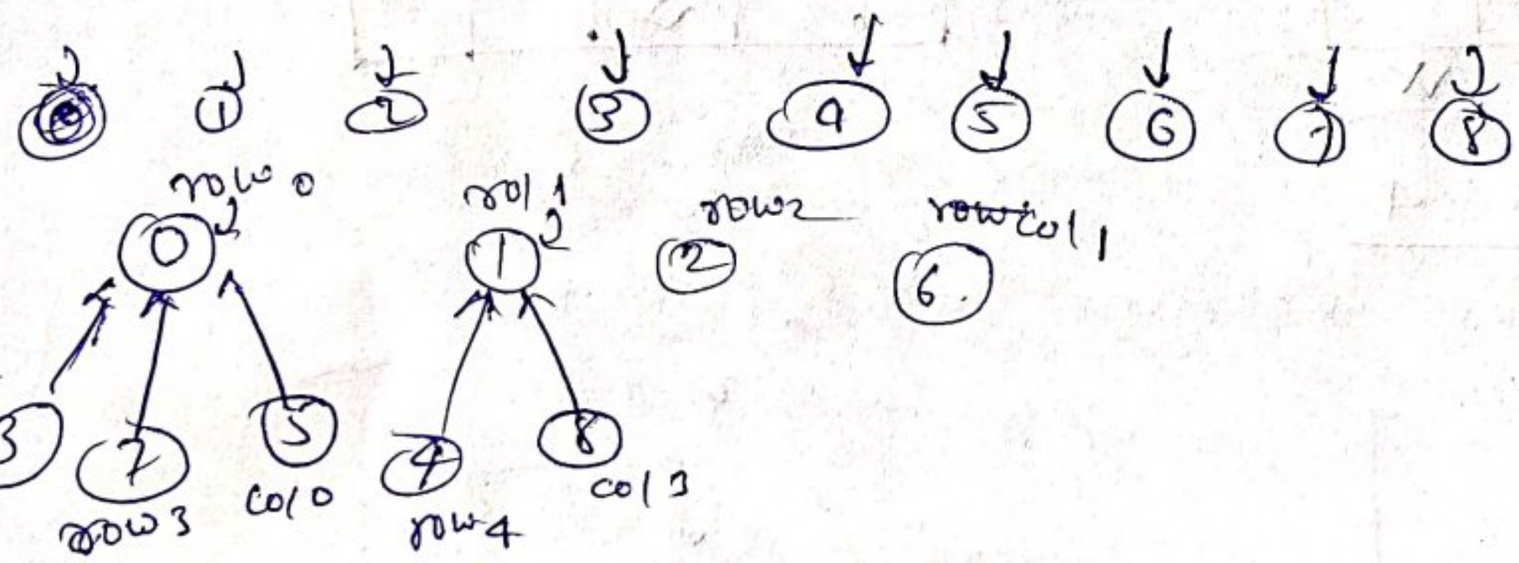
if there is stone in a row we will say it belongs to ①





nodes is DS

nodes on DS



2 connected components

for all the stone there is 2 ultimate parents

ans = 6 − 2 = 4 Ans

~~Code:~~

we just need the nodes in DISJOINT set which are involved in having a stone.
so we store the rows and columns in map as they will have stones. And we just need to count them once for ultimate parents.

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Code :

```
class DisJointSet {
    int(mo
    }
int maxRemove(vector<vector<int>> & stones, int n)
{   int maxRow = 0;
    int maxcol = 0;
    for (auto it : stones)
    {   maxRow = max(maxRow, it[0]);
        maxcol = max(maxcol, it[1]);
    }
    DisJointSet ds (maxRow + maxcol + 1);
    unordered_map<int, int> stoneNodes;
    for (auto it : stones)
    {   int noderow = it[0];
        int nodecol = it[1] + maxRow + 1;
        ds.unionBysize(noderow, nodecol);
        stoneNodes [noderow] = 1;
        stoneNodes [node col] = 1;
    }
    int cnt = 0;
    for(auto it : stonenodes)
    {   if(ds.findupar(it.first) == it.first)
        {   cnt ++;
        }
    }
    return n - cnt;
}
}
```

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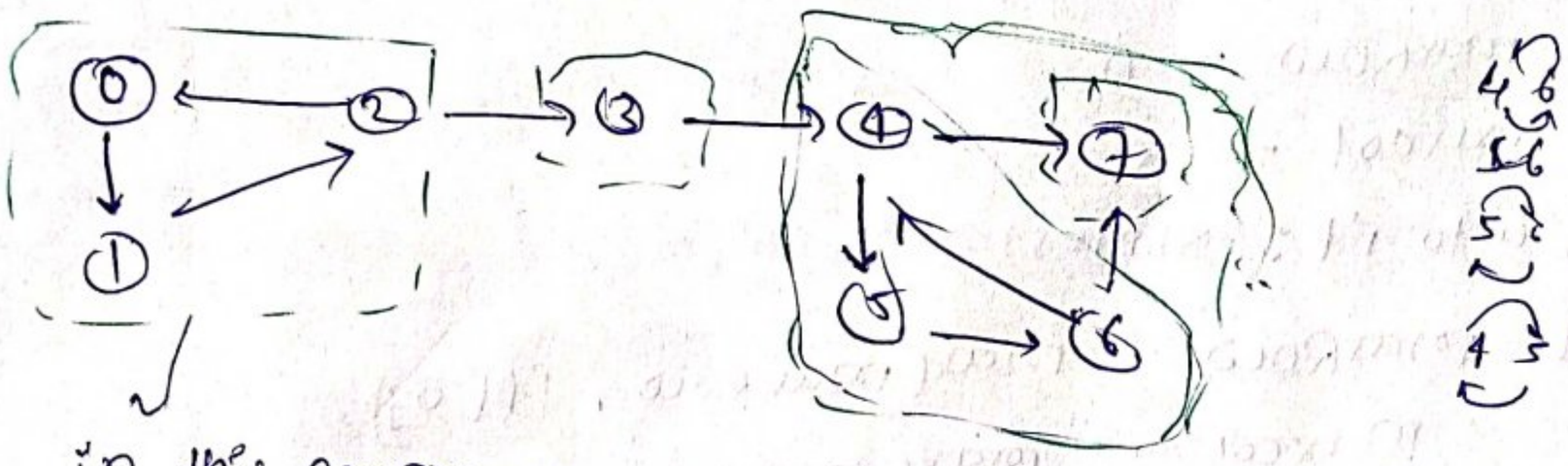
Strongly connected components (SCC) :-

only valid for DG (directed graph) (Kosaraju's Algorithm)



in this component every pair is reachable

0 2
2 0
1 2
2 1
1 0
0 1

Strongly connected component

0 1 2 | 3 | 4 5 6 | 7

4 Strongly connected component

- sort all the edges according to finishing time.
- Reverse the graph
- Do a dfs.

top →

0
1
2
3
4
5

Code :-

```
void dfs(int node, vector<int> &vis, vector<int> adj[],
stack<int> &st)
{
    vis[node] = 1;
    for(auto it : adj[node])
    {
        if(!vis[it])
        {
            dfs(it, vis, adj, st);
        }
    }
    st.push(node);
}
```

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```
void dfs3(int node, vector<int> &vis, vector<int> adjT[])
{ vis[node] = 1;
  for(auto id : adjT[Node])
    { if(!vis[id])
        { dfs3(id, vis, adjT);
        }
    }
}

int kosaraju(int v, vector<int> adj[])
{
    vector<int> & vis(v, 0);
    stack<int> st;
  for(int i = 0; i<v; i++)
    { if(!vis[i])
        { dfs(i, vis, adj, st);
        }
    }

    vector<int> ~~adjT[v]~~
                adjT[v];
    for(int i=0; i<v; i++)
    { vis[i] = 0;
      for(auto id : adj[i])
        {
            adjT[id].push_back(i);
        }
    }
    int scc = 0;
    while(!st.empty())
    { int node = st.top();
      st.pop();
      if(!vis[node])
      { scc++;
        dfs3(node, vis, adjT);
      }
    }
    return scc;
}
```

T.C. $O(V+E)$
$+ O(V+E)$
$+ O(V+E)$
$\approx O(N+E)$

S.C. $\approx$ ~~$O(N)$~~
$\approx O(N+E)$

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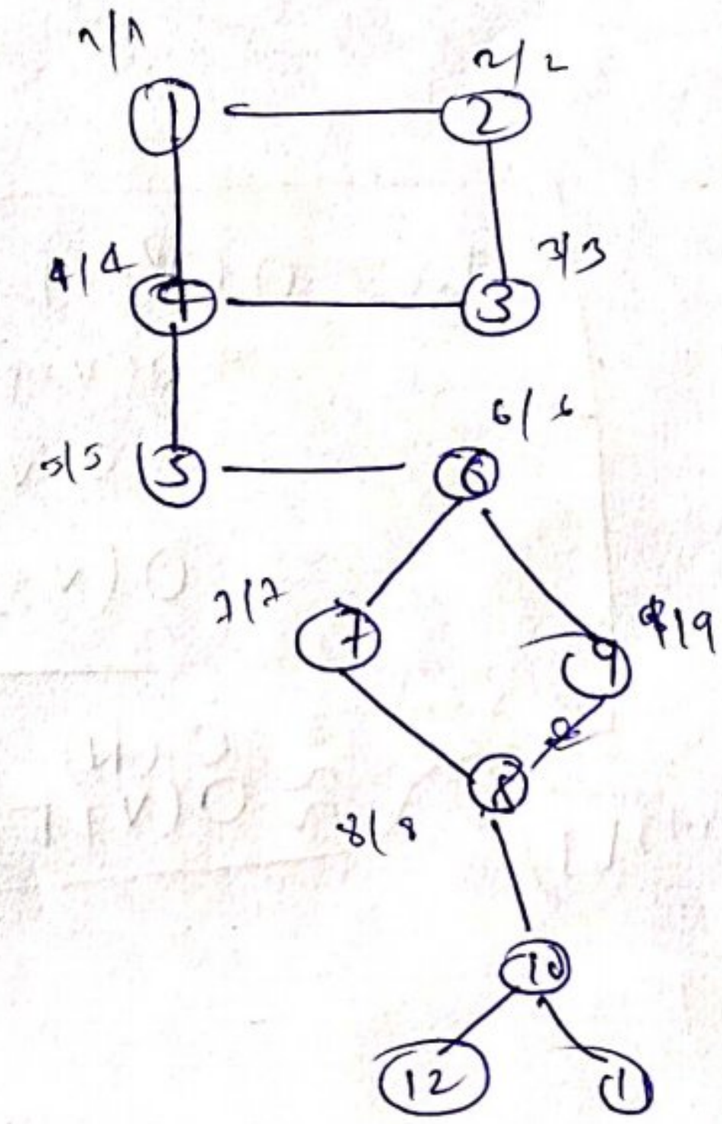
Bridges in Graph :-



Any edge on whose removal the graph is broken down into two or more components.

4 – 5
5 – 6
10 – 8

dis[] → DFS time inserts on
low[] → Min lowest time insertion of all adjacent nodes apart from parent.

DFS(8)
⇅
DFS(9)

if I can reach you then it is not a bridge.

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Code :-

```
int timer = 1;
void dfs( int node, int parent, vector<int> &vis, vector<int> adj[],
int tin[], int low[], vector<vector<int>> )
{
    vis[node] = 1;
    tin[node] = low[node] = timer;
    time++;
    for(auto it: adj[node])
    {
        if(it == parent)
            continue;
        if(vis[it] == 0)
        {
            dfs(it, node, vis, adj, tin, low);
            low[node] = min(low[node], low[it]);
            if(low[it] > tin[node])
            {
                bridges.push_back({it, node});
            }
        }
        else{
            low[node] = min{low[node], low[it]};
        }
    }
}
vector<vector<int>> criticalConnections( int n, vector<vector<int>&
connections) { vector<int> adj[n];
    for(auto it: connections)
    {
        adj[it[0]].push_back(it[1]);
        adj[it[1]].push_back(it[0]);
    }
    vector<int> vis(n,0);
    int tin[n], low[n];
    vector<vector<int>> bridges;
    dfs(0,-1, vis, adj, tin, low, bridges);
    return bridges;
}
```

T.C
$\simeq O(V+2E)$

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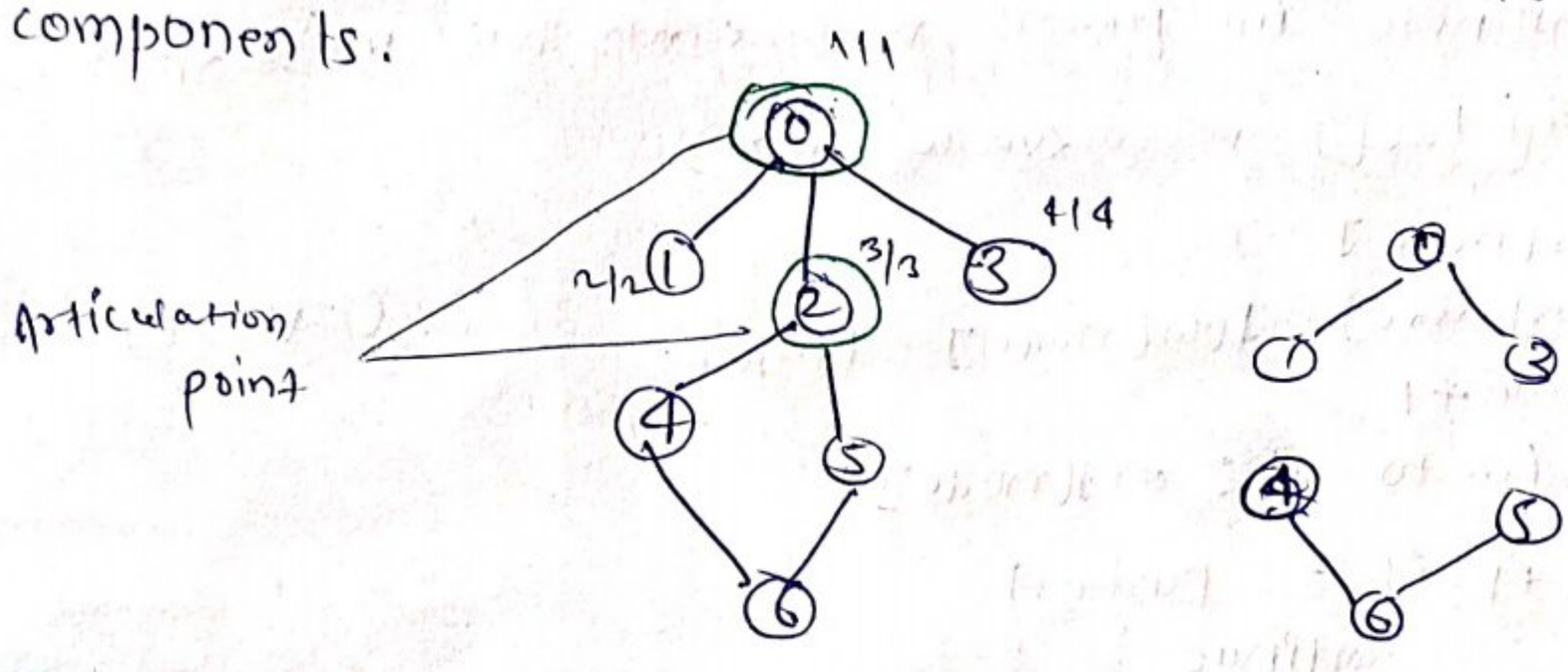
Articulation point :-

Nodes on whose removal the graph breaks into multiple components.



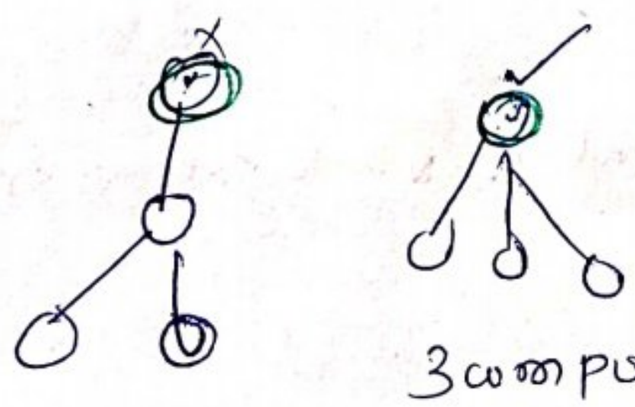
Time of insertion $T_{in}[\,]$ → store the time of insertion during the BFS.

low $low[\,]$ → min of all adjacent nodes apart from the parent & visited nodes.

if (low [it] >= tm [node] && parent != -1)

dfs(2) → 3

dfs(3) → 1 it can reach to 3.



3 component.

1 component

Component should be ≥ 2

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Code :-

```
int timer=0;

void dfs( int node, int parent, vector<int> &vis, int tin[], int
int low[], vector<int> &mark, vector<int> adj[])
{
    vis[node] = 1;
    tin[node] = low[node] = timer;
    timer++;
    int child = 0;

    for(auto it : adj[node])
    {
        if(it == parent)
            continue;
        if(!vis[it])
        {
            dfs(it, node, vis, tin, low, mark, adj);
            low[node] = min(low[node], low[it]);
            if(low[it] >= tin[node] && parent != -1)
            {
                mark[node] = 1;
            }
            child++;
        }
        else {
            low[node] = min(low[node], tin[it]);
        }
    }
    if (child > 1 && parent == -1)
    {
        mark[node] = 1;
    }

public : vector<int> articulation points(int n, vector<int>
adj[])
{
    int tin[n];
    int low[n];
    vector<int> mark (n,0);
    for(int i=0; i<n; i++)
    {
        if(!vis[i]){
            dfs(i,-1, vis, tin, low, mark, adj);
        }
    }
```

T.C. ≈ O(V+2E)
S.C. ≈ O(N)

@Aashish Kumar Nayak

```
vector<int> ans;
  for( int i=0; i<n; i++)
    { if(mark[i] == 1)
      {ans.push_back(i); }
    }

    if(ans.size() == 0)
      {return {-1}; }
  } return ans;
```

END

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