1 Data Structure

1.1 dsu class

```cpp
#include <bits/stdc++.h>
using namespace std;

class DSU{
    public:
    DSU(int n ){
        this->n = n;
        reset();
    }
    int n;
    vector<int> boss;
    vector<int> rank;
    vector<int> size;

    void reset(){
        this->boss.resize(n);
        this->rank.resize(n,0);
        this->size.resize(n,0);
        for(int i =0;i<n;i++){
            boss[i] = i;
        }
    }
    int find(int x){
        if(boss[x]!= x){
            boss[x] = find(boss[x]);
        }
        return boss[x];
    }
    int get_size(int x){
        return size[find(x)];
    }
    void merge(int x, int y){
        int a = find(x);
        int b = find(y);
        if(a!=b){
            if(rank[a]<rank[b]){
                boss[a] = b;
                size[b] += size[a];
            }else if (rank[a]<rank[b]){
                boss[b] = a;
                size[a] += size[b];
            }else{
                boss[a] = b;
                size[b] += size[a];
                rank[b]++;
            }
        }
    }
    bool aresame(int a,int b){
        return find(a)==find(b);
    }
};
```

1.2 monotonic queue

```cpp
#include<bits/stdc++.h>
using namespace std;

class Monotonic_queue{
private:
    deque<int> qu;
public:
    void push(int n){
        while(!qu.empty()&&qu.back()<n){
            qu.pop_back();
        }
        qu.push_back(n);
    }
    int max(){
        return qu.front();
    }
    int min(){
        return qu.back();
    }
    int  size(){
        return qu.size();
    }
    void pop(){
        qu.pop_front();
    }
};
```

1.3 BIT

```cpp
#include <bits/stdc++.h>
using namespace std;

class BIT{
public:
    vector<int> bit;
    int N;
    BIT(int n){
        this->N = n;
        this->bit.resize(n);
    }
    void update(int x,int d){
        while(x<=N){
            bit[x] +=d;
            x +=x&(-x);// lowest bit in x;
        }
    }
    int query(int x){
        int res = 0;
        while(x){
            res+= bit[x];
            x -= x& -x;
        }
        return res;
    }
};
```

1.4 segment tree simple add

```cpp
#include <bits/stdc++.h>
using namespace std;

struct node{
    int left;
    int right;
    int value;
};
vector<node> segment_tree;
void build(int left ,int right ,int x ,vector<int> & nums){
    segment_tree[x].left = left;
    segment_tree[x].right = right;
    // cout <<left <<" "<<right<<" "<<x<<endl;
    if(left == right){ // here is leaf
        segment_tree[x].value = nums[left];
        return;
    }
    int mid = (left+right)/2;
    build(left ,mid,x<<1,nums);
    build(mid+1,right ,x<<1|1,nums);
    segment_tree[x].value = segment_tree[x<<1].value+
        segment_tree[x<<1|1].value;
}
void modify(int position ,int x,int value){
    if(segment_tree[x].left == position && segment_tree[x].
        right ==position){ // here is leaf
        segment_tree[x].value = value;
        return;
    }
    int mid = (segment_tree[x].left+segment_tree[x].right)/2;

    if(position<=mid){
        modify(position ,x<<1,value);
    }else{
        modify(position ,x<<1|1,value);
    }
    segment_tree[x].value = segment_tree[x<<1].value+
        segment_tree[x<<1|1].value;
}
int query(int i ,int j ,int x){
    int res = 0;
    int left = segment_tree[x].left;
    int right = segment_tree[x].right;
    int mid = (left+right)/2;
    if(segment_tree[x].left==i && segment_tree[x].right ==j){
        return segment_tree[x].value;
    }
    if(i>mid)return query(i ,j ,x*2+1);
    if(mid>=j)return query(i ,j ,x*2);
    return query(i ,mid,x*2)+ query(mid+1,j ,x*2+1);
}
```

1.5 monotonic stack

```cpp
#include<bits/stdc++.h>
using namespace std;

vector<int> monotonic_stack(vector<int> nums){
    int n = nums.size();
    vector<int> res(n);
    stack<int>  st;
    for(int i = n-1;i>=0;i--){
        while(!st.empty() && st.top()<=nums[i]){
            st.pop();
        }
        if(st.empty())res[i] = -1;
```

```
        else res[i] = st.top();
        st.push(nums[i]);
    }
    return res;
}
```

2 Flow

2.1 dicnic

```
#include <bits/stdc++.h>
#define maxn 2005
#define INF 0x3f3f3f3f
using namespace std;
struct MaxFlow{
    struct edge{
        int  to, cap, flow,rev;
        edge( int v, int c, int f,int r) :  to(v), cap(c),
             flow(f),rev(r) {}
      };
    vector<edge> G[maxn];
    int s,t,dis[maxn],cur[maxn],vis[maxn];
    void add_edge(int from,int to,int cap){
        G[from].push_back(edge(to,cap,0,G[to].size()));
        G[to].push_back(edge(from,0,0,G[from].size()-1));
    }
    bool bfs(){
        memset(dis, -1, sizeof(dis));
        queue<int> qu;
        qu.push(s);
        dis[s] = 0;
        while (!qu.empty()) {
            int from = qu.front();
            qu.pop();
            for (auto &e: G[from]) {
                if (dis[e.to]==-1 && e.cap != e.flow) {
                    dis[e.to] = dis[from] + 1;
                    qu.push(e.to);
                }
            }
        }
        return dis[t]!=-1;
    }
    int dfs(int from,int cap){
        if(from==t ||cap==0)return cap;
        for(int &i = cur[from];i<G[from].size();i++){
            edge &e = G[from][i];
            if(dis[e.to]==dis[from]+1 && e.flow!=e.cap){
                int df = dfs(e.to,min(e.cap-e.flow,cap));
                if(df){
                    e.flow+=df;
                    G[e.to][e.rev].flow-=df;
                    return df;
                }
            }
        }
        dis[from] = -1;
        return 0;
    }
    int Maxflow(int s,int t){
        this->s = s,this->t =t;
        int flow = 0;
        int df;
        while(bfs()){
            memset(cur,0,sizeof(cur));
            while(df = dfs(s,INF)){
                flow +=df;
            }
        }
        return flow;
    }
};
int main(){
    int n = 4,m = 6;
    MaxFlow maxflow;
    for(int i =0;i<m;i++){
        int a,b,cap;
        cin >>a>>b>>cap;
        maxflow.add_edge(a,b,cap);
    }
    cout << maxflow.Maxflow(1,3)<<endl;;
}
```

3 Gaph

3.1 planar

```
#include <iostream>
#include <vector>
#include <unordered_set>

using namespace std;

class Graph {
public:
    int V;
    vector<vector<int>> adj;
    Graph(int vertices) : V(vertices), adj(vertices) {}
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
};

bool containsSubgraph(const Graph& graph, const vector<int>&
     subgraph) {
    unordered_set<int> subgraphVertices(subgraph.begin(),
         subgraph.end());
    for (int vertex : subgraphVertices) {
        for (int neighbor : graph.adj[vertex]) {
            if (subgraphVertices.count(neighbor) == 0) {
                bool found = true;
                for (int v : subgraph) {
                    if (v != vertex && v != neighbor) {
                        if (graph.adj[v].size() < 3) {
                            found = false;
                            break;
                        }
                    }
                }
                if (found)
                    return true;
            }
        }
    }
    return false;
}

bool isPlanar(const Graph& graph) {
    // Subgraphs isomorphic to K  and K ,
    vector<int> k5 = {0, 1, 2, 3, 4};        // Vertices of K
    vector<int> k33a = {0, 1, 2};            // Vertices of K
          , (part A)
    vector<int> k33b = {3, 4, 5};            // Vertices of K
          , (part B)

    if (containsSubgraph(graph, k5) || containsSubgraph(graph
         , k33a) || containsSubgraph(graph, k33b)) {
        return false; // The graph is non-planar
    }
    return true; // The graph is planar
}
int main() {
    int vertices, edges;
    Graph graph(vertices);
    for (int i = 0; i < edges; ++i) {
        int u, v;cin >> u >> v;
        graph.addEdge(u, v);
    }
    if (isPlanar(graph)) {
        cout << "The graph is planar." << endl;
    } else {
        cout << "The graph is non-planar." << endl;
    }
}
```

3.2 Dijkstra

```
#include <bits/stdc++.h>
using namespace std;

#define maxn 200005
vector<int> dis(maxn,-1);
vector<int> parent(maxn,-1);
vector<bool> vis(maxn,false);
vector<vector<pair<int,int>>> graph;
void dijsktra(int source){
    dis[source] =0 ;

    priority_queue<pair<int,int>,vector<pair<int,int>>,
         greater<pair<int,int>>> pq;
    pq.push({0,source});
    while(!pq.empty()){
        int from  = pq.top().second;
        pq.pop();
        // cout <<vis[from]<<endl;
        if(vis[from])continue;
        vis[from] = true;
        for(auto next : graph[from]){
            int to = next.second;
            int weight = next.first;
            // cout <<from<<' '<<to<<' '<<weight;
            if(dis[from]+weight< dis[to] || dis[to]==-1){
                dis[to] = dis[from]+weight;
                parent[to] = from;
```

```
                pq.push({dis[from]+weight,to});
            }
        }
    }
}
int main(){
    int startpoint;
    dijsktra(startpoint);
    //dis and parent
}
```

3.3 Floyd Warshall

```
#include <bits/stdc++.h>
using namespace std;

#define maxn 2005
vector<vector<int>> dis(maxn,vector<int>(maxn,9999999));
vector<vector<int>> mid(maxn,vector<int>(maxn,-1));
vector<vector<pair<int,int>>> graph;

void floyd_warshall(int n ){ // n is n nodes
  for(int i =0;i<n;i++){
        for(auto path:graph[i]){
            dis[i][path.second] = path.first;
        }
    }
  for (int i=0; i<n; i++)
    dis[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 (dis[i][k] + dis[k][j] < dis[i][j] || dis[i][j]==-1){
          dis[i][j] = dis[i][k] + dis[k][j];
          mid[i][j] = k;  // 由i點走到j點經過了k點
        }
            }
        }
    }
}
void find_path(int s, int t){   // 印出最短路徑
  if (mid[s][t] == -1) return;  // 🅴有中繼點就結束
  find_path(s, mid[s][t]);    // 前半段最短路徑
  cout << mid[s][t];        // 中繼點
  find_path(mid[s][t], t);    // 後半段最短路徑
}
int main(){
    int n;
    floyd_warshall(n);
    for(int i =0;i<4;i++){
        for(int j = 0 ; j <4;j++)
            cout << dis[i][j]<<" ";
        cout << endl;
    }
    find_path(0,2);
}
```

3.4 2 sat

```
#include <bits/stdc++.h>
using namespace std;

class TwoSAT {
public:
    TwoSAT(int n) : n(n), graph(2 * n), visited(2 * n, false) {}
    void addClause(int a, int b) {// 0-base;
        a *=2;
        b *=2;
        // Add implications (~a => b) and (~b => a)
        graph[a ^ 1].push_back(b);
        graph[b ^ 1].push_back(a);
    }
    bool solve() {// Find SCCs and check for contradictions
        for (int i = 0; i < 2 * n; ++i) {
            if (!visited[i]) {
                dfs1(i);
            }
        }
        reverse(processingOrder.begin(), processingOrder.end());//topological sort
        for (int i = 0; i < 2 * n; ++i) {
            visited[i] = false;
        }
        for (int node : processingOrder) {
            if (!visited[node]) {
                scc.clear();
                dfs2(node);
                if (!checkSCCConsistency()) {
                    return false;
                }
            }
        }

        return true;
    }

private:
    int n;
    vector<vector<int>> graph;
    vector<bool> visited;
    vector<int> processingOrder;
    vector<int> scc;

    void dfs1(int node) {
        visited[node] = true;
        for (int neighbor : graph[node]) {
            if (!visited[neighbor]) {
                dfs1(neighbor);
            }
        }
        processingOrder.push_back(node);
    }

    void dfs2(int node) {
        visited[node] = true;
        scc.push_back(node);
        for (int neighbor : graph[node]) {
            if (!visited[neighbor]) {
                dfs2(neighbor);
            }
        }
    }

    bool checkSCCConsistency() {
        for (int node : scc) {
            if (find(scc.begin(), scc.end(), node ^ 1) != scc.end()) {
                return false; // Contradiction found in the same SCC
            }
        }
        return true;
    }
};
int main() {
    int n, m;// Number of variables and clauses
    TwoSAT twoSat(n);
    for (int i = 0; i < m; ++i) {
        int a, b;
        twoSat.addClause(a, b);
    }
    if (twoSat.solve()) {
        cout << "Satisfiable" << endl;
    } else {
        cout << "Unsatisfiable" << endl;
    }
}
```

3.5 Kosaraju 2dfs

```
#include <bits/stdc++.h>
using namespace std;

const int n = 16;
vector<vector<int>> graph;
vector<vector<int>> reverse_graph;
int visit[n];
int contract[n]; // 每個點收縮到的點
vector<vector<int>> block;
vector<int> finish;//fake topological sort
// need graph and reverse praph
void dfs1(int x){
    visit[x] = true;
    for(auto to:graph[x]){
        if(!visit[to]){
            dfs1(to);
        }
    }
    finish.push_back(x);
}
void dfs2(int x,int c){
    contract[x] = c;
    block[c].push_back(x);
    visit[x] = true;
    for(auto to:reverse_graph[x]){
        if(!visit[to]){
            dfs2(to,c);
        }
    }
}
int main(){
    graph = {};
    reverse_graph = {};

    for(int i =0;i<n;i++){
        if (!visit[i])
      dfs1(i);
```

```
    }
    int c =0;
    memset(visit,0,sizeof(visit));
    for(int i =  n-1;i>=0;i--){
        if(!visit[finish[i]]){
            block.push_back({});
            dfs2(finish[i],c++);
        }
    }
    for(auto t: block){
        for(auto x:t){
            cout << x <<" ";
        }cout <<endl;
    }
}
```

3.6 bipartite matching

```
#include <bits/stdc++.h>
using namespace std;
const int MAXN = 100;

struct Bipartite_matching{
    int mx[MAXN], my[MAXN], vy[MAXN]; //matchX, matchY, visitY
    vector<int> edge[MAXN]; //adjcent list;
    int x_cnt;
    bool dfs(int x){
        for(auto y: edge[x]){ //對 x 可以碰到的邊進行檢查
            if(vy[y] == 1) continue; //避免遞F error

            vy[y] = 1;
            if(my[y] == -1 || dfs(my[y])){ //分析 3
                mx[x] = y;
                my[y] = x;
                return true;
            }
        }
        return false; //分析 4
    }

    int bipartite_matching(){
        memset(mx, -1, sizeof(mx)); //分析 1,2
        memset(my, -1, sizeof(my));
        int ans = 0;
        for(int i = 0; i < x_cnt; i++){  //對每一個 x 節點進行 DFS(最大匹配)
            memset(vy, 0, sizeof(vy));
            if(dfs(i)) ans++;
        }
        return ans;
    }
    vector<vector<int>> get_match(){
        vector<vector<int>> res;
        for(int i =0 ;i<x_cnt;i++){
            if(mx[i]!=-1){
                res.push_back({i,mx[i]});
            }
        }
        return res;
    }
    void add_edge(int i,int j){
        edge[i].push_back(j);
    }
    void init(int x){
        x_cnt = x;
    }
};
int main(){
    int n,m;
    Bipartite_matching bm;
    for(int i = 0;i<m;i++){
        int a , b;cin >>a>>b;
        bm.add_edge(a,b);
    }
    bm.init(n);
    cout << bm.bipartite_matching()<<endl;
    auto match = bm.get_match();
    for(auto t: match){
        cout << t[0]<<" "<<t[1]<<endl;
    }

}
```

3.7 tarjan SCC

```
#include <bits/stdc++.h>
using namespace std;
const int n = 16;
vector<vector<int>> graph;
int visit[n], low[n],t = 0;
int st[n], top =0;
bool instack[n];
int contract[n]; // 每個點收縮到的點
vector<vector<int>> block;
void dfs(int x,int parent){
    // cout <<x<<endl;
    visit[x] = low[x] = ++t;
  st[top++] = x;
  instack[x] = true;
    for(auto to: graph[x]){
        if(!visit[to])
            dfs(to,x);

        if(instack[to])
            low[x] = min(low[x],low[to]);
    }
    if(visit[x]==low[x]){ //scc 最早拜訪的
        int j;
        block.push_back({});
        do{
            j = st[--top];
            instack[j] = false;
            block[block.size()-1].push_back(j);
            contract[j] =x;
        }while(j!=x);
    }
}
int main(){
    for(int i =0;i<n;i++){
        if (!visit[i])
      dfs(i, i);
    }
    for(auto t: block){
        for(auto x:t){
            cout << x <<" ";
        }cout <<endl;
    }
}
```

3.8 topological sort

```

#include <bits/stdc++.h>
using namespace std;
vector<vector<int>> graph;
vector<int> visit(10,0);
vector<int> order;
int n;
bool cycle;   // 記F DFS的過程中是否偵測到環
void DFS(int i){ //reverse(order) is topo
  if (visit[i] == 1) {cycle = true; return;}
  if (visit[i] == 2) return;
  visit[i] = 1;
  for(auto to :graph[i])
        DFS(to);
  visit[i] = 2;
    order.push_back(i);
}//for() if(!vis[i])DFS(i)
int main() {
  for (int i=0; i<n; ++i){
    if (!visit[i])
      DFS(i);
    }
  if (cycle)
    cout << "圖上有環";
  else
    for (int i=n-1; i>=0; --i)
      cout << order[i];
}
```

3.9 bridge

```
#include <bits/stdc++.h>
using namespace std;
const int n = 9;
vector<vector<int>> graph;
vector<int> visit(n, 0);
vector<int> trace(n, 0);
vector<vector<int>> bridge;
int t = 0;
void dfs(int x, int parent){
    visit[x] = ++t;
    trace[x] = x; // 最高祖先預設F自己
    for (auto to : graph[x]){
        if (visit[to]){ // back edge
            if (to != parent){
                trace[x] = to;
            }
        }
        else{ // treeedge
            dfs(to, x);
            if (visit[trace[to]] < visit[trace[x]])
                trace[x] = trace[to];
```

```
            // 子樹回不到祖先暨自身。
            if (visit[trace[to]] > visit[x])
                bridge.push_back({x, to});
        }
    }
}//call for()dfs(i,-1)
int main(){
    for(int i =0;i<9;i++){
        if(!visit[i])
            dfs(i,-1);
    }
    for(auto x: bridge){
        cout << x[0]<<" "<< x[1]<<endl;
    }
}
```

3.10 Articulation vertex

```
#include <bits/stdc++.h>
using namespace std;
const int n = 9;
int t = 0;
vector<int> disc(n, -1);          // Discovery time
vector<int> low(n, -1);           // Low time
vector<int> parent_array(n, -1); // Parent in DFS tree
vector<bool> visited(n, false);
vector<bool> is_articulation(n, false);
vector<vector<int>> graph;
void dfs_articulation(int node, int parent)
{
    visited[node] = true;
    disc[node] = t;
    low[node] = t;
    t++;
    int children = 0;

    for (int neighbor : graph[node])
    {
        if (!visited[neighbor])
        {
            children++;
            parent_array[neighbor] = node;
            dfs_articulation(neighbor, node);
            low[node] = min(low[node], low[neighbor]);

            if (low[neighbor] >= disc[node] && parent != -1)
            {
                is_articulation[node] = true;
            }
        }
        else if (neighbor != parent)
        {
            low[node] = min(low[node], disc[neighbor]);
        }
    }

    if (parent == -1 && children > 1)
    {
        is_articulation[node] = true;
    }
}//call for() dfs(i,-1)
int main(){
    for (int i = 0; i < n; ++i) {
        if (!visited[i]) {
            dfs_articulation(i, -1);
        }
    }
    cout << "Articulation Points: ";
    for (int i = 0; i < n; ++i) {
        if (is_articulation[i]) {
            cout << i << " ";
        }
    }cout << endl;
}
```

4 Math

4.1 extgcd

```
#include<bits/stdc++.h>
using namespace std;

int extgcd(int a,int b,int &x,int &y){//a*x +b*y = 1
    if(b==0){
        x = 1;
        y = 0;
        return a;  //到達遞歸邊界開始向上一層返回
    }
    int r = extgcd(b,a%b,x,y);
    int temp=y;     //把x y變成上一層的
    y = x - (a / b) * y;
    x = temp;
    return r;      //得到a b的最大公因數
}
int main(){
    int a = 55,b = 80;
    int x,y;//a*x+b*y = 1;
    int GCD = extgcd(a,b,x,y);
}
```

5 Original Code/Data Structure

5.1 dsu class

```
#include <bits/stdc++.h>

using namespace std;

class DSU{
    public:
    DSU(int n ){
        this->n = n;
        reset();
    }
    int n;
    vector<int> boss;
    vector<int> rank;
    vector<int> size;

    void reset(){
        this->boss.resize(n);
        this->rank.resize(n,0);
        this->size.resize(n,0);
        for(int i =0;i<n;i++){
            boss[i] = i;
        }
    }
    int find(int x){
        if(boss[x]!= x){
            boss[x] = find(boss[x]);
        }
        return boss[x];
    }
    int get_size(int x){
        return size[find(x)];
    }
    void merge(int x, int y){
        int a = find(x);
        int b = find(y);
        // if(a!=b){
        //     boss[a] = b;
        //     size[b] += size[a];
        // }
        if(a!=b){
            if(rank[a]<rank[b]){
                boss[a] = b;
                size[b] += size[a];
            }else if (rank[a]<rank[b]){
                boss[b] = a;
                size[a] += size[b];
            }else{
                boss[a] = b;
                size[b] += size[a];
                rank[b]++;
            }
        }
    }
    bool aresame(int a,int b){
        return find(a)==find(b);
    }
};
int main(){
    DSU dsu(10);

    dsu.merge(0, 1);
    dsu.merge(2, 3);
    dsu.merge(4, 5);
    dsu.merge(6, 7);

    cout << "Are 0 and 1 connected? " << (dsu.aresame(0, 1) ?
        "Yes" : "No") << endl;
    cout << "Are 2 and 3 connected? " << (dsu.aresame(2, 3) ?
        "Yes" : "No") << endl;
    cout << "Are 4 and 5 connected? " << (dsu.aresame(4, 5) ?
        "Yes" : "No") << endl;
    cout << "Are 6 and 7 connected? " << (dsu.aresame(6, 7) ?
        "Yes" : "No") << endl;
    cout << "Are 1 and 2 connected? " << (dsu.aresame(1, 2) ?
        "Yes" : "No") << endl;

    dsu.merge(1, 2);

}
```

```
    cout << "Are 0 and 2 connected? " << (dsu.aresame(0, 2) ? "Yes" : "No") << endl;
    cout << "Are 1 and 3 connected? " << (dsu.aresame(1, 3) ? "Yes" : "No") << endl;

    return 0;
}
```

5.2 monotonic queue

```
//ref:leetcode
#include<bits/stdc++.h>

using namespace std;

class Monotonic_queue{
private:
    deque<int> qu;
public:
    void push(int n){
        while(!qu.empty()&&qu.back()<n){
            qu.pop_back();
        }
        qu.push_back(n);
    }
    int max(){
        return qu.front();
    }
    int min(){
        return qu.back();
    }
    int  size(){
        return qu.size();
    }
    void pop(){
        qu.pop_front();
    }
};

vector<int> maxSlidingWindow(vector<int> nums, int k) {
    Monotonic_queue window;
    vector<int> res;
    for (int i = 0; i < nums.size(); i++) {
        if (i < k - 1) {
            window.push(nums[i]);
        } else {
            window.push(nums[i]);
            res.push_back(window.max());
            if(window.max() == nums[i-k+1]){
                window.pop();
            }

        }
    }
    return res;

}
int main(){
    vector<int> nums = {1,3,-1,-3,5,3,6,7};
    int k = 3;
    vector<int> res = maxSlidingWindow(nums,k);
    for (auto r:res)cout <<r <<" ";
}
```

5.3 BIT

```
#include <bits/stdc++.h>
using namespace std;

class BIT{
public:
    vector<int> bit;
    int N;
    BIT(int n){
        this->N = n;
        this->bit.resize(n);
    }
    void update(int x,int d){
        while(x<=N){
            bit[x] +=d;
            x +=x&(-x);// lowest bit in x;
        }
    }
    int query(int x){
        int res = 0;
        while(x){
            res+= bit[x];
            x -= x& -x;
        }
        return res;
    }
};
// Driver program to test above functions
int main()
{
    vector<int> freq =  {0, 2, 1, 1, 3, 2, 3, 4, 5, 6, 7, 8, 9};
    int n = freq.size();
    BIT bit(n);
    for(int i = 1;i<n;i++){
        bit.update(i,freq[i]);
    }
    for(int i = 1;i<n;i++){
        cout << bit.query(i)<<" ";
    }cout << endl;
    for(int i = 1;i<n;i++){
        bit.update(i,-1);
    }
    for(int i = 1;i<n;i++){
        cout << bit.query(i)<<" ";
    }cout << endl;
}
```

5.4 segment tree simple add

```
#include <bits/stdc++.h>

using namespace std;
struct node{
    int left;
    int right;
    int value;
};
vector<node> segment_tree;
void build(int left,int right,int x ,vector<int> & nums){
    segment_tree[x].left = left;
    segment_tree[x].right = right;
    // cout <<left <<" "<<right<<" "<<x<<endl;
    if(left == right){ // here is leaf
        segment_tree[x].value = nums[left];
        return;
    }
    int mid = (left+right)/2;
    build(left,mid,x<<1,nums);
    build(mid+1,right,x<<1|1,nums);
    segment_tree[x].value = segment_tree[x<<1].value+segment_tree[x<<1|1].value;
}
void modify(int position ,int x,int value){
    if(segment_tree[x].left == position && segment_tree[x].right ==position){ // here is leaf
        segment_tree[x].value = value;
        return;
    }
    int mid = (segment_tree[x].left+segment_tree[x].right)/2;

    if(position<=mid){
        modify(position,x<<1,value);
    }else{
        modify(position,x<<1|1,value);
    }
    segment_tree[x].value = segment_tree[x<<1].value+segment_tree[x<<1|1].value;
}
int query(int i,int j,int x){
    // cout <<i <<" "<<j <<" "<<segment_tree[x].left<<" " << segment_tree[x].right<<endl;
    int res = 0;
    int left = segment_tree[x].left;
    int right = segment_tree[x].right;
    int mid = (left+right)/2;
    if(segment_tree[x].left==i && segment_tree[x].right ==j){

        return segment_tree[x].value;
    }
    if(i>mid)return query(i,j,x*2+1);
    if(mid>=j)return query(i,j,x*2);
    return query(i,mid,x*2)+ query(mid+1,j,x*2+1);
}
int main(){
    vector<int> nums = {1,10,5,148,78,2,56,231,5,64,65,32,1,8};
    int n  = nums.size();
    segment_tree.resize(n*4);
    build(0,n-1,1,nums);
    modify(5,1,100);
    // cout << "++++++++++\n";
    for(int i =0;i<n;i++){
        for(int j = i ;j<n;j++){
            cout << query(i,j,1)<<" ";
        }cout << endl;
    }
}
```

5.5 monotonic stack

```cpp
/*
input: array A
ouput: array B
bi is the value aj such that j>i and aj>bi   (j)
ex:
A = [2,1,2,4,3]
B = [4,3,4,-1,-1
*/
#include<bits/stdc++.h>

using namespace std;

vector<int> monotonic_stack(vector<int> nums){
    int n = nums.size();
    vector<int> res(n);
    stack<int>  st;
    for(int i = n-1;i>=0;i--){
        while(!st.empty() && st.top()<=nums[i]){
            st.pop();
            // we want the value greater than nums[i], so we pop the value smaller and equal nums[i]
        }
        if(st.empty())res[i] = -1;
        else res[i] = st.top();
        st.push(nums[i]);
    }
    return res;
}

int main(){
    vector<int> res = monotonic_stack({2,1,2,4,3});
    for(auto r:res){
        cout << r<<" ";
    }
}
```

6 Original Code/Flow

6.1 dicnic

```cpp
#include <bits/stdc++.h>
#define maxn 2005
#define INF 0x3f3f3f3f
using namespace std;
struct MaxFlow{
    struct edge{
        int  to, cap, flow,rev;
        edge( int v, int c, int f,int r) :  to(v), cap(c), flow(f),rev(r) {}
      };
    vector<edge> G[maxn];
    int s,t,dis[maxn],cur[maxn],vis[maxn];
    void add_edge(int from,int to,int cap){
        G[from].push_back(edge(to,cap,0,G[to].size()));
        G[to].push_back(edge(from,0,0,G[from].size()-1));
    }
    bool bfs(){
        memset(dis, -1, sizeof(dis));
        queue<int> qu;
        qu.push(s);
        dis[s] = 0;
        while (!qu.empty()) {
            int from = qu.front();
            qu.pop();
            for (auto &e: G[from]) {
                if (dis[e.to]==-1 && e.cap != e.flow) {
                    dis[e.to] = dis[from] + 1;
                    qu.push(e.to);
                }
            }
        }
        return dis[t]!=-1;
    }
    int dfs(int from,int cap){
        if(from==t ||cap==0)return cap;
        for(int &i = cur[from];i<G[from].size();i++){
            edge &e = G[from][i];
            if(dis[e.to]==dis[from]+1 && e.flow!=e.cap){
                int df = dfs(e.to,min(e.cap-e.flow,cap));
                if(df){
                    e.flow+=df;
                    G[e.to][e.rev].flow-=df;
                    return df;
                }
            }
        }
        dis[from] = -1;
        return 0;
    }
    int Maxflow(int s,int t){
        this->s = s,this->t =t;
        int flow = 0;
        int df;
        while(bfs()){
            memset(cur,0,sizeof(cur));
            while(df = dfs(s,INF)){
                flow +=df;
            }
        }
        return flow;
    }
};
```

7 Original Code/Graph

7.1 planar

```cpp
#include <iostream>
#include <vector>
#include <unordered_set>

using namespace std;

class Graph {
public:
    int V;
    vector<vector<int>> adj;
    Graph(int vertices) : V(vertices), adj(vertices) {}
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
};

bool containsSubgraph(const Graph& graph, const vector<int>& subgraph) {
    unordered_set<int> subgraphVertices(subgraph.begin(), subgraph.end());
    for (int vertex : subgraphVertices) {
        for (int neighbor : graph.adj[vertex]) {
            if (subgraphVertices.count(neighbor) == 0) {
                bool found = true;
                for (int v : subgraph) {
                    if (v != vertex && v != neighbor) {
                        if (graph.adj[v].size() < 3) {
                            found = false;
                            break;
                        }
                    }
                }
                if (found)
                    return true;
            }
        }
    }
    return false;
}

bool isPlanar(const Graph& graph) {
    // Subgraphs isomorphic to K  and K ,
    vector<int> k5 = {0, 1, 2, 3, 4};       // Vertices of K
    vector<int> k33a = {0, 1, 2};           // Vertices of K , (part A)
    vector<int> k33b = {3, 4, 5};           // Vertices of K , (part B)

    if (containsSubgraph(graph, k5) || containsSubgraph(graph, k33a) || containsSubgraph(graph, k33b)) {
        return false; // The graph is non-planar
    }
    return true; // The graph is planar
}

int main() {
    int vertices, edges;
    cin >> vertices;
    cin >> edges;

    Graph graph(vertices);
    for (int i = 0; i < edges; ++i) {
        int u, v;
        cin >> u >> v;
        graph.addEdge(u, v);
    }
    if (isPlanar(graph)) {
        cout << "The graph is planar." << endl;
    } else {
        cout << "The graph is non-planar." << endl;
    }

    return 0;
}
```

7.2 Dijkstra

```cpp
#include <bits/stdc++.h>
using namespace std;

#define maxn 200005
vector<int> dis(maxn,-1);
vector<int> parent(maxn,-1);
vector<bool> vis(maxn,false);
vector<vector<pair<int,int>>> graph;
void dijsktra(int source){
    dis[source] =0 ;

    priority_queue<pair<int,int>,vector<pair<int,int>>,
        greater<pair<int,int>>> pq;
    pq.push({0,source});
    while(!pq.empty()){
        int from  = pq.top().second;
        pq.pop();
        // cout <<vis[from]<<endl;
        if(vis[from])continue;
        vis[from] = true;
        for(auto next : graph[from]){
            int to = next.second;
            int weight = next.first;
            // cout <<from<<' '<<to<<' '<<weight;
            if(dis[from]+weight< dis[to] || dis[to]==-1){
                dis[to] = dis[from]+weight;
                parent[to] = from;
                pq.push({dis[from]+weight,to});
            }
        }
    }

}
int main(){
    graph = {
        {{4,1},{5,3}},
        {{3,3}},
        {{}},
        {{4,0},{2,1},{7,2}}
    };
    dijsktra(0);
    for(int i =0;i<4;i++){
        cout << dis[i]<<" ";
    }
    for(int i =0;i<4;i++){
        cout << parent[i]<<" ";
    }
}
```

7.3 Floyd Warshall

```cpp
#include <bits/stdc++.h>
using namespace std;

#define maxn 2005
vector<vector<int>> dis(maxn,vector<int>(maxn,9999999));
vector<vector<int>> mid(maxn,vector<int>(maxn,-1));
vector<vector<pair<int,int>>> graph;

void floyd_warshall(int n ){ // n is n nodes
  for(int i =0;i<n;i++){
        for(auto path:graph[i]){
            dis[i][path.second] = path.first;
        }
    }
  for (int i=0; i<n; i++)
    dis[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 (dis[i][k] + dis[k][j] < dis[i][j] || dis[i][j
            ]==-1){
          dis[i][j] = dis[i][k] + dis[k][j];
          mid[i][j] = k;  // 由i點走到j點經過了k點
        }
          }
        }
    }
}
void find_path(int s, int t){   // 印出最短路徑
  if (mid[s][t] == -1) return;  // 🅵有中繼點就結束
  find_path(s, mid[s][t]);     // 前半段最短路徑
  cout << mid[s][t];       // 中繼點
  find_path(mid[s][t], t);     // 後半段最短路徑
}
int main(){
    graph = {
        {{4,1},{5,3}},
        {{3,3}},
        {{}},
        {{4,0},{2,1},{7,2}}
    };
    floyd_warshall(4);
    for(int i =0;i<4;i++){
        for(int j = 0 ; j <4;j++)
            cout << dis[i][j]<<" ";
        cout << endl;
    }
    find_path(0,2);
}
```

7.4 2 sat

```cpp
#include <iostream>
#include <vector>
#include <stack>
#include <algorithm>

using namespace std;

class TwoSAT {
public:
    TwoSAT(int n) : n(n), graph(2 * n), visited(2 * n, false)
        {}

    void addClause(int a, int b) {// 0-base;
        a *=2;
        b *=2;
        // Add implications (~a => b) and (~b => a)
        graph[a ^ 1].push_back(b);
        graph[b ^ 1].push_back(a);
    }

    bool solve() {
        // Find SCCs and check for contradictions
        for (int i = 0; i < 2 * n; ++i) {
            if (!visited[i]) {
                dfs1(i);
            }
        }
        reverse(processingOrder.begin(), processingOrder.end
            ());//topological sort
        for (int i = 0; i < 2 * n; ++i) {
            visited[i] = false;
        }
        for (int node : processingOrder) {
            if (!visited[node]) {
                scc.clear();
                dfs2(node);
                if (!checkSCCConsistency()) {
                    return false;
                }
            }
        }

        return true;
    }

private:
    int n;
    vector<vector<int>> graph;
    vector<bool> visited;
    vector<int> processingOrder;
    vector<int> scc;

    void dfs1(int node) {
        visited[node] = true;
        for (int neighbor : graph[node]) {
            if (!visited[neighbor]) {
                dfs1(neighbor);
            }
        }
        processingOrder.push_back(node);
    }

    void dfs2(int node) {
        visited[node] = true;
        scc.push_back(node);
        for (int neighbor : graph[node]) {
            if (!visited[neighbor]) {
                dfs2(neighbor);
            }
        }
    }

    bool checkSCCConsistency() {
        for (int node : scc) {
            if (find(scc.begin(), scc.end(), node ^ 1) != scc
                .end()) {
                return false; // Contradiction found in the
                    same SCC
            }
        }
        return true;
    }
};

int main() {
    int n, m;
    cin >> n >> m; // Number of variables and clauses

    TwoSAT twoSat(n);
```

```
86
87      for (int i = 0; i < m; ++i) {
88          int a, b;
89          cin >> a >> b;
90          twoSat.addClause(a, b);
91      }
92
93      if (twoSat.solve()) {
94          cout << "Satisfiable" << endl;
95      } else {
96          cout << "Unsatisfiable" << endl;
97      }
98
99      return 0;
100 }
```

7.5 bipartite matching

```
1  #include <bits/stdc++.h>
2  using namespace std;
3  const int MAXN = 100;
4
5
6  struct Bipartite_matching{
7      int mx[MAXN], my[MAXN], vy[MAXN]; //matchX, matchY,
           visitY
8      vector<int> edge[MAXN]; //adjcent list;
9      int x_cnt;
10     bool dfs(int x){
11         for(auto y: edge[x]){ //對 x 可以碰到的邊進行檢查
12             if(vy[y] == 1) continue; //避免遞Ｆ error
13
14             vy[y] = 1;
15             if(my[y] == -1 || dfs(my[y])){ //分析 3
16                 mx[x] = y;
17                 my[y] = x;
18                 return true;
19             }
20         }
21         return false; //分析 4
22     }
23
24     int bipartite_matching(){
25         memset(mx, -1, sizeof(mx)); //分析 1,2
26         memset(my, -1, sizeof(my));
27         int ans = 0;
28         for(int i = 0; i < x_cnt; i++){  //對每一個 x 節點進
               行 DFS(最大匹配)
29             memset(vy, 0, sizeof(vy));
30             if(dfs(i)) ans++;
31         }
32         return ans;
33     }
34     vector<vector<int>> get_match(){
35         vector<vector<int>> res;
36         for(int i =0 ;i<x_cnt;i++){
37             if(mx[i]!=-1){
38                 res.push_back({i,mx[i]});
39             }
40         }
41         return res;
42     }
43     void add_edge(int i,int j){
44         edge[i].push_back(j);
45     }
46     void init(int x){
47         x_cnt = x;
48     }
49 };
50 int main(){
51     /*
52     0 3
53     0 4
54     1 3
55     1 5
56     2 3
57     2 4
58     2 5
59     */
60     Bipartite_matching bm;
61     for(int i = 0;i<7;i++){
62         int a , b;
63         cin >>a>>b;
64         bm.add_edge(a,b);
65     }
66     bm.init(3);
67     cout << bm.bipartite_matching()<<endl;
68     auto match = bm.get_match();
69     for(auto t: match){
70         cout << t[0]<<" "<<t[1]<<endl;
71     }
72
73 }
```

7.6 tarjan SCC

```
1  #include <bits/stdc++.h>
2  using namespace std;
3  const int n = 16;
4  vector<vector<int>> graph;
5  int visit[n], low[n],t = 0;
6  int st[n], top =0;
7  bool instack[n];
8  int contract[n]; // 每個點收縮到的點
9  vector<vector<int>> block;
10 void dfs(int x,int parent){
11     // cout <<x<<endl;
12     visit[x] = low[x] = ++t;
13   st[top++] = x;
14   instack[x] = true;
15     for(auto to: graph[x]){
16         if(!visit[to])
17             dfs(to,x);
18
19         if(instack[to])
20             low[x] = min(low[x],low[to]);
21     }
22     if(visit[x]==low[x]){ //scc Ｆ最早拜訪的
23         int j;
24         block.push_back({});
25         do{
26             j = st[--top];
27             instack[j] = false;
28             block[block.size()-1].push_back(j);
29             contract[j] =x;
30         }while(j!=x);
31     }
32 }
33 int main(){
34     graph = {
35         {1},
36         {3,4,5},
37         {6},
38         {2},
39         {7},
40         {11,15},
41         {2,3},
42         {4,6,9},
43         {},
44         {},
45         {},
46         {15},
47         {14},
48         {13,5},
49         {15},
50         {10,12,13}
51     };
52     for(int i =0;i<n;i++){
53         if (!visit[i])
54       dfs(i, i);
55     }
56     for(auto t: block){
57         for(auto x:t){
58             cout << x <<" ";
59         }cout <<endl;
60     }
61 }
```

7.7 topological sort

```
1
2  #include <bits/stdc++.h>
3  using namespace std;
4  vector<vector<int>> graph;
5  vector<int> visit(10,0);
6  vector<int> order;
7  int n;
8  bool cycle;   // 記ＦDFS的過程中是否偵測到環
9  void DFS(int i)
10 {
11   if (visit[i] == 1) {cycle = true; return;}
12   if (visit[i] == 2) return;
13   visit[i] = 1;
14   for(auto to :graph[i])
15         DFS(to);
16   visit[i] = 2;
17     order.push_back(i);
18 }
19
20
21 int main() {
22     graph = {
23         {1, 2},
24         {3},
25         {3, 4},
26         {4},
27         {}
28     };
```

```
    n = 5;
  cycle = false;
  for (int i=0; i<n; ++i){
    if (!visit[i])
      DFS(i);
    }
  if (cycle)
    cout << "圖上有環";
  else
    for (int i=n-1; i>=0; --i)
      cout << order[i];
}
```

8 Original Code/Math

8.1 extgcd

```

#include<bits/stdc++.h>

using namespace std;

int extgcd(int a,int b,int &x,int &y)//擴展歐幾里得算法
{
    if(b==0)
    {
        x = 1;
        y = 0;
        return a;  //到達遞歸邊界開始向上一層返回
    }
    int r = extgcd(b,a%b,x,y);
    int temp=y;     //把x y變成上一層的
    y = x - (a / b) * y;
    x = temp;
    return r;      //得到a b的最大公因數
}

int main(){
    int a = 55,b = 80;
    int x,y;
    int GCD = extgcd(a,b,x,y);
    cout << "GCD: "<<GCD<<endl;;
    cout <<x<<" "<<y<<endl;
    cout <<a*x+b*y<<endl;
}
```

9 Original Code/Tree

9.1 LCA

```
#include<bits/stdc++.h>
using namespace std;
int n;
int logn;
vector<vector<int>> graph;
vector<vector<int>>ancestor;
vector<int> tin,tout;
int t = 0;
void dfs(int x){
    tin[x] = t++;
  for(auto y:graph[x]){
        if(y!= ancestor[x][0]){
            ancestor[y][0] = x;
            dfs(y);
        }
    }
    tout[x] = t++;
}
bool is_ancestor(int x, int y){
  return tin[x] <= tin[y] && tout[x] >= tout[y];
}
void table(){
    // 上兩輩祖先、上四輩祖先、上八輩祖先、……
  for (int i=1; i<logn; i++)
    for (int x=0; x<n; ++x)
      ancestor[x][i] = ancestor[ancestor[x][i-1]][i-1];
}

int kth_ancestor(int x, int k){
  // k拆解成二進位位數，找到第k祖先。不斷上升逼近之。
  for (int i=0; i<logn; i++)
    if (k & (1<<i))
      x = ancestor[x][i];
  return x;
}

void rooted_tree(int root){
  ancestor[root][0] = root;
  dfs(root);
  table();
}
int LCA(int x,int y){
    if (is_ancestor(x, y)) return x;
  if (is_ancestor(y, x)) return y;
    for (int i=logn-1; i>=0; i--)
    if (!is_ancestor(ancestor[x][i], y))
      x = ancestor[x][i];
  return ancestor[x][0];
}
int main(){
    graph = {
        {1,2},
        {3},
        {5,6},
        {7},
        {},
        {},
        {},
        {8},
        {4},
    };
    n = 9;
    logn = ceil(log2(n));
    ancestor.resize(n,vector<int>(logn));
    tin.resize(n);
    tout.resize(n);

    rooted_tree(0);
    while(true){
        int a,b;
        cin >>a>>b;
        cout <<LCA(a,b)<<endl;;
    }
}
```

9.2 diameter

```
#include <bits/stdc++.h>

using namespace std;

vector<vector<int>> graph;
int diameter = 0;
int dfs(int start, int parent){
    int h1 = 0,h2 = 0;
    for(auto child: graph[start]){
        if(child!= parent){
            int h = dfs(child,start)+1;
            if(h>h1){
                h2= h1;
                h1 = h;
            }
            else if(h>h2){
                h2 = h;
            }
        }
    }
    diameter = max(diameter,h1+h2);
    return h1;
}

int main(){
    graph = {
        {1,3},
        {0},
        {3},
        {0,2,4},
        {3}
    };
    dfs(0,-1);
    cout << diameter<<endl;
}
```

9.3 radius

```
#include<bits/stdc++.h>
using namespace std;
// Perform DFS to find the farthest node and its distance
    from the given node
pair<int, int> dfs(int node, int distance, vector<bool>&
    visited, const vector<vector<int>>& adj_list) {
    visited[node] = true;
    int max_distance = distance;
    int farthest_node = node;

    for (int neighbor : adj_list[node]) {
        if (!visited[neighbor]) {
            auto result = dfs(neighbor, distance + 1, visited
                , adj_list);
            if (result.first > max_distance) {
```

```
                max_distance = result.first;
                farthest_node = result.second;
            }
        }
    }

    return make_pair(max_distance, farthest_node);
}

// Calculate the radius of the tree using DFS
int tree_radius(const vector<vector<int>>& adj_list) {
    int num_nodes = adj_list.size();
    vector<bool> visited(num_nodes, false);

    // Find the farthest node from the root (node 0)
    auto farthest_result = dfs(0, 0, visited, adj_list);

    // Reset visited array
    fill(visited.begin(), visited.end(), false);

    // Calculate the distance from the farthest node
    int radius = dfs(farthest_result.second, 0, visited,
         adj_list).first;

    return radius;
}

int main() {
    vector<vector<int>> adj_list = {
        {1, 2},
        {0, 3, 4},
        {0, 5},
        {1},
        {1},
        {2}
    };

    int radius = tree_radius(adj_list);
    cout << "Tree radius: " << radius << endl;

    return 0;
}
```

9.4 bridge

```
#include<bits/stdc++.h>
using namespace std;
const int n = 9;
vector<vector<int>> graph;
vector<int> visit(n,0);
vector<int> trace(n,0);
vector<vector<int>> bridge;
int t = 0;
void dfs(int x,int parent){
    visit[x] = ++t;
    trace[x] =x;// 最高祖先預設🅴自己
    for(auto to:graph[x]){
        if(visit[to]){ //back edge
            if(to!=parent  ){
                trace[x] = to;
            }
        }else{  //treeedge
            dfs(to,x);
            if (visit[trace[to]] < visit[trace[x]])
          trace[x] = trace[to];

        // 子樹回不到祖先暨自身。
        if (visit[trace[to]] > visit[x])
          bridge.push_back({x,to});
        }
    }
}
int main(){
    graph = {
        {1,2},
        {3},
        {5,6},
        {7},
        {},
        {},
        {},
        {8},
        {4},
    };
    for(int i =0;i<9;i++){
        if(!visit[i])
            dfs(i,-1);
    }
    for(auto x: bridge){
        cout << x[0]<<" "<< x[1]<<endl;
    }
}
```

9.5 Articulation vertex

```
#include<bits/stdc++.h>
using namespace std;
const int n = 9;
int t =0;
vector<int> disc(n,-1); // Discovery time
vector<int> low(n,-1); // Low time
vector<int> parent_array(n,-1); // Parent in DFS tree
vector<bool> visited(n,false);
vector<bool> is_articulation(n,false);
vector<vector<int>> graph;
void dfs_articulation(int node, int parent) {
    visited[node] = true;
    disc[node] = t;
    low[node] = t;
    t++;
    int children = 0;

    for (int neighbor : graph[node]) {
        if (!visited[neighbor]) {
            children++;
            parent_array[neighbor] = node;
            dfs_articulation(neighbor, node);
            low[node] = min(low[node], low[neighbor]);

            if (low[neighbor] >= disc[node] && parent != -1)
                {
                is_articulation[node] = true;
            }
        } else if (neighbor != parent) {
            low[node] = min(low[node], disc[neighbor]);
        }
    }

    if (parent == -1 && children > 1) {
        is_articulation[node] = true;
    }
}
int main(){
    graph = {
        {1,2},
        {3},
        {5,6},
        {7},
        {},
        {},
        {},
        {8},
        {4},
    };
    for (int i = 0; i < n; ++i) {
        if (!visited[i]) {
            dfs_articulation(i, -1);
        }
    }
    cout << "Articulation Points: ";
    for (int i = 0; i < n; ++i) {
        if (is_articulation[i]) {
            cout << i << " ";
        }
    }
    cout << endl;
}
```

10 Tree

10.1 LCA

```
#include<bits/stdc++.h>
using namespace std;
int n, logn,t=0;
vector<vector<int>> graph;
vector<vector<int>> ancestor;
vector<int> tin, tout;
void dfs(int x){
    tin[x] = t++;
  for(auto y:graph[x]){
        if(y!= ancestor[x][0]){
            ancestor[y][0] = x;
            dfs(y);
        }
    }
    tout[x] = t++;
}
bool is_ancestor(int x, int y){
  return tin[x] <= tin[y] && tout[x] >= tout[y];
}
void table(){
  for (int i=1; i<logn; i++)// 上兩輩祖先、上四輩祖先、上八輩
      祖先、……
    for (int x=0; x<n; ++x)
      ancestor[x][i] = ancestor[ancestor[x][i-1]][i-1];
}
```

```

int kth_ancestor(int x, int k){
  for (int i=0; i<logn; i++)// k拆解成二進位位數, 找到第k祖先。不斷上升逼近之。
    if (k & (1<<i))
      x = ancestor[x][i];
  return x;
}

void rooted_tree(int root){// build the tree with root at "root"
  ancestor[root][0] = root;
  dfs(root);
  table();
}
int LCA(int x,int y){
    if (is_ancestor(x, y)) return x;
  if (is_ancestor(y, x)) return y;
    for (int i=logn-1; i>=0; i--)
    if (!is_ancestor(ancestor[x][i], y))
      x = ancestor[x][i];
  return ancestor[x][0];
}
int main(){
    graph = {
        {1,2},
        {3},
        {5,6},
        {7},
        {},
        {},
        {},
        {8},
        {4},
    };
    n = 9;
    logn = ceil(log2(n));
    ancestor.resize(n,vector<int>(logn));
    tin.resize(n);
    tout.resize(n);

    rooted_tree(0);
    while(true){
        int a,b;
        cin >>a>>b;
        cout <<LCA(a,b)<<endl;;
    }
}
int main(){
    n = 9;
    logn = ceil(log2(n));
    ancestor.resize(n,vector<int>(logn));
    tin.resize(n);
    tout.resize(n);
    rooted_tree(0);
    while(true){
        int a,b;
        cin >>a>>b;
        cout <<LCA(a,b)<<endl;;
    }
}
```

10.2 diameter

```
#include <bits/stdc++.h>
using namespace std;

vector<vector<int>> graph;
int diameter = 0;
int dfs(int start, int parent){
    int h1 = 0, h2 = 0;
    for (auto child : graph[start]){
        if (child != parent){
            int h = dfs(child, start) + 1;
            if (h > h1){
                h2 = h1;
                h1 = h;
            }
            else if (h > h2){
                h2 = h;
            }
        }
    }
    diameter = max(diameter, h1 + h2);
    return h1;
}
// call diameter
int main(){
    dfs(0,-1);
    cout << diameter<<endl;
}
```

10.3 radius

```
#include <bits/stdc++.h>
using namespace std;
// Perform DFS to find the farthest node and its distance from the given node
pair<int, int> dfs(int node, int distance, vector<bool> & visited, const vector<vector<int>> &adj_list){
    visited[node] = true;
    int max_distance = distance;
    int farthest_node = node;

    for (int neighbor : adj_list[node]){
        if (!visited[neighbor]){
            auto result = dfs(neighbor, distance + 1, visited, adj_list);
            if (result.first > max_distance){
                max_distance = result.first;
                farthest_node = result.second;
            }
        }
    }

    return make_pair(max_distance, farthest_node);
}

// Calculate the radius of the tree using DFS
int tree_radius(const vector<vector<int>> &adj_list){
    int num_nodes = adj_list.size();
    vector<bool> visited(num_nodes, false);

    // Find the farthest node from the root (node 0)
    auto farthest_result = dfs(0, 0, visited, adj_list);

    // Reset visited array
    fill(visited.begin(), visited.end(), false);

    // Calculate the distance from the farthest node
    int radius = dfs(farthest_result.second, 0, visited, adj_list).first;

    return radius;
}
int main() {
    vector<vector<int>> adj_list;
    int radius = tree_radius(adj_list);
    cout << "Tree radius: " << radius << endl;
    return 0;
}
```

NYCU_Segmentree Codebook

Contents