

1. TEMPLATE

Main

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

#define MAX(a, b) (a > b) ? a : b
#define MIN(a, b) (a < b) ? a : b
#define int long long
#define vi vector<int>
#define pii pair<int, int>
#define vii vector<pii>

using namespace std;

void solve()
{
}
```

```
int32_t main()
{
    ios_base::sync_with_stdio(0);
    cin.tie(0);

    int t;
    cin >> t;

    for (int i = 0; i < t; i++)
    {
        solve();
    }

    return 0;
}
```

2. GRAPH

Prim

```
int spanningTreePrim(int V, vector<vector<int>> adj[])
{
    priority_queue<pair<int, int>> q;

    vector<bool> mask;
    mask.assign(V, false);
    mask[0] = true;

    int cost = 0;

    for (int i = 0; i < adj[0].size(); i++)
    {
        q.push({-adj[0][i][1], adj[0][i][0]});
    }

    while (q.size() != 0)
    {
        auto aux = q.top();
        q.pop();
```

```
        int k = aux.second;
        if (mask[k])
            continue;

        mask[k] = true;
        cost += abs(aux.first);

        for (int i = 0; i < adj[k].size(); i++)
        {
            if (!mask[adj[k][i][0]])
            {
                q.push({-adj[k][i][1], adj[k][i][0]});
            }
        }
    }

    return cost;
}
```

Dfs Bfs

```

void dfs_g(int n, int c, vi adj[], vector<bool> &visited, vi &cc)
{
    visited[n] = true;
    cc[n] = c;

    for (int i = 0; i < adj[n].size(); i++)
    {
        if (!visited[adj[n][i]])
            dfs_g(adj[n][i], c, adj, visited, cc);
    }
}

void dfs_t(int n, int p, int d, vi adj[], vi &deep)
{
    deep[n] = d;

    for (int i = 0; i < adj[n].size(); i++)
    {
        if (p != adj[n][i])
            dfs_t(adj[n][i], n, d + 1, adj, deep);
    }
}

vi bfs(int node, int n, vi adj[])
{
    vi result(n);

```

Max Flow

```

template <typename flow_type>
struct dinic
{
    struct edge
    {
        size_t src, dst, rev;
        flow_type flow, cap;
    };

    int n;
    vector<vector<edge>> adj;

    dinic(int n) : n(n), adj(n), level(n), q(n), it(n) {}

```

```

    vector<bool> visited;
    visited.assign(n, false);

    queue<int> q;
    visited[node] = true;

    q.push(node);

    while (q.size() != 0)
    {
        int w = q.front();
        q.pop();

        for (int i = 0; i < adj[w].size(); i++)
        {
            if (!visited[adj[w][i]])
            {
                q.push(adj[w][i]);
                result[adj[w][i]] = result[w] + 1;
                visited[adj[w][i]] = true;
            }
        }
    }

    return result;
}

```

```

void add_edge(size_t src, size_t dst, flow_type cap, flow_type rcap = 0)
{
    adj[src].push_back({src, dst, adj[dst].size(), 0, cap});
    if (src == dst)
        adj[src].back().rev++;
    adj[dst].push_back({dst, src, adj[src].size() - 1, 0, rcap});
}

vector<int> level, q, it;

bool bfs(int source, int sink)
{
    fill(level.begin(), level.end(), -1);
    for (int qf = level[q[0] = sink] = 0, qb = 1; qf < qb; ++qf)

```

```

    {
        sink = q[qf];
        for (edge &e : adj[sink])
        {
            edge &r = adj[e.dst][e.rev];
            if (r.flow < r.cap && level[e.dst] == -1)
                level[q[qb++]] = e.dst = 1 + level[sink];
        }
    }
    return level[source] != -1;
}

flow_type augment(int source, int sink, flow_type flow)
{
    if (source == sink)
        return flow;
    for (; it[source] != adj[source].size(); ++it[source])
    {
        edge &e = adj[source][it[source]];
        if (e.flow < e.cap && level[e.dst] + 1 == level[source])
        {
            flow_type delta = augment(e.dst, sink, min(flow, e.cap - e.flow));
            if (delta > 0)
            {
                e.flow += delta;
                adj[e.dst][e.rev].flow -= delta;
            }
        }
    }
    return flow;
}

```

Articulation Point

```

vector<bool> visited;
vi t;
vi low;
vector<bool> art;

void dfs_art(vi adj[], int n, int p, int q)
{
    t[n] = q;
    low[n] = q++;
    visited[n] = true;

    int j = 0;

    for (int i = 0; i < adj[n].size(); i++)
    {
        if (!visited[adj[n][i]])
        {

```

```

                return delta;
            }
        }
    }
    return 0;
}

flow_type max_flow(int source, int sink)
{
    for (int u = 0; u < n; ++u)
        for (edge &e : adj[u])
            e.flow = 0;
    flow_type flow = 0;
    flow_type oo = numeric_limits<flow_type>::max();

    while (bfs(source, sink))
    {
        fill(it.begin(), it.end(), 0);
        for (flow_type f; (f = augment(source, sink, oo)) > 0;)
            flow += f;
    } // level[u] = -1 => source side of min cut
    return flow;
}
};

```

```

    dfs_art(adj, adj[n][i], n, q);
    low[n] = min(low[adj[n][i]], low[n]);
    j++;

    if (low[adj[n][i]] >= t[n] && p != -1)
    {
        art[n] = true;
    }
}
else if (adj[n][i] != p)
{
    low[n] = min(t[adj[n][i]], low[n]);
}
}

if (p == -1)
{

```

```

    art[n] = j >= 2;
}
}

void articulationPoints(int V, vi adj[])
{
    visited.assign(V, false);
    t.assign(V, -1);
    low.assign(V, -1);
    art.assign(V, false);
}

```

Dijkstra

```

int infinite = (int)1e9;

// O(V^2)
vector<int> dijkstral(int V, vector<vector<int>> adj[], int S)
{
    vector<int> d;

    d.assign(V, infinite);
    d[S] = 0;

    vector<bool> mask;

    mask.assign(V, false);

    for (int i = 0; i < V; i++)
    {
        int m = infinite;
        int act = -1;

        for (int j = 0; j < V; j++)
        {
            if (mask[j])
                continue;

            if (m > d[j])
            {
                m = d[j];
                act = j;
            }
        }

        for (int j = 0; j < adj[act].size(); j++)
        {

```

```

        for (int i = 0; i < V; i++)
        {
            if (!visited[i])
            {
                dfs_art(adj, i, -1, 1);
            }
        }
    }
}

```

```

            if (d[act] + adj[act][j][1] < d[adj[act][j][0]])
            {
                d[adj[act][j][0]] = d[act] + adj[act][j][1];
            }
        }

        mask[act] = true;
    }

    return d;
}

// O((V+E)log(E))
vi dijkstra2(int V, vii adj[], int S)
{
    vector<int> d;

    d.assign(V, infinite);
    d[S] = 0;

    priority_queue<pair<int, int>> q;
    q.push({d[S], S});

    while (!q.empty())
    {
        int act = q.top().second;
        int m = abs(q.top().first);
        q.pop();

        if (m > d[act])
            continue;

        for (int j = 0; j < adj[act].size(); j++)

```

```

{
    if (d[act] + adj[act][j].second < d[adj[act][j].first])
    {
        d[adj[act][j].first] = d[act] + adj[act][j].second;
        q.push({-d[adj[act][j].first], adj[act][j].first});
    }
}

```

Bellman Ford

```

int infinite = (int)1e9;

vector<int> bellman_ford(int V, vector<vector<int>> &edges, int S)
{
    vector<int> d;
    d.assign(V, infinite);
    d[S] = 0;

    for (int i = 0; i < V - 1; i++)
    {
        for (int j = 0; j < edges.size(); j++)
        {
            if (d[edges[j][0]] + edges[j][2] < d[edges[j][1]])
            {
                d[edges[j][1]] = d[edges[j][0]] + edges[j][2];
            }
        }
    }
}

```

Centroid Decomposition

```

const int maxn = 10;

vi adj[maxn];
bool mk[maxn];
int q[maxn], p[maxn], sz[maxn], mc[maxn];

int centroid(int c)
{
    int b = 0, e = 0;
    q[e++] = c, p[c] = -1, sz[c] = 1, mc[c] = 0;

    while (b < e)
    {
        int u = q[b++];
        for (auto v : adj[u])
            if (v != p[u] && !mk[v])

```

```

    }
}

return d;
}

```

```

    }
}

for (int j = 0; j < edges.size(); j++)
{
    if (d[edges[j][0]] + edges[j][2] < d[edges[j][1]])
    {
        vector<int> resp(1);
        resp[0] = -1;

        return resp;
    }
}

return d;
}

```

```

        p[v] = u, sz[v] = 1, mc[v] = 0, q[e++] = v;
    }

    for (int i = e - 1; ~i; --i)
    {
        int u = q[i];
        int bc = max(e - sz[u], mc[u]);
        if (2 * bc <= e)
            return u;
        sz[p[u]] += sz[u], mc[p[u]] = max(mc[p[u]], sz[u]);
    }

    assert(false);
    return -1;
}

```

Floyd Warshall

```

int infinite = (int)1e8;

void shortest_distance(vector<vector<int>> &matrix)
{
    for (int k = 0; k < matrix.size(); k++)
    {
        for (int i = 0; i < matrix.size(); i++)
        {
            for (int j = 0; j < matrix[0].size(); j++)
            {
                matrix[i][j] = min(matrix[i][j], matrix[i][k] + matrix[k][j]);
            }
        }
    }
}

```

Lca

```

class SparseTable
{
private:
    vector<vi> lookup;

    vi arr;

    int rmq(int a, int b)
    {
        if (arr[a] <= arr[b])
            return a;

        return b;
    }

    int operation(int a, int b)
    {
        return rmq(a, b);
    }

    void build_sparse_table()
    {
        int n = arr.size();

```

```

void find_path_k(vector<vector<bool>> &matrix, int k)
{
    for (int x = 0; x < k; x++)
    {
        for (int i = 0; i < matrix.size(); i++)
        {
            for (int j = 0; j < matrix[0].size(); j++)
            {
                matrix[i][j] = matrix[i][j] || (matrix[i][x] && matrix[x][j]);
            }
        }
    }
}

```

```

        for (int i = 0; i < n; i++)
            lookup[i][0] = i;

        for (int j = 1; (1 << j) <= n; j++)
        {
            for (int i = 0; i <= n - (1 << j); i++)
                lookup[i][j] = operation(lookup[i][j - 1], lookup[i + (1 << (j - 1))][j - 1]);
        }
    }

public:
    SparseTable(vi &a)
    {
        int q = (int)log2(a.size());

        arr.assign(a.size(), 0);
        lookup.assign(a.size(), vi(q + 1));

        for (int i = 0; i < a.size(); i++)
            arr[i] = a[i];

        build_sparse_table();
    }

    int query(int l, int r)

```

```

{
    int q = (int)log2(r - 1 + 1);

    return operation(lookup[l][q],
                    lookup[r - (1 << q) + 1][q]);
}

int get(int i) { return arr[i]; }
};

void dfs(int n, int p, int d, vi adj[], vi &deep, vi &arr)
{
    deep[n] = d;
    arr.push_back(n);

    for (int i = 0; i < adj[n].size(); i++)
    {
        if (p != adj[n][i])
        {
            dfs(adj[n][i], n, d + 1, adj, deep, arr);
            arr.push_back(n);
        }
    }
}

vi lca(int root, int n, vi adj[], vii &querys)
{
    vi deep(n);
    vi first(n);
    vi last(n);
    vi arr;
    vi resp(querys.size());

```

```

dfs(root, -1, 0, adj, deep, arr);

for (int i = 0; i < arr.size(); i++)
    last[arr[i]] = i;

for (int i = arr.size() - 1; i >= 0; i--)
    first[arr[i]] = i;

vi arr_deep(arr.size());

for (int i = 0; i < arr_deep.size(); i++)
    arr_deep[i] = deep[arr[i]];

auto s = SparseTable(arr_deep);

for (int i = 0; i < querys.size(); i++)
{
    int l = first[querys[i].first];
    int r = last[querys[i].second];

    if (l > r)
    {
        r = last[querys[i].first];
        l = first[querys[i].second];
    }

    int q = s.query(l, r);
    resp[i] = arr[q];
}

return resp;
}

```

Topological Sort

```

vector<int> topoSort(int V, vector<int> adj[])
{
    vector<int> in(V);
    vector<int> resp;

    for (int i = 0; i < V; i++)
    {
        for (int j = 0; j < adj[i].size(); j++)
        {
            in[adj[i][j]]++;

```

```

        }
    }

    queue<int> q;

    for (int i = 0; i < V; i++)
    {
        if (in[i] == 0)
            q.push(i);
    }

```

```

while (q.size() != 0)
{
    int n = q.front();
    q.pop();

    for (int i = 0; i < adj[n].size(); i++)
    {
        in[adj[n][i]]--;
    }
}

```

Kruskal

```

class udfs
{
private:
    vector<int> p, rank, sizeSet;
    int disjointSet;

public:
    udfs(int n)
    {
        p.assign(n, 0);
        rank.assign(n, 0);
        sizeSet.assign(n, 1);
        disjointSet = n;
        for (int i = 0; i < n; i++)
        {
            p[i] = i;
        }
    }

    int find(int n)
    {
        if (n == p[n])
            return n;
        p[n] = find(p[n]);
        return p[n];
    }

    bool isSameSet(int i, int j) { return find(i) == find(j); }

    void unionSet(int i, int j)
    {
        if (!isSameSet(i, j))
        {

```

```

            if (in[adj[n][i]] == 0)
                q.push(adj[n][i]);
        }

        resp.push_back(n);
    }

    return resp;
}

```

```

        disjointSet--;
        int x = find(i);
        int y = find(j);
        if (rank[x] > rank[y])
        {
            p[y] = x;
            sizeSet[x] += sizeSet[y];
        }
        else
        {
            p[x] = y;
            sizeSet[y] += sizeSet[x];
            if (rank[x] == rank[y])
                rank[y]++;
        }
    }
}

int numDisjoinset() { return disjointSet; }

int sizeofSet(int i) { return sizeSet[find(i)]; }
};

// Function to find sum of weights of edges of the Minimum Spanning Tree.
int spanningTreeKruskal(int V, vector<vector<int>>> adj[])
{
    udfs dsu(V);

    vector<pair<int, pair<int, int>>>> a;

    for (int i = 0; i < V; i++)
    {
        for (int j = 0; j < adj[i].size(); j++)

```



```

    {
        a.push_back({adj[i][j][1], {i, adj[i][j][0]}});
    }
}

sort(a.begin(), a.end());

int cost = 0;

for (int i = 0; i < a.size(); i++)
{

```

Bridge Edges

```

vector<bool> visited;
vector<int> t;
vector<int> low;
set<pair<int, int>> bridges;

void dfs_bridges(vector<int> adj[], int n, int p, int q)
{
    t[n] = q;
    low[n] = q++;
    visited[n] = true;

    int j = 0;

    for (int i = 0; i < adj[n].size(); i++)
    {
        if (!visited[adj[n][i]])
        {
            dfs_bridges(adj, adj[n][i], n, q);
            low[n] = min(low[adj[n][i]], low[n]);
            j++;
        }
        else if (adj[n][i] != p)
        {
            low[n] = min(t[adj[n][i]], low[n]);
        }
    }
}

```

Scc Tarjans

```

        if (!dsu.isSameSet(a[i].second.first, a[i].second.second))
        {
            cost += a[i].first;

            dsu.unionSet(a[i].second.first, a[i].second.second);
        }
    }

    return cost;
}

```

```

    }

    if (t[n] == low[n] && p != -1)
    {
        bridges.insert({min(n, p), max(n, p)});
    }
}

set<pair<int, int>> bridge_edges(int V, vector<int> adj[])
{
    visited.assign(V, false);
    t.assign(V, -1);
    low.assign(V, -1);
    bridges = set<pair<int, int>>();

    for (int i = 0; i < V; i++)
    {
        if (!visited[i])
        {
            dfs_bridges(adj, i, -1, 1);
        }
    }

    return bridges;
}

```

```

stack<int> q;
vector<bool> mask;
vector<int> cc_list;

void g_transp(int V, vector<int> adj[], vector<int> new_adj[])
{
    for (int i = 0; i < V; i++)
    {
        for (int j = 0; j < adj[i].size(); j++)
        {
            new_adj[adj[i][j]].push_back(i);
        }
    }
}

void dfs_visit(int n, vector<int> adj[], int cc)
{
    mask[n] = true;

    for (int i = 0; i < adj[n].size(); i++)
    {
        if (!mask[adj[n][i]])
            dfs_visit(adj[n][i], adj, cc);
    }

    if (cc == -1)
        q.push(n);
    else
    {
        cc_list[n] = cc;
    }
}

void tarjans(int V, vector<int> adj[])

```

```

{
    vector<int> new_adj[V];
    g_transp(V, adj, new_adj);

    mask.assign(V, false);
    cc_list.assign(V, -1);

    for (int i = 0; i < V; i++)
    {
        if (mask[i])
            continue;

        dfs_visit(i, adj, -1);
    }

    for (int i = 0; i < V; i++)
        mask[i] = false;

    int ind = 0;

    while (q.size() != 0)
    {
        int act = q.top();

        q.pop();

        if (!mask[act])
        {
            dfs_visit(act, new_adj, ind);
            ind++;
        }
    }
}

```

3. GEOMETRY

Polygon

```

struct polygon {
    vector<point> P;
    polygon(const vector<point> &_P) : P(_P) {}

    db perimeter() {
        db ans = 0.0;

```

```

        for (int i = 0; i < (int)P.size()-1; ++i)
            ans += P[i].dist(P[i+1]);
        return ans;
    }

    db area() {
        db ans = 0.0;

```

```

    for (int i = 0; i < (int)P.size()-1; ++i)
        ans += (P[i].x*P[i+1].y - P[i+1].x*P[i].y);
    return fabs(ans) / 2.0;
}

bool isConvex(const vector<point> &P) {
    int n = (int)P.size();
    if (n <= 3) return false;
    bool firstTurn = vec().ccw(P[0], P[1], P[2]);
    for (int i = 1; i < n-1; ++i)
        if (vec().ccw(P[i], P[i+1], P[(i+2) == n ? 1 : i+2]) != firstTurn)
            return false;
    return true;
}

int insidePolygon(point pt) {
    int n = (int)P.size();

```

Basics

```

db DEG_to_RAD(db d) { return d*M_PI / 180.0; }
db RAD_to_DEG(db r) { return r*180.0 / M_PI; }

db EPS = 1e-9;

struct point {
    db x, y;
    point() { x = y = 0.0; }
    point(db _x, db _y) : x(_x), y(_y) {}

    bool operator < (const point &other) const {
        if (fabs(x-other.x) > EPS)
            return x < other.x;
        return y < other.y;
    }

    bool operator == (const point &other) const {
        return (fabs(x-other.x) < EPS) && (fabs(y-other.y) < EPS);
    }

    db dist(const point &other) {
        return hypot(x-other.x, y-other.y);
    }

    point rotate(db theta) {

```

```

        if (n <= 3) return -1;
        bool on_polygon = false;
        for (int i = 0; i < n-1; ++i)
            if (fabs(pt.dist(P[i]) + pt.dist(P[i+1]) - P[i].dist(P[i+1])) < EPS)
                on_polygon = true;
        if (on_polygon) return 0;
        double sum = 0.0;
        for (int i = 0; i < n-1; ++i) {
            if (vec().ccw(pt, P[i], P[i+1]))
                sum += vec().angle(P[i], pt, P[i+1]);
            else
                sum -= vec().angle(P[i], pt, P[i+1]);
        }
        return fabs(sum) > M_PI ? 1 : -1;
    }
};

```

```

        db rad = DEG_to_RAD(theta);
        return point(x*cos(rad) - y*sin(rad), x*sin(rad) + y*cos(rad));
    }
};

struct line {
    db a, b, c;
    line() {}
    line(db _a, db _b, db _c) : a(_a), b(_b), c(_c) {}

    void pointsToLine(const point &p1, const point &p2) {
        if (fabs(p1.x-p2.x) < EPS) {
            a = 1.0;
            b = 0.0;
            c = -p1.x;
        }
        else {
            a = -(db)(p1.y-p2.y) / (p1.x-p2.x);
            b = 1.0;
            c = -(db)(a*p1.x) - p1.y;
        }
    }

    void pointsSlopeToLine(point p, db m) {
        a = -m;
        b = 1.0;

```

```

    c = -((a * p.x) + (b * p.y));
}

bool areParallel(const line &other) {
    return (fabs(a-other.a) < EPS) && (fabs(b-other.b) < EPS);
}

bool areSame(const line &other) {
    return areParallel(other) && (fabs(c-other.c) < EPS);
}

bool areIntersect(const line &other, point &p) {
    if (areParallel(other)) return false;
    p.x = (other.b*c - b*other.c) / (other.a*b - a*other.b);
    if (fabs(b) > EPS) p.y = -(a*p.x + c);
    else p.y = -(other.a*p.x + other.c);
    return true;
}
};

struct vec{
    db x, y;
    vec(db _x, db _y) : x(_x), y(_y) {}
    vec(const point &a, const point &b) : x(b.x - a.x), y(b.y - a.y) {}

    vec scale(db s) {
        return vec(x*s, y*s);
    }

    point translate(const point &p) {
        return point(x+p.x, y+p.y);
    }

    db dot(vec a, vec b) { return a.x*b.x + a.y*b.y; }

    db norm_sq(vec v) { return v.x*v.x + v.y*v.y; }

    db angle(const point &a, const point &o, const point &b){
        vec oa = vec(o, a), ob = vec(o, b);
        return acos(dot(oa, ob) / sqrt(norm_sq(oa) * norm_sq(ob)));
    }

    db cross(vec a, vec b) { return a.x*b.y - a.y*b.x; }

    bool ccw(point p, point q, point r) {
        return cross(vec(p, q), vec(p, r)) > EPS;
    }
}

```

```

bool collinear(point p, point q, point r) {
    return fabs(cross(vec(p, q), vec(p, r))) < EPS;
}

db distToLine(point p, point a, point b) {
    vec ap = vec(a, p), ab = vec(a, b);
    db u = dot(ap, ab) / norm_sq(ab);
    point c = ab.scale(u).translate(a);
    return c.dist(p);
}

db distToLineSegment(point p, point a, point b) {
    vec ap = vec(a, p), ab = vec(a, b);
    db u = dot(ap, ab) / norm_sq(ab);
    if (u < 0.0) {
        point c = point(a.x, a.y);
        return c.dist(p);
    }
    if (u > 1.0) {
        point c = point(b.x, b.y);
        return c.dist(p);
    }
    return distToLine(p, a, b);
}

struct circle {
    point c;
    db r;
    circle(const point &c, db _r) : c(_c), r(_r) {}

    int inside(const point &p) {
        db dist = c.dist(p);
        return dist < r ? 1 : (fabs(dist-r) < EPS ? 0 : -1);
    }

    point inCircle(point p1, point p2, point p3) {
        line l1, l2;
        double ratio = p1.dist(p2) / p1.dist(p3);
        point p = vec(p2, p3).scale(ratio / (1+ratio)).translate(p2);
        l1.pointsToLine(p1, p);
        ratio = p2.dist(p1) / p2.dist(p3);
        p = vec(p1, p3).scale(ratio / (1+ratio)).translate(p1);
        l2.pointsToLine(p2, p);
        point c;
        l1.areIntersect(l2, c);
    }
}

```

```

    return c;
}

```

```
};
```

4. MATH

Matrix Pow

```

const int MAXN = 2;

struct Matrix
{
    ll mat[MAXN][MAXN];
};

Matrix operator*(const Matrix &a, const Matrix &b)
{
    Matrix c;
    for (int i = 0; i < MAXN; ++i)
        for (int j = 0; j < MAXN; ++j)
            c.mat[i][j] = 0;

    for (int i = 0; i < MAXN; i++)
    {
        for (int k = 0; k < MAXN; k++)
        {
            if (a.mat[i][k] == 0)
                continue;
            for (int j = 0; j < MAXN; j++)
            {

```

```

                c.mat[i][j] += a.mat[i][k] * b.mat[k][j];
            }
        }
    }
    return c;
}

Matrix operator^(Matrix &base, ll e)
{
    Matrix c;
    for (int i = 0; i < MAXN; i++)
        for (int j = 0; j < MAXN; j++)
            c.mat[i][j] = (i == j);
    while (e)
    {
        if (e & 1ll)
            c = c * base;
        base = base * base;
        e >>= 1;
    }
    return c;
}

```

5. DATASTRUCTURE

Segment Tree

```

class SegmentTree
{
private:
    vi values;

    vi p_values;
    int n;

    int left(int p) { return p << 1; };

    int right(int p) { return (p << 1) + 1; }

```

```

    int simple_node(int index) { return values[index]; }

    int prop(int x, int y) { return x + y; }

    void build(int p, int l, int r)
    {
        if (l == r)
        {
            p_values[p] = simple_node(l);
            return;

```

```

    }

    build(left(p), l, (l + r) / 2);
    build(right(p), (l + r) / 2 + 1, r);

    p_values[p] = prop(p_values[left(p)], p_values[right(p)]);
}

void set(int p, int l, int r, int i, int v)
{
    if (l == r)
    {
        values[l] = v;
        p_values[p] = simple_node(l);
        return;
    }

    if (i <= (l + r) / 2)
        set(left(p), l, (l + r) / 2, i, v);
    else
        set(right(p), (l + r) / 2 + 1, r, i, v);

    p_values[p] = prop(p_values[left(p)], p_values[right(p)]);
}

int query(int p, int l, int r, int lq, int rq)
{
    if (lq <= l && r <= rq)
        return p_values[p];
}

```

Sparse Table

```

class SparseTable
{
private:
    vector<vi> lookup;

    vi arr;

    int operation(int a, int b)
    {
        if (arr[a] <= arr[b])
            return a;
    }
}

```

```

    int l1 = l, r1 = (l + r) / 2;
    int l2 = (l + r) / 2 + 1, r2 = r;

    if (l1 > rq || lq > r1)
        return query(right(p), l2, r2, lq, rq);
    if (l2 > rq || lq > r2)
        return query(left(p), l1, r1, lq, rq);

    int lt = query(left(p), l1, r1, lq, rq);
    int rt = query(right(p), l2, r2, lq, rq);

    return prop(lt, rt);
}

public:
    SegmentTree(vi &a)
    {
        values = a;
        n = a.size();
        p_values.assign(4 * n, 0);
        build(1, 0, n - 1);
    }

    int query(int i, int j) { return query(1, 0, n - 1, i, j); }

    void set(int i, int v) { set(1, 0, n - 1, i, v); }

    int get(int i) { return values[i]; }
};

```

```

        return b;
    }

    int simple_node(int i) { return i; }

    void build_sparse_table()
    {
        int n = arr.size();

        for (int i = 0; i < n; i++)
            lookup[i][0] = simple_node(i);

        for (int j = 1; (1 << j) <= n; j++)

```

```

    {
        for (int i = 0; i <= n - (1 << j); i++)
            lookup[i][j] = operation(lookup[i][j - 1],
                                     lookup[i + (1 << (j - 1))][j - 1]);
    }
}

public:
    SparseTable(vi &a)
    {
        int q = (int)log2(a.size());

        arr.assign(a.size(), 0);
        lookup.assign(a.size(), vi(q + 1));
    }

```

```

        for (int i = 0; i < a.size(); i++)
            arr[i] = a[i];

        build_sparse_table();
    }

    int query(int l, int r)
    {
        int q = (int)log2(r - l + 1);

        return operation(lookup[l][q], lookup[r - (1 << q) + 1][q]);
    }

    int get(int i) { return arr[i]; }
};

```

Sqrt Decomposition

```

struct sqd {
    int n;
    int b;
    vi a;
    vi bsum;
    sqd(vi &a) {
        n = a.size();
        b = sqrt(n);
        this->a = a;
        bsum.assign(b + 1, 0);
        for (int i = 0; i < n; i++)
            bsum[i / b] += a[i];
    }
    void update(int i, int v) {

```

```

        bsum[i / b] += v - a[i];
        a[i] = v;
    }

    int query(int l, int r) {
        int sum = 0;
        for (int i = l; i <= r; i++)
            if (i % b == 0 && i + b - 1 <= r) {
                sum += bsum[i / b];
                i += b - 1;
            } else
                sum += a[i];
        return sum;
    }
};

```

Pbds

```

#include <bits/extc++.h> // pbds
using namespace __gnu_pbds;
typedef tree<int, null_type, less<int>, rb_tree_tag,
            tree_order_statistics_node_update>
    ost;

int main()
{
    int n = 9;

```

```

    int A[] = {2, 4, 7, 10, 15, 23, 50, 65, 71}; // as in Chapter 2
    ost tree;
    for (int i = 0; i < n; ++i) // O(n log n)
        tree.insert(A[i]);
    // O(log n) select
    cout << *tree.find_by_order(0) << "\n"; // 1-smallest = 2
    cout << *tree.find_by_order(n - 1) << "\n"; // 9-smallest/largest = 71
    cout << *tree.find_by_order(4) << "\n"; // 5-smallest = 15
    // O(log n) rank

```

```
cout << tree.order_of_key(2) << "\n"; // index 0 (rank 1)
cout << tree.order_of_key(71) << "\n"; // index 8 (rank 9)
cout << tree.order_of_key(15) << "\n"; // index 4 (rank 5)
```

Abi

```
class Abi
{
private:
    vi p;
    int _size;

    int ls_one(int i) { return i & (-i); }

public:
    Abi(int n)
    {
        _size = n;
        p.assign(n + 1, 0);
    }

    int rsq(int k)
    {
        int sum = 0;

        for (int i = k; i > 0; i -= ls_one(i))
```

```
        return 0;
    }
```

```
        {
            sum += p[i];
        }

        return sum;
    }

    int sum(int a, int b) { return rsq(b) - rsq(a - 1); }

    void adjust_sum(int k, int v)
    {
        for (int i = k; i < p.size(); i += ls_one(i))
            p[i] += v;
    }

    int size()
    {
        return _size;
    }
};
```

Avl

```
struct avl {
    int key;
    int height;
    int size;
    avl *left;
    avl *right;

    avl(int k) {
        key = k;
        height = 1;
        size = 1;
        left = NULL;
        right = NULL;
    }
};
```

```
int getBalance() {
    int leftHeight = 0;
    int rightHeight = 0;

    if (left != NULL)
        leftHeight = left->height;

    if (right != NULL)
        rightHeight = right->height;

    return leftHeight - rightHeight;
}

void updateSize() {
```



```

    int leftSize = 0;
    int rightSize = 0;

    if (left != NULL)
        leftSize = left->size;

    if (right != NULL)
        rightSize = right->size;

    size = leftSize + rightSize + 1;
}

void updateHeight() {
    int leftHeight = 0;
    int rightHeight = 0;

    if (left != NULL)
        leftHeight = left->height;

    if (right != NULL)
        rightHeight = right->height;

    height = max(leftHeight, rightHeight) + 1;
}

avl *rotateLeft() {
    avl *newRoot = right;
    right = newRoot->left;
    newRoot->left = this;
    updateHeight();
    newRoot->updateHeight();
    return newRoot;
}

avl *rotateRight() {
    avl *newRoot = left;
    left = newRoot->right;
    newRoot->right = this;
    updateHeight();
    newRoot->updateHeight();
    return newRoot;
}

avl *balance() {
    updateHeight();
    updateSize();
    int balance = getBalance();

```

```

    if (balance == 2) {
        if (left->getBalance() < 0)
            left = left->rotateLeft();
        return rotateRight();
    }

    if (balance == -2) {
        if (right->getBalance() > 0)
            right = right->rotateRight();
        return rotateLeft();
    }

    return this;
}

avl *insert(int k) {
    if (k < key) {
        if (left == NULL)
            left = new avl(k);
        else
            left = left->insert(k);
    }
    else {
        if (right == NULL)
            right = new avl(k);
        else
            right = right->insert(k);
    }

    return balance();
}

avl *findMin() {
    if (left == NULL)
        return this;
    else
        return left->findMin();
}

avl *removeMin() {
    if (left == NULL)
        return right;
    left = left->removeMin();
    return balance();
}

```

```

avl *remove(int k) {
    if (k < key)
        left = left->remove(k);
    else if (k > key)
        right = right->remove(k);
    else {
        avl *leftChild = left;
        avl *rightChild = right;

        delete this;

        if (rightChild == NULL)
            return leftChild;

        avl *min = rightChild->findMin();
        min->right = rightChild->removeMin();
        min->left = leftChild;
        return min->balance();
    }

    return balance();
}

int getRank(int k) {
    if (k < key) {
        if (left == NULL)
            return 0;
        else
            return left->getRank(k);
    }
    else if (k > key) {
        if (right == NULL)
            return 1 + left->size;
        else
            return 1 + left->size + right->getRank(k);
    }
    else
        return left->size;
}

```

```

int getKth(int k) {
    if (k < left->size)
        return left->getKth(k);
    else if (k > left->size)
        return right->getKth(k - left->size - 1);
    else
        return key;
}

static avl *join(avl *left, avl *right) {
    if (left->height < right->height) {
        right->left = join(left, right->left);
        return right->balance();
    }
    else if (left->height > right->height) {
        left->right = join(left->right, right);
        return left->balance();
    }
    else {
        avl *min = right->findMin();
        min->right = right->removeMin();
        min->left = left;
        return min->balance();
    }
}

pair<avl *, avl *> split(int k) {
    if (k < key) {
        pair<avl *, avl *> p = left->split(k);
        left = p.second;
        return {p.first, join(this, left)};
    }
    else {
        pair<avl *, avl *> p = right->split(k);
        right = p.first;
        return {join(this, right), p.second};
    }
}
};

```

Disjoint Set Union

```

struct dsu {
    vi p;
    void init(int n) {
        p = vi(n, -1);
    }
    int get(int x) {
        if (p[x] < 0)
            return x;
        return p[x] = get(p[x]);
    }
}

```

Segment Tree Lazy

```

class SegmentTreeLazy
{
private:
    vi values;
    vector<bool> lazy;
    vi l_values;
    vi p_values;
    int n;

    int left(int p) { return p << 1; };

    int right(int p) { return (p << 1) + 1; }

    int simple_node(int index) { return values[index]; }

    int prop(int x, int y) { return x + y; }

    int prop_lazy(int x, int y) { return x + y; }

    int prop_lazy_up(int x, int y, int s) { return x + y * s; }

    void update_lazy(int p, int l, int r)
    {
        if (l == r)
        {
            values[l] = prop_lazy(values[l], l_values[p]);
        }

        p_values[p] = prop_lazy_up(p_values[p], l_values[p], r - l + 1);
    }

    void propagate_lazy(int p, int l, int r)

```

```

void unite(int a, int b) {
    a = get(a);
    b = get(b);
    if (a != b) {
        if (p[a] > p[b])
            swap(a, b);
        p[a] += p[b];
        p[b] = a;
    }
}
};

```

```

{
    lazy[p] = false;

    if (l == r)
        return;

    l_values[left(p)] = lazy[left(p)]
        ? prop_lazy(l_values[left(p)], l_values[p])
        : l_values[p];
    l_values[right(p)] = lazy[right(p)]
        ? prop_lazy(l_values[right(p)], l_values[p])
        : l_values[p];

    lazy[left(p)] = true;
    lazy[right(p)] = true;
}

void build(int p, int l, int r)
{
    if (l == r)
    {
        p_values[p] = simple_node(l);
        return;
    }

    build(left(p), l, (l + r) / 2);
    build(right(p), (l + r) / 2 + 1, r);

    p_values[p] = prop(p_values[left(p)], p_values[right(p)]);
}

void set(int p, int l, int r, int i, int v)

```

```

{
    if (lazy[p])
    {
        update_lazy(p, l, r);
        propagate_lazy(p, l, r);
    }

    if (l == r)
    {
        values[l] = v;
        p_values[p] = simple_node(l);
        return;
    }

    if (i <= (l + r) / 2)
        set(left(p), l, (l + r) / 2, i, v);
    else
        set(right(p), (l + r) / 2 + 1, r, i, v);

    p_values[p] = prop(p_values[left(p)], p_values[right(p)]);
}

int query(int p, int l, int r, int lq, int rq)
{
    if (lazy[p])
    {
        update_lazy(p, l, r);
        propagate_lazy(p, l, r);
    }

    if (lq <= l && r <= rq)
        return p_values[p];

    int l1 = l, r1 = (l + r) / 2;
    int l2 = (l + r) / 2 + 1, r2 = r;

    if (l1 > rq || lq > r1)
        return query(right(p), l2, r2, lq, rq);
    if (l2 > rq || lq > r2)
        return query(left(p), l1, r1, lq, rq);

    int lt = query(left(p), l1, r1, lq, rq);
    int rt = query(right(p), l2, r2, lq, rq);

    return prop(lt, rt);
}

```

```

void set_rank(int p, int l, int r, int lq, int rq, int value)
{
    if (lazy[p])
    {
        update_lazy(p, l, r);
        propagate_lazy(p, l, r);
    }

    if (l > rq || lq > r)
        return;

    if (lq <= l && r <= rq)
    {
        lazy[p] = true;
        l_values[p] = value;
        update_lazy(p, l, r);
        propagate_lazy(p, l, r);
        return;
    }

    set_rank(left(p), l, (l + r) / 2, lq, rq, value);
    set_rank(right(p), (l + r) / 2 + 1, r, lq, rq, value);

    p_values[p] = prop(p_values[left(p)], p_values[right(p)]);
}

int get(int p, int l, int r, int i)
{
    if (lazy[p])
    {
        update_lazy(p, l, r);
        propagate_lazy(p, l, r);
    }

    if (l == r)
        return values[i];

    if (i <= (l + r) / 2)
        return get(left(p), l, (l + r) / 2, i);

    return get(right(p), (l + r) / 2 + 1, r, i);
}

public:
    SegmentTreeLazy(vi &a)
    {
        values = a;
    }
}

```

```

n = a.size();
p_values.assign(4 * n, 0);
lazy.assign(4 * n, false);
l_values.assign(4 * n, 0);
build(1, 0, n - 1);
}

int query(int i, int j) { return query(1, 0, n - 1, i, j); }

```

Z Function

```

// Z[i] is the length of the longest substring
// starting from S[i] which is also a prefix of S.
vi z_function(string s)
{
    int n = (int)s.length();
    vi z(n);

    for (int i = 1, l = 0, r = 0; i < n; ++i)
    {
        if (i <= r)
            z[i] = min(r - i + 1, z[i - l]);
        while (i + z[i] < n && s[z[i]] == s[i + z[i]])
            ++z[i];
        if (i + z[i] - 1 > r)
            l = i, r = i + z[i] - 1;
    }
    return z;
}

// suff[i] = length of the longest common suffix of s and s[0..i]

```

Suffix Array

```

class SuffixArray
{
public:
    SuffixArray(string s)
    {
        n = s.size() + 1;
        s_value = s + "$";
    }

```

```

    void set(int i, int v) { set(1, 0, n - 1, i, v); }

    void set_rank(int i, int j, int v) { set_rank(1, 0, n - 1, i, j, v); }

    int get(int i) { return get(1, 0, n - 1, i); }
};

```

6. STRING

```

vi suffixes(const string &s)
{
    int n = s.length();

    vi suff(n, n);

    for (int i = n - 2, g = n - 1, f; i >= 0; --i)
    {
        if (i > g && suff[i + n - 1 - f] != i - g)
            suff[i] = min(suff[i + n - 1 - f], i - g);
        else
        {
            for (g = min(g, f = i); g >= 0 && s[g] == s[g + n - 1 - f]; --g)
                ;
            suff[i] = f - g;
        }
    }

    return suff;
}

```

```

ra.assign(n, 0);
sa.assign(n, 0);
temp_ra.assign(n, 0);
temp_sa.assign(n, 0);

```

```

    construct_sa();
    build_lcp();
}

```

```

int size() { return n; }

int get_int(int i) { return sa[i]; }

int cant_match(string p)
{
    pii ans = matching(p);

    if (ans.first == -1 && ans.second == -1)
        return 0;

    return ans.second - ans.first + 1;
}

int get_lcp(int i) { return plcp[sa[i]]; }

int cant_substr() { return v_cant_substr; }

string get_str(int i) { return s_value.substr(sa[i], n - sa[i] - 1); }

private:
string s_value;
int n;
int v_cant_substr;

vi ra;
vi sa;
vi c;
vi temp_ra;
vi temp_sa;
vi phi;
vi plcp;

void counting_sort(int k)
{
    int sum = 0;
    int maxi = max((int)300, n);

    c.assign(maxi, 0);

    for (int i = 0; i < n; i++)
        c[i + k < n ? ra[i + k] : 0]++;

    for (int i = 0; i < maxi; i++)
    {
        int tx = c[i];
        c[i] = sum;

```

```

        sum += tx;
    }

    for (int i = 0; i < n; i++)
        temp_sa[c[sa[i] + k < n ? ra[sa[i] + k] : 0]++] = sa[i];

    for (int i = 0; i < n; i++)
        sa[i] = temp_sa[i];
}

void construct_sa()
{
    int k, r;

    for (int i = 0; i < n; i++)
    {
        ra[i] = s_value[i];
        sa[i] = i;
    }

    for (k = 1; k < n; k <= 1)
    {
        counting_sort(k);
        counting_sort(0);

        temp_ra[sa[0]] = r = 0;

        for (int i = 1; i < n; i++)
            temp_ra[sa[i]] = (ra[sa[i]] == ra[sa[i] - 1]) && ra[sa[i] + k] == ra[sa[i] + k - 1] ? r : r + 1;

        for (int i = 0; i < n; i++)
            ra[i] = temp_ra[i];

        if (ra[sa[n - 1]] == n - 1)
            break;
    }
}

pii matching(string p)
{
    int l = 0;
    int r = n - 1;
    int p_size = p.size();

    string comp;

    while (l < r)

```

```

{
    int m = (l + r) / 2;

    comp = s_value.substr(sa[m], min(n - sa[m], p_size));

    if (comp >= p)
        r = m;
    else
        l = m + 1;
}

comp = s_value.substr(sa[l], min(n - sa[l], p_size));

if (comp != p)
    return {-1, -1};

int ans_l = l;

l = 0;
r = n - 1;

while (l < r)
{
    int m = (l + r) / 2;

    comp = s_value.substr(sa[m], min(n - sa[m], p_size));

    if (comp > p)
        r = m;
    else
        l = m + 1;
}

comp = s_value.substr(sa[r], min(n - sa[r], p_size));

if (comp != p)
    r--;

```

Trie

```

class Trie
{
private:
    int cant_string;
    int cant_string_me;
    int cant_node;

```

```

    int ans_r = r;

    return {ans_l, ans_r};
}

void build_lcp()
{
    phi.assign(n, 0);
    plcp.assign(n, 0);

    phi[0] = -1;

    for (int i = 1; i < n; i++)
        phi[sa[i]] = sa[i - 1];

    int l = 0;
    int q = 0;
    for (int i = 0; i < n; i++)
    {
        if (phi[i] == -1)
        {
            plcp[i] = 0;
            continue;
        }

        while (s_value[i + 1] == s_value[phi[i] + 1])
            l++;

        plcp[i] = l;
        q += l;
        l = max(l - 1, (int)0);
    }

    v_cant_substr = n * (n - 1) / 2 - q;
}
};

```

```

    char value;
    Trie *children[alphabet];

public:
    Trie(char a)
    {

```

```

    cant_string = 0;
    cant_node = 1;
    cant_string_me = 0;
    value = a;

    for (int i = 0; i < alphabet; i++)
        children[i] = NULL;
}

pair<Trie *, int> search(string s)
{
    Trie *node = this;
    int i = 0;

    while (i < s.size() && node->children[s[i] - first_char] != NULL)
    {
        node = node->children[s[i] - first_char];

        i++;
    }

    return {node, i};
}

void insert(string s)
{
    int q = s.size() - search(s).second;

    Trie *node = this;

    for (int i = 0; i < s.size(); i++)
    {
        node->cant_node += q;

        if (node->children[s[i] - first_char] == NULL)
        {
            node->children[s[i] - first_char] = new Trie(s[i]);
            q--;
        }

        node = node->children[s[i] - first_char];
        node->cant_string_me++;
    }

    node->cant_string++;
}

```

```

void eliminate(string s)
{
    if (!contains(s))
        return;

    Trie *node = this;
    int q = 0;

    for (int i = 0; i < s.size(); i++)
    {
        if (node->children[s[i] - first_char] == NULL)
        {
            node->children[s[i] - first_char] = new Trie(s[i]);
        }

        if (node->children[s[i] - first_char]->cant_string_me == 1)
        {
            node->children[s[i] - first_char] = NULL;

            q = s.size() - i;
            break;
        }

        node = node->children[s[i] - first_char];
        node->cant_string_me--;

        if (i == s.size() - 1)
            node->cant_string--;
    }

    node = this;

    for (int i = 0; i < s.size() - q + 1; i++)
    {
        node->cant_node -= q;
        node = node->children[s[i] - first_char];
    }
}

bool contains(string s)
{
    auto q = search(s);
    return q.second == s.size() && q.first->cant_string >= 1;
}

int cant_words_me() { return cant_string_me; }

```



```
int cant_words() { return cant_string; }

Trie *get(char a) { return children[a - first_char]; }
```

Kmp Pf

```
vi prefix_function(string p)
{
    vi pf(p.size());

    pf[0] = 0;
    int k = 0;

    for (int i = 1; i < p.size(); i++)
    {
        while (k > 0 && p[k] != p[i])
            k = pf[k - 1];

        if (p[k] == p[i])
            k++;

        pf[i] = k;
    }

    return pf;
}

vi kmp(string t, string p)
```

```
int size() { return cant_node; }
};

{
    vi result;
    vi pf = prefix_function(p);
    int k = 0;

    for (int i = 0; i < t.size(); i++)
    {
        while (k > 0 && p[k] != t[i])
            k = pf[k - 1];

        if (p[k] == t[i])
            k++;

        if (k == p.size())
        {
            result.push_back(i - (p.size() - 1));
            k = pf[k - 1];
        }
    }

    return result;
}
```