

# Содержание

<b>1</b>	<b>Общее</b>	<b>1</b>
<b>2</b>	<b>Коды</b>	<b>1</b>
2.1	Basic setup	1
2.2	Бесполезное	2
2.3	Мосты	2
2.4	Точки сочленения	2
2.5	DCP (TheEvilBird)	2
2.6	MaxFlow (TheEvilBird)	3
2.7	MinCostMaxFlow (TheEvilBird)	4
2.8	Эйлеров цикл	4
2.9	Кун	4
2.10	HLD (TheEvilBird)	4
2.11	Dominator tree (TheEvilBird)	5
2.12	Link-Cut (TheEvilBird)	6
2.13	Личао (FedShat)	7
2.14	Segment Tree (TheEvilBird)	7
2.15	Segment Tree Down (TheEvilBird)	8
2.16	Segment Tree Beats (TheEvilBird)	8
2.17	Persistent Segment Tree (Sweezyk)	9
2.18	Fenwick (TheEvilBird)	10
2.19	Sparse table (TheEvilBird)	10
2.20	Treap (Sweezyk)	10
2.21	Extended GCD (Sweezyk)	10
2.22	FFT (FedShat)	11
2.23	КТО (FedShat)	12
2.24	Обратные по простому модулю	12
2.25	Обратные факториалы	12
2.26	Гаусс	12
2.27	Быстрая факторизация (FedShat)	13
2.28	Префикс-функция	13
2.29	Z-функция	13
2.30	Суфмас (TheEvilBird)	13
2.31	Суфавтомат (TheEvilBird)	14
2.32	Ахо-Корасик (Sweezyk)	14
2.33	Манакер	15
2.34	СНТ (FedShat)	15
2.35	Дебаг Туриста	15
2.36	Геометрия (TheEvilBird)	15
2.37	Стрессы (TheEvilBird)	18

## 1 Общее

- Собственное вращение на угол  $\varphi$  с центром вращения в начале координат:  

$$\begin{aligned} x' &= x \cos \varphi - y \sin \varphi \\ y' &= x \sin \varphi + y \cos \varphi \end{aligned}$$
- Расстояние между точками по сфере:  $L = R \cdot \arccos(\cos \theta_1 \cdot \cos \theta_2 + \sin \theta_1 \cdot \sin \theta_2 \cdot \cos(\varphi_1 - \varphi_2))$  где  $\theta$  — широты (от  $-\pi$  до  $\pi$ ),  $\varphi$  — долготы (от  $-\pi$  до  $\pi$ )
- Объем шарового сегмента:  $V = \pi h^2(R - \frac{1}{3}h)$ , где  $h$  — высота от вершины сектора до секущей плоскости
- Площадь поверхности шарового сегмента:  $S = 2\pi Rh$ , где  $h$  — высота
- Код Грея:  $g_n = n \oplus \frac{n}{2}$
- Числа Фибоначчи:  

$$F_0 = 0, F_1 = 1, F_n = \frac{(\frac{1+\sqrt{5}}{2})^n - (\frac{1-\sqrt{5}}{2})^n}{\sqrt{5}}$$
- Sum-xor property:  $a + b = a \oplus b + 2(a \& b), a + b = a|b + a \& b, a \oplus b = a|b - a \& b$

- Число граней в планарном графе(с учётом бесконечной):  $R = 2 - V + E$

- Сумма арифметической прогрессии:  $S_n = \frac{n(a_1 + a_n)}{2}$

- Сумма геометрической прогрессии:  $S_n = \frac{b_1(q^n - 1)}{q - 1}$

- Определители матриц

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} = ad - bc$$

$$\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} = a_1 b_1 c_1 + a_3 b_1 c_2 + a_2 b_3 c_1 - a_3 b_2 c_1 - a_1 b_3 c_2 - a_2 b_1 c_3$$

$\Delta = \sum_{j=1}^n (-1)^{j+1} \cdot a_{1,j} \cdot \bar{M}_j^1$ ,  $\bar{M}_j^1$  — определитель матрицы, полученной вычеркиванием 1 строки и  $j$  столбца.

- Метод Крамера.**  $\det A \neq 0 \implies$  единственное решение. Иначе 0 или  $\infty$ . Решения:  $x_i = \frac{\Delta_i}{\Delta}$ . В  $\Delta_i$  столбец коэффициентов при соответствующей неизвестной заменяется столбцом свободных членов системы.

## 2 Коды

### 2.1 Basic setup

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

using namespace std;

#define sz(x) ((int) (x).size())
#define all(x) (x).begin(), (x).end()
#define rall(x) (x).rbegin(), (x).rend()

typedef long long ll;
typedef __int128 int128;
typedef pair<int, int> pii;
typedef pair<ll, ll> pll;

const char en = '\n';
const int INF = 1e9 + 7;
const ll INFL = 1e18;

mt19937 rnd(chrono::high_resolution_clock::now().time_since_epoch().count());

template<class T>
istream &operator>>(istream &is, vector<T> &a) {
    for (auto &i : a) {
        is >> i;
    }
    return is;
}

void solve() {
}

int32_t main() {
    #ifdef LOCAL
        freopen("input.txt", "r", stdin);
    #else
        ios_base::sync_with_stdio(0);
        cin.tie(0);
    #endif
    solve();
    return 0;
}
```

## 2.2 Бесплезное

Санитайзеры:

```
set(CMAKE_CXX_FLAGS "${CMAKE_CXX_FLAGS} -Wall -Wshadow -g -fsanitize=
  undefined-fsanitize=bounds -fsanitize=address -D_GLIBCXX_DEBUG")

-Wall -Wextra -pedantic -Wformat=2 -Wfloat-equal -Wconversion -Wlogical-
  op -Wshift-overflow=2 -Wduplicated-cond -Wcast-qual -Wcast-align -
  Werror
```

Прагмы:

```
#pragma GCC optimize("Ofast,no-stack-protector")
#pragma GCC target("sse,sse2,sse3,ssse3,sse4")
#pragma GCC target("popcnt,abm,mmx,avx,avx2,tune=native")
#pragma GCC optimize("unroll-loops")
#pragma GCC optimize("fast-math")
#pragma GCC optimize("section-anchors")
#pragma GCC optimize("profile-values")
#pragma GCC optimize("profile-reorder-functions")
#pragma GCC optimize("tracer")
#pragma GCC optimize("vpt")
#pragma GCC optimize("rename-registers")
#pragma GCC optimize("move-loop-invariants")
#pragma GCC optimize("unswitch-loops")
#pragma GCC optimize("function-sections")
#pragma GCC optimize("data-sections")
#pragma GCC optimize("branch-target-load-optimize")
#pragma GCC optimize("branch-target-load-optimize2")
#pragma GCC optimize("btr-bb-exclusive")
```

Встроенный декартач:

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
template<class T>
using ordered_set = tree<T, null_type, less<T>, rb_tree_tag,
  tree_order_statistics_node_update>;
ordered_set q;
q.find_by_order(1);
q.order_of_key(2);
```

Atomic hashset, hashmap:

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
gp_hash_table<int, int> table;
// -----
const int RANDOM = chrono::high_resolution_clock::now().time_since_epoch
  ().count();
struct chash {
  int operator()(int x) const { return x ^ RANDOM; }
};
gp_hash_table<key, int, chash> table;
// -----
typedef cc_hash_table<int, int, hash<int>> ht;
```

Перебор всех подмасок и надмасок:

```
for (int submask = mask;; submask = (submask - 1) & mask) {
  // use submask
  if (submask == 0) break;
}

for (int upmask = mask;; upmask = (upmask + 1) | mask) {
  // use upmask
  if (upmask == maxmask) break;
}
```

## 2.3 Мосты

```
void dfs(int v, int p = -1) {
  used[v] = true;
  tin[v] = fup[v] = timer++;
  for (auto to : g[v]) {
    if (to == p) {
      continue;
    }
    if (used[to]) {
      fup[v] = min(fup[v], tin[to]);
    } else {
      dfs(to, v);
      fup[v] = min(fup[v], fup[to]);
      if (fup[to] > tin[v]) {
        IS_BRIDGE(v, to);
      }
    }
  }
}
```

## 2.4 Точки сочленения

```
void dfs(int v, int p = -1) {
  used[v] = true;
  tin[v] = fup[v] = timer++;
  int children = 0;
  for (auto to : g[v]) {
    if (to == p) {
      continue;
    }
    if (used[to]) {
      fup[v] = min(fup[v], tin[to]);
    } else {
      dfs(to, v);
      fup[v] = min(fup[v], fup[to]);
      if (fup[to] >= tin[v] && p != -1) {
        IS_CUTPOINT(v);
      }
      ++children;
    }
  }
  if (p == -1 && children > 1) {
    IS_CUTPOINT(v);
  }
}
```

## 2.5 DCP (TheEvilBird)

```
struct Query {
  char type;
  int v, u;

  Query(char type) : type(type) {}
  Query(char type, int v, int u) : type(type), v(v), u(u) {}
};
```

```
struct DCP {
  int n, k, ans; // n - vertex, k - queries
  vector<int> par, rk;
  vector<pair<pii, int>> hist;
  // 0 - par, 1 - rk, 2 - ans;

  int qL, qR;
  pii edge;
  vector<vector<pii>> tree;
  vector<Query> qs;

  DCP(int _n, int _k) {
    n = ans = _n;
    par.resize(n);
    rk.resize(n, 1);
    for (int i = 0; i < n; ++i) par[i] = i;
    k = _k;
    tree.assign(4 * k, vector<pii>());
  }
```

```
int dsu_get(int v) {
  while (par[v] != v) v = par[v];
  return v;
}
```

```
void dsu_unite(int a, int b) {
  a = dsu_get(a);
  b = dsu_get(b);
  if (a == b) return;
  if (rk[a] > rk[b]) swap(a, b);
  hist.emplace_back((pii){0, a, par[a]});
  hist.emplace_back((pii){2, -1, ans});
  par[a] = b;
  --ans;
  if (rk[a] == rk[b]) {
    hist.emplace_back((pii){1, b, rk[b]});
    ++rk[b];
  }
}
```

```
void dsu_unite(pii e) {
  dsu_unite(e.first, e.second);
}
```

```
void cancel(pair<pii, int> &el) {
  int &type = el.first.first;
  int &id = el.first.second;
  int &val = el.second;
  if (type == 0) {
    par[id] = val;
  } else if (type == 1) {
    rk[id] = val;
  } else if (type == 2) {
    ans = val;
  }
}
```

```

void add_edge(int _qL, int _qR, pii e) { // [L, R]
    qL = _qL;
    qR = _qR + 1;
    edge = e;
    add_edge_tree(1, 0, k);
}

void add_edge_tree(int v, int l, int r) {
    if (qL <= l && r <= qR) {
        tree[v].emplace_back(edge);
        return;
    }
    int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
    if (qL < m) add_edge_tree(vL, l, m);
    if (m < qR) add_edge_tree(vR, m, r);
}

void go(vector<Query> &_qs) {
    qs = _qs;
    go_tree(1, 0, k);
}

void go_tree(int v, int l, int r) {
    int siz = sz(hist);
    for (auto &e : tree[v]) {
        dsu_unite(e);
    }
    if (l + 1 == r) {
        if (qs[l].type == '??') {
            cout << ans << endl;
        }
    } else {
        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        go_tree(vL, l, m);
        go_tree(vR, m, r);
    }
    while (sz(hist) > siz) {
        cancel(hist.back());
        hist.pop_back();
    }
}

void solve() {
    int n, k;
    cin >> n >> k;
    DCP dcp(n, k);
    set<pair<pii, int>> edges;
    vector<Query> qs;
    for (int i = 0; i < k; ++i) {
        char tp;
        cin >> tp;
        if (tp == '??') {
            qs.emplace_back(tp);
        } else {
            int v, u;
            cin >> v >> u;
            --v;
            --u;
            if (v > u) swap(v, u);
            qs.emplace_back(tp, v, u);
            if (tp == '+') {
                edges.emplace((pii){v, u}, i);
            } else {
                auto it = edges.lower_bound({(pii){v, u}, 0});
                dcp.add_edge(it->second, i, it->first);
                edges.erase(it);
            }
        }
    }
    for (auto &e : edges) {
        dcp.add_edge(e.second, k - 1, e.first);
    }
    if (k) dcp.go(qs);
}

```

## 2.6 MaxFlow (TheEvilBird)

```

struct MaxFlow {
    struct Edge {
        ll flow, cap;
        int to, id;

        Edge() {}

        Edge(ll flow, ll cap, int to, int id) : flow(flow), cap(cap), to(to), id(id) {}
    };

    int n;
    vector<vector<Edge>> g;
    vector<int> d, head, used;
    ll max_cap;
    int s, t;

```

```

MaxFlow() {}

MaxFlow(int _n) {
    n = _n;
    g.resize(n);
}

void add_edge(int from, int to, ll cap) {
    g[from].emplace_back(0, cap, to, sz(g[to]));
    g[to].emplace_back(0, 0, from, sz(g[from]) - 1);
}

bool bfs() {
    d.assign(n, INF);
    d[s] = 0;
    queue<int> q;
    q.push(s);
    while (!q.empty()) {
        int v = q.front();
        q.pop();
        for (auto e : g[v]) {
            if (d[e.to] == INF && e.cap - e.flow >= max_cap) {
                d[e.to] = d[v] + 1;
                q.push(e.to);
            }
        }
    }
    return d[t] != INF;
}

ll dfs(int v, ll cur_flow) {
    if (v == t) {
        return cur_flow;
    }
    for (; head[v] < sz(g[v]); ++head[v]) {
        auto &e = g[v][head[v]];
        if (e.cap - e.flow >= max_cap && d[v] + 1 == d[e.to]) {
            ll new_flow = dfs(e.to, min(cur_flow, e.cap - e.flow));
            if (new_flow) {
                e.flow += new_flow;
                g[e.to][e.id].flow -= new_flow;
                return new_flow;
            }
        }
    }
    return 0;
}

ll find_max_flow(int _s, int _t) {
    s = _s;
    t = _t;
    ll res = 0;
    for (int k = 30; k >= 0; --k) {
        max_cap = (1 << k);
        while (bfs()) {
            head.assign(n, 0);
            ll flow = 0;
            do {
                flow = dfs(s, INFL);
                res += flow;
            } while (flow);
        }
    }
    return res;
}

ll dfs_const_flow(int v, ll cur_flow) {
    used[v] = 1;
    if (v == t) {
        return cur_flow;
    }
    for (auto &e : g[v]) {
        if (!used[e.to] && e.cap - e.flow > 0) {
            ll new_flow = dfs_const_flow(e.to, min(cur_flow, e.cap - e.flow));
            if (new_flow) {
                e.flow += new_flow;
                g[e.to][e.id].flow -= new_flow;
                return new_flow;
            }
        }
    }
    return 0;
}

bool find_const_flow(int _s, int _t, ll F) {
    s = _s;
    t = _t;
    ll res = 0, flow = 0;
    max_cap = F;
    do {
        used.assign(n, 0);
        flow = dfs_const_flow(s, INF);
        res += flow;
    } while (flow && res < F);
    return res == F;
}

```

```

ll get_edge_flow(int v, int id) {
    return g[v][id].flow;
}
};

```

## 2.7 MinCostMaxFlow (TheEvilBird)

```

struct MinCostMaxFlow {
    struct Edge {
        ll flow, cap, price;
        int to, id;

        Edge() {}

        Edge(ll flow, ll cap, ll price, int to, int id) : flow(flow), cap
(cap), price(price), to(to), id(id) {}
    };

    int n;
    int s, t;
    ll ans;
    vector<vector<Edge>> g;
    vector<int> d;
    vector<ll> add_f;
    vector<pii> par;

    MinCostMaxFlow() {}

    MinCostMaxFlow(int _n) {
        n = _n;
        g.resize(n);
    }

    void add_edge(int from, int to, ll cap, ll price) {
        g[from].emplace_back(0, cap, price, to, sz(g[to]));
        g[to].emplace_back(0, 0, -price, from, sz(g[from]) - 1);
    }

    ll get_edge_flow(int v, int id) {
        return g[v][id].flow;
    }

    void FB() {
        d.assign(n, INF);
        add_f.assign(n, 0);
        par.assign(n, {-1, -1});
        d[s] = 0;
        add_f[0] = INF;
        queue<int> q;
        q.push(s);
        vector<int> used(n, 0);
        used[s] = 1;
        while (!q.empty()) {
            int v = q.front();
            q.pop();
            used[v] = 0;
            for (int i = 0; i < sz(g[v]); ++i) {
                auto &e = g[v][i];
                if (e.flow < e.cap && d[e.to] > d[v] + e.price) {
                    d[e.to] = d[v] + e.price;
                    add_f[e.to] = min(add_f[v], e.cap - e.flow);
                    par[e.to] = {v, i};
                    if (!used[e.to]) {
                        q.push(e.to);
                        used[e.to] = 1;
                    }
                }
            }
        }
    }

    void push_flow(ll flow) {
        int cur = t;
        while (cur != s) {
            int prev = par[cur].first, id = par[cur].second;
            g[prev][id].flow += flow;
            g[cur][g[prev][id].id].flow -= flow;
            ans += g[prev][id].price * flow;
            cur = prev;
        }
    }

    ll min_cost_max_flow(int _s, int _t) {
        ans = 0;
        s = _s;
        t = _t;
        while (true) {
            FB();
            ll flow = add_f[t];
            if (flow == 0) {
                break;
            }
            push_flow(flow);
        }
    }
};

```

```

    }
    return ans;
}
};

```

## 2.8 Эйлеров цикл

```

vector<vector<int>> g;
vector<bool> used;
vector<int> ed, tour;

void dfs(int v) {
    while (!g[v].empty()) {
        int u = g[v].back();
        g[v].pop_back();
        if (used[u]) {
            continue;
        }
        used[u] = 1;
        dfs(ed[u] ^ v);
    }
    tour.push_back(v);
}

```

## 2.9 Кун

```

vector<vector<int>> g;
vector<int> used, mt;
int timer = 1;
bool dfs(int v) {
    if (used[v] == timer) {
        return false;
    }
    used[v] = timer;
    for (auto u : g[v]) {
        if (mt[u] == -1) {
            mt[u] = v;
            return true;
        }
    }
    for (auto u : g[v]) {
        if (dfs(mt[u])) {
            mt[u] = v;
            return true;
        }
    }
    return false;
}

for (int i = 0; i < n; ++i) {
    if (dfs(i)) {
        ++timer;
    }
}

```

Вершинное покрытие графа — множество вершин, что каждое ребро графа инцидентно хотя бы одной вершине из множества.

Пусть  $M$  — макс. парсоч. Мысленно ориентируем ребра графа: ребра из  $M$  проведем из правой доли в левую, остальные — из левой в правую, после чего запустим обход в глубину из всех вершин левой доли, не включенных в  $M$ . Граф разбился на несколько множеств:  $L^+$ ,  $L^-$ ,  $R^+$ ,  $R^-$ , где «плюсовые» множества — это множества посещенных в процессе обхода вершин. Тогда  $V_{min} = L^- \cup R^+$ .

Независимое множество вершин — множество вершин, что никакая пара вершин не соединена ребром. Дополнение минимального вершинного покрытия является максимальным независимым множеством.

Покрытие дага путями:  $n - matching$

## 2.10 HLD (TheEvilBird)

```

struct HLD {

    // insert SegTree code
    struct SegTree {};

    int n, T;
    SegTree st;
    vector<vector<int>> tree;
    vector<int> par, siz, tin, tout, head;
    ll ans;
};

```

```

HLD(int _n) {
    n = _n;
    tree.resize(n);
    par.resize(n, -1);
    siz.resize(n, 0);
    tin.resize(n);
    tout.resize(n);
    head.resize(n);
    st = SegTree(n);
}

void add_edge(int v, int u) {
    tree[v].emplace_back(u);
    tree[u].emplace_back(v);
}

void build(int v = 0) {
    dfs_siz(v, v);
    T = 0;
    head[v] = v;
    dfs_hld(v, v);
}

void dfs_siz(int v, int p) {
    par[v] = p;
    siz[v] = 1;
    for (auto &u : tree[v]) {
        if (u != p) {
            dfs_siz(u, v);
            siz[v] += siz[u];
        }
    }
    for (int i = 0; i < sz(tree[v]); ++i) {
        int x = tree[v][0], u = tree[v][i];
        if (x == p || siz[u] > siz[x]) {
            swap(tree[v][0], tree[v][i]);
        }
    }
}

void dfs_hld(int v, int p) {
    tin[v] = T++;
    for (auto u : tree[v]) {
        if (u == p) {
            continue;
        }
        if (u == tree[v][0]) {
            head[u] = head[v];
        } else {
            head[u] = u;
        }
        dfs_hld(u, v);
    }
    tout[v] = T;
}

void update(int v, int val) {
    st.update_segment(tin[v], tin[v], val);
}

bool is_anc(int v, int u) {
    return tin[v] <= tin[u] && tout[u] <= tout[v];
}

void go_up(int &v, int u) {
    while (!is_anc(head[v], u)) {
        ans = max(ans, st.get(tin[head[v]], tin[v]));
        v = par[head[v]];
    }
}

ll get(int v, int u) { // max on path
    ans = -INFL;
    go_up(v, u);
    go_up(u, v);
    if (!is_anc(v, u)) {
        swap(v, u);
    }
    ans = max(ans, st.get(tin[v], tin[u]));
    return ans;
}
};

```

## 2.11 Dominator tree (TheEvilBird)

```

struct Edge {
    int from, to, id;

    Edge() = default;
    Edge(int from, int to, int id) : from(from), to(to), id(id) {}
};

struct DSU {
    int n;

```

```

vector<int> par;
vector<pii> mn;

DSU() = default;
DSU(int n) : n(n) {
    par.resize(n);
    mn.resize(n);
    init();
}

void init() {
    for (int i = 0; i < n; ++i) {
        par[i] = i;
        mn[i] = {INF, i};
    }
}

int get(int v) {
    if (par[v] == v) {
        return v;
    }
    int p = get(par[v]);
    mn[v] = min(mn[v], mn[par[v]]);
    if (mn[par[v]].first < mn[v].first) {
        mn[v] = mn[par[v]];
    }
    par[v] = p;
    return p;
}

void unite(int a, int b) {
    par[a] = b;
}

};

struct DominatorTree {
    int n;
    vector<Edge> edges;
    vector<int> sdom, idom, tin, order, par, used, dp;
    vector<vector<int>> g, rg, queries;
    DSU dsu_sdom, dsu_idom;

    DominatorTree() = default;
    DominatorTree(int n) : n(n), dsu_sdom(n), dsu_idom(n) {
        sdom.resize(n, INF); // semi-dominator
        idom.resize(n, INF); // immediate dominator
        tin.resize(n, -1);
        par.resize(n);
        used.resize(n, 0);
        dp.resize(n, INF);
        g.resize(n);
        rg.resize(n);
        queries.resize(n);
    }

    void add_edge(int from, int to) {
        edges.emplace_back(from, to, sz(edges));
    }

    void dfs(int v) {
        tin[v] = sz(order);
        order.emplace_back(v);
        for (auto i: g[v]) {
            const auto &e = edges[i];
            if (tin[e.to] == -1) {
                par[e.to] = v;
                dfs(e.to);
            }
        }
    }

    void dfs_idom(int v) {
        used[v] = 1;
        for (auto i: g[v]) {
            const auto &e = edges[i];
            if (!used[e.to]) {
                dfs_idom(e.to);
            }
        }
        for (auto u: queries[v]) {
            dsu_idom.get(u);
            dp[u] = dsu_idom.mn[u].second;
        }
        dsu_idom.mn[v] = {sdom[v], v};
        for (auto i: g[v]) {
            const auto &e = edges[i];
            if (par[e.to] == v) {
                dsu_idom.unite(e.to, v);
            }
        }
    }

    void build(int s) {
        for (int i = 0; i < sz(edges); ++i) {
            g[edges[i].from].emplace_back(i);
            rg[edges[i].to].emplace_back(i);
        }
        // reorder vertex

```

```

dfs(s);

// build sdom
for (int _ = sz(order) - 1; _ >= 0; --_) {
    int v = order[_];
    if (v == s) {
        continue;
    }
    for (auto i: rg[v]) {
        const auto &e = edges[i];
        if (tin[e.from] == -1) {
            continue;
        }
        if (tin[e.from] < tin[v]) {
            sdom[v] = min(sdom[v], tin[e.from]);
        }
        else {
            int u = dsu_sdom.get(e.from);
            sdom[v] = min(sdom[v], dsu_sdom.mn[e.from].first);
        }
    }
    dsu_sdom.mn[v] = {sdom[v], v};
    for (auto i: g[v]) {
        const auto &e = edges[i];
        if (v == par[e.to]) {
            dsu_sdom.unite(e.to, v);
        }
    }
}

// build queries for idoms
for (int i = 0; i < n; ++i) {
    if (i == s || sdom[i] == INF || tin[i] == -1) {
        continue;
    }
    queries[order[sdom[i]]].emplace_back(i);
}
dfs_idom(s);

// build idom
idom[s] = tin[s];
for (auto v: order) {
    if (v == s) {
        continue;
    }
    if (v == dp[v]) {
        idom[v] = sdom[v];
    }
    else {
        idom[v] = idom[dp[v]];
    }
}

int get_idom(int v) {
    return (idom[v] == INF ? -1 : order[idom[v]]);
}
};

```

## 2.12 Link-Cut (TheEvilBird)

```

struct Node {
    Node *ch[2] = {nullptr, nullptr};
    Node *par = nullptr;
    bool rev = false;
    int val, mn;
    int siz = 1;

    Node() {}

    Node(int val) : val(val), mn(val) {}
};

typedef Node *pnode;

int get_siz(pnode v) {
    return (v == nullptr ? 0 : v->siz);
}

int get_min(pnode v) {
    return (v == nullptr ? INF : v->mn);
}

void update(pnode v) {
    v->siz = 1 + get_siz(v->ch[0]) + get_siz(v->ch[1]);
    v->mn = min(v->val, min(get_min(v->ch[0]), get_min(v->ch[1])));
}

void push(pnode v) {
    if (v == nullptr || !v->rev) {
        return;
    }
    if (v->ch[0] != nullptr) {
        v->ch[0]->rev ^= 1;
    }
}

```

```

if (v->ch[1] != nullptr) {
    v->ch[1]->rev ^= 1;
}
swap(v->ch[0], v->ch[1]);
v->rev = 0;
}

bool is_root(pnode v) {
    return (v->par == nullptr ||
            (v->par->ch[0] != v && v->par->ch[1] != v));
}

int child_num(pnode v) {
    return (v->par->ch[1] == v);
}

void attach(pnode v, pnode p, int num) {
    if (v != nullptr) {
        v->par = p;
    }
    if (p != nullptr) {
        p->ch[num] = v;
    }
}

void rotate(pnode v) {
    int num = child_num(v);
    pnode p = v->par, vb = v->ch[num ^ 1];
    pnode g = (p == nullptr ? nullptr : p->par);
    if (g != nullptr) {
        if (!is_root(p)) {
            g->ch[child_num(p)] = v;
        }
    }
    v->par = g;
    attach(p, v, num ^ 1);
    attach(vb, p, num);
    update(p);
    update(v);
}

void splay(pnode v) {
    vector<pnode> st;
    pnode cur = v;
    st.emplace_back(cur);
    while (!is_root(cur)) {
        cur = cur->par;
        st.emplace_back(cur);
    }
    for (int i = sz(st) - 1; i >= 0; --i) {
        push(st[i]);
    }
    while (!is_root(v)) {
        if (!is_root(v->par)) {
            if (child_num(v) == child_num(v->par)) {
                rotate(v->par);
            } else {
                rotate(v);
            }
        }
        rotate(v);
    }
}

void expose(pnode v) {
    splay(v);
    v->ch[1] = nullptr;
    update(v);
    while (v->par != nullptr) {
        splay(v->par);
        attach(v, v->par, 1);
        update(v->par);
        splay(v);
    }
}

void make_root(pnode v) {
    expose(v);
    v->rev ^= 1;
}

void link(pnode v, pnode u) {
    make_root(v);
    make_root(u);
    u->par = v;
}

void cut(pnode v, pnode u) {
    make_root(v);
    make_root(u);
    push(u);
    u->ch[1] = nullptr;
    v->par = nullptr;
}

bool is_connected(pnode v, pnode u) {
    make_root(v);
    make_root(u);
}

```

```

    if (is_root(v) && u != v) {
        return false;
    } else {
        return true;
    }
}

int get_min(pnode v, pnode u) {
    make_root(v);
    make_root(u);
    return get_min(u);
}

```

## 2.13 Личао (FedShat)

```

struct LiChao {// max
    struct Line {
        ll k = 0, b = -INFL;

        Line() = default;

        Line(ll k, ll b) : k(k), b(b){};

        ll operator()(ll x) {
            return k * x + b;
        }
    };

    struct Node {
        Node *l = nullptr, *r = nullptr;
        Line cur;

        Node() = default;
    };

    Node *root = nullptr;
    int n = 1e9 + 1;

    void make_node(Node *&v) {
        if (v == nullptr) {
            v = new Node();
        }
    }

    void add(Node *&v, int l, int r, Line cur) {
        make_node(v);
        int m = (l + r) / 2;
        if (cur(m) > v->cur(m)) {
            swap(cur, v->cur);
        }
        if (l + 1 == r) {
            return;
        }
        if (cur(l) > v->cur(l)) {
            add(v->l, l, m, cur);
        } else {
            add(v->r, m, r, cur);
        }
    }

    void add(Line cur) {
        add(root, 0, n, cur);
    }

    ll get(Node *v, int l, int r, int x) {
        if (v == nullptr) {
            return -INFL;
        }
        ll ans = v->cur(x);
        if (l + 1 == r) {
            return ans;
        }
        int m = (l + r) / 2;
        if (x < m) {
            ans = max(ans, get(v->l, l, m, x));
        } else {
            ans = max(ans, get(v->r, m, r, x));
        }
        return ans;
    }

    ll get(int x) {
        return get(root, 0, n, x);
    }
};

```

## 2.14 Segment Tree (TheEvilBird)

```

struct SegTree {

    static const ll off = 0;

```

```

    struct Node {
        ll val = 0;
        ll push = off;

        Node() {}

        Node(ll val) : val(val) {}

        Node operator+(const Node &other) const {
            return Node(val + other.val);
        }

        void operator+=(const Node &other) {
            val += other.val;
        }

        void use_push(int len = 1) {
            val += push * (ll) (len);
        }

        void update_push(ll pushed) {
            push += pushed;
        }
    };

    int n, qL, qR;
    ll val;
    Node ans;

    vector<Node> tree;
    vector<ll> a;

    SegTree() {}

    SegTree(int _n) {
        n = _n;
        tree.assign(4 * n, 0);
    }

    void update_vertex(int v, int l, int r) {// [l, r)
        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        push(vL, l, m);
        push(vR, m, r);
        tree[v] = tree[vL] + tree[vR];
    }

    void push(int v, int l, int r) {// [l, r)
        if (tree[v].push == off) return;
        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        tree[v].use_push(r - l);
        if (l + 1 != r) {
            tree[vL].update_push(tree[v].push);
            tree[vR].update_push(tree[v].push);
        }
        tree[v].push = off;
    }

    void build(vector<ll> &a) {
        a = _a;
        build_tree(1, 0, n);
    }

    void build_tree(int v, int l, int r) {// [l, r)
        if (l + 1 == r) {
            tree[v] = Node(a[l]);
            return;
        }
        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        build_tree(vL, l, m);
        build_tree(vR, m, r);
        update_vertex(v, l, r);
    }

    void update_segment(int _qL, int _qR, ll _val) {// [_qL, _qR]
        qL = _qL;
        qR = _qR + 1;
        val = _val;
        update_segment_tree(1, 0, n);
    }

    void update_segment_tree(int v, int l, int r) {// [l, r)
        push(v, l, r);
        if (qL <= l && r <= qR) {
            tree[v].update_push(val);
            push(v, l, r);
            return;
        }
        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        if (qL < m) update_segment_tree(vL, l, m);
        if (m < qR) update_segment_tree(vR, m, r);
        update_vertex(v, l, r);
    }

    ll get(int _qL, int _qR) {// [_qL, _qR]
        qL = _qL;
        qR = _qR + 1;
        ans = Node();

```

```

    get_tree(1, 0, n);
    return ans.val;
}

void get_tree(int v, int l, int r) { // [l, r)
    push(v, l, r);
    if (ql <= l && r <= qR) {
        ans = ans + tree[v];
        return;
    }
    int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
    if (ql < m) get_tree(vL, l, m);
    if (m < qR) get_tree(vR, m, r);
}
};

```

## 2.15 Segment Tree Down (TheEvilBird)

```

struct SegTreeDown {
    struct Node {
        ll val = 0;

        Node() {}
        Node(ll val) : val(val) {}

        Node operator+(const Node &other) const {
            return Node(val + other.val);
        }

        void operator+=(const Node &other) {
            val += other.val;
        }
    };

    int n;
    vector<Node> tree;

    SegTreeDown(int _n) {
        n = _n;
        tree.assign(2 * n, Node());
    }

    void build(vector<ll> &a) {
        for (int i = 0; i < n; ++i) {
            tree[i + n] = Node(a[i]);
        }
        for (int i = n - 1; i >= 1; --i) {
            tree[i] = tree[2 * i] + tree[2 * i + 1];
        }
    }

    void update(int i, ll val) {
        i += n;
        tree[i] = val;
        i /= 2;
        while (i != 0) {
            tree[i] = tree[2 * i] + tree[2 * i + 1];
            i /= 2;
        }
    }

    ll get(int l, int r) { // [l, r)
        --r;
        l += n;
        r += n;
        Node ans;
        while (l <= r) {
            if (l % 2 == 1) {
                ans += tree[l];
                ++l;
            }
            if (r % 2 == 0) {
                ans += tree[r];
                --r;
            }
            l /= 2;
            r /= 2;
        }
        return ans.val;
    }
};

```

## 2.16 Segment Tree Beats (TheEvilBird)

```

struct SegTree {
    struct Node {
        ll max, sec_max;
        int cnt_max;
        ll min, sec_min;
        int cnt_min;
        ll sum;
    };
};

```

```

    ll push_add;
    ll push_eq;
};

int n, ql, qR;
ll val, ans;

vector<Node> tree;
vector<ll> a;

SegTree(int _n) {
    n = _n;
    tree.assign(4 * n, {0, -INFL, 1, 0, INFL, 1, 0, 0, -1});
}

void update_vertex(int v, int l, int r) {
    int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;

    tree[v].sum = tree[vL].sum + tree[vR].sum;

    tree[v].max = max(tree[vL].max, tree[vR].max);
    tree[v].sec_max = max(tree[vL].sec_max, tree[vR].sec_max);
    tree[v].cnt_max = 0;
    if (tree[vL].max == tree[v].max) {
        tree[v].cnt_max += tree[vL].cnt_max;
    } else {
        tree[v].sec_max = max(tree[v].sec_max, tree[vL].max);
    }
    if (tree[vR].max == tree[v].max) {
        tree[v].cnt_max += tree[vR].cnt_max;
    } else {
        tree[v].sec_max = max(tree[v].sec_max, tree[vR].max);
    }

    tree[v].min = min(tree[vL].min, tree[vR].min);
    tree[v].sec_min = min(tree[vL].sec_min, tree[vR].sec_min);
    tree[v].cnt_min = 0;
    if (tree[vL].min == tree[v].min) {
        tree[v].cnt_min += tree[vL].cnt_min;
    } else {
        tree[v].sec_min = min(tree[v].sec_min, tree[vL].min);
    }
    if (tree[vR].min == tree[v].min) {
        tree[v].cnt_min += tree[vR].cnt_min;
    } else {
        tree[v].sec_min = min(tree[v].sec_min, tree[vR].min);
    }
}

void recalc_eq(int v, int l, int r, ll cur) {
    tree[v].max = tree[v].min = tree[v].push_eq = cur;
    tree[v].sec_max = -INFL;
    tree[v].sec_min = INFL;
    tree[v].cnt_max = tree[v].cnt_min = r - l;
    tree[v].sum = cur * (ll) (r - l);
    tree[v].push_add = 0;
}

void recalc_add(int v, int l, int r, ll cur) {
    if (tree[v].min == tree[v].max) {
        recalc_eq(v, l, r, tree[v].max + cur);
        return;
    }
    tree[v].max += cur;
    if (tree[v].sec_max != -INFL) {
        tree[v].sec_max += cur;
    }

    tree[v].min += cur;
    if (tree[v].sec_min != INFL) {
        tree[v].sec_min += cur;
    }

    tree[v].sum += (ll) (r - l) * cur;
    tree[v].push_add += cur;
}

void recalc_min(int v, int l, int r, ll cur) {
    if (tree[v].min >= cur) {
        recalc_eq(v, l, r, cur);
        return;
    }
    if (tree[v].max <= cur) return;
    if (tree[v].sec_min == tree[v].max) {
        tree[v].sec_min = cur;
    }
    tree[v].sum -= (ll) (tree[v].max - cur) *
        (ll) (tree[v].cnt_max);
    tree[v].max = cur;
}

void recalc_max(int v, int l, int r, ll cur) {
    if (tree[v].max <= cur) {
        recalc_eq(v, l, r, cur);
        return;
    }
    if (tree[v].min >= cur) return;
    if (tree[v].sec_max == tree[v].min) {

```



```

        tree[v].sec_max = cur;
    }
    tree[v].sum += (ll) (tree[v].max - cur) *
        (ll) (tree[v].cnt_max);
    tree[v].min = cur;
}

void push(int v, int l, int r) {
    if (l + 1 == r) return;
    int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
    if (tree[v].push_eq != -1) {
        recalc_eq(vL, l, m, tree[v].push_eq);
        recalc_eq(vR, m, r, tree[v].push_eq);
        tree[v].push_eq = -1;
        return;
    }

    recalc_add(vL, l, m, tree[v].push_add);
    recalc_add(vR, m, r, tree[v].push_add);
    tree[v].push_add = 0;

    recalc_min(vL, l, m, tree[v].max);
    recalc_min(vR, m, r, tree[v].max);

    recalc_max(vL, l, m, tree[v].min);
    recalc_max(vR, m, r, tree[v].min);
}

void build(vector<ll> &a) {
    a = _a;
    build_tree(1, 0, n);
}

void build_tree(int v, int l, int r) {
    if (l + 1 == r) {
        tree[v] = {a[l], -INFL, 1, a[l],
            INFL, 1, a[l], 0, -1};
        return;
    }
    int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
    build_tree(vL, l, m);
    build_tree(vR, m, r);
    update_vertex(v, l, r);
}

void update_segment_min(int _qL, int _qR, ll _val) {
    qL = _qL;
    qR = _qR + 1;
    val = _val;
    update_segment_min_tree(1, 0, n);
}

void update_segment_min_tree(int v, int l, int r) {
    if (tree[v].max <= val) return;
    if (qL <= l && r <= qR && tree[v].sec_max < val) {
        recalc_min(v, l, r, val);
        return;
    }
    push(v, l, r);
    int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
    if (qL < m) update_segment_min_tree(vL, l, m);
    if (m < qR) update_segment_min_tree(vR, m, r);
    update_vertex(v, l, r);
}

void update_segment_max(int _qL, int _qR, ll _val) {
    qL = _qL;
    qR = _qR + 1;
    val = _val;
    update_segment_max_tree(1, 0, n);
}

void update_segment_max_tree(int v, int l, int r) {
    if (tree[v].min >= val) return;
    if (qL <= l && r <= qR && tree[v].sec_min > val) {
        recalc_max(v, l, r, val);
        return;
    }
    push(v, l, r);
    int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
    if (qL < m) update_segment_max_tree(vL, l, m);
    if (m < qR) update_segment_max_tree(vR, m, r);
    update_vertex(v, l, r);
}

void update_segment_add(int _qL, int _qR, ll _val) {
    qL = _qL;
    qR = _qR + 1;
    val = _val;
    update_segment_add_tree(1, 0, n);
}

void update_segment_add_tree(int v, int l, int r) {
    if (qL <= l && r <= qR) {
        recalc_add(v, l, r, val);
        return;
    }
    push(v, l, r);

```

```

        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        if (qL < m) update_segment_add_tree(vL, l, m);
        if (m < qR) update_segment_add_tree(vR, m, r);
        update_vertex(v, l, r);
    }

    ll get(int _qL, int _qR) {
        qL = _qL;
        qR = _qR + 1;
        ans = 0;
        get_tree(1, 0, n);
        return ans;
    }

    void get_tree(int v, int l, int r) {
        if (qL <= l && r <= qR) {
            ans += tree[v].sum;
            return;
        }
        push(v, l, r);
        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        if (qL < m) get_tree(vL, l, m);
        if (m < qR) get_tree(vR, m, r);
    }

    void print_all() {
        print_all_tree(1, 0, n);
    }

    void print_all_tree(int v, int l, int r) {
        if (l + 1 == r) {
            cout << tree[v].sum << en;
            return;
        }
        push(v, l, r);
        int m = (l + r) / 2, vL = 2 * v, vR = vL + 1;
        print_all_tree(vL, l, m);
        print_all_tree(vR, m, r);
    }
}
};

```

## 2.17 Persistent Segment Tree (Sweezyk)

```

struct Node {
    Node *l, *r;
    int mx;
    Node() {
        mx = -1;
        l = r = nullptr;
    }
};

const int N = 1e7 + 4e6;
const int LG = 20;

Node *nodes[N];
int ptr;

Node *new_node() {
    return nodes[ptr++];
}

Node *get_left(Node *t) {
    if (t && t->l) return t->l;
    return nullptr;
}

Node *get_right(Node *t) {
    if (t && t->r) return t->r;
    return nullptr;
}

int get_max(Node *t) {
    if (!t) return 0;
    return t->mx;
}

void update(int i, int val, Node *t, Node *old_t, int lx, int rx) {
    if (lx + 1 == rx) {
        t->mx = max(t->mx, val);
        return;
    }
    int m = (lx + rx) / 2;
    if (i < m) {
        t->l = new_node();
        if (old_t && old_t->l) {
            t->l->mx = old_t->l->mx;
        }
        t->r = get_right(old_t);
        update(i, val, t->l, get_left(old_t), lx, m);
    } else {
        t->r = new_node();
        if (old_t && old_t->r) {
            t->r->mx = old_t->r->mx;
        }
    }
}

```

```

        t->l = get_left(old_t);
        update(i, val, t->r, get_right(old_t), m, rx);
    }
    t->mx = max(get_max(get_left(t)), get_max(get_right(t)));
};

int get(int l, int r, Node *t, int lx, int rx) {
    if (!t || lx >= r || rx <= l) return -1;
    if (lx >= l && rx <= r) return t->mx;
    int m = (lx + rx) / 2;
    return max(get(l, r, t->l, lx, m), get(l, r, t->r, m, rx));
}

```

## 2.18 Fenwick (TheEvilBird)

```

struct Fenwick {
    int n;
    vector<ll> f;

    Fenwick(int _n) {
        n = _n;
        f.assign(n + 1, 0);
    }

    void update(int x, ll delta) {
        for (int i = x; i <= n; i += i & -i) {
            f[i] += delta;
        }
    }

    ll get_sum(int x) {
        ll s = 0;
        for (int i = x; i > 0; i -= i & -i) {
            s += f[i];
        }
        return s;
    }

    ll get(int L, int R) { // [L, R]
        return get_sum(R) - get_sum(L - 1);
    }
};

```

## 2.19 Sparse table (TheEvilBird)

```

struct Sparse {
    int n;
    vector<int> lg;
    vector<vector<ll>> table;

    Sparse(int _n) {
        n = _n;
        lg.resize(n + 1);
        for (int i = 2; i <= n; ++i) {
            lg[i] = lg[i / 2] + 1;
        }
        table.resize(lg[n] + 1, vector<ll>(n));
        for (int i = 0; i < n; ++i) table[0][i] = INF;
    }

    void build() {
        for (int i = 1; i < table.size(); ++i) {
            for (int j = 0; j + (1 << i) <= n; ++j) {
                table[i][j] = min(table[i - 1][j],
                                   table[i - 1][j + (1 << (i - 1))]);
            }
        }
    }

    ll get(int L, int R) { // [L, R]
        int D = R - L + 1, x = lg[D];
        return min(table[x][L], table[x][R - (1 << x) + 1]);
    }
};

```

## 2.20 Treap (Sweezyk)

```

struct Node {
    int x, y, size, push, cnt;
    Node *l, *r;

    Node(int val) : x(val), y(rng()), size(1), push(0), cnt(0), l(nullptr),
                  r(nullptr) {}
};

void push(Node *t) {
    if (t == nullptr) return;
    int p = t->push;

```

```

    if (p == 0) return;
    if (t->l != nullptr) {
        t->l->cnt += p;
        t->l->push += p;
    }
    if (t->r != nullptr) {
        t->r->cnt += p;
        t->r->push += p;
    }
    t->push = 0;
}

int size(Node *t) {
    return (t ? t->size : 0);
}

void update(Node *t) {
    if (t == nullptr) return;
    t->size = size(t->l) + size(t->r) + 1;
}

pair<Node *, Node *> split(Node *t, int k) {
    if (t == nullptr) return {nullptr, nullptr};
    if (k == 0) return {nullptr, t};
    push(t);
    if (size(t->l) + 1 <= k) {
        auto [l, r] = split(t->r, k - size(t->l) - 1);
        t->r = l;
        update(t);
        return {t, r};
    } else {
        auto [l, r] = split(t->l, k);
        t->l = r;
        update(t);
        return {l, t};
    }
}

Node *merge(Node *tl, Node *tr) {
    if (tl == nullptr) return tr;
    if (tr == nullptr) return tl;
    push(tl);
    push(tr);
    if (tl->y > tr->y) {
        tl->r = merge(tl->r, tr);
        update(tl);
        return tl;
    } else {
        tr->l = merge(tl, tr->l);
        update(tr);
        return tr;
    }
}

void dfs(Node *t) {
    if (t == nullptr) return;
    push(t);
    dfs(t->l);
    cout << t->x << ' ' << t->cnt << '\n';
    dfs(t->r);
}

void solve() {
    int n, m;
    cin >> n >> m;
    Node *root = nullptr;
    for (int i = 1; i <= n; ++i) {
        Node *add = new Node(i);
        root = merge(root, add);
    }
    for (int i = 0; i < m; ++i) {
        int l, r;
        cin >> l >> r;
        auto [L, R] = split(root, r);
        auto [L1, L2] = split(L, l - 1);
        L2->push = 1;
        L2->cnt += 1;
        root = merge(L2, merge(L1, R));
    }
    dfs(root);
}

```

## 2.21 Extended GCD (Sweezyk)

```

template<typename T>
T extgcd(T a, T b, T &x, T &y) {
    if (a == 0) {
        x = 0;
        y = 1;
        return b;
    }
    T p = b / a;
    T g = extgcd(b - p * a, a, y, x);
    x -= p * y;
    return g;
}

```

```

}

template<typename T>
bool diophantine(T a, T b, T c, T &x, T &y, T &g) {
    if (a == 0 && b == 0) {
        if (c == 0) {
            x = y = g = 0;
            return true;
        }
        return false;
    }
    if (a == 0) {
        if (c % b == 0) {
            x = 0;
            y = c / b;
            g = abs(b);
            return true;
        }
        return false;
    }
    if (b == 0) {
        if (c % a == 0) {
            x = c / a;
            y = 0;
            g = abs(a);
            return true;
        }
        return false;
    }
    g = extgcd(a, b, x, y);
    if (c % g != 0) {
        return false;
    }
    T dx = c / a;
    c -= dx * a;
    T dy = c / b;
    c -= dy * b;
    x = dx + (T) ((__int128) x * (c / g) % b);
    y = dy + (T) ((__int128) y * (c / g) % a);
    g = abs(g);
    return true;
    // |x|, |y| <= max(|a|, |b|, |c|) [tested]
}

bool crt(long long k1, long long m1, long long k2, long long m2, long
        long &k, long long &m) {
    k1 %= m1;
    if (k1 < 0) k1 += m1;
    k2 %= m2;
    if (k2 < 0) k2 += m2;
    long long x, y, g;
    if (!diophantine(m1, -m2, k2 - k1, x, y, g)) {
        return false;
    }
    long long dx = m2 / g;
    long long delta = x / dx - (x % dx < 0);
    k = m1 * (x - dx * delta) + k1;
    m = m1 / g * m2;
    assert(0 <= k && k < m);
    return true;
}

```

## 2.22 FFT (FedShat)

```

constexpr int P = 998244353;
using i64 = long long;

// assume -P <= x < 2P
int norm(int x) {
    if (x < 0) {
        x += P;
    }
    if (x >= P) {
        x -= P;
    }
    return x;
}

template<class T>
T power(T a, int b) {
    T res = 1;
    for (; b /= 2, a *= a) {
        if (b % 2) {
            res *= a;
        }
    }
    return res;
}

struct Z {
    int x;
    Z(int x = 0) : x(norm(x)) {}
    int val() const {
        return x;
    }
}

```

```

Z operator-() const {
    return Z(norm(P - x));
}

Z inv() const {
    assert(x != 0);
    return power(*this, P - 2);
}

Z &operator*=(const Z &rhs) {
    x = i64(x) * rhs.x % P;
    return *this;
}

Z &operator+=(const Z &rhs) {
    x = norm(x + rhs.x);
    return *this;
}

Z &operator-=(const Z &rhs) {
    x = norm(x - rhs.x);
    return *this;
}

Z &operator/=(const Z &rhs) {
    return *this *= rhs.inv();
}

friend Z operator*(const Z &lhs, const Z &rhs) {
    Z res = lhs;
    res *= rhs;
    return res;
}

friend Z operator+(const Z &lhs, const Z &rhs) {
    Z res = lhs;
    res += rhs;
    return res;
}

friend Z operator-(const Z &lhs, const Z &rhs) {
    Z res = lhs;
    res -= rhs;
    return res;
}

friend Z operator/(const Z &lhs, const Z &rhs) {
    Z res = lhs;
    res /= rhs;
    return res;
}
};

std::vector<int> rev;
std::vector<Z> roots{0, 1};
void dft(std::vector<Z> &a) {
    int n = a.size();

    if (int(rev.size()) != n) {
        int k = __builtin_ctz(n) - 1;
        rev.resize(n);
        for (int i = 0; i < n; i++) {
            rev[i] = rev[i >> 1] >> 1 | (i & 1) << k;
        }
    }

    for (int i = 0; i < n; i++) {
        if (rev[i] < i) {
            std::swap(a[i], a[rev[i]]);
        }
    }

    if (int(roots.size()) < n) {
        int k = __builtin_ctz(roots.size());
        roots.resize(n);
        while ((1 << k) < n) {
            Z e = power(Z(3), (P - 1) >> (k + 1));
            for (int i = 1 << (k - 1); i < (1 << k); i++) {
                roots[2 * i] = roots[i];
                roots[2 * i + 1] = roots[i] * e;
            }
            k++;
        }
    }

    for (int k = 1; k < n; k *= 2) {
        for (int i = 0; i < n; i += 2 * k) {
            for (int j = 0; j < k; j++) {
                Z u = a[i + j];
                Z v = a[i + j + k] * roots[k + j];
                a[i + j] = u + v;
                a[i + j + k] = u - v;
            }
        }
    }
}

void idft(std::vector<Z> &a) {
    int n = a.size();
    std::reverse(a.begin() + 1, a.end());
    dft(a);
    Z inv = (1 - P) / n;
    for (int i = 0; i < n; i++) {
        a[i] *= inv;
    }
}

```

## 2.23 KTO (FedShat)

```
struct Eq {// x = a (mod m)
    ll a, m;

    Eq(){};

    Eq(ll a, ll m) : a(a), m(m){};
};

ll binpow(ll a, ll n, ll m) {
    if (n == 0) {
        return 1;
    }
    if (n % 2 == 0) {
        int128_t b = binpow(a, n / 2, m);
        return (b * b) % m;
    }
    int128_t x = binpow(a, n - 1, m);
    return (a * x) % m;
}

ll binpow(ll a, ll n) {
    if (n == 0) {
        return 1;
    }
    if (n % 2 == 0) {
        ll b = binpow(a, n / 2);
        return b * b;
    }
    return a * binpow(a, n - 1);
}

ll phi(ll a) {
    ll d = 2, k = a;
    map<ll, int> cnt;
    while (d * d <= a) {
        if (k % d == 0) {
            k /= d;
            ++cnt[d];
        } else {
            ++d;
        }
    }
    if (k != 1) {
        ++cnt[k];
    }
    ll ans = 1;
    for (auto i : cnt) {
        ans *= binpow(i.first, i.second - 1) * (i.first - 1);
    }
    return ans;
}

ll gcd(ll a, ll b) {
    return std::gcd(abs(a), abs(b));
}

Eq solve(Eq ai, Eq bi) {
    if (ai.m == -1 || bi.m == -1) {
        return {0, -1};
    }
    ll a = ai.m, b = bi.m, c = ai.a - bi.a;
    ll d = ::gcd(a, b);
    a /= d;
    b /= d;
    if (c % d != 0) {
        return {0, -1};
    }
    c /= d;
    ll x = (((int128_t) -c * (int128_t) binpow(a, phi(b) - 1, b)) % b + b) % b;
    x = (((int128_t) ai.m * (int128_t) x + ai.a) % lcm(ai.m, bi.m);
    return {x, lcm(ai.m, bi.m)};
}
```

## 2.24 Обратные по простому модулю

Пусть дан простой модуль  $m$ . Для каждого числа из  $[1, m-1]$  найти обратное к нему.

```
r[1] = 1;
for (int i = 2; i < m; ++i) {
    r[i] = (m - (m / i) * r[m % i] % m) % m;
}
```

## 2.25 Обратные факториалы

```
int inv(int a, int m) {
    if (a == 1)
        return 1;
```

```
    return (1 - inv(m % a, a) * m) / a + m;
}

{
    f[0] = 1;
    for (int i = 1; i < N; i++) {
        f[i] = i * f[i - 1] % mod;
    }

    r[N - 1] = inv(f[N - 1]) for (int i = N - 1; i >= 1; i--) {
        r[i - 1] = r[i] * i % mod;
    }
}
```

## 2.26 Гаусс

```
const double eps = 1e-9;
int Gauss(vector<vector<double>> a, vector<double> &ans) {
    int n = (int)a.size(), m = (int)a[0].size() - 1;
    vector<int> pos(m, -1);
    double det = 1; int rank = 0;
    for(int col = 0, row = 0; col < m && row < n; ++col) {
        int mx = row;
        for (int i = row; i < n; i++) {
            if (fabs(a[i][col]) > fabs(a[mx][col])) { mx = i; }
        }
        if (fabs(a[mx][col]) < eps) { det = 0; continue; }
        for (int i = col; i <= m; i++) {
            swap(a[row][i], a[mx][i]);
        }
        if (row != mx) { det = -det; }
        det *= a[row][col];
        pos[col] = row;
        for (int i = 0; i < n; i++) {
            if (i != row && fabs(a[i][col]) > eps) {
                double c = a[i][col] / a[row][col];
                for (int j = col; j <= m; j++) {
                    a[i][j] -= a[row][j] * c;
                }
            }
        }
        ++row; ++rank;
    }
    ans.assign(m, 0);
    for(int i = 0; i < m; i++) {
        if (pos[i] != -1) { ans[i] = a[pos[i]][m] / a[pos[i]][i]; }
    }
    for(int i = 0; i < n; i++) {
        double sum = 0;
        for (int j = 0; j < m; j++) {
            sum += ans[j] * a[i][j];
        }
        if(fabs(sum - a[i][m]) > eps) {
            return -1; //no solution
        }
    }
    for (int i = 0; i < m; i++) {
        if (pos[i] == -1) {
            return 2; //infinte solutions
        }
    }
    return 1; //unique solution
}
```

## Бинарный

```
//n = number of equations, m = number of variables
int Gauss(int n, int m, vector<bitset<N>> a, bitset<N> &ans) {
    //reversing for lexicographically largest solution
    for (int i = 0; i < n; i++) {
        bitset<N> tmp;
        for (int j = 0; j < m; j++) tmp[j] = a[i][m - j - 1];
        tmp[m] = a[i][m];
        a[i] = tmp;
    }

    int rank = 0, det = 1;
    vector<int> pos(N, -1);
    for(int col = 0, row = 0; col < m && row < n; ++col) {
        int mx = row;
        for(int i = row; i < n; ++i) if(a[i][col]) { mx = i; break; }
        if(!a[mx][col]) { det = 0; continue; }
        swap(a[mx], a[row]);
        if (row != mx) { det = (det == 0 ? 0 : 1); }
        det &= a[row][col];
        pos[col] = row;
        //forward elimination
        for (int i = row + 1; i < n; ++i) {
            if (i != row && a[i][col]) {
                a[i] ^= a[row];
            }
        }
        ++row, ++rank;
    }
    ans.reset();
    //backward substitution
```

```

for (int i = m - 1; i >= 0; i--) {
    if (pos[i] == -1) {
        ans[i] = true;
    } else {
        int k = pos[i];
        for (int j = i + 1; j < m; j++) if (a[k][j]) ans[i] = ans[i]
        ~ ans[j];
        ans[i] = ans[i] ^ a[k][m];
    }
}
for (int i = rank; i < n; ++i) {
    if (a[i][m]) {
        return -1; //no solution
    }
}
//reversing again beacuse we reversed earlier
bitset<N> tmp;
for (int j = 0; j < m; j++) {
    tmp[j] = ans[m - j - 1];
}
ans = tmp;
int free_var = 0;
for(int i = 0; i < m; ++i) {
    if (pos[i] == -1) {
        free_var++;
    }
}
return free_var; //has solution
}

```

## 2.27 Быстрая факторизация (FedShat)

```

ll binpow(ll a, ll n, ll mod) {
    if (n == 0) {
        return 1;
    }
    if (n % 2 == 0) {
        int128_t b = binpow(a, n / 2, mod);
        return (b * b) % mod;
    }
    return (((int128_t) a) * binpow(a, n - 1, mod)) % mod;
}

```

```

constexpr int N = 1e7;
vector<int> pr, lp;

bool prime(ll n) {
    if (n <= N) {
        return binary_search(all(pr), n);
    }
    int iter = 60;
    int s = 0;
    ll d = n - 1;
    while (d % 2 == 0) {
        d /= 2;
        ++s;
    }
    auto test = [&](ll a) {
        if (binpow(a, d, n) == 1) {
            return true;
        }
        ll _2r = 1;
        for (int r = 0; r < s; ++r) {
            auto tmp = binpow(binpow(a, d, n), _2r, n);
            if (tmp == n - 1) {
                return true;
            }
            _2r *= 2;
        }
        return false;
    };
    for (int _ = 0; _ < iter; ++_) {
        ll a = uniform_int_distribution<ll>(1, n - 1)(rnd);
        if (!test(a)) {
            return false;
        }
    }
    return true;
}

ll f(ll x, ll n) {
    return ((int128_t) x * (int128_t) x + (int128_t) 2) % n;
}

ll pollard(ll n) {
    ll a = uniform_int_distribution<ll>(0, n - 1)(rnd);
    ll x = a, y = a, d = 1;
    constexpr int iter = 5e4;
    for (int _ = 0; _ < iter; ++_) {
        x = f(f(x, n), n);
        y = f(y, n);
        d = gcd(abs(x - y), n);
        if (d != 1 && d != n) {
            break;
        }
    }
}

```

```

}
if (d == 1 || d == n) {
    pollard(n);
}
return d;
}

vector<ll> res;

void factor(ll n) {
    if (n <= N) {
        while (true) {
            if (lp[n] == 0) {
                break;
            }
            res.push_back(lp[n]);
            n /= lp[n];
        }
        return;
    }
    if (prime(n)) {
        res.push_back(n);
        return;
    }
    ll d = pollard(n);
    factor(n / d);
    factor(d);
}

void solve() {
    ll n;
    cin >> n;
    lp.resize(N + 1);
    for (int i = 2; i <= N; ++i) {
        if (lp[i] == 0) {
            lp[i] = i;
            pr.push_back(i);
        }
        for (int j = 0; j < (int) pr.size() && pr[j] <= lp[i] && i * pr[j]
        ] <= N; ++j) {
            lp[i * pr[j]] = pr[j];
        }
    }
    factor(n);
}

```

## 2.28 Префикс-функция

```

vector<int> prefix_function(string &s) {
    int n = (int) s.length();
    vector<int> pi(n);
    for (int i = 1; i < n; ++i) {
        int j = pi[i - 1];
        while (j > 0 && s[i] != s[j])
            j = pi[j - 1];
        if (s[i] == s[j]) {
            ++j;
        }
        pi[i] = j;
    }
    return pi;
}

```

## 2.29 Z-функция

```

vector<int> z_function(string &s) {
    int n = (int) s.length();
    vector<int> 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;
}

```

## 2.30 Суфмас (TheEvilBird)

```

int mod(int x, int m) {
    if (x < 0) x += m;
    if (x >= m) x -= m;
}

```

```

    return x;
}

vector<int> suffix_array(string s) {
    s += '$';
    int n = sz(s);
    vector<int> arr(n), narr(n), head(n), c(n), nc(n);
    for (int i = 0; i < n; ++i) {
        arr[i] = i;
    }
    sort(all(arr), [&](int x, int y) {
        return s[x] < s[y];
    });
    int cl = 0;
    c[arr[0]] = cl;
    head[0] = 0;
    for (int i = 1; i < n; ++i) {
        if (s[arr[i]] != s[arr[i - 1]]) {
            head[++cl] = i;
        }
        c[arr[i]] = cl;
    }
    for (int k = 1; k < n && cl < n; k *= 2) {
        for (int i = 0; i < n; i++) {
            int j = mod(arr[i] - k, n);
            narr[head[c[j]]++] = j;
        }
        cl = 0;
        head[0] = 0;
        pii prev = {c[narr[0]], c[mod(narr[0] + k, n)]};
        for (int i = 1; i < n; i++) {
            pii cur = {c[narr[i]], c[mod(narr[i] + k, n)]};
            if (cur != prev) {
                head[++cl] = i;
            }
            nc[narr[i]] = cl;
            prev = cur;
        }
        swap(arr, narr);
        swap(c, nc);
    }
    // returns suffix array without $
    return vector<int>(arr.begin() + 1, arr.end());
}

vector<int> build_lcp(string &s, vector<int> &suf) {
    int n = sz(s);
    vector<int> lcp(n - 1), order(n);
    for (int i = 0; i < n; ++i) {
        order[suf[i]] = i;
    }
    int l = 0;
    for (int i = 0; i < n; ++i) {
        int id = order[i];
        if (id + 1 == n) {
            l = 0;
            continue;
        }
        int j = suf[id + 1];
        if (l) --l;
        while (max(i + l, j + l) < n && s[i + l] == s[j + l]) {
            ++l;
        }
        lcp[id] = l;
    }
    return lcp;
}

```

## 2.31 Суфавтомат (TheEvilBird)

```

struct Node {
    int go[26];
    int suf, prev, term, len;

    Node() {
        for (auto &i : go) {
            i = -1;
        }
        len = 0;
        suf = -1;
        prev = -1;
        term = 0;
    }
};

vector<Node> automat;

int add(int a, int ch) {
    int b = sz(automat);
    automat.emplace_back();
    automat[b].prev = a;
    automat[b].suf = 0;
    automat[b].len = automat[a].len + 1;
    for (; a != -1; a = automat[a].suf) {

```

```

        if (automat[a].go[ch] == -1) {
            automat[a].go[ch] = b;
            continue;
        }
        int c = automat[a].go[ch];
        if (automat[c].prev == a) {
            automat[b].suf = c;
            break;
        }
        int d = sz(automat);
        automat.emplace_back();
        automat[d].suf = automat[c].suf;
        automat[d].len = automat[a].len + 1;
        automat[c].suf = d;
        automat[b].suf = d;
        automat[d].prev = a;
        for (int i = 0; i < 26; ++i) {
            automat[d].go[i] = automat[c].go[i];
        }
        for (; a != -1 && automat[a].go[ch] == c; a = automat[a].suf) {
            automat[a].go[ch] = d;
        }
        break;
    }
    // returns id of the added vertex
    return b;
}

```

## 2.32 Ахо-Корасик (Sweezyk)

```

struct Node {
    int par;
    int par_c;
    int go[26];
    int term;
    int link;
    int super;
    int cnt;
};

const int N = 1e6 + 5;
int ptr = 1;
Node trie[N];

void add(string s) {
    int cur = 1;
    for (auto &q : s) {
        int c = q - 'a';
        if (trie[cur].go[c]) {
            cur = trie[cur].go[c];
        } else {
            ++ptr;
            trie[cur].go[c] = ptr;
            trie[ptr].par = cur;
            trie[ptr].par_c = c;
            cur = ptr;
        }
    }
    trie[cur].cnt++;
}

void build() {
    queue<int> q;
    q.push(1);
    while (!q.empty()) {
        int v = q.front();
        q.pop();
        if (v != 1) {
            if (trie[v].par == 1) {
                trie[v].link = trie[v].super = 1;
            } else {
                trie[v].link = trie[trie[trie[v].par].link].go[trie[v].par_c];
                trie[v].super = (trie[trie[v].link].cnt ? trie[v].link : trie[trie[v].link].super);
            }
        }
        trie[v].cnt += trie[trie[v].link].cnt;
        for (int c = 0; c < 26; c++) {
            if (trie[v].go[c]) {
                q.push(trie[v].go[c]);
            } else {
                if (v == 1) {
                    trie[v].go[c] = 1;
                } else {
                    trie[v].go[c] = trie[trie[v].link].go[c];
                }
            }
        }
    }
}

trie[1].link = trie[1].super = trie[1].par = 1;
build();

```

## 2.33 Манакер

```
vector<int> d1(n);
int l = 0, r = -1;
for (int i = 0; i < n; ++i) {
    int k = (i > r ? 1 : min(d1[l + r - i], r - i + 1));
    while (i + k < n && i - k >= 0 && s[i + k] == s[i - k]) {
        ++k;
    }
    d1[i] = k;
    if (i + k - 1 > r) {
        l = i - k + 1;
        r = i + k - 1;
    }
}
vector<int> d2(n);
l = 0;
r = -1;
for (int i = 0; i < n; ++i) {
    int k = (i > r ? 0 : min(d2[l + r - i + 1], r - i + 1));
    while (i + k < n && i - k - 1 >= 0 && s[i + k] == s[i - k - 1]) {
        ++k;
    }
    d2[i] = k;
    if (i + k - 1 > r) {
        l = i - k;
        r = i + k - 1;
    }
}
}
```

## 2.34 CHT (FedShat)

```
struct Line {
    ll k = 0, b = -INFL;
    Line() = default;
    Line(ll k, ll b) : k(k), b(b){};

    ld operator()(ld x) {
        return k * x + b;
    }
};

bool operator<(Line a, Line b) {
    return a.k < b.k || (a.k == b.k && a.b > b.b);
}

bool operator<(pair<Line, ld> a, pair<Line, ld> b) {
    return a.second < b.second;
}

struct CHT {
    vector<pair<Line, ld>> convex;

    void add(Line a) {
        while (!convex.empty() && a(convex.back().second) > convex.back().first(convex.back().second)) {
            convex.pop_back();
        }
        ld xn = -INFL;
        if (!convex.empty()) {
            xn = (a.b - convex.back().first.b + 0.0) / (convex.back().first.k - a.k);
        }
        convex.push_back({a, xn});
    }

    CHT(vector<Line> lines) {
        sort(all(lines));
        for (int i = 0; i < (int) lines.size(); i) {
            int j = i;
            while (j < (int) lines.size() && lines[i].k == lines[j].k) {
                ++j;
            }
            add(lines[i]);
            i = j;
        }
    }

    ld get(ld x) {
        auto it = upper_bound(all(convex), pair<Line(), x) - convex.begin();
        return convex[it - 1].first(x);
    }
};
```

## 2.35 Дебаг Туриста

```
template<typename A, typename B>
string to_string(pair<A, B> p);

template<typename A, typename B, typename C>
```

```
string to_string(tuple<A, B, C> p);
```

```
template<typename A, typename B, typename C, typename D>
string to_string(tuple<A, B, C, D> p);
```

```
string to_string(const string &s) {
    return ',' + s + ',';
}
```

```
string to_string(const char *s) {
    return to_string((string) s);
}
```

```
string to_string(bool b) {
    return (b ? "true" : "false");
}
```

```
string to_string(vector<bool> v) {
    bool first = true;
    string res = "{";
    for (int i = 0; i < static_cast<int>(v.size()); i++) {
        if (!first) {
            res += ", ";
        }
        first = false;
        res += to_string(v[i]);
    }
    res += "}";
    return res;
}
```

```
template<size_t N>
string to_string(bitset<N> v) {
    string res = "";
    for (size_t i = 0; i < N; i++) {
        res += static_cast<char>('0' + v[i]);
    }
    return res;
}
```

```
template<typename A>
string to_string(A v) {
    bool first = true;
    string res = "{";
    for (const auto &x : v) {
        if (!first) {
            res += ", ";
        }
        first = false;
        res += to_string(x);
    }
    res += "}";
    return res;
}
```

```
template<typename A, typename B>
string to_string(pair<A, B> p) {
    return "(" + to_string(p.first) + ", " + to_string(p.second) + ")";
}
```

```
template<typename A, typename B, typename C>
string to_string(tuple<A, B, C> p) {
    return "(" + to_string(get<0>(p)) + ", " + to_string(get<1>(p)) + ", " + to_string(get<2>(p)) + ")";
}
```

```
template<typename A, typename B, typename C, typename D>
string to_string(tuple<A, B, C, D> p) {
    return "(" + to_string(get<0>(p)) + ", " + to_string(get<1>(p)) + ", " + to_string(get<2>(p)) + ", " + to_string(get<3>(p)) + ")";
}
```

```
void debug_out() { cerr << endl; }
```

```
template<typename Head, typename... Tail>
void debug_out(Head H, Tail... T) {
    cerr << " " << to_string(H);
    debug_out(T...);
}
```

```
#ifndef LOCAL
#define debug(...) cerr << "[" << __VA_ARGS__ << "]:", debug_out(
    __VA_ARGS__)
#else
#define debug(...) 42
#endif
```

## 2.36 Геометрия (TheEvilBird)

```
const long double PI = 3.1415926535897932384626433832795;
const long double EPS = 1e-7;
```

```
/*
 * Rotate relative to the origin, a - rotation angle:
 * new_x = x cos(a) - y sin(a)
```

```

* new_y = x sin(a) + y cos(a)
*
* new_x = x cos(a) + y sin(a)
* new_y = x sin(a) - y cos(a)
*
*
* rad = degree * PI / 180
* degree = rad * 180 / PI
*/

typedef long long T;

struct Point {
    T x, y;

    Point() : x(0), y(0) {}
    Point(T _x, T _y) : x(_x), y(_y) {}

    ld len() const {
        return sqrtl(x * x + y * y);
    }

    ll len_sq() const {
        return (x * x + y * y);
    }

    Point operator*(ll k) const {
        return {x * k, y * k};
    }

    void operator*=(ll k) {
        x *= k;
        y *= k;
    }

    Point operator+(const Point other) const {
        return {x + other.x, y + other.y};
    }

    Point operator-(const Point other) const {
        return {x - other.x, y - other.y};
    }

    bool operator==(const Point other) const {
        return x == other.x && y == other.y;
    }

    bool operator!=(const Point other) const {
        return !(*this == other);
    }

    T operator*(const Point other) const {// dot product}
    return x * other.x + y * other.y;
    }

    T operator%(const Point other) const {// cross product}
    return x * other.y - y * other.x;
    }
};

istream &operator>>(istream &is, Point &vec) {
    is >> vec.x >> vec.y;
    return is;
}

ostream &operator<<(ostream &os, const Point &vec) {
    os << vec.x << ' ' << vec.y;
    return os;
}

typedef vector<Point> Polygon;

bool cmp_vectors(Point a, Point b) {
    if ((a.y < 0 || (a.y == 0 && a.x < 0)) &&
        (b.y > 0 || (b.y == 0 && b.x > 0))) {
        return true;
    }
    if ((b.y < 0 || (b.y == 0 && b.x < 0)) &&
        (a.y > 0 || (a.y == 0 && a.x > 0))) {
        return false;
    }
    return (a % b > 0 || (a % b == 0 && a.len_sq() < b.len_sq()));
}

int get_sign(ld x) {
    if (x < -EPS) return -1;
    if (EPS < x) return 1;
    return 0;
}

Polygon build_convex_hull(Polygon &a) {
    int n = sz(a);
    for (int i = 1; i < n; ++i) {
        if ((a[i].y < a[0].y) || (a[i].y == a[0].y && a[i].x < a[0].x))
            swap(a[0], a[i]);
    }
    sort(a.begin() + 1, a.end(), [&](Point A, Point B) {
        Point oa = A - a[0], ob = B - a[0];

```

```

        if ((oa % ob) == 0) return oa.len_sq() < ob.len_sq();
        return (oa % ob) > 0;
    });
    Polygon hull = {a[0]};
    for (int i = 1; i < n; ++i) {
        while (sz(hull) >= 2) {
            Point ab = hull[sz(hull) - 1] - hull[sz(hull) - 2], bp = a[i] - hull[sz(hull) - 1];
            if ((ab % bp) <= 0) {
                hull.pop_back();
            } else {
                break;
            }
        }
        hull.emplace_back(a[i]);
    }
    return hull;
}

ll area_of_polygon(Polygon &poly) {
    ll res = 0;
    int n = sz(poly);
    for (int i = 2; i < n; ++i) {
        Point ab = poly[i - 1] - poly[0], ac = poly[i] - poly[0];
        res += (ab % ac);
    }
    // don't forget to divide the result by 2!
    return res;
}

ld perimeter_of_polygon(Polygon &poly) {
    ld res = 0;
    int n = sz(poly);
    for (int i = 0; i < n; ++i) {
        Point v = poly[(i + 1 == n ? 0 : i + 1)] - poly[i];
        res += v.len();
    }
    return res;
}

ll diameter_of_polygon(Polygon &poly) {
    int n = sz(poly), x = 1;
    ll ans = 0;
    for (int i = 0; i < n; ++i) {
        int j = (i + 1) % n;
        while (true) {
            Point ac = poly[x] - poly[i], ab = poly[j] - poly[i], cd =
                poly[(x + 1) % n] - poly[x];
            ans = max(ans, ac.len_sq());
            if ((ab % cd) <= 0) {
                break;
            }
            x++;
            x %= n;
        }
    }
    // don't forget to extract root!
    return ans;
}

ld angle(const Point &a, const Point &b) {
    return fabsl(atan2(a % b, a * b) / PI * 180);
}

ld angle_rad(const Point &a, const Point &b) {
    return (atan2(a % b, a * b));
}

ld angle_rad(const Point &a) {
    return atan2(a.y, a.x);
}

ld from_point_to_line(const Point &p, const Point &a, const Point &b) {
    // point p, line ab
    Point ba = a - b, ap = p - a;
    return fabsl((ba % ap) / ba.len());
}

ld from_point_to_ray(const Point &p, const Point &a, const Point &b) { //
    point p, ray ab
    Point ba = a - b, ap = p - a, ab = b - a;
    if ((ab * ap) < 0) {
        return ap.len();
    } else {
        return fabsl((ba % ap) / ba.len());
    }
}

ld from_point_to_segment(const Point &p, const Point &a, const Point &b)
    { // point p, segment ab
    Point ab = b - a, ap = p - a, bp = p - b, ba = a - b;
    if ((ab * ap) < 0) {
        return fabsl(ap.len());
    } else if ((ab * bp) > 0) {
        return fabsl(bp.len());
    } else {
        return fabsl((ba % ap) / ba.len());
    }
}

```



```

}

bool point_on_line(const Point &p, const Point &a, const Point &b) { //
    point p, line ab
    Point ab = b - a, ap = p - a;
    return (ab % ap) == 0;
}

bool point_on_ray(const Point &p, const Point &a, const Point &b) { //
    point p, ray ab
    Point ab = b - a, ap = p - a;
    return ((ab % ap) == 0 && (ab * ap) > 0) || (a == p);
}

bool point_on_segment(const Point &p, const Point &a, const Point &b) {
    // point p, segment ab
    Point ap = p - a, bp = p - b, ab = b - a;
    return (ap * bp) <= 0 && (ap % ab) == 0;
}

bool point_in_angle(const Point &p, const Point &a, const Point &o, const
    Point &b) { // point p, angle aob
    Point oa = a - o, ob = b - o, op = p - o;
    if ((oa % ob) < 0) swap(oa, ob);
    return ((oa % op) >= 0 && (ob % op) <= 0);
}

bool segment_intersection(const Point &a, const Point &b, const Point &c,
    const Point &d) { // segment ab, segment, cd
    Point ab = b - a, cd = d - c, ac = c - a, ad = d - a, cb = b - c, ca
    = a - c;
    if (get_sign((ab % ac)) * get_sign((ab % ad)) <= 0 && get_sign((cd %
    ca)) * get_sign((cd % cb)) <= 0) {
        ll x1 = max(min(a.x, b.x), min(c.x, d.x)), x2 = min(max(a.x, b.x)
        , max(c.x, d.x));
        ll y1 = max(min(a.y, b.y), min(c.y, d.y)), y2 = min(max(a.y, b.y)
        , max(c.y, d.y));
        return (x1 <= x2 && y1 <= y2);
    }
    return false;
}

bool lines_intersection(const Point &a, const Point &b, const Point &c,
    const Point &d) { // line ab, line cd
    Point ab = b - a, cd = d - c;
    return ((ab % cd) != 0 || (ab % (c - a) == 0));
}

bool line_ray_intersection(const Point &a, const Point &b, const Point &c
    , const Point &d) { // line ab, ray cd
    if (!lines_intersection(a, b, c, d)) {
        return 0;
    }
    Point ab = b - a, dp = d + (a - c);
    if (get_sign(ab % (dp - a)) * get_sign(ab % (c - a)) <= 0) {
        return 1;
    }
    return 0;
}

Point get_inf(const Point &a, const Point &b) { // returns inf point on
    ray ab
    if (a.x == b.x) {
        if (a.y < b.y) {
            return {a.x, INFLL};
        } else {
            return {a.x, -INFLL};
        }
    }
    if (a.x < b.x) {
        if (a.y < b.y) {
            return {INFLL, INFLL};
        } else if (a.y == b.y) {
            return {INFLL, a.y};
        } else {
            return {INFLL, -INFLL};
        }
    }
    // a.x > b.x
    if (a.y < b.y) {
        return {-INFLL, INFLL};
    } else if (a.y == b.y) {
        return {-INFLL, a.y};
    } else {
        return {-INFLL, -INFLL};
    }
}

bool rays_intersection(const Point &a, const Point &b, const Point &c,
    const Point &d) { // ray ab, ray cd
    if (line_ray_intersection(a, b, c, d) && line_ray_intersection(c, d,
    a, b)) {
        Point bp = get_inf(a, b), dp = get_inf(c, d);
        ll x1 = max(min(a.x, bp.x), min(c.x, dp.x)), x2 = min(max(a.x, bp
        .x), max(c.x, dp.x));
        ll y1 = max(min(a.y, bp.y), min(c.y, dp.y)), y2 = min(max(a.y, bp
        .y), max(c.y, dp.y));
        return (x1 <= x2 && y1 <= y2);
    }
}

```

```

}
return 0;
}

int point_in_polygon(const Point &p, const Polygon &poly) {
    // 0 - outside, 1 - inside, 2 - border;
    int n = sz(poly);
    if (point_in_angle(p, poly[n - 1], poly[0], poly[1])) {
        int l = 1, r = n - 1;
        while (r - l > 1) {
            int md = (l + r) / 2;
            if (point_in_angle(p, poly[md], poly[0], poly[1])) {
                r = md;
            } else {
                l = md;
            }
        }
        if (point_in_angle(p, poly[r], poly[0], poly[1]) &&
            point_in_angle(p, poly[0], poly[1], poly[r]) &&
            point_in_angle(p, poly[1], poly[r], poly[0])) {
            if (point_on_segment(p, poly[l], poly[r]) ||
                point_on_segment(p, poly[(l ? l - 1 : n - 1)], poly[1])
                ||
                point_on_segment(p, poly[r], poly[(r + 1 == n ? 0 : r +
                1)])) {
                return 2;
            } else {
                return 1;
            }
        } else {
            return 0;
        }
    } else {
        return 0;
    }
}

int point_in_nonconvex_polygon(const Point &p, const Polygon &poly) {
    // 0 - outside, 1 - inside, 2 - border;
    int n = sz(poly);
    for (int i = 0; i < n; ++i) {
        if (point_on_segment(p, poly[i], poly[(i + 1) % n])) {
            return 2;
        }
    }
    ld s = 0.0;
    for (int i = 0; i < n; ++i) {
        Point pa = poly[i] - p, pb = poly[(i + 1 == n ? 0 : i + 1)] - p;
        s += angle_rad(pa, pb);
    }
    if (s >= PI || s <= -PI) {
        return 1;
    } else {
        return 0;
    }
}

Polygon minkowski_sum(Polygon &a, Polygon &b) {
    // a[0], b[0]: y - max, y1 = y2 => x - max. Against clockwise
    int n = sz(a), m = sz(b);
    assert(n >= 3 && m >= 3);
    Point high_a = a[0], high_b = b[0];
    Polygon va(n), vb(m);
    for (int i = 0; i < n; ++i) {
        va[i] = a[(i + 1) % n] - a[i];
    }
    for (int i = 0; i < m; ++i) {
        vb[i] = b[(i + 1) % m] - b[i];
    }
    // sort(all(va), cmp_vectors);
    // sort(all(vb), cmp_vectors);
    Polygon vc(sz(va) + sz(vb));
    merge(all(va), all(vb), vc.begin(), cmp_vectors);
    Point high_c(high_a.x + high_b.x, high_a.y + high_b.y);
    Polygon c(sz(vc) + 1);
    c[0] = high_c;
    for (int i = 0; i < sz(c) - 1; ++i) {
        c[i + 1] = c[i] + vc[i];
    }
    return c;
}

ld from_polygon_to_polygon(Polygon a, Polygon b) {
    for (auto &i : b) {
        i *= -1;
    }
    int pos = 0;
    for (int i = 1; i < sz(b); ++i) {
        if ((b[i].y > b[pos].y) ||
            (b[i].y == b[pos].y && b[i].x > b[pos].x)) {
            pos = i;
        }
    }
    rotate(b.begin(), b.begin() + pos, b.end());
    Polygon c = minkowski_sum(a, b);
    int n = sz(c);
    Point p(0, 0);
    ld ans = 1e20;
}

```

```

    for (int i = 0; i < n - 1; ++i) {
        ans = min(ans, from_point_to_segment(p, c[i], c[i + 1]));
    }
    return ans;
}

ll diameter_of_polygon_minkowski(Polygon &a) {
    Polygon ra = a;
    for (auto &i : ra) {
        i *= -1;
    }
    int pos = 0;
    for (int i = 1; i < sz(a); ++i) {
        if ((a[i].y > a[pos].y) ||
            (a[i].y == a[pos].y && a[i].x > a[pos].x)) {
            pos = i;
        }
    }
    rotate(a.begin(), a.begin() + pos, a.end());
    pos = 0;
    for (int i = 1; i < sz(a); ++i) {
        if ((ra[i].y > ra[pos].y) ||
            (ra[i].y == ra[pos].y && ra[i].x > ra[pos].x)) {
            pos = i;
        }
    }
    rotate(ra.begin(), ra.begin() + pos, ra.end());
    Polygon c = minkowski_sum(a, ra);
    int n = sz(c);
    ll ans = 0;
    for (int i = 0; i < n; ++i) {
        ans = max(ans, c[i].len_sq());
    }
    // don't forget to extract root!
    return ans;
}

ld from_segment_to_segment(const Point &a, const Point &b, const Point &c
, const Point &d) { // segment ab, segment cd
    if (segment_intersection(a, b, c, d)) {
        return 0;
    }
    return min({from_point_to_segment(a, c, d), from_point_to_segment(b,
        c, d),
                from_point_to_segment(c, a, b), from_point_to_segment(d,
        a, b)});
}

bool segment_line_intersection(const Point &a, const Point &b, const
    Point &c, const Point &d) { // segment ab, line cd
    Point cd = d - c;
    if (get_sign(cd % (a - c)) * get_sign(cd % (b - c)) <= 0) {
        return 1;
    }
    return 0;
}

bool ray_segment_intersection(const Point &a, const Point &b, const Point
    &c, const Point &d) { // ray ab, segment cd
    if (line_ray_intersection(c, d, a, b) && segment_line_intersection(c,
        d, a, b)) {
        Point bp = get_inf(a, b);
        ll x1 = max(min(a.x, bp.x), min(c.x, d.x)), x2 = min(max(a.x, bp.
            x), max(c.x, d.x));
        ll y1 = max(min(a.y, bp.y), min(c.y, d.y)), y2 = min(max(a.y, bp.
            y), max(c.y, d.y));
        return (x1 <= x2 && y1 <= y2);
    }
    return 0;
}

ld from_segment_to_ray(const Point &a, const Point &b, const Point &c,
    const Point &d) { // segment ab, ray cd
    if (ray_segment_intersection(c, d, a, b)) {
        return 0;
    }
    return min({from_point_to_ray(a, c, d),
                from_point_to_ray(b, c, d),
                from_point_to_segment(c, a, b)});
}

ld from_segment_to_line(const Point &a, const Point &b, const Point &c,
    const Point &d) { // segment ab, line cd
    Point cd = d - c;
    if (get_sign(cd % (a - c)) * get_sign(cd % (b - c)) <= 0) {
        return 0;
    }
    return min(from_point_to_line(a, c, d), from_point_to_line(b, c, d));
}

ld from_ray_to_ray(const Point &a, const Point &b, const Point &c, const
    Point &d) { // ray ab, ray cd
    if (rays_intersection(a, b, c, d)) {
        return 0;
    }
    return min(from_point_to_ray(a, c, d), from_point_to_ray(c, a, b));
}

```

```

ld from_ray_to_line(const Point &a, const Point &b, const Point &c, const
    Point &d) { // ray ab, line cd
    if (line_ray_intersection(c, d, a, b)) {
        return 0;
    }
    return from_point_to_line(a, c, d);
}

ld from_line_to_line(const Point &a, const Point &b, const Point &c,
    const Point &d) { // line ab, line cd
    if (lines_intersection(a, b, c, d)) {
        return 0;
    }
    return from_point_to_line(a, c, d);
}

pii tangent_from_point(const Point &p, const Polygon &poly) {
    // returns id of tangent point: {left tangent, right tangent} (maybe {
    // right, left}, but i believe no)
    // 2**20 ~ 1e6, 2**17 ~ 1e5
    int n = sz(poly);
    int i_min = 0;
    int i_max = 0;
    vector<int> order;
    for (int k = 17; k >= 0; --k) {
        {
            int l = (i_min + (1 << k)) % n;
            int r = ((i_min - (1 << k)) % n + n) % n;
            order = {l, r, i_min};
            sort(all(order), [&](int i, int j) {
                return ((poly[i] - p) % (poly[j] - p)) < 0 ||
                    (((poly[i] - p) % (poly[j] - p)) == 0 && (poly[i]
                    - p).len_sq() < (poly[j] - p).len_sq());
            });
            i_min = order[0];
        }
        {
            int l = (i_max + (1 << k)) % n;
            int r = ((i_max - (1 << k)) % n + n) % n;
            order = {l, r, i_max};
            sort(all(order), [&](int i, int j) {
                return ((poly[i] - p) % (poly[j] - p)) < 0 ||
                    (((poly[i] - p) % (poly[j] - p)) == 0 && (poly[i]
                    - p).len_sq() > (poly[j] - p).len_sq());
            });
            i_max = order[2];
        }
    }
    return {i_min, i_max};
}

```

## 2.37 Стрессы (TheEvilBird)

```

# files: generators.py gen.py stress.py

# =====

import random
import heapq

# =====

def gen_num(L: int, R: int):
    """
    Generates a number between L and R.
    """
    return random.randint(L, R)

# =====

# abcdefghijklmnopqrstuvwxyz

def gen_string_abc(LEN: int, ALPH_LEN: int = 26):
    """
    Generates a string of length LEN using the first ALPH_LEN lowercase
    letters of the alphabet.
    """
    abc = "abcdefghijklmnopqrstuvwxyz"
    s = abc[:ALPH_LEN]
    res = ""
    for i in range(LEN):
        res += random.choice(s)
    return res

def gen_string_any_aplh(LEN: int, ALPH: str):
    """
    Generates a string of length LEN using ALPH as the alphabet.
    """
    res = ""
    # ALPH_LEN = len(ALPH)
    for i in range(LEN):
        kek = 1
        res += random.choice(ALPH)
    return res

```

```
# =====

def gen_tree(N: int):
    """
    Generates a tree with N vertices.
    """
    edges = []
    for i in range(2, N + 1):
        v = gen_num(1, i - 1)
        edges.append((v, i))
    return edges

def gen_DAG(N: int, M: int):
    """
    Generates a directed acyclic graph with N vertices and M edges.
    """
    edges = []
    # for i in range(1, N):
    #     if len(edges) == M:
    #         break
    #     v = gen_num(i + 1, N)
    #     edges.append((i, v))
    while len(edges) < M:
        v = gen_num(1, N - 1)
        u = gen_num(v + 1, N)
        edges.append((v, u))
    return edges

# =====

def gen_graph(N: int, M: int):
    """
    Generates a graph with N vertices and M edges.
    """
    edges_set = set()
    for i in range(M):
        v, u = 0, 0
        while (v, u) in edges_set or v == u:
            v, u = gen_num(1, N), gen_num(1, N)
            v, u = min(v, u), max(v, u)
        edges_set.add((v, u))
    return list(edges_set)

def gen_multigraph(N: int, M: int):
    """
    Generates a multigraph with N vertices and M edges.
    """
    edges = []
    for i in range(M):
        v, u = -1, 0
        while v == -1:
            v, u = gen_num(1, N), gen_num(1, N)
            v, u = min(v, u), max(v, u)
        edges.append((v, u))
    return edges

def gen_directed_graph(N: int, M: int):
    """
    Generates a directed graph with N vertices and M edges.
    """
    edges_set = set()
    for i in range(M):
        v, u = 0, 0
        while (v, u) in edges_set or v == u:
            v, u = gen_num(1, N), gen_num(1, N)
        edges_set.add((v, u))
    return list(edges_set)

def gen_connected_directed_graph(N: int, M: int):
    """
    Generates a directed connected graph with N vertices and M edges.
    """
    edges_set = set(gen_tree(N))
    for i in range(M - (N - 1)):
        v, u = 0, 0
        while (v, u) in edges_set or v == u:
            v, u = gen_num(1, N), gen_num(1, N)
        edges_set.add((v, u))
    return list(edges_set)

def gen_connected_graph(N: int, M: int):
    """
    Generates a connected graph with N vertices and M edges.
    """
    edges_set = set(gen_tree(N))
    for i in range(M - (N - 1)):
        v, u = 0, 0
        while (v, u) in edges_set or v == u:
            v, u = gen_num(1, N), gen_num(1, N)
            v, u = min(v, u), max(v, u)
        edges_set.add((v, u))
    return list(edges_set)

def gen_connected_multigraph(N: int, M: int):
    """
    Generates a connected multigraph with N vertices and M edges.
    """
```

```
edges = gen_tree(N)
for i in range(M - (N - 1)):
    v, u = 0, 0
    while v == u:
        v, u = gen_num(1, N), gen_num(1, N)
    edges.append((v, u))
return edges

# =====

def gen_perm(N: int, FIR: int = 1):
    """
    Generates a permutation of length N with min element FIR.
    """
    arr = [FIR + i for i in range(N)]
    # arr = arr[1:]
    random.shuffle(arr)
    return arr

def gen_array(N: int, L: int, R: int):
    """
    Generates an array of length N with elements between L and R.
    """
    arr = [gen_num(L, R) for i in range(N)]
    return arr

def gen_array_pairs(N: int, L: int, R: int):
    """
    Generates an array of pairs of length N with elements between L and R
    .
    """
    arr = [(gen_num(L, R), gen_num(L, R)) for i in range(N)]
    return arr

def gen_array_pairs(N: int, L1: int, R1: int, L2: int, R2: int):
    """
    Generates an array of pairs of length N with the first elements of
    each pair between L1 and R1 and between L2 and R2 for the second
    element.
    """
    arr = [(gen_num(L1, R1), gen_num(L2, R2)) for i in range(N)]
    return arr

# =====

def gen_tree_ivanq(N: int):
    """
    Generates a tree with N vertices. Code by IvanQ.
    """
    code = [random.randint(1, N) for _ in range(N - 2)]
    histogram = [0] * (N + 1)
    unused = list(set(range(1, N + 1)) - set(code))
    heapq.heapify(unused)
    for u in code:
        histogram[u] += 1

    res = []
    for u in code:
        v = heapq.heappop(unused)
        res.append((v, u))
        histogram[u] -= 1
        if histogram[u] == 0:
            heapq.heappush(unused, u)
    return res + [tuple(unused)]

# =====

import sys
import random
from generators import *

SEED = 228
if len(sys.argv) > 1:
    SEED = int(sys.argv[1])
random.seed(SEED)

# print(gen_num(1, 666))

# =====

import os
import sys

os.system("g++ -std=c++17 smart.cpp -o smart")
# os.system("g++ -std=c++17 -g -fsanitize=undefined -fsanitize=bounds -
# fsanitize=address -D_GLIBCXX_DEBUG smart.cpp -o smart")
os.system("g++ -std=c++17 stupid.cpp -o stupid")

def print_testcase():
    test = open("test.txt").read().strip()
    print(test)
    print("=====")
    ans1 = open("smart.out").read().strip()
    ans2 = open("stupid.out").read().strip()
    print(ans1)
    print("=====")
    print(ans2)
    print("=====")
```

```
i = 0
while True:
    os.system(f"python3 gen.py {i} > test.txt")

    r1 = os.system("./smart < test.txt > smart.out")
    r2 = os.system("./stupid < test.txt > stupid.out")

    if r1 + r2 != 0:
        print(f"Runtime! {i}")
        print_testcase()
        exit(0)

    ans1 = open("smart.out").read()
    ans2 = open("stupid.out").read()

    if ans1 != ans2:
        print(f"POPALCYA! {i}\n")
        print_testcase()
        exit(0)
    print(f"OK: {i}")
    i += 1
```

Задача	Саша	Дима	Федя	О чём
A				
B				
C				
D				
E				
F				
G				
H				
I				
J				
K				
L				
M				
N				
O				
P				