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1 Basic

1.1 .vimrc

```
1 "This file should be placed at ~/.vimrc"
1 se nu ai hls et ru ic is sc cul
1 se re=1 ts=4 sts=4 sw=4 ls=2 mouse=a
1 syntax on
1 hi cursorline cterm=none ctermfg=89
1 set bg=dark
1 inoremap {<CR>} {<CR>}<Esc>ko<tab>
```

1.2 Default Bear

```
2 #include <bits/stdc++.h>
2 using namespace std;
2 typedef long long ll;
2 #define int ll
2 typedef pair<int, int> pii;
2 #define X first
2 #define Y second
2 #define pb push_back
2 #define All(a) a.begin(), a.end()
2 #define SZ(a) ((int)a.size())
2 #define endl '\n'

3 signed main() {
4   ios_base::sync_with_stdio(0);
5   cin.tie(0);
6 }
```

1.3 IO Optimize

```
7 bool rit(auto& x) {
8   x = 0; char c = cin.rdbuf()->sbumpc(); bool neg = 0;
9   while (!isdigit(c)) {
10     if (c == EOF) return 0;
11     if (c == '-') neg = 1;
12     c = cin.rdbuf()->sbumpc();
13   }
14   while (isdigit(c))
15     x = x * 10 + c - '0', c = cin.rdbuf()->sbumpc();
16   return x = neg ? -x : x, 1;
17 }
18 void wit(auto x) {
19   if (x < 0) cout.rdbuf()->sputc('-'), x = -x;
20   char s[20], len = 0;
21   do s[len++] = x % 10 + '0'; while (x /= 10);
22   while (len) cout.rdbuf()->sputc(s[--len]);
23 }
```

1.4 PBDS

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
// #include <bits/extc++.h>
#include <bits/stdc++.h>
using namespace __gnu_pbds;
using namespace std;
template <typename T>
using rbtree = tree<T, null_type, less<T
    >, rb_tree_tag, tree_order_statistics_node_update>;
// less<T> : increasing, greater<T> : decreasing
// rb_tree_tag, splay_tree_tag, ov_tree_tag

int main() {
  int x;
  rbtree<int> t, rhs, rhs2;
  t.insert(x); // return 1 or 0
  cout << t.order_of_key(x) << '\n'; // rank
  cout << *t.find_by_order(x) << '\n'; // x-th
  cout << *t.lower_bound(x) << '\n'; // iterator >= x
  cout << *t.upper_bound(x) << '\n'; // iterator > x
  t.join(rhs
    ); // merge // same type, no duplicate elements
  t.split(x, rhs2
    ); // tree : elements <= x, rhs : elements > x
}
```

1.5 Set Comperator

```
20 auto cmp = [](<int a, int b> {
21   return a > b;
22 };
23 set<int, decltype(cmp)> s = {1, 2, 3, 4, 5};
24 cout << *s.begin() << '\n';
```

1.6 Random

```
#include <random>
#include <chrono>
#include <algorithm>
mt19937 rng(chrono
    ::system_clock::now().time_since_epoch().count());
int randint(int lb, int ub) {
    return uniform_int_distribution<int>(lb, ub)(rng);
}
// shuffle(v.begin(), v.end(), rng);
```

1.7 Python

```
from decimal import *
setcontext(Context(prec
    =MAX_PREC, Emax=MAX_EMAX, rounding=ROUND_FLOOR))
print(Decimal(input()) * Decimal(input()))
from fractions import Fraction
Fraction
('3.14159').limit_denominator(10).numerator # 22
```

1.8 Stress Test

```
#!/bin/bash
while true; do
    ./random > input
    ./a.out < input > out1
    ./brute < input > out2
    if diff -w out1 out2 > /dev/null; then
        echo "OK"
    else
        echo "WA:"
        cat input
        break
    fi
done
```

2 Graph

2.1 2SAT

```
struct TwoSAT {
    int n;
    Scc scc;
    void init(int _n) {
        // (0,1),(2,3),...
        n = _n; scc.init(n * 2);
    }
    void add_disjunction(int a, int na, int b, int nb) {
        a = 2 * a ^ na, b = 2 * b ^ nb;
        scc.addEdge(a ^ 1, b);
        scc.addEdge(b ^ 1, a);
    }
    vector<int> solve() {
        scc.solve();
        vector<int> assignment(n, 0);
        for (int i = 0; i < n; i++) {
            if (scc
                .bln[2 * i] == scc.bln[2 * i ^ 1]) return {};
            assignment
                [i] = scc.bln[2 * i] > scc.bln[2 * i ^ 1];
        }
        return assignment;
    }
};
```

2.2 Bellman Ford

```
struct edge{
    int u, v;
    int cost;
};
vector<int> d(n, inf);
bool bellman_ford(vector<edge> &ee, int n, int s){
    d[s] = 0;
    auto relax = [&](edge e){
        if(d[e.v] > d[e.u] + e.cost){
            d[e.v] = d[e.u] + e.cost;
            return 1;
        }
        return 0;
    }
    for(int t = 1; t <= n; ++t){
        bool update = 0;
        for(auto &e: ee)
            update |= relax(e);
        if(t == n && update) return 0;
    }
    return 1;
}
```

2.3 Biconnected Component

```
// beware of multiple inputs
#define ep emplace
#define eb emplace_back
const int N = 2e5 + 5;

int d[N], low[N];
vector<int> g[N];
vector<vector<int>> bcc;
stack<int> st;

void dfs(int x, int p) {
    d[x] = ~p ? d[p] + 1 : 1, low[x] = d[x];
    st.ep(x);
    for (const auto& i : g[x]) {
        if (i == p) continue;
        if (!d[i]) {
            dfs(i, x);
            low[x] = min(low[x], low[i]);
            if (d[x] <= low[i]) {
                int tmp;
                bcc.eb();
                do tmp = st.top(), st.pop()
                    (), bcc.back().eb(tmp); while (tmp != x);
                st.ep(x);
            }
        }
        low[x] = min(low[x], d[i]);
    }
}
```

2.4 Bridge Connected Component

```
#define ep emplace
constexpr int N = 2e5 + 1;

int d[N], low[N], bcc[N], nbcc;
vector<int> g[N];
stack<int> st;

void dfs(int x, int p) {
    d[x] = ~p ? d[p] + 1 : 1, low[x] = d[x];
    st.ep(x);
    for (const auto& i : g[x]) {
        if (i == p) continue;
        if (!d[i]) {
            dfs(i, x);
            low[x] = min(low[x], low[i]);
        }
        low[x] = min(low[x], d[i]);
    }
    if (low[x] == d[x]) {
        nbcc++;
        int tmp;
        do tmp = st.top()
            , st.pop(), bcc[tmp] = nbcc; while (tmp != x);
    }
}
```

2.5 Bridge

```
#define eb emplace_back
using pii = pair<int, int>;
const int N = 2e5 + 5;

int d[N], low[N];
vector<int> g[N];
vector<int> ap; // articulation point
vector<pii> bridge;

void dfs(int x, int p) {
    d[x] = ~p ? d[p] + 1 : 1, low[x] = d[x];
    int cnt = 0;
    bool isap = 0;
    for (const auto& i : g[x]) {
        if (i == p) continue;
        if (!d[i]) {
            dfs(i, x), cnt++;
            if (d[x] <= low[i]) isap = 1;
            if (d[x] < low[i]) bridge.eb(x, i);
            low[x] = min(low[x], low[i]);
        }
        low[x] = min(low[x], d[i]);
    }
    if (p == -1 && cnt < 2) isap = 0;
    if (isap) ap.eb(x);
}
```

2.6 C3C4

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

signed main() {
    cin.tie(0)->sync_with_stdio(0);

    int N, M;
    cin >> N >> M;

    vector<int> deg(N);
    vector<array<int, 2>> e(M);
    for (auto &[u, v] : e) {
        cin >> u >> v;
        --u, --v;
        ++deg[u], ++deg[v];
    }

    vector<int> ord(N), rk(N);
    iota(all(ord), 0);
    sort(all(ord),
         [&](int x, int y) { return deg[x] > deg[y]; });
    for (int i = 0; i < N; i++) rk[ord[i]] = i;

    vector<vector<int>> D(N), adj(N);
    for (auto [u, v] : e) {
        if (rk[u] > rk[v]) swap(u, v);
        D[u].emplace_back(v);
        adj[u].emplace_back(v);
        adj[v].emplace_back(u);
    }

    vector<int> vis(N);

    int64_t c3 = 0, c4 = 0;
    // ord = sort by deg decreasing, rk[ord[i]] = i
    // D[i] = edge point from rk small to rk big
    for (int x : ord) { // c3
        for (int y : D[x]) vis[y] = 1;
        for (int y : D[x]) for (int z : D[y]) c3 += vis[z];
        for (int y : D[x]) vis[y] = 0;
    }
    for (int x : ord) { // c4
        for (int y : D[x]) for (int z : adj[y])
            if (rk[z] > rk[x]) c4 += vis[z]++;
        for (int y : D[x]) for (int z : adj[y])
            if (rk[z] > rk[x]) --vis[z];
    } //
    both are O(M*sqrt(M)), test @ 2022 CCPC guangzhou
    cout << c4 * 8 << '\n';
}
```

2.7 Centroid Decomposition

```
const int MAXN = 1e5 + 5;
int n, q, vis[MAXN], sz[MAXN];
vector<int> adj[MAXN], pa[MAXN], mx[MAXN], dis[MAXN];

void dfs_sz(int x, int p) {
    sz[x] = 1;
    for (int i : adj[x]) {
        if (i == p || vis[i]) continue;
        dfs_sz(i, x);
        sz[x] += sz[i];
    }
}
int cen;
void dfs_cen(int x, int p, int all) {
    int tmp = all - sz[x];
    for (int i : adj[x]) {
        if (i == p || vis[i]) continue;
        dfs_cen(i, x, all);
        chmax(tmp, sz[i]);
    }
    if (tmp * 2 <= all) cen = x;
}
void dfs(int x, int p, int d) {
    pa[x].pb(cen);
    dis[x].pb(d);
    if (d >= mx[cen].size()) mx[cen].pb(x);
    else chmax(mx[cen][d], x);
    for (int i : adj[x]) {
        if (i == p || vis[i]) continue;
        dfs(i, x, d + 1);
    }
}
```

```
} // Step 1: find the centroid
current_centroid = -1; find_centroid(n, u);
removed[u = current_centroid] = true;

} // place the discovered centroid in current_centroid
int find_centroid
    (const int n, const int u, const int p = -1) {
    if (n == 1) { current_centroid = u; return 0; }
    int subtree_sum = 0;
    for (const auto
        &[v, w] : tree[u]) if (v != p && !removed[v]) {
        subtree_sum += find_centroid(n, v, u);
        if (current_centroid > -1) return 0;
        if (subtree_sum >
            n >> 1) { current_centroid = u; return 0; }
    }
    return subtree_sum + 1;
}
void DFS(const int u, const int p, const int length,
         const int weight, vector<pair<int, int>> &record) {
    record.emplace_back(weight, length);
    for (const auto
        &[v, w] : tree[u]) if (v != p && !removed[v])
        DFS(v, u, length + 1, weight + w, record);
}
bool greater_size(const vector<pair
    <int, int>> &v, const vector<pair<int, int>> &w) {
    return v.size() > w.size();
}
long long centroid_decomposition(const int n, int u) {
    long long ans = 0;
    // Step 1: find the centroid
    current_centroid = -1; find_centroid(n, u);
    removed[u = current_centroid] = true;
```

2.8 Close Vertices

```
#include <iostream>
#include <vector>
#include <set>
#include <algorithm>
#include <cstring>
using namespace std;
int l, w;
vector<pair<int, short>> tree[100000];
set<int> removed;
int current_centroid, BIT[100000];
// Return subtree size internally
// and
// place the discovered centroid in current_centroid
int find_centroid
    (const int n, const int u, const int p = -1) {
    if (n == 1) { current_centroid = u; return 0; }
    int subtree_sum = 0;
    for (const auto
        &[v, w] : tree[u]) if (v != p && !removed[v]) {
        subtree_sum += find_centroid(n, v, u);
        if (current_centroid > -1) return 0;
        if (subtree_sum >
            n >> 1) { current_centroid = u; return 0; }
    }
    return subtree_sum + 1;
}
void DFS(const int u, const int p, const int length,
         const int weight, vector<pair<int, int>> &record) {
    record.emplace_back(weight, length);
    for (const auto
        &[v, w] : tree[u]) if (v != p && !removed[v])
        DFS(v, u, length + 1, weight + w, record);
}
bool greater_size(const vector<pair
    <int, int>> &v, const vector<pair<int, int>> &w) {
    return v.size() > w.size();
}
long long centroid_decomposition(const int n, int u) {
    long long ans = 0;
```

```

// Step 2: DFS from the centroid (again)
// and continue the centroid decomposition
vector<vector<pair<int, int>> root2subtree_paths;
for (const auto &[v, w] : tree[u]) if (!removed[v]) {
    root2subtree_paths.emplace_back();
    DFS(v, u, 1, w, root2subtree_paths.back());
    // Sort mainly according to weight
    ranges::sort(root2subtree_paths.back());
    ans += centroid_decomposition
        (root2subtree_paths.back().size(), v);
}
for (const auto &v : root2subtree_paths)
    for (const auto &[weight, length] : v)
        if (length <= l && weight <= w) ++ans;
// Step 3: optimal merging
ranges::make_heap(root2subtree_paths, greater_size);
while (root2subtree_paths.size() > 1) {
    ranges::pop_heap(root2subtree_paths, greater_size);
    // Merge
        front() (with maybe larger size) and back()
    // Count cross-centroid paths
    memset(BIT, 0, root2subtree_paths
        .back().size() * sizeof(int));
    auto p = root2subtree_paths.front().crbegin();
    for (auto q = root2subtree_paths.back().cbegin()
        ; q != root2subtree_paths.back().cend(); ++q) {
        int L;
        while (p != root2subtree_paths.front().crend()
            && p->first + q->first > w) {
            L = min(l - p->second,
                static_cast<int>(root2subtree_paths.back().size()));
            while (L > 0) { ans += BIT[L - 1]; L -= L & -L; }
            ++p;
        }
        L = q->second;
        while (L <= static_cast
            <int>(root2subtree_paths.back().size()))
        {
            ++BIT[L - 1]; L += L & -L;
        }
    }
    while (p != root2subtree_paths.front().crend()) {
        int L = min(l - p++>second, static_cast
            <int>(root2subtree_paths.back().size()));
        while (L > 0) { ans += BIT[L - 1]; L -= L & -L; }
    }
    // Actually merge the lists
    vector<pair<int, int>> buffer;
    buffer.reserve(root2subtree_paths.front
        ().size() + root2subtree_paths.back().size());
    ranges::merge
        (root2subtree_paths.front(), root2subtree_paths
            .back(), back_inserter(buffer));

    root2subtree_paths.pop_back();
    ranges::pop_heap(root2subtree_paths, greater_size);
    root2subtree_paths.back() = move(buffer);
    ranges
        ::push_heap(root2subtree_paths, greater_size);
}
return ans;
}
int main() {
ios_base::sync_with_stdio(false);
int n; cin >> n >> l >> w;
for (int i = 1; i < n; ++i) {
    int p; short w; cin >> p >> w;
    tree[--p].emplace_back(i, w);
    tree[i].emplace_back(p, w);
}
cout << centroid_decomposition(n, 0) << endl;
}

```

2.9 Disjoint Set

```

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

struct disjoint_set {
    static const int maxn = (int)5e5 + 5;
    int n, fa[maxn], sz[maxn];
    vector<pair<int*, int>> h;
    vector<int> sp;
    void init(int _n) {
        n = _n;

```

```

        for (int i = 0; i < n; ++i)
            fa[i] = i, sz[i] = 1;
        sp.clear(); h.clear();
    }
    void assign(int *k, int v) {
        h.push_back({k, *k});
        *k = v;
    }
    void save() { sp.push_back((int)h.size()); }
    void undo() {
        assert(!sp.empty());
        int last = sp.back(), cnt = 0; sp.pop_back();
        while (h.size() > last) {
            auto x = h.back(); h.pop_back();
            *x.first = x.second;
            cnt++;
        }
        n += cnt / 2;
    }
    int f(int x) {
        while (fa[x] != x) x = fa[x];
        return x;
    }
    bool merge(int x, int y) {
        x = f(x); y = f(y);
        if (x == y) return 0;
        if (sz[x] < sz[y]) swap(x, y);
        assign(&sz[x], sz[x] + sz[y]);
        assign(&fa[y], x);
        n--;
        return 1;
    }
} djs;

```

2.10 Heavy Light Decomposition

```

#include <bits/stdc++.h>
using namespace std;
const int N = 2e5 + 5;
#define eb emplace_back
int t, n, q, seg[N << 1]; // t := time-stamp
int sz[N], fa[N], dep[N], to[N], fr[N], dfn[N], arr[N];
// size, father, depth
// , to-heavy-child, from-head, dfs-order, a_i value
vector<int> g[N];
void upd(int x, int v) {
    for (seg[x += n] = v; x > 1; x >>= 1)
        seg[x >> 1] = max(seg[x], seg[x ^ 1]);
}
int qry(int l, int r) { // [l, r]
    int ret = -1e9; // -max
    for (l += n, r += n + 1; l < r; l >>= 1, r >>= 1) {
        if (l & 1) ret = max(ret, seg[l++]);
        if (r & 1) ret = max(ret, seg[--r]);
    }
    return ret;
}
void dfs(int x, int p) {
    sz[x] = 1, fa[x] = p, to[x] = -1, dep[x] = ~p ? dep[p] + 1 : 0;
    for (auto i : g[x])
        if (i != p) {
            dfs(i, x);
            if (to[x] == -1 || sz[i] > sz[to[x]]) to[x] = i;
            sz[x] += sz[i];
        }
}
void dfs2(int x, int f) {
    fr[x] = f, dfn[x] = ++t, upd(dfn[x], arr[x]);
    if (to[x] != -1) dfs2(to[x], f);
    for (auto i : g[x])
        if (i != fa[x] && i != to[x]) dfs2(i, i);
}
int qry2(int u, int v) { // query on tree
    int fu = fr[u], fv = fr[v], ret = -1e9;
    while (fu != fv) {
        if (dep[fu] < dep[fv]) swap(fu, fv), swap(u, v);
        ret = max(ret, qry(dfn
            [fu], dfn[u]));
        u = fa[fu], fu = fr[u];
    }
    if (dep[u] > dep[v]) swap(u, v);
    // u is the LCA
    ret = max(ret, qry(dfn[u], dfn[v]));
    return ret;
}
int main() {

```

```

ios::sync_with_stdio(false), cin.tie(nullptr);
cin >> n >> q;
for (int i = 1; i <= n; i++) cin >> arr[i];
for (int i = 1, a, b; i < n; i++)
    cin >> a >> b, g[a].eb(b), g[b].eb(a);
dfs(1, -1), dfs2(1, 1);
while (q--) {
    int op; cin >> op;
    if (op == 1) {
        int x,
            v; cin >> x >> v, arr[x] = v, upd(dfn[x], v);
    }
    else {
        int a, b; cin >> a >> b;
        cout << qry2(a, b) << '\n';
    }
}

```

2.11 KSP

```

// from CRyptoGRapher
// time: O(|E| \lg |E| + |V| \lg |V| + K)
// memory: O(|E| \lg |E| + |V|)
struct KSP { // 1-base
    struct nd {
        int u, v; ll d;
        nd(int ui = 0, int vi = 0, ll di = INF) { u = ui; v = vi; d = di; }
    };
    struct heap { nd* edge; int dep; heap* chd[4]; };
    static int cmp(heap* a, heap* b) { return a->edge->d > b->edge->d; }
    struct node {
        int v; ll d; heap* H; nd* E;
        node() {}
        node(nd _d, int _v, nd* _E) { d = _d; v = _v; E = _E; }
        node(heap* _H, ll _d) { H = _H; d = _d; }
        friend bool operator<(node a, node b)
        { return a.d > b.d; }
    };
    int n, k, s, t, dst[N]; nd *nxt[N];
    vector<nd*> g[N], rg[N]; heap *nullNd, *head[N];
    void init(int _n, int _k, int _s, int _t) {
        n = _n; k = _k; s = _s; t = _t;
        for (int i = 1; i <= n; i++) {
            g[i].clear(); rg[i].clear();
            nxt[i] = NULL; head[i] = NULL; dst[i] = -1;
        }
    }
    void addEdge(int ui, int vi, ll di) {
        nd* e = new nd(ui, vi, di);
        g[ui].push_back(e); rg[vi].push_back(e);
    }
    queue<int> dfsQ;
    void dijkstra() {
        while (dfsQ.size()) dfsQ.pop();
        priority_queue<node> Q; Q.push(node(0, t, NULL));
        while (!Q.empty()) {
            node p = Q
                .top(); Q.pop(); if (dst[p.v] != -1) continue;
            dst[p.v] = p.d; nxt[p.v] = p.E; dfsQ.push(p.v);
            for (auto e : rg[p.v]) Q.push(node(p.d + e->d, e->u, e));
        }
    }
    heap* merge(heap* curNd, heap* newNd) {
        if (curNd == nullNd) return newNd;
        heap* root
            = new heap; memcpy(root, curNd, sizeof(heap));
        if (newNd->edge->d < curNd->edge->d) {
            root->edge = newNd->edge;
            root->chd[2] = newNd->chd[2];
            root->chd[3] = newNd->chd[3];
            newNd->edge = curNd->edge;
            newNd->chd[2] = curNd->chd[2];
            newNd->chd[3] = curNd->chd[3];
        }
        if (root->chd[0]->dep < root->chd[1]->dep)
            root->chd[0] = merge(root->chd[0], newNd);
        else root->chd[1] = merge(root->chd[1], newNd);
        root->dep = max(root->chd[0]->dep,
                         root->chd[1]->dep) + 1;
        return root;
    }
    vector<heap*> V;

```

```

void build() {
    nullNd = new
        heap; nullNd->dep = 0; nullNd->edge = new nd;
    fill(nullNd->chd, nullNd->chd + 4, nullNd);
    while (not dfsQ.empty()) {
        int u = dfsQ.front(); dfsQ.pop();
        if (!nxt[u]) head[u] = nullNd;
        else head[u] = head[nxt[u]->v];
        V.clear();
        for (auto &e : g[u]) {
            int v = e->v;
            if (dst[v] == -1) continue;
            e->d += dst[v] - dst[u];
            if (nxt[u] != e) {
                heap* p = new
                    heap; fill(p->chd, p->chd + 4, nullNd);
                p->dep = 1; p->edge = e; V.push_back(p);
            }
        }
        if (V.empty()) continue;
        make_heap(V.begin(), V.end(), cmp);
#define L(X) ((X << 1) + 1)
#define R(X) ((X << 1) + 2)
        for (size_t i = 0; i < V.size(); i++) {
            if (L(i) < V.size()) V[i]->chd[2] = V[L(i)];
            else V[i]->chd[2] = nullNd;
            if (R(i) < V.size()) V[i]->chd[3] = V[R(i)];
            else V[i]->chd[3] = nullNd;
        }
        head[u] = merge(head[u], V.front());
    }
    vector<ll> ans;
    void first_K() {
        ans.clear(); priority_queue<node> Q;
        if (dst[s] == -1) return;
        ans.push_back(dst[s]);
        if (head[s] != nullNd)
            Q.push(node(head[s], dst[s] + head[s]->edge->d));
        for (int _ = 1; _ < k and not Q.empty(); _++) {
            node p = Q.top(), q; Q.pop(); ans.push_back(p.d);
            if (head[p.H->edge->v] != nullNd) {
                q.H = head
                    [p.H->edge->v]; q.d = p.d + q.H->edge->d;
                Q.push(q);
            }
            for (int i = 0; i < 4; i++)
                if (p.H->chd[i] != nullNd) {
                    q.H = p.H->chd[i];
                    q.d = p
                        .d - p.H->edge->d + p.H->chd[i]->edge->d;
                    Q.push(q);
                }
        }
    }
    solve() { // ans[i] stores the i-th shortest path
        dijkstra(); build();
        first_K(); // ans.size() might less than k
    }
} solver;

```

2.12 LCA

```

#define eb emplace_back
const int N = 2e5 + 5, logN = __lg(N) + 1, inf = 1e9;
int n, q, logN;
int dep[N], fa[N][logN];
vector<int> g[N];
void dfs(int x, int p) {
    dep[x] = ~p ? dep[p] + 1 : 0;
    fa[x][0] = p;
    for (int i = 1; (1 << i) <= dep[x]; i++)
        fa[x][i] = fa[fa[x][i - 1]][i - 1];
    for (const auto &u : g[x])
        if (u != p) dfs(u, x);
}
int LCA(int u, int v) {
    if (dep[u] > dep[v]) swap(u, v);
    for (int i = 0; i < logN; i++)
        if ((dep[v] - dep[u]) >> i & 1) v = fa[v][i];
    if (u == v) return u;
    for (int i = logN - 1; i >= 0; i--)
        if (fa[u][i] != fa[v][i])
            u = fa[u][i], v = fa[v][i];

```

```

    return fa[u][0];
}
// logn = __lg(n) + 1
// g[a].eb(b)
// dfs(root, -1)
// query -> LCA(u, v)
// distance
    of (u, v) = dep[u] + dep[v] - 2 * dep[LCA(u, v)]

```

2.13 Maximum Clique

```

struct Maximum_Clique {
    typedef bitset<MAXN> bst;
    bst N[MAXN], empty;
    int p[MAXN], n, ans;
    void BronKerbosch2(bst R, bst P, bst X) {
        if (P == empty && X == empty)
            return ans = max(ans, (int)R.count()), void();
        bst tmp = P | X;
        int u;
        if ((R | P | X).count() <= ans) return;
        for (int uu = 0; uu < n; ++uu) {
            u = p[uu];
            if (tmp[u] == 1) break;
        }
        // if (double(clock()) / CLOCKS_PER_SEC > .999)
        // return;
        bst now2 = P & ~N[u];
        for (int vv = 0; vv < n; ++vv) {
            int v = p[vv];
            if (now2[v] == 1) {
                R[v] = 1;
                BronKerbosch2(R, P & N[v], X & N[v]);
                R[v] = 0, P[v] = 0, X[v] = 1;
            }
        }
    }
    void init(int _n) {
        n = _n;
        for (int i = 0; i < n; ++i) N[i].reset();
    }
    void add_edge(int u, int v) {
        N[u][v] = N[v][u] = 1;
    }
    int solve() { // remember srand
        bst R, P, X;
        ans = 0, P.flip();
        for (int i = 0; i < n; ++i) p[i] = i;
        random_shuffle(p, p + n), BronKerbosch2(R, P, X);
        return ans;
    }
};

```

2.14 SCC Kosaraju

```

#define eb emplace_back
const int N = 2e5 + 5;
vector<int> g[N], rg[N], ord;
int scc[N];
bool v[N];
void rdfs(int x) {
    v[x] = 1;
    for (const auto& i : rg[x])
        if (!v[i]) rdfs(i);
    ord.eb(x);
}
void dfs(int x, int nscc) {
    scc[x] = nscc;
    for (const auto& i : g[x])
        if (scc[i] == -1) dfs(i, nscc);
}
void kosaraju(int n) {
    memset(v, 0, sizeof(v));
    memset(scc, -1, sizeof(scc));
    for (int i = 0; i < n; i++)
        if (!v[i]) rdfs(i);
    int nscc = 0;
    for (int i = n - 1; i >= 0; i--) {
        int x = ord[i];
        if (scc[x] == -1)
            dfs(x, nscc++);
    }
}

```

2.15 SCC Tarjan

```
#define ep emplace
```

```

const int N = 2e5 + 5;
int d[N], low[N], scc[N], ins[N], nscc;
vector<int> g[N];
stack<int> st;
void dfs(int x, int p) {
    d[x] = ~p ? d[p] + 1 : 1, low[x] = d[x];
    st.ep(x), ins[x] = 1;
    for (const auto& i : g[x]) {
        if (!d[i]) dfs(i, x), low[x] = min(low[x], low[i]);
        else if (ins[i]) low[x] = min(low[x], d[i]);
    }
    if (d[x] == low[x]) {
        nscc++;
        int tmp;
        do tmp = st.top(), st.pop(), scc
            [tmp] = nscc, ins[tmp] = 0; while (tmp != x);
    }
}

```

2.16 Tree Centroid

```

const int N = 2e5 + 5, inf = 1e9;
vector<int> g[N];
int n, sz[N], center, csize; // set csize = inf

void dfs(int x, int p) {
    int mxsub = 0;
    sz[x] = 1;
    for (const auto& i : g[x])
        if (i != p) dfs(i,
            x), sz[x] += sz[i], mxsub = max(mxsub, sz[i]);
    mxsub = max(mxsub, n - sz[x]);
    if (mxsub < csize) center = x, csize = mxsub;
}

```

2.17 Virtual Tree

```

vector<int> vG[N];
int top, st[N];

void insert(int u) {
    if (top == -1) return st[++top] = u, void();
    int p = LCA(st[top], u);
    if (p == st[top]) return st[++top] = u, void();
    while (top >= 1 && dep[st[top - 1]] >= dep[p])
        vG[st[top - 1]].pb(st[top]), --top;
    if (st[top] != p)
        vG[p].pb(st[top]), --top, st[++top] = p;
    st[++top] = u;
}

void reset(int u) {
    for (int i : vG[u]) reset(i);
    vG[u].clear();
}

void solve(vector<int> &v) {
    top = -1;
    sort(ALL(v),
        [&](int a, int b) { return dfn[a] < dfn[b]; });
    for (int i : v) insert(i);
    while (top > 0) vG[st[top - 1]].pb(st[top]), --top;
    // do something
    reset(v[0]);
}

```

3 Data Structure

3.1 2D BIT

```

const int N = 1000 + 5;
int a[N][N];

struct BIT { // 1-based
    ll bit[N][N];
    int n, m;
    void init(int _n, int _m) { // O(nm)
        n = _n, m = _m;
        for (int i = 1; i <= n; i++)
            for (int j = 1; j <= m; j++)
                bit[i][j] = a[i][j];
        for (int b = 1; b << 1 <= max(n, m); b <<= 1)
            for (int i = b; i + b <= n; i += b << 1)
                for (int j = 1; j <= m; j++)
                    bit[i + b][j] += bit[i][j];
        for (int i = 1; i <= n; i++)
    }
}

```

```

        for (int j = b; j + b <= m; j += b << 1)
            bit[i][j + b] += bit[i][j];
    }
}
void upd(int x, int y, int v) {
    for (int i = x; i <= n; i += i & -i)
        for (int j = y; j <= m; j += j & -j)
            bit[i][j] += v;
}
ll qry(int x, int y) {
    ll ret = 0;
    for (int i = x; i -= i & -i)
        for (int j = y; j -= j & -j)
            ret += bit[i][j];
    return ret;
}
ll qry(int x1, int y1, int x2, int y2) { // closed-interval
    return qry(x2, y2) - qry(x1 - 1, y2) - qry(x2, y1 - 1) + qry(x1 - 1, y1 - 1);
}
} tree;
// tree.init(n, m)

```

3.2 2D Segment Tree

```

const int inf = 1e9;
#define lc(x) (x << 1)
#define rc(x) (x << 1 | 1)
int N, M; // N : row max, M : col max
struct seg {
    vector<int> st;
    void pull(int);
    void merge(const seg&, const seg&, int, int, int);
    void build(int, int, int);
    void upd(int, int, int, int, int);
    int qry(int, int, int, int, int);
    seg(int size): st(size << 2 | 1) {}
};
void seg::pull(int id) {
    st[id] = max(st[lc(id)], st[rc(id)]);
}
void seg::merge(const seg& a, const seg& b, int id = 1, int l = 1, int r = M) {
    st[id] = max(a.st[id], b.st[id]);
    if (l == r) return;
    int m = (l + r) >> 1;
    merge(a, b, lc(id), l, m), merge(a, b, rc(id), m + 1, r);
}
void seg::build(int id = 1, int l = 1, int r = M) {
    if (l == r) {cin >> st[id]; return;}
    int m = (l + r) >> 1;
    build(lc(id), l, m), build(rc(id), m + 1, r);
    pull(id);
}
void seg::upd(int x, int v, int id = 1, int l = 1, int r = M) {
    if (l == r) {st[id] = v; return;}
    int m = (l + r) >> 1;
    if (x <= m) upd(x, v, lc(id), l, m);
    else upd(x, v, rc(id), m + 1, r);
    pull(id);
}
int seg::qry(int ql, int qr, int id = 1, int l = 1, int r = M) {
    if (ql <= l && r <= qr) return st[id];
    int m = (l + r) >> 1, ret = -inf;
    if (ql <= m) ret = max(ret, qry(ql, qr, lc(id), l, m));
    if (qr > m) ret = max(ret, qry(ql, qr, rc(id), m + 1, r));
    return ret;
}

struct segseg {
    vector<seg> st;
    void pull(int, int);
    void build(int, int, int);
    void upd(int, int, int, int, int);
    int qry(int, int, int, int, int, int);
    segseg(int n, int m): st(n << 2 | 1, seg(m)) {}
};
void segseg::pull(int id, int x) {
    st[id].upd(x, max(st[lc(id)].qry(x, x), st[rc(id)].qry(x, x)));
}

```

```

void segseg::build(int id = 1, int l = 1, int r = N) {
    if (l == r) {st[id].build(); return;}
    int m = (l + r) >> 1;
    build(lc(id), l, m), build(rc(id), m + 1, r);
    st[id].merge(st[lc(id)], st[rc(id)]);
}
void segseg::upd(int y, int x, int v, int id = 1, int l = 1, int r = N) {
    if (l == r) {st[id].upd(x, v); return;}
    int m = (l + r) >> 1;
    if (y <= m) upd(y, x, v, rc(id), m + 1, r);
    else upd(y, x, v, lc(id), l, m);
    pull(id, x);
}
int segseg::qry(int y1, int y2, int x1, int x2, int id = 1, int l = 1, int r = N) {
    if (y1 <= l && r <= y2) return st[id].qry(x1, x2);
    int m = (l + r) >> 1, ret = -inf;
    if (y1 <= m) ret = max(ret, qry(y1, y2, x1, x2, lc(id), l, m));
    if (y2 > m) ret = max(ret, qry(y1, y2, x1, x2, rc(id), m + 1, r));
    return ret;
}

```

3.3 BIT

```

const int N = 2e5 + 5;
int n, a[N];

struct BIT { // 1-based
    ll bit1[N], bit2[N];
    ll sum(ll* bit, int x) {
        ll ret = 0;
        for (; x; x -= x & -x) ret += bit[x];
        return ret;
    }
    void upd(ll* bit, int x, ll v) {
        for (; x <= n; x += x & -x) bit[x] += v;
    }
    ll qry(int x) {
        return (x + 1) * sum(bit1, x) - sum(bit2, x);
    }
    ll qry(int l, int r) { // [l, r]
        return qry(r) - qry(l - 1);
    }
    void upd(int l, int r, ll v) { // [l, r]
        upd(bit1, l, v), upd(bit2, l, l * v);
        upd(bit1, r + 1, -v), upd(bit2, r + 1, (r + 1) * -v);
    }
    BIT() {
        fill_n(bit1, N, 0), fill_n(bit2, N, 0);
    }
    BIT(int* a) { // O(n) build
        fill_n(bit1, N, 0), fill_n(bit2, N, 0);
        for (int i = 1; i <= n; i++) bit1[i] = a[i] - a[i - (i & -i)];
        for (int i = n; i; i--) a[i] -= a[i - 1];
        for (int i = 1; i <= n; i++) a[i] = a[i - 1] + a[i] * i;
        for (int i = 1; i <= n; i++) bit2[i] = a[i] - a[i - (i & -i)];
    }
}

```

3.4 chtholly tree

```

// 存 {x, v} , 從 x 開始到下一個位置前都是v
map<int, int> s;
// [l, r)
void ins(int l, int r, int i) {
    auto it1 = s.find(l);
    auto it2 = s.find(r);
    for (auto it = it1; it != it2; it++) {
        }
    s.erase(it1, it2); // [it`, it2)
    s[l] = ;
}
void split(int pos) {
    auto it = s.lower_bound(pos);
    if (it == s.end() or it->pos) {
        s[pos] = prev(it)->v;
    }
}

```

3.5 LiChaoST

```

struct LiChao_min {
    struct line {
        LL m, c;
        line(LL _m = 0, LL _c = 0) {
            m = _m;
            c = _c;
        }
        LL eval(LL x) { return m * x + c; }
    };
    struct node {
        node *l, *r;
        line f;
        node(line v) {
            f = v;
            l = r = NULL;
        }
    };
    typedef node *pnode;
    pnode root;
    int sz;
#define mid ((l + r) >> 1)
    void insert(line &v, int l, int r, pnode &nd) {
        if (!nd) {
            nd = new node(v);
            return;
        }
        LL trl = nd->f.eval(l), trr = nd->f.eval(r);
        LL vl = v.eval(l), vr = v.eval(r);
        if (trl <= vl && trr <= vr) return;
        if (trl > vl && trr > vr) {
            nd->f = v;
            return;
        }
        if (trl > vl) swap(nd->f, v);
        if (nd->f.eval(mid) < v.eval(mid))
            insert(v, mid + 1, r, nd->r);
        else swap(nd->f, v), insert(v, l, mid, nd->l);
    }
    LL query(int x, int l, int r, pnode &nd) {
        if (!nd) return LLONG_MAX;
        if (l == r) return nd->f.eval(x);
        if (mid >= x)
            return min(
                nd->f.eval(x), query(x, l, mid, nd->l));
        return min(
            nd->f.eval(x), query(x, mid + 1, r, nd->r));
    }
/* -sz <= query_x <= sz */
void init(int _sz) {
    sz = _sz + 1;
    root = NULL;
}
void add_line(LL m, LL c) {
    line v(m, c);
    insert(v, -sz, sz, root);
}
LL query(LL x) { return query(x, -sz, sz, root); }
};

```

3.6 persistent

```

const int MAXN = 2e5 + 5;
int a[MAXN];
int sum[MAXN * 25], lc[MAXN * 25], rc[MAXN * 25];
int add_node() {
    static int now = 0;
    return ++now;
}
void pull(int x) {
    sum[x] = sum[lc[x]] + sum[rc[x]];
}
void init(int &x, int lx, int rx) {
    if (!x) x = add_node();
    if (lx + 1 == rx) return;
    int mid = (lx + rx) / 2;
    init(lc[x], lx, mid);
    init(rc[x], mid, rx);
}
void update(int fa, int &x, int lx, int rx, int i) {
    if (!x) x = add_node();
    if (lx + 1 == rx) return sum[x]++;
    int mid = (lx + rx) / 2;
    if (i < mid) {
        rc[x] = rc[fa];
    }
    else {
        lc[x] = lc[fa];
        update(rc[fa], rc[x], mid, rx, i);
    }
    pull(x);
}
int query(int x, int lx, int rx, int l, int r) {
    if (lx >= r or rx <= l) return 0;
    if (lx >= l and rx <= r) return sum[x];
    int mid = (lx + rx) / 2;
    return query(lc[x],
        lx, mid, l, r) + query(rc[x], mid, rx, l, r);
}

```

```

        update(lc[fa], lc[x], lx, mid, i);
    }
    else {
        lc[x] = lc[fa];
        update(rc[fa], rc[x], mid, rx, i);
    }
    pull(x);
}
int query(int x, int lx, int rx, int l, int r) {
    if (lx >= r or rx <= l) return 0;
    if (lx >= l and rx <= r) return sum[x];
    int mid = (lx + rx) / 2;
    return query(lc[x],
        lx, mid, l, r) + query(rc[x], mid, rx, l, r);
}

```

3.7 Sparse Table

```

const int N = 5e5 + 5, logN = __lg(N) + 1;
int a[N];
struct sparse_table { // 0-based
    int st[logN][N];
    void init(int n) {
        copy(a, a + n, st[0]);
        for (int i = 1; (1 << i) <= n; i++)
            for (int j = 0; j + (1 << i) - 1 <= n; j++)
                st[i][j] = max(st
                    [i - 1][j], st[i - 1][j + (1 << (i - 1))]);
    }
    int qry(int l, int r) {
        int k = __lg(r - l + 1);
        return max(st[k][l], st[k][r - (1 << k) + 1]);
    }
} st;
// st.init(n)
// st.qry(l - 1, r - 1)

```

3.8 Treap

```

#include <bits/stdc++.h>
using namespace std;
mt19937 rng;
struct node {
    node *l, *r;
    int v, p, s; bool t; // val, pri, size, tag
    void pull() {
        s = 1;
        for (auto x : {l, r})
            if (x) s += x->s;
    }
    void push() {
        if (t) {
            swap(l, r), t = 0;
            for (auto& x : {l, r})
                if (x) x->t ^= 1;
        }
    }
    node(int _v
        = 0): v(_v), p(rng()), s(1), t(0), l(0), r(0) {}
};
int sz(node* o) {return o ? o->s : 0;}
node* merge(node* a, node* b) {
    if (!a || !b) return a ? : b;
    if (a->p < b->p) return
        a->push(), a->r = merge(a->r, b), a->pull(), a;
    else return
        b->push(), b->l = merge(a, b->l), b->pull(), b;
}
void split(node
    *o, node*& a, node*& b, int k) { // a < k, b >= k
    if (!o) return a = b = nullptr, void();
    o->push();
    if (o->v < k) a = o, split(o->r, a->r, b, k);
    else b = o, split(o->l, a, b->l, k);
    o->pull();
}
void insert(node*& o, int k) {
    node *a, *b;
    split(
        o, a, b, k), o = merge(a, merge(new node(k), b));
}
void ssplit(node* o, node
    *&a, node*& b, int k) { // split first k things
    if (!o) return a = b = nullptr, void();
    o->push();
    if (sz(o->l) + 1 <= k
        ) a = o, ssplit(o->r, a->r, b, k - sz(o->l) - 1);
}

```

```

else b = o, ssplit(o->l, a, b->l, k);
o->pull();
}
void reverse(node* o, int l, int r) { // [l, r]
    node *a, *b, *c;
    ssplit(o, a, b, l - 1), ssplit(b, b, c, r - l + 1);
    b->t ^= 1, o = merge(a, merge(b, c));
}
/*
node* root = nullptr;
for (int i = 0; i < n; i++)
    root = merge(root, new node(x));
*/

```

3.9 ZKW Segment Tree

```

const int N = 5e5 + 5;
int a[N];

struct seg_tree { // 0-based
    int seg[N << 1], n;
    void upd(int x, int v) {
        for (seg[x += n] = v; x > 1; x >>= 1)
            seg[x >> 1] = max(seg[x], seg[x ^ 1]);
    }
    int qry(int l, int r) { // [ql, qr]
        int ret = -1e9;
        for (l += n, r += n + 1; l < r; l >>= 1, r >>= 1) {
            if (l & 1) ret = max(ret, seg[l++]);
            if (r & 1) ret = max(ret, seg[--r]);
        }
        return ret;
    }
    void init(int _n) {
        n = _n;
        copy(a, a + n, seg + n);
        for (int i = n - 1; i >= 0; i--)
            seg[i] = max(seg[i << 1], seg[i << 1 | 1]);
    }
} tree;
// tree.init(n)
// tree.qry(l - 1, r - 1)

```

4 Flow

4.1 Bipartite Matching

```

// O(E * sqrt(V))
struct Bipartite_Matching { // 0-base
    int l, r;
    int mp[MAXN], mq[MAXN];
    int dis[MAXN], cur[MAXN];
    vector<int> G[MAXN];
    bool dfs(int u) {
        for (int &i = cur[u]; i < SZ(G[u]); ++i) {
            int e = G[u][i];
            if (!~mq[e])
                || (dis[mq[e]] == dis[u] + 1 && dfs(mq[e])))
                    return mp[mq[e]] = u = e, 1;
        }
        dis[u] = -1;
        return 0;
    }
    bool bfs() {
        int rt = 0;
        queue<int> q;
        fill_n(dis, l, -1);
        for (int i = 0; i < l; ++i)
            if (!~mp[i])
                q.push(i), dis[i] = 0;
        while (!q.empty()) {
            int u = q.front();
            q.pop();
            for (int e : G[u])
                if (!~mq[e])
                    rt = 1;
                else if (!~dis[mq[e]]) {
                    q.push(mq[e]);
                    dis[mq[e]] = dis[u] + 1;
                }
        }
        return rt;
    }
    int matching() {
        int rt = 0;
        fill_n(mp, l, -1);
        fill_n(mq, r, -1);

```

```

        while (bfs()) {
            fill_n(cur, l, 0);
            for (int i = 0; i < l; ++i)
                if (!~mp[i] && dfs(i))
                    ++rt;
        }
        return rt;
    }
    void add_edge(int s, int t) {
        G[s].pb(t);
    }
    void init(int _l, int _r) {
        l = _l, r = _r;
        for (int i = 0; i < l; ++i)
            G[i].clear();
    }
}



## 4.2 Bounded Flow


// time complexity: same as Dinic
struct BoundedFlow { // 0-base
    struct edge {
        int to, cap, flow, rev;
    };
    vector<edge> G[N];
    int n, s, t, dis[N], cur[N], cnt[N];
    void init(int _n) {
        n = _n;
        for (int i = 0; i < n + 2; ++i)
            G[i].clear(), cnt[i] = 0;
    }
    void add_edge(int u, int v, int lcap, int rcap) {
        cnt[u] -= lcap, cnt[v] += lcap;
        G[u].pb(edge{v, rcap, lcap, SZ(G[v])});
        G[v].pb(edge{u, 0, 0, SZ(G[u]) - 1});
    }
    void add_edge(int u, int v, int cap) {
        G[u].pb(edge{v, cap, 0, SZ(G[v])});
        G[v].pb(edge{u, 0, 0, SZ(G[u]) - 1});
    }
    int dfs(int u, int cap) {
        if (u == t || !cap) return cap;
        for (int &i = cur[u]; i < SZ(G[u]); ++i) {
            edge &e = G[u][i];
            if (dis[e.to] == dis[u] + 1 && e.cap != e.flow) {
                int df = dfs(e.to, min(e.cap - e.flow, cap));
                if (df) {
                    e.flow += df, G[e.to][e.rev].flow -= df;
                    return df;
                }
            }
        }
        dis[u] = -1;
        return 0;
    }
    bool bfs() {
        fill_n(dis, n + 3, -1);
        queue<int> q;
        q.push(s), dis[s] = 0;
        while (!q.empty()) {
            int u = q.front();
            q.pop();
            for (edge &e : G[u])
                if (!~dis[e.to] && e.flow != e.cap)
                    q.push(e.to), dis[e.to] = dis[u] + 1;
        }
        return dis[t] != -1;
    }
    int maxflow(int _s, int _t) {
        s = _s, t = _t;
        int flow = 0, df;
        while (bfs()) {
            fill_n(cur, n + 3, 0);
            while ((df = dfs(s, INF))) flow += df;
        }
        return flow;
    }
    bool solve() {
        int sum = 0;
        for (int i = 0; i < n; ++i)
            if (cnt[i] > 0)
                add_edge(n + 1, i, cnt[i]), sum += cnt[i];
            else if (cnt[i] < 0) add_edge(i, n + 2, -cnt[i]);
        if (sum != maxflow(n + 1, n + 2)) sum = -1;
        for (int i = 0; i < n; ++i)
            if (cnt[i] > 0)

```

```

        G[n + 1].pop_back(), G[i].pop_back();
    else if (cnt[i] < 0)
        G[i].pop_back(), G[n + 2].pop_back();
    return sum != -1;
}
int solve(int _s, int _t) {
    add_edge(_t, _s, INF);
    if (!solve()) return -1; // invalid flow
    int x = G[_t].back().flow;
    return G[_t].pop_back(), G[_s].pop_back(), x;
}

```

4.3 Dinic

```

// O(V^2 * E)
// O(min(V^(2/3), E^(1/2)) * E) for unit graph (all cap are same)
// O(E * sqrt(V)) for bipartite matching
struct MaxFlow { // 0-base
    struct edge {
        int to, cap, flow, rev;
    };
    vector<edge> G[MAXN];
    int s, t, dis[MAXN], cur[MAXN], n;
    int dfs(int u, int cap) {
        if (u == t || !cap) return cap;
        for (int &i = cur[u]; i < (int)G[u].size(); ++i) {
            edge &e = G[u][i];
            if (dis[e.to] == dis[u] + 1 && e.flow != e.cap) {
                int df = dfs(e.to, min(e.cap - e.flow, cap));
                if (df) {
                    e.flow += df;
                    G[e.to][e.rev].flow -= df;
                    return df;
                }
            }
        }
        dis[u] = -1;
        return 0;
    }
    bool bfs() {
        fill_n(dis, n, -1);
        queue<int> q;
        q.push(s), dis[s] = 0;
        while (!q.empty()) {
            int tmp = q.front();
            q.pop();
            for (auto &u : G[tmp])
                if (!~dis[u.to] && u.flow != u.cap) {
                    q.push(u.to);
                    dis[u.to] = dis[tmp] + 1;
                }
        }
        return dis[t] != -1;
    }
    int maxflow(int _s, int _t) {
        s = _s, t = _t;
        int flow = 0, df;
        while (bfs()) {
            fill_n(cur, n, 0);
            while ((df = dfs(s, INF))) flow += df;
        }
        return flow;
    }
    void init(int _n) {
        n = _n;
        for (int i = 0; i < n; ++i) G[i].clear();
    }
    void reset() {
        for (int i = 0; i < n; ++i)
            for (auto &j : G[i]) j.flow = 0;
    }
    void add_edge(int u, int v, int cap) {
        G[u].pb(edge{v, cap, 0, (int)G[v].size()});
        G[v].pb(edge{u, 0, 0, (int)G[u].size() - 1});
    }
};

```

4.4 KM

```

// O(n^3), where n is the number
// of vertices on one side of the bipartite graph
// Finds
// the maximum weight matching in a bipartite graph
struct KM { // 0-base
    int w[MAXN][MAXN], hl[MAXN], hr[MAXN], slk[MAXN], n;

```

```

    int fl[MAXN], fr[MAXN], pre[MAXN], qu[MAXN], ql, qr;
    bool vl[MAXN], vr[MAXN];
    void init(int _n) {
        n = _n;
        for (int i = 0; i < n; ++i)
            for (int j = 0; j < n; ++j) w[i][j] = -INF;
    }
    void add_edge(int a, int b, int wei) {
        w[a][b] = wei;
    }
    bool Check(int x) {
        if (vl[x] == 1, ~fl[x])
            return vr[qu[qr++]] = fl[x] = 1;
        while (~x) swap(x, fr[fl[x] = pre[x]]);
        return 0;
    }
    void Bfs(int s) {
        fill(slk, slk + n, INF);
        fill(vl, vl + n, 0), fill(vr, vr + n, 0);
        ql = qr = 0, qu[qr++] = s, vr[s] = 1;
        while (1) {
            int d;
            while (ql < qr)
                for (int x = 0; x < n; ++x)
                    if (!vl[x] && slk[x] >= (d = hl[x] + hr[y] - w[x][y]))
                        if (pre[x] = y, d) slk[x] = d;
                    else if (!Check(x)) return;
            d = INF;
            for (int x = 0; x < n; ++x)
                if (!vl[x] && d > slk[x]) d = slk[x];
            for (int x = 0; x < n; ++x) {
                if (vl[x]) hl[x] += d;
                else slk[x] -= d;
                if (vr[x]) hr[x] -= d;
            }
            for (int x = 0; x < n; ++x)
                if (!vl[x] && !slk[x] && !Check(x)) return;
        }
    }
    int Solve() {
        fill(fl, fl + n, -1), fill(fr, fr + n, -1),
            fill(hr, hr + n, 0);
        for (int i = 0; i < n; ++i)
            hl[i] = *max_element(w[i], w[i] + n);
        for (int i = 0; i < n; ++i) Bfs(i);
        int res = 0;
        for (int i = 0; i < n; ++i) res += w[i][fl[i]];
        return res;
    }
};

```

4.5 Maximum Simple Graph Matching

```

// O(V^3), where V is the number of vertices
struct Matching { // 0-base
    queue<int> q; int n;
    vector<int> fa, s, vis, pre, match;
    vector<vector<int>> G;
    int Find(int u) {
        if (u == fa[u]) return u;
        return u == fa[u] ? u : fa[u] = Find(fa[u]);
    }
    int LCA(int x, int y) {
        static int tk = 0; tk++; x = Find(x); y = Find(y);
        for (;;) swap(x, y) if (x != n) {
            if (vis[x] == tk) return x;
            vis[x] = tk;
            x = Find(pre[match[x]]);
        }
    }
    void Blossom(int x, int y, int l) {
        for (; Find(x) != l; x = pre[y]) {
            pre[x] = y, y = match[x];
            if (s[y] == 1) q.push(y), s[y] = 0;
            for (int z : {x, y}) if (fa[z] == z) fa[z] = l;
        }
    }
    bool Bfs(int r) {
        iota(ALL(fa), 0); fill(ALL(s), -1);
        q = queue<int>(); q.push(r); s[r] = 0;
        for (; !q.empty(); q.pop()) {
            for (int x = q.front(); int u : G[x])
                if (s[u] == -1) {
                    if (pre[u] == x, s[u] = 1, match[u] == n) {
                        for (int a = u, b = x, last;
                            b != n; a = last, b = pre[a])
                            last =
                                match[b], match[b] = a, match[a] = b;
                    }
                }
        }
    }
};

```

```

        return true;
    }
    q.push(match[u]); s[match[u]] = 0;
} else if (!s[u] && Find(u) != Find(x)) {
    int l = LCA(u, x);
    Blossom(x, u, l); Blossom(u, x, l);
}
return false;
}
Matching(int _n) : n(_n), fa(n + 1), s(n + 1), vis
(n + 1), pre(n + 1, n), match(n + 1, n), G(n) {}
void add_edge(int u, int v)
{ G[u].pb(v), G[v].pb(u); }
int solve() {
    int ans = 0;
    for (int x = 0; x < n; ++x)
        if (match[x] == n) ans += Bfs(x);
    return ans;
} // match[x] == n means not matched
};

```

4.6 MCMF

```

// O(FE * logV), where F is
// the maximum flow, E is edges, and V is vertices.
struct MinCostMaxFlow { // 0-base
    struct Edge {
        ll from, to, cap, flow, cost, rev;
    } *past[N];
    vector<Edge> G[N];
    int inq[N], n, s, t;
    ll dis[N], up[N], pot[N];
    bool BellmanFord() {
        fill_n(dis, n, INF), fill_n(inq, n, 0);
        queue<int> q;
        auto relax = [&](int u, ll d, ll cap, Edge * e) {
            if (cap > 0 && dis[u] > d) {
                dis[u] = d, up[u] = cap, past[u] = e;
                if (!inq[u]) inq[u] = 1, q.push(u);
            }
        };
        relax(s, 0, INF, 0);
        while (!q.empty()) {
            int u = q.front();
            q.pop(), inq[u] = 0;
            for (auto &e : G[u]) {
                ll d2 = dis[u] + e.cost + pot[u] - pot[e.to];
                relax(e.to, d2, min(up[u], e.cap - e.flow), &e);
            }
        }
        return dis[t] != INF;
    }
    void solve(int _s
        , int _t, ll &flow, ll &cost, bool neg = true) {
        s = _s, t = _t, flow = 0, cost = 0;
        if (neg) BellmanFord(), copy_n(dis, n, pot);
        for (; BellmanFord(); copy_n(dis, n, pot)) {
            for (int i = 0; i < n; ++i) dis[i] += pot[i] - pot[s];
            flow += up[t], cost += up[t] * dis[t];
            for (int i = t; past[i]; i = past[i]->from) {
                auto &e = *past[i];
                e.flow += up[t], G[e.to][e.rev].flow -= up[t];
            }
        }
        init(_n);
        n = _n, fill_n(pot, n, 0);
        for (int i = 0; i < n; ++i) G[i].clear();
    }
    void add_edge(ll a, ll b, ll cap, ll cost) {
        G[a].pb(Edge{a, b, cap, 0, cost, SZ(G[b])});
        G[b].pb(Edge{b, a, 0, 0, -cost, SZ(G[a]) - 1});
    }
};

```

4.7 Minimum Vertex Cover

```

// O(VE)
struct Maximum_cardinality_matching {
    int n, k;
    int match[1005]; // right
    int vis[1005]; // left
    vector<int> adj[1005]; // left
    int dfs(int x) {

```

```

        vis[x] = 1;
        for (int i : adj[x]) {
            if (match[i] ==
                -1 || (!vis[match[i]] and dfs(match[i]))) {
                match[i] = x;
                return true;
            }
        }
        return false;
    }
    int paired[1005];
    int vis2[1005];
    void dfs2(int x) {
        vis[x] = 1;
        for (int i : adj[x]) {
            if (!vis2[i]) {
                vis2[i] = 1;
                dfs2(match[i]);
            }
        }
    }
    void matching() {
        fill(match + 1, match + 1 + k, -1);
        int res = 0;
        FOR (i, 1, k) {
            fill(vis + 1, vis + 1 + k, 0);
            res += dfs(i);
        }
        FOR (i, 1, k) {
            if (match[i] != -1) {
                paired[match[i]] = 1;
            }
        }
        fill(vis + 1, vis + 1 + k, 0);
        fill(vis2 + 1, vis2 + 1 + k, 0);
        FOR (i, 1, k) {
            if (!paired[i]) {
                dfs2(i);
            }
        }
        vector<int> a, b;
        FOR (i, 1, k) {
            if (!vis[i]) a.pb(i);
            if (vis2[i]) b.pb(i);
        }
        cout << SZ(a) << ' ' << SZ(b) << '\n';
        for (int i : a) cout << i << ' '; cout << '\n';
        for (int i : b) cout << i << ' '; cout << '\n';
        assert(SZ(a) + SZ(b) == res);
    }
}
```

4.8 Theorem

- Maximum Independent Set: A largest set of non-adjacent vertices.
- Maximum Matching: A largest set of edges with no shared vertices.
- Minimum Vertex Cover: A smallest set of vertices that covers all edges.
- Minimum Edge Cover: A smallest set of edges that covers all vertices.
- Maximum Clique: A largest complete subgraph.
- Properties:
 - $|\text{Maximum Matching}| = |\text{Minimum Vertex Cover}|$
 - $|\text{Maximum Matching}| + |\text{Minimum Edge Cover}| = |V|$
 - $|\text{Maximum Independent Set}| + |\text{Minimum Vertex Cover}| = |V|$
 - $|\text{Maximum Independent Set}| = |V| - |\text{Maximum Matching}|$
 - $|\text{Maximum Clique}| = |\text{Maximum Independent Set in the Complement Graph}|$

5 Geometry

5.1 Basic 2D

```

// Courtesy of Jinkela
const double PI = atan2(0.0, -1.0);
template<typename T>
struct point {
    T x, y;
    point() {}
    point(const T&x, const T&y): x(x), y(y) {}
    point operator+(const point &b) const {
        return point(x + b.x, y + b.y);
    }
    point operator-(const point &b) const {
        return point(x - b.x, y - b.y);
    }
    point operator*(const T &b) const {
        return point(x * b, y * b);
    }
    point operator/(const T &b) const {
        return point(x / b, y / b);
    }
}
```

```

bool operator==(const point &b) const {
    return x == b.x && y == b.y;
}
T dot(const point &b) const { return x * b.x + y * b.y; }
T cross(const point &b) const { return x * b.y - y * b.x; }
point normal() const { //求法向量
    return point(-y, x);
}
T abs2() const { return dot(*this); }
T rad(const point &b) const { //兩向量的弧度
    return fabs(atan2(fabs(cross(b)), dot(b)));
}
T getA() const { //對x軸的弧度
    T A = atan2(y, x); //超過180度會變負的
    if (A <= -PI / 2) A += PI * 2;
    return A;
}
};

template<typename T>
struct line {
    line() {}
    point<T> p1, p2;
    T a, b, c; //ax+by+c=0
    line(const point<T>&x, const point<T>&y): p1(x), p2(y) {}
    void pton() { //轉成一般式
        a = p1.y - p2.y;
        b = p2.x - p1.x; c = -a * p1.x - b * p1.y;
    }
    T ori(const point<T> &p) const
        { //點和有向直線的關係, >0左邊、=0在線上<0右邊
        return (p2 - p1).cross(p - p1);
    }
    T btw(const point<T> &p) const { //點投影落在線段上<=0
        return (p1 - p).dot(p2 - p);
    }
    bool point_on_segment(const point<T>&p) const {
        return ori(p) == 0 && btw(p) <= 0;
    }
    T dis2(const point<T> &p, bool
        is_segment = 0) const { //點跟直線/線段的距離平方
        point<T> v = p2 - p1, v1 = p - p1;
        if (is_segment) {
            point<T> v2 = p - p2;
            if (v.dot(v1) <= 0) return v1.abs2();
            if (v.dot(v2) >= 0) return v2.abs2();
        }
        T tmp = v.cross(v1); return tmp * tmp / v.abs2();
    }
    T seg_dis2(const line<T> &l) const { //兩線段距離平方
        return min({dis2(l.p1, 1),
                    dis2(l.p2, 1), l.dis2(p1, 1), l.dis2(p2, 1)});
    }
    point<T> projection
        (const point<T> &p) const { //點對直線的投影
        point<T> n = (p2 - p1).normal();
        return p - n * (p - p1).dot(n) / n.abs2();
    }
    point<T> mirror(const point<T> &p) const {
        //點對直線的鏡射, 要先呼叫pton轉成一般式
        point<T> R; T d = a * a + b * b;
        R.x = (b * b * p.x -
               a * a * p.x - 2 * a * b * p.y - 2 * a * c) / d;
        R.y = (a * a * p.y -
               b * b * p.y - 2 * a * b * p.x - 2 * b * c) / d;
        return R;
    }
    bool parallel(const line &l) const {
        return (p1 - p2).cross(l.p1 - l.p2) == 0;
    }
};

template<typename T>
struct polygon {
    polygon() {}
    vector<point<T>> p; //逆時針順序
    T double_signed_area() const {
        T ans = 0;
        for (int i = p.size() - 1, j = 0; j < (int)p.size(); i = j++)
            ans += p[i].cross(p[j]);
        return ans;
    }
};

```

```

point<T> center_of_mass() const {
    T cx = 0, cy = 0, w = 0;
    for (int i = p.size()
        () - 1, j = 0; j < (int)p.size(); i = j++) {
        T a = p[i].cross(p[j]);
        cx += (p[i].x + p[j].x) * a; cy += (p[i].y + p[j].y) * a;
        w += a;
    }
    return point<T>(cx / 3 / w, cy / 3 / w);
}

int ahas(const point<T>& t) const { //點是否在簡單多邊形
    是的話回傳1、在邊上回傳-1、否則回傳0
    int c = 0; //Works for clockwise input as well
    for (int i
        = 0, j = p.size() - 1; i < p.size(); j = i++) {
        if (line<
            T>(p[i], p[j]).point_on_segment(t)) return -1;
        if ((p[i].y > t.y) != (p[j].y > t.y)) {
            T L = (t.x - p[i].x) * (p[j].y - p[i].y);
            T R = (p[j].x - p[i].x) * (t.y - p[i].y);
            if (p[j].y < p[i].y) {L = -L; R = -R;}
            if (L < R)c = !c;
        }
    }
    return c;
}

int point_in_convex(const point<T>&x) const {
    int l = 1, r = (int)p.size() - 2;
    while (l <= r) { //點是否在凸多邊形
        多邊形是的話回傳1、在邊上回傳-1、否則回傳0
        int mid = (l + r) / 2;
        T a1 = (p[mid] - p[0]).cross(x - p[0]);
        T a2 = (p[mid + 1] - p[0]).cross(x - p[0]);
        if (a1 >= 0 && a2 <= 0) {
            T res
                = (p[mid + 1] - p[mid]).cross(x - p[mid]);
            return res > 0 ? 1 : (res >= 0 ? -1 : 0);
        }
        if (a1 < 0)r = mid - 1; else l = mid + 1;
    }
    return 0;
}

vector<T> getA() const { //凸包邊對x軸的夾角
    vector<T> res; //一定是遞增的
    for (size_t i = 0; i < p.size(); ++i)
        res.push_back
            ((p[(i + 1) % p.size()] - p[i]).getA());
    return res;
}

bool line_intersect(const vector<T>&A, const line<T> &l) const { //O(logN)
    int f1 = upper_bound(A.begin
        (), A.end(), (l.p1 - l.p2).getA()) - A.begin();
    int f2 = upper_bound(A.begin
        (), A.end(), (l.p2 - l.p1).getA()) - A.begin();
    return l.cross_seg(line<T>(p[f1], p[f2]));
}

T diam() {
    int n = p.size(), t = 1;
    T ans = 0; p.push_back(p[0]);
    for (int i = 0; i < n; i++) {
        point<T> now = p[i + 1] - p[i];
        while (now.cross(p[t + 1] - p[
            i]) > now.cross(p[t] - p[i]))t = (t + 1) % n;
        ans = max(ans, (p[i] - p[t]).abs2());
    }
    return p.pop_back(), ans;
}

T min_cover_rectangle() {
    int n = p.size(), t = 1, r = 1, l;
    if (n < 3) return 0; //也可以做最小周長矩形
    T ans = 1e99; p.push_back(p[0]);
    for (int i = 0; i < n; i++) {
        point<T> now = p[i + 1] - p[i];
        while (now.cross(p[t + 1] - p[
            i]) > now.cross(p[t] - p[i]))t = (t + 1) % n;
        while (now.dot(p[r + 1] -
            p[i]) > now.dot(p[r] - p[i]))r = (r + 1) % n;
        if (!i)l = r;
        while (now.dot(p[l + 1] - p[
            i]) <= now.dot(p[l] - p[i]))l = (l + 1) % n;
        T d = now.abs2();
        T tmp = now.cross(p[t] - p[i]) * (now.
            dot(p[r] - p[i]) - now.dot(p[l] - p[i])) / d;
        ans = min(ans, tmp);
    }
    return p.pop_back(), ans;
}

T dis2(polygon &pl) { //凸包最近距離平方

```

```

vector<point<T>> &P = p, &Q = pl.p;
int n = P.size(), m = Q.size(), l = 0, r = 0;
for (int i = 0; i < n; ++i) if (P[i].y < P[l].y) l = i;
for (int i = 0; i < m; ++i) if (Q[i].y < Q[r].y) r = i;
P.push_back(P[0]), Q.push_back(Q[0]);
T ans = 1e99;
for (int i = 0; i < n; ++i) {
    while ((P[l] - P[l + 1]).cross(Q[r + 1] - Q[r]) < 0) r = (r + 1) % m;
    ans = min(ans, line<T>(P[l], P[l + 1]).seg_dis2(line<T>(Q[r], Q[r + 1])));
    l = (l + 1) % n;
}
return P.pop_back(), Q.pop_back(), ans;
}
static int sign(const point<T>&t) {
    return (t.y ? t.y : t.x) < 0;
}
static bool
angle_cmp(const line<T>& A, const line<T>& B) {
    point<T> a = A.p2 - A.p1, b = B.p2 - B.p1;
    return sign(a) < sign(b) || (sign(a) == sign(b) && a.cross(b) > 0);
}
int halfplane_intersection(vector<line<T>> &s) {
    sort(s.begin()
        , s.end(), angle_cmp); // 半平面
    int L, R, n = s.size();
    vector<point<T>> px(n);
    vector<line<T>> q(n);
    q[L = R = 0] = s[0];
    for (int i = 1; i < n; ++i) {
        while (L < R && s[i].ori(px[R - 1]) <= 0) --R;
        while (L < R && s[i].ori(px[L]) <= 0) ++L;
        q[++R] = s[i];
        if (q[R].parallel(q[R - 1]) && q[--R].ori(s[i].p1) > 0) q[R] = s[i];
        if (L < R)
            px[R - 1] = q[R - 1].line_intersection(q[R]);
    }
    while (L < R && q[L].ori(px[R - 1]) <= 0) --R;
    px.clear();
    if (R - L <= 1) return 0;
    px[R] = q[R].line_intersection(q[L]);
    for (int i = L; i <= R; ++i) p.push_back(px[i]);
    return R - L + 1;
}

```

5.2 Convex Hull

```

#define f first
#define s second
#define ALL(x) (x).begin(), (x).end()
template <typename T>
pair<T, T> operator-
(const pair<T, T>& a, const pair<T, T>& b) {
    return {a.f - b.f, a.s - b.s};
}
template <typename T>
int cross(const pair<T,
    T>& o, const pair<T, T>& a, const pair<T, T>& b) {
    auto p = a - o, q = b - o;
    return p.f * q.s - q.f * p.s;
}
template <typename T>
vector<
    <pair<T, T>>> convex_hull(vector<pair<T, T>> hull) {
    if (hull.size() <= 2) return hull;
    sort(ALL(hull));
    vector<pair<T, T>> stk;
    int n = hull.size();
    for (int i = 0; i < n; i++) {
        while (stk.size() >= 2 && cross
            (stk.end()[-2], stk.end()[-1], hull[i]) <= 0)
            stk.pop_back();
        stk.push_back(hull[i]);
    }
    for (
        int i = n - 2, t = stk.size() + 1; i >= 0; i--) {
        while ((int)stk.size() >= t && cross
            (stk.end()[-2], stk.end()[-1], hull[i]) <= 0)
            stk.pop_back();
        stk.push_back(hull[i]);
    }
    return stk.pop_back(), stk;
}

```

| }

5.3 Dynamic Convex Hull

```

struct Line {
    ll a, b, l = MIN, r = MAX;
    Line(ll a, ll b): a(a), b(b) {}
    ll operator()(ll x) const {
        return a * x + b;
    }
    bool operator<(Line b) const {
        return a < b.a;
    }
    bool operator<(ll b) const {
        return r < b;
    }
};

ll ceil(ll a, ll b) {
    if (b < 0) a *= -1, b *= -1;
    if (a > 0) return (a + b - 1) / b;
    else return a / b;
}

ll intersect(Line a, Line b) {
    return ceil(a.b - b.b, b.a - a.a);
}

struct DynamicConvexHull {
    multiset<Line, less<>> ch;

    void add(Line ln) {
        auto it = ch.lower_bound(ln);
        while (it != ch.end()) {
            Line tl = *it;
            if (tl(tl.r) <= ln(tl.r)) {
                it = ch.erase(it);
            } else break;
        }
        auto it2 = ch.lower_bound(ln);
        while (it2 != ch.begin()) {
            Line tl = *prev(it2);
            if (tl(tl.l) <= ln(tl.l)) {
                it2 = ch.erase(prev(it2));
            } else break;
        }
        it = ch.lower_bound(ln);
        if (it != ch.end()) {
            Line tl = *it;
            if (tl(tl.l) >= ln(tl.l)) ln.r = tl.l - 1;
            else {
                ll pos = intersect(ln, tl);
                tl.l = pos;
                ln.r = pos - 1;
                ch.erase(it);
                ch.insert(tl);
            }
        }
        it2 = ch.lower_bound(ln);
        if (it2 != ch.begin()) {
            Line tl = *prev(it2);
            if (tl(tl.r) >= ln(tl.r)) ln.l = tl.r + 1;
            else {
                ll pos = intersect(tl, ln);
                tl.r = pos - 1;
                ln.l = pos;
                ch.erase(prev(it2));
                ch.insert(tl);
            }
        }
        if (ln.l <= ln.r) ch.insert(ln);
    }

    ll query(ll pos) {
        auto it = ch.lower_bound(pos);
        if (it == ch.end()) return 0;
        return (*it)(pos);
    }
};

int sign(ll x) {
    return (x > 0 ? 1 : (x < 0 ? -1 : 0));
}

```

5.4 Segmentation Intersection

```

ll cross
    (pair<ll, ll> o, pair<ll, ll> a, pair<ll, ll> b) {
        return (a.first - o.first) * (b.second - o.second)
            - (a.second - o.second) * (b.first - o.first);
    }

bool intersect1D(ll a, ll b, ll c, ll d) {
    if (a > b) swap(a, b);
    if (c > d) swap(c, d);
    return max(a, c) <= min(b, d);
}

bool intersect2D(pair<ll, ll> a
    , pair<ll, ll> b, pair<ll, ll> c, pair<ll, ll> d) {
    return
        intersect1D(a.first, b.first, c.first, d.first)
        && intersect1D
            (a.second, b.second, c.second, d.second)
        && sign(cross
            (a, b, c)) * sign(cross(a, b, d)) <= 0
        && sign(cross
            (c, d, a)) * sign(cross(c, d, b)) <= 0;
}

```

5.5 Theorem

- Pick's Theorem:
 - If a polygon has vertices with integer coordinates (lattice points), then the area is given by:

$$\text{Area}(P) = i + \frac{1}{2}p - 1$$

where i is the number of lattice points inside the polygon, and p is the number of lattice points on the perimeter of the polygon.

6 Math

6.1 Big Int

```

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

template<typename T>
inline string to_string(const T& x) {
    stringstream ss;
    return ss << x, ss.str();
}

using ll = long long;
struct bigN: vector<ll> {
    const static
        int base = 1000000000, width = log10(base);
    bool negative;
    bigN(const_iterator
        a, const_iterator b): vector<ll>(a, b) {}
    bigN(string s) {
        if (s.empty()) return;
        if (s[0] == '-') negative = 1, s = s.substr(1);
        else negative = 0;
        for (int
            i = int(s.size()) - 1; i >= 0; i -= width) {
            ll t = 0;
            for (int j = max(0, i - width + 1); j <= i; ++j)
                t = t * 10 + s[j] - '0';
            push_back(t);
        }
        trim();
    }
    template<typename T>
    bigN(const T &x): bigN(to_string(x)) {}
    bigN(): negative(0) {}
    void trim() {
        while (size() && !back()) pop_back();
        if (empty()) negative = 0;
    }
    void carry(int _base = base) {
        for (size_t i = 0; i < size(); ++i)
            if (at(i) >= 0 && at(i) < _base) continue;
            if (i + 1u == size()) push_back(0);
            int r = at(i) % _base;
            if (r < 0) r += _base;
            at(i + 1) += (at(i) - r) / _base;
            at(i) = r;
    }
    int abscmp(const bigN &b) const {
        if (size() > b.size()) return 1;
        if (size() < b.size()) return -1;

```

```

        for (int i = int(size()) - 1; i >= 0; --i) {
            if (at(i) > b[i]) return 1;
            if (at(i) < b[i]) return -1;
        }
        return 0;
    }
    int cmp(const bigN &b) const {
        if (negative
            != b.negative) return negative ? -1 : 1;
        return negative ? -abscmp(b) : abscmp(b);
    }
    bool operator
        <(const bigN&b) const {return cmp(b) < 0;}
    bool operator
        >(const bigN&b) const {return cmp(b) > 0;}
    bool operator
        ==(const bigN&b) const {return cmp(b) == 0;}
    bool operator
        >=(const bigN&b) const {return cmp(b) >= 0;}
    bool operator==(const bigN&b) const {return !cmp(b);}
    bool operator
        !=(const bigN&b) const {return cmp(b) != 0;}
    bigN abs() const {
        bigN res = *this;
        return res.negative = 0, res;
    }
    bigN operator-() const {
        bigN res = *this;
        return res.negative = !negative, res.trim(), res;
    }
    bigN operator+(const bigN &b) const {
        if (negative) return -(>(*this) + (-b));
        if (b.negative) return *this - (-b);
        bigN res = *this;
        if (b.size() > size()) res.resize(b.size());
        for (size_t
            i = 0; i < b.size(); ++i) res[i] += b[i];
        return res.carry(), res.trim(), res;
    }
    bigN operator-(const bigN &b) const {
        if (negative) return -(-(*this) - (-b));
        if (b.negative) return *this + (-b);
        if (abscmp(b) < 0) return -(b - (*this));
        bigN res = *this;
        if (b.size() > size()) res.resize(b.size());
        for (size_t
            i = 0; i < b.size(); ++i) res[i] -= b[i];
        return res.carry(), res.trim(), res;
    }
    bigN convert_base
        (int old_width, int new_width) const {
        vector<
            long long> p(max(old_width, new_width) + 1, 1);
        for (size_t
            i = 1; i < p.size(); ++i)p[i] = p[i - 1] * 10;
        bigN ans;
        long long cur = 0;
        int cur_id = 0;
        for (size_t i = 0; i < size(); ++i) {
            cur += at(i) * p[cur_id];
            cur_id += old_width;
            while (cur_id >= new_width) {
                ans.push_back(cur % p[new_width]);
                cur /= p[new_width];
                cur_id -= new_width;
            }
        }
        return ans.push_back(cur), ans.trim(), ans;
    }
    bigN karatsuba(const bigN &b) const {
        bigN res; res.resize(size() * 2);
        if (size() <= 32) {
            for (size_t i = 0; i < size(); ++i)
                for (size_t j = 0; j < size(); ++j)
                    res[i + j] += at(i) * b[j];
            return res;
        }
        size_t k = size() / 2;
        bigN a1(begin(), begin() + k);
        bigN a2(begin() + k, end());
        bigN b1(b.begin(), b.begin() + k);
        bigN b2(b.begin() + k, b.end());
        bigN a1b1 = a1.karatsuba(b1);
        bigN a2b2 = a2.karatsuba(b2);
        for (size_t i = 0; i < k; ++i)a2[i] += a1[i];
        for (size_t i = 0; i < k; ++i)b2[i] += b1[i];
    }

```

```

bigN r = a2.karatsuba(b2);
for (size_t i = 0; i < a1b1.size(); ++i)r[i] -= a1b1[i];
for (size_t i = 0; i < a2b2.size(); ++i)r[i] -= a2b2[i];
for (size_t i = 0; i < r.size(); ++i)res[i + k] += r[i];
for (size_t i = 0; i < a1b1.size(); ++i)res[i] += a1b1[i];
for (size_t i = 0; i < a2b2.size(); ++i)res[i + size()] += a2b2[i];
return res;
}
bigN operator*(const bigN &b) const {
const static int mul_base
    = 10000000, mul_width = log10(mul_base);
bigN A = convert_base(width, mul_width);
bigN B = b.convert_base(width, mul_width);
int n = max(A.size(), B.size());
while (n & (n - 1))++n;
A.resize(n), B.resize(n);
bigN res = A.karatsuba(B);
res.negative = negative != b.negative;
res.carry(mul_base);
res = res.convert_base(mul_width, width);
return res.trim(), res;
}
bigN operator*(long long b) const {
bigN res = *this;
if (b < 0)res.negative = !negative, b = -b;
for (size_t i = 0, is = 0; i < res.size() || is; ++i) {
    if (i == res.size()) res.push_back(0);
    long long a = res[i] * b + is;
    is = a / base;
    res[i] = a % base;
}
return res.trim(), res;
}
bigN operator/(const bigN &b) const {
int norm = base / (b.back() + 1);
bigN x = abs() * norm;
bigN y = b.abs() * norm;
bigN q, r;
q.resize(x.size());
for (int i = int(x.size()) - 1; i >= 0; --i) {
    r = r * base + x[i];
    int s1 = r.size() <= y.size() ? 0 : r[y.size()];
    int s2
        = r.size() < y.size() ? 0 : r[y.size() - 1];
    int d = (ll(base) * s1 + s2) / y.back();
    r = r - y * d;
    while (r.negative) r = r + y, --d;
    q[i] = d;
}
q.negative = negative != b.negative;
return q.trim(), q;
}
bigN operator%(const bigN &b) const {
return *this - (*this / b) * b;
}
friend istream& operator>>(istream &ss, bigN &b) {
string s;
return ss >> s, b = s, ss;
}
friend
ostream& operator<<(ostream &ss, const bigN &b) {
if (b.negative) ss << '-';
ss << (b.empty() ? 0 : b.back());
for (int i = int(b.size()) - 2; i >= 0; --i)
    ss << setw(width) << setfill('0') << b[i];
return ss;
}
template<typename T>
operator T() {
stringstream ss;
ss << *this;
T res;
return ss >> res, res;
}
};

```

6.2 Chinese Remainder

```

int solve(int n, vector<int> &a, vector<int> &m){
    int M = 1;
    for (auto i : m) M *= i;
}
```

```

int ans = 0;
for (int i = 0; i < n; i++) {
    int m1 = M / m[i], m2 = extgcd(m1, m[i]).X;
    ans += (a[i] * m1 * m2) % M;
}
ans = ans % M + M;
ans %= M;
return ans;
}
```

6.3 Extgcd

```

pair<ll, ll> extgcd(ll a, ll b) {
if (b == 0) return {1, 0};
auto [xp, yp] = extgcd(b, a % b);
return {yp, xp - a / b * yp};
}
```

6.4 FFT

```

// Remember not to output -0
/*
polynomial multiply:
DFT(a, len); DFT(b, len);
for (int i=0;i<len;i++) c[i] = a[i]*b[i];
iDFT(c, len);
(len must be 2^k and >= 2*(max(a, b)))
Hand written Cplx would be 2x faster
*/
Cplx omega[2][N];
void init_omega(int n) {
    static constexpr llf PI = acos(-1);
    const llf arg = (PI + PI) / n;
    for (int i = 0; i < n; ++i)
        omega[0][i] = {cos(arg * i), sin(arg * i)};
    for (int i = 0; i < n; ++i)
        omega[1][i] = conj(omega[0][i]);
}
void tran(Cplx arr[], int n, Cplx omg[]) {
    for (int i = 0, j = 0; i < n; ++i) {
        if (i > j)swap(arr[i], arr[j]);
        for (int l = n >> 1; (j ^= l) < l; l >>= 1);
    }
    for (int l = 2; l <= n; l <= 1) {
        int m = l >> 1;
        for (auto p = arr; p != arr + n; p += l) {
            for (int i = 0; i < m; ++i) {
                Cplx t = omg[n / l * i] * p[m + i];
                p[m + i] = p[i] - t; p[i] += t;
            }
        }
    }
}
void DFT(Cplx arr[], int n) {tran(arr, n, omega[0]);}
void iDFT(Cplx arr[], int n) {
    tran(arr, n, omega[1]);
    for (int i = 0; i < n; ++i) arr[i] /= n;
}
```

6.5 Gauss Elimination

```

#include <bits/stdc++.h>

std::bitset<1000> a[500];

int main() {
    int n; std::cin >> n;
    for (int i = 0; i < n; ++i) {
        for (int j = 0, t; j < n; ++j)
            std::cin >> t, a[i][j] = t;
        a[i][i + n] = 1;
    }
    for (int i = 0; i < n; ++i) {
        int t;
        for (t = i; t < n; ++t) if (a[t][i]) break;
        if (t == n) return std::cout << "-1\n", 0;
        std::swap(a[i], a[t]);
        for (int j
            = i + 1; j < n; ++j) if (a[j][i]) a[j] ^= a[i];
    }
    for (int i = n - 1; i >= 0; --i)
        for (int j = i - 1; j >= 0; --j)
            if (a[j][i]) a[j] ^= a[i];
    for (int i = 0; i < n; ++i) {
        std::vector<int> ans;
        for (int j = n; j < 2 *
            n; ++j) if (a[i][j]) ans.push_back(j - n + 1);
    }
}
```

```

    for (size_t j = 0; j < ans.size(); ++j)
        std::cout << ans[j] << "\n"[j == ans.size()];
}
return 0;
}

```

6.6 Gauss Elimination2

```

using ll = long long;
const ll mod = 998244353;
ll fp(ll a, ll b) {
    ll ret = 1;
    for (; b; b >>= 1, a = a * a % mod)
        if (b & 1) ret = ret * a % mod;
    return ret;
}
vector<ll> gauss_elimination
{
    (vector<vector<ll>>& a) { // n * (n+1)
// if a[i][j] < 0, a[i][j] += mod
        int n = a.size();
        bool swp = 0;
        for (int i = 0; i < n; i++) {
            for (int k = i; k < n; k++) {
                if (a[i][k] == 0 && a[k][i] != 0) {
                    swap(a[i], a[k]), swp ^= 1; // det = -det
                    break;
                }
            }
            if (a[i][i] == 0) return {};
        }
        ll inv = fp(a[i][i], mod - 2);
        for (int j = 0; j < n; j++) {
            if (i != j) {
                ll tmp = a[j][i] * inv % mod;
                for (int k = i; k <= n; k++)
                    a[j][k] = (a[j][k] - tmp * a[i][k] % mod + mod) % mod;
            }
        }
    }
    // general solution
    vector<ll> ans(n);
    for (int i = 0; i < n; i++)
        ans[i] = a[i][n] * fp(a[i][i], mod - 2) % mod;
    return ans;
}
// det
// ll ret = 1;
// for (
//     int i = 0; i < n; i++) ret = ret * a[i][i] % mod;
// return swp ? mod - ret : ret;
}

```

6.7 Karatsuba

```

const ll base = 10000000;
void karatsuba(const vector<ll>
    & f, const vector<ll>& g, vector<ll>& c, int n) {
    if (n <= 32) {
        for (int i = 0; i < n; i++)
            for (int j = 0; j < n; j++)
                c[i + j] += f[i] * g[j];
        return;
    }
    vector<ll> f1(n / 2), f2(n / 2), g1(n / 2), g2(n / 2);
    copy(f.begin(), f.begin() + n / 2, f1.begin())
        , copy(f.begin() + n / 2, f.end(), f2.begin());
    copy(g.begin(), g.begin() + n / 2, g1.begin())
        , copy(g.begin() + n / 2, g.end(), g2.begin());
    vector<ll> t1(n), t2(n), t3(n);
    karatsuba(
        f1, g1, t1, n / 2), karatsuba(f2, g2, t2, n / 2);
    for (int i = 0; i < n / 2; i++) f1[i] += f2[i];
    for (int i = 0; i < n / 2; i++) g1[i] += g2[i];
    karatsuba(f1, g1, t3, n / 2);
    for (int i = 0; i < n; i++) t3[i] -= t1[i] + t2[i];
    for (int i = 0; i < n; i++)
        c[i] += t1
            [i], c[i + n] += t2[i], c[i + n / 2] += t3[i];
}
void mul(const vector<ll>& a, const vector<ll>& b, vector<ll>& c) {
    int n = a.size(), m = b.size(), t = max(n, m), p = 1;
    while (p < t) p <= 1;
    vector<ll> aa(p), bb(p);
    copy(a.begin(), a.end(), aa
        .begin()), copy(b.begin(), b.end(), bb.begin());
    c.assign(p <= 1, 0), karatsuba(aa, bb, c, p);
}

```

```

    p = n + m - 1;
    for (int i = 0; i < p; i++)
        c[i + 1] += c[i] / base, c[i] %= base;
    if (c[p]) p++;
    c.resize(p);
}

```

6.8 Linear Sieve

```

vector<bool> isp;
vector<int> p;
void sieve(int n) {
    p.clear(), isp.assign(n + 1, 1);
    isp[0] = isp[1] = 0;
    for (int i = 2; i <= n; i++) {
        if (isp[i]) p.push_back(i);
        for (const auto& x : p) {
            if (1LL * i * x > n) break;
            isp[i * x] = 0;
            if (i % x == 0) break;
        }
    }
}

```

6.9 Matrix

```

template <typename T> using vec = vector<T>;
template <typename T> using matrix = vec<vec<T>>;
constexpr int mod = 1e9 + 7;
template <typename T>
matrix<T>
operator*(const matrix<T>& a, const matrix<T>& b) {
    int n = a.size(), r = b.size(), m = b.front().size();
    matrix<T> ret(n, vec<T>(m));
    for (int i = 0; i < n; i++)
        for (int j = 0; j < m; j++)
            for (int k = 0; k < r; k++)
                ret[i][j] += 1LL *
                    a[i][k] * b[k][j] % mod, ret[i][j] %= mod;
    return ret;
}

```

6.10 Miller Rabin

```

using ll = ll;
ll mod_mul(ll a, ll b, ll m) {
    a %= m, b %= m;
    ll y = (ll)((
        double)a * b / m + 0.5); /* fast for m < 2^58 */
    ll r = (a * b - y * m) % m;
    return r < 0 ? r + m : r;
}
template<typename T>
T pow(T a, T b, T mod) { // a^b % mod
    T ans = 1;
    for (; b; a = mod_mul(a, a, mod), b >>= 1)
        if (b & 1) ans = mod_mul(ans, a, mod);
    return ans;
}
int sprp[3] = {2, 7, 61}; // range of int
int ll_sprp[7] = {2, 325, 9375, 28178, 450775,
    9780504, 1795265022}; // range of unsigned ll
template<typename T>
bool isprime(T n, int *sprp, int num) {
    if (n == 2) return 1;
    if (n < 2 || n % 2 == 0) return 0;
    int t = 0;
    T u = n - 1;
    for (; u % 2 == 0; ++t) u >>= 1;
    for (int i = 0; i < num; ++i) {
        T a = sprp[i] % n;
        if (a == 0 || a == 1 || a == n - 1) continue;
        T x = pow(a, u, n);
        if (x == 1 || x == n - 1) continue;
        for (int j = 1; j < t; ++j) {
            x = mod_mul(x, x, n);
            if (x == 1) return 0;
            if (x == n - 1) break;
        }
        if (x == n - 1) continue;
        return 0;
    }
    return 1;
}

```

6.11 Möbius

```
int mu[MAXN], lp[MAXN];
void build() {
    mu[1] = 1;
    FOR (i, 2, MAXN - 1) {
        if (!lp[i]) {
            for (int j = i; j < MAXN; j += i) {
                lp[j] = i;
            }
            if (i / lp[i] % lp[i])
                mu[i] = -mu[i / lp[i]];
        }
    }
}
```

6.12 NTT

```
const int G = 3, P = 998244353;
const int sval = 100, split = log10(sval);
int fpow(int x, int y) {
    int ret = 1;
    for (; y >= 1, x = 1LL * x * x % P)
        if (y & 1) ret = 1LL * ret * x % P;
    return ret;
}
void ntt(vector<int>& x, int lim, int opt) {
    for (int i = 1, j = 0; i < lim; i++) {
        for (int k = lim >> 1; !(j ^= k) & k; k >>= 1);
        if (i < j) swap(x[i], x[j]);
    }
    for (int m = 2; m <= lim; m <= 1) {
        int k = m >> 1;
        int gn = fpow(G, (P - 1) / m);
        for (int i = 0; i < lim; i += m) {
            int g = 1;
            for (int
                j = 0; j < k; ++j, g = 1LL * g * gn % P) {
                int tmp = 1LL * x[i + j + k] * g % P;
                x[i + j + k] = (x[i + j] - tmp + P) % P;
                x[i + j] = (x[i + j] + tmp) % P;
            }
        }
        if (opt == -1) {
            reverse(x.begin() + 1, x.begin() + lim);
            int inv = fpow(lim, P - 2);
            for (int i = 0; i < lim; ++i)
                x[i] = 1LL * x[i] * inv % P;
        }
    }
    vector<int> mul(vector<int> a, vector<int> b) {
        int lim = 1, n = a.size(), m = b.size();
        while (lim < (n + m - 1)) lim <= 1;
        a.resize(lim + 1), b.resize(lim + 1);
        ntt(a, lim, 1), ntt(b, lim, 1);
        for (int i = 0; i < lim; ++i)
            a[i] = 1LL * a[i] * b[i] % P;
        ntt(a, lim, -1);
        int len = 0;
        for (int i = 0; i < lim; ++i) {
            if (a[i] >= sval) len
                = i + 1, a[i + 1] += a[i] / sval, a[i] %= sval;
            if (a[i]) len = max(len, i);
        }
        while (a[len] >= sval) a[
            len + 1] += a[len] / sval, a[len] %= sval, len++;
        return a.resize(len + 1), a;
    }
    void print(const vector<int>& v) {
        if (!v.size()) return;
        cout << v.back();
        for (int i = v.size() - 2; ~i; --i)
            cout << setfill('0') << setw(split) << v[i];
        cout << '\n';
    }
    int main() {
        ios::sync_with_stdio(false), cin.tie(nullptr);
        string stra, strb;
        while (cin >> stra >> strb) {
            vector<int> a((stra.size() + split - 1) / split);
            vector<int> b((strb.size() + split - 1) / split);
            int tmp = stra.size();
            for (auto& i : a)
                tmp -= split, i = atoi(stra.substr(max
                    (0, tmp), min(split, split + tmp)).data());
            tmp = strb.size();
            for (auto& i : b)
                tmp -= split, i = atoi(strb.substr(max
                    (0, tmp), min(split, split + tmp)).data());
        }
    }
}
```

```
for (auto& i : b)
    tmp -= split, i = atoi(strb.substr(max
        (0, tmp), min(split, split + tmp)).data());
    print(mul(a, b));
}
return 0;
}
```

6.13 Pollard Rho

```
// does not work when n is prime
ll add(ll
    a, ll b, ll m) {return (a += b) > m ? a - m : a;}
ll mul(ll a, ll b, ll m) {
    a %= m, b %= m;
    ll y = (ll)((
        double)a * b / m + 0.5); /* fast for m < 2^58 */
    ll r = (a * b - y * m) % m;
    return r < 0 ? r + m : r;
}
ll f(ll
    x, ll mod) {return add(mul(x, x, mod), 1, mod);}
ll pollard_rho(ll n) {
    if (!(n & 1)) return 2;
    while (true) {
        ll y =
            2, x = rand() % (n - 1) + 1, res = 1, tmp = 1;
        for (int sz = 2; res == 1; sz *= 2, y = x) {
            for (int
                i = 0, t = 0; i < sz && res <= 1; i++, t++) {
                x = f(x, n); tmp = mul(tmp, abs(x - y), n);
                if (!(t & 31) ||
                    i + 1 == sz) res = __gcd(tmp, n), tmp = 1;
            }
            if (res != 0 && res != n) return res;
        }
    }
}
```

6.14 Primes

```
/* 12721 13331 14341 75577 123457 222557
556679 999983 1097774749 1076767633 100102021
999997771 1001010013 1000512343 987654361 999991231
999888733 98789101 98777733 999991921 1010101333
1010102101 1000000000039 1000000000000037
2305843009213693951 4611686018427387847
9223372036854775783 18446744073709551557 */
```

6.15 Primitive Root

```
// g is O(log^6 n).
// Runtime is O(ans * log
//     phi(n) * log n), which is approximately O(log^8 n).
// #define int long long
int fp(int a, int b, int p) {
    int ret = 1;
    for (; b; b >>= 1, a = a * a % m)
        if (b & 1) ret = ret * a % m;
    return ret;
}

int generator(int p) {
    vector<int> fact;
    int phi = p - 1, n = phi;
    for (int i = 2; i * i <= n; ++i)
        if (n % i == 0) {
            fact.push_back(i);
            while (n % i == 0) n /= i;
        }
    if (n > 1) fact.push_back (n);

    for (int res = 2; res <= p; ++res) {
        bool ok = true;
        for (size_t i = 0; i < fact.size() && ok; ++i)
            ok &= fp(res, phi / fact[i], p) != 1;
        if (ok) return res;
    }
    return -1;
}
```

7 String

7.1 AC

```
struct ACautomata {
    struct Node {
        int cnt;
```

```

Node *go[26], *fail, *dic;
Node () {
    cnt = 0, fail = 0, dic = 0;
    memset(go, 0, sizeof(go));
}
pool[1048576], *root;
int nMem;
Node* new_Node() {
    pool[nMem] = Node();
    return &pool[nMem++];
}
void init() { nMem = 0, root = new_Node(); }
void add(const string &str) { insert(root, str, 0); }
void insert(Node *cur, const string &str, int pos) {
    for (int i = pos; i < str.size(); i++) {
        if (!cur->go[str[i] - 'a'])
            cur->go[str[i] - 'a'] = new_Node();
        cur = cur->go[str[i] - 'a'];
    }
    cur->cnt++;
}
void make_fail() {
    queue<Node*> que;
    que.push(root);
    while (!que.empty()) {
        Node* fr = que.front(); que.pop();
        for (int i = 0; i < 26; i++) {
            if (fr->go[i]) {
                Node *ptr = fr->fail;
                while (ptr && !ptr->go[i]) ptr = ptr->fail;
                fr->go[i] = ptr = (ptr ? ptr->go[i] : root);
                fr->go[i]->dic = (ptr->cnt ? ptr : ptr->dic);
                que.push(fr->go[i]);
            }
        }
    }
}
} AC;

```

7.2 Hash

```

struct Hash {
    vector<ll> h;
    vector<ll> f;
    Hash(string s, int p = 127) {
        h.assign((int)s.size() + 1, 0);
        f.assign((int)s.size() + 1, 0);
        f[0] = 1;
        for (int i = 1; i <= (int)s.size(); ++i) f[i] = f[i - 1] * p % MOD;
        for (int i = 1; i <= (int)s.size(); ++i)
            h[i] = (h[i - 1] * p + s[i - 1]) % MOD;
    }
    int query(int l, int r) { // 0-based [l, r]
        if (r < l) return 0;
        return ((h[r + 1] - h[l] * f[r - l + 1]) % MOD + MOD) % MOD;
    }
};

```

7.3 KMP

```

#define pb push_back
const int N = 1e6 + 5;
int F[N];
vector<int> match(string A, string B) {
    vector<int> ans;
    F[0] = -1, F[1] = 0;
    for (int i = 1, j = 0; i < (int)B.size(); F[++i] = ++j) {
        if (B[i] == B[j]) F[i] = F[j]; // optimize
        while (j != -1 && B[i] != B[j]) j = F[j];
    }
    for (int i = 0, j = 0; i < (int)A.size(); ++i) {
        while (j != -1 && A[i] != B[j]) j = F[j];
        if (++j == (int)B.size()) ans.pb(i + 1 - j), j = F[j];
    }
    return ans;
}

```

7.4 Manacher

```

// P[2i] := max 2j+1: s[i-j, i+j] is palindromic
// P[2i-1] := max 2j: s[i-j, i+j] is palindromic
// maximal
    palindrome: s.substr((1 + i - P[i]) >> 1, P[i])

```

```

vector<unsigned> Manacher(const string &s) {
    unsigned L = 0, R = 1;
    vector<unsigned> P; P.reserve((s.size() << 1) - 1);
    P.push_back(1);
    for (unsigned i = 1; i < s.size(); ++i)
        for (int j = 0; j < 2; ++j) {
            if (i < R) {
                const int k = ((L + R - i) << 1) - j - 1;
                if (P[k] >> 1 < R - i - j) { P.push_back(P[k]); continue; }
                L = (i << 1) - R + j;
            }
            else R = (L = i) + j;
            while (L > 0 && R < s.size() && s[L - 1] == s[R]) { --L; ++R; }
            P.push_back(R - L);
        }
    return P;
}

```

7.5 SA

```

const int N = 2e5 + 5;

string s;
int sa[N], tmp[2][N], c[N], rk[N], h[N];
// lcp(sa[i], sa[j]) = min{h[k]} where i <= k <= j

void suffix_array() {
    int *x = tmp[0], *y = tmp[1], m = 256, n = s.size();
    fill(c, c + m, 0);
    for (int i = 0; i < n; i++) c[x[i]] = s[i]++;
    partial_sum(c, c + m, c);
    for (int i = n - 1; i >= 0; i--) sa[--c[x[i]]] = i;
    for (int k = 1; k < n; k <= m) {
        fill(c, c + m, 0);
        for (int i = 0; i < n; i++) c[x[i]]++;
        partial_sum(c, c + m, c);
        int p = 0;
        for (int i = n - k; i < n; i++) y[p++] = i;
        for (int i = 0; i < n; i++)
            if (sa[i] >= k) y[p++] = sa[i] - k;
        for (int i = n - 1; i >= 0; i--) sa[--c[x[y[i]]]] = y[i];
        y[sa[0]] = p = 0;
        for (int i = 1; i < n; i++) {
            int a = sa[i], b = sa[i - 1];
            if (x[a] != x[b] || a + k >= n || b + k >= n || x[a + k] != x[b + k]) p++;
            y[sa[i]] = p;
        }
        if (n == p + 1) break;
        swap(x, y), m = p + 1;
    }
}

void LCP() {
    int n = s.size(), val = 0;
    for (int i = 0; i < n; i++) rk[sa[i]] = i;
    for (int i = 0; i < n; i++) {
        if (rk[i] == 0) h[rk[i]] = 0;
        else {
            if (val) val--;
            int p = sa[rk[i] - 1];
            while (val + i < n && val + p < n && s[val + i] == s[val + p]) val++;
            h[rk[i]] = val;
        }
    }
}
// cin >> s, suffix_array(), LCP();

```

7.6 SA2

```

void counting_sort
    (vector<int> &dest, const vector<int> &src
     , int bucket_count, function<int(const int&)> f) {
    int *bucket_begin = new int[bucket_count];
    int buf[bucket_count], *buf = new int[src.size()];
    fill(bucket_begin, bucket_begin + bucket_count, 0);
    for (int i = 0; i < src.size(); ++i)
        if ((buf[i] = f(src[i])) + 1 < bucket_count)
            ++bucket_begin[buf[i] + 1];
    partial_sum(bucket_begin
               , bucket_begin + bucket_count, bucket_begin);
    dest.resize(src.size());
    for (int i = 0; i < src.size(); ++i)

```

```

    dest[bucket_begin[buf[i]]++] = src[i];
    delete[] bucket_begin; delete[] buf;
}
#define
    a 'a' // The smallest character in the alphabet
#define sz 26 // The
        size of the alphabet. The alphabet is [a, a + sz)
vector<int> suffix_array(const string &s) {
    vector<int> SA, sa(s.size());
    SA.reserve(s.size()); iota(sa.begin(), sa.end(), 0);
    counting_sort(SA,
        sa, sz, [&](const int &i) { return s[i] - a; });
    int *R = new int[SA.size()], *r = new int[SA.size()];
    R[SA[0]] = 1; // R = 0 is reserved for the empty string
    for (int i = 1; i < SA.size(); ++i)
        R[SA[i]] = s[SA[i]] == s[SA[i - 1]] ? R[SA[i - 1]] : i + 1;
    int L = 1;
    while (L < s.size()) {
        auto R2 = [&](const int &i) {
            if (i + L < SA.size()) return R[i + L];
            return 0; // so
                that when L = 1, "a" is ordered before "aa"
        };
        counting_sort(sa, SA, SA.size() + 1, R2);
        counting_sort(SA, sa, SA.size()
            (), [&](const int &i) { return R[i] - 1; });
        r[SA[0]] = 1;
        for (int i = 1; i < SA.size(); ++i)
            if (R[SA[i]] ==
                R[SA[i - 1]] && R2(SA[i]) == R2(SA[i - 1]))
                r[SA[i]] = r[SA[i - 1]];
            else r[SA[i]] = i + 1;
        swap(R, r); L <= 1;
    }
    delete[] R; delete[] r; return SA;
}
#undef a
#undef sz

```

7.7 SAIS

```

const int N = 300010;
struct SA {
#define REP(i,n) for(int i=0;i<int(n);i++)
#define REP1(i,a,b) for(int i=(a);i<=int(b);i++)
    bool _t[N * 2]; int _s[N * 2], _sa[N * 2];
    int _c[N * 2], x[N], _p[N], _q[N * 2], hei[N], r[N];
    int operator [] (int i) { return _sa[i]; }
    void build(int *s, int n, int m) {
        memcpy(_s, s, sizeof(int)*n);
        sais(_s, _sa, _p, _q, _t, _c, n, m); mkhei(n);
    }
    void mkhei(int n) {
        REP(i, n) r[_sa[i]] = i;
        hei[0] = 0;
        REP(i, n) if (r[i]) {
            int ans = i > 0 ? max(hei[r[i - 1]] - 1, 0) : 0;
            while (_s
                [i + ans] == _s[_sa[r[i] - 1] + ans]) ans++;
            hei[r[i]] = ans;
        }
    }
    void sais(int *s, int *sa,
        int *p, int *q, bool *t, int *c, int n, int z) {
        bool uniq = t[n - 1] = true, neq;
        int nn = 0, nmxz
            = -1, *nsa = sa + n, *ns = s + n, lst = -1;
#define MS0(x,n) memset((x),0,n*sizeof(*x))
#define MAGIC(XD) MS0(sa,n);\n
        memcpy(x,c,sizeof(int)*z); XD;\n
        memcpy(x+1,c,sizeof(int)*(z-1));\n
        REP(i,n) if
            (sa[i]&&!t[sa[i]-1]) sa[x[s[sa[i]-1]]++]=sa[i]-1;\n
        memcpy(x,c,sizeof(int)*z);\n
        for(int i=n-1;i>=0;i--)
            if(sa[i]&&t[sa[i]-1]) sa[--x[s[sa[i]-1]]]=sa[i]-1;\n
        MS0(c, z); REP(i, n) uniq &= ++c[s[i]] < 2;
        REP(i, z - 1) c[i + 1] += c[i];
        if (uniq) { REP(i, n) sa[--c[s[i]]] = i; return; }
        for (int i = n - 2; i >= 0; i--)
            t[i] = (s[
                i] == s[i + 1] ? t[i + 1] : s[i] < s[i + 1]);
        MAGIC(REP1(i, 1, n - 1) if (t[i] &&
            !t[i - 1]) sa[--x[s[i]]] = p[q[i] = nn++ = i];
        REP(i, n) if (sa[i] && t[sa[i]] && !t[sa[i] - 1]) {

```

```

            neq = lst < 0 || memcmp(s + sa[i], s + lst
                , (p[q[sa[i]] + 1] - sa[i]) * sizeof(int));
            ns[q[lst = sa[i]]] = nmxz += neq;
        }
        sais(ns, nsa
            , p + nn, q + n, t + n, c + z, nn, nmxz + 1);
        MAGIC(for (int i = nn - 1; i
            >= 0; i--) sa[--x[s[p[nsa[i]]]]] = p[nsa[i]]);
    }
    } sa;
    int H[N], SA[N], RA[N];
    void suffix_array(int* ip, int len) {
        // should padding a zero in the back
        // ip is int array, len is array length
        // ip[0..n-1] != 0, and ip[len]=0
        ip[len++] = 0; sa.build(ip, len, 128);
        memcpy(H, sa.hei
            + 1, len << 2); memcpy(SA, sa._sa + 1, len << 2);
        for (int i = 0; i < len; i++) RA[i] = sa.r[i] - 1;
        // resulting height, sa array \in [0,len)
    }
}
```

7.8 Suffix Automaton

```

// O(n)
// find all suffix substrings in lexicographical order
#include <bits/stdc++.h>
class SuffixAutomaton {
public:
    static const int MAXN = 500 << 1;
    static const int MAXC = 26;
    struct Node {
        Node *next[MAXC], *pre;
        int step;
        Node() {
            pre = NULL, step = 0;
            memset(next, 0, sizeof(next));
        }
    } _mem[MAXN];
    int size;
    Node *root, *tail;
    void init() {
        size = 0;
        root = tail = newNode();
    }
    Node* newNode() {
        Node *p = &_mem[size++];
        *p = Node();
        return p;
    }
    int toIndex(char c) { return c - 'A'; }
    char toChar(int c) { return c + 'A'; }
    void add(char c, int len) {
        c = toIndex(c);
        Node *p, *q, *np, *nq;
        p = tail, np = newNode();
        np->step = len;
        for (; p && p->next[c] == NULL; p = p->pre)
            p->next[c] = np;
        tail = np;
        if (p == NULL) {
            np->pre = root;
        } else {
            if (p->next[c]->step == p->step + 1) {
                np->pre = p->next[c];
            } else {
                q = p->next[c], nq = newNode();
                *nq = *q;
                nq->step = p->step + 1;
                q->pre = np->pre = nq;
                for (; p && p->next[c] == q; p = p->pre)
                    p->next[c] = nq;
            }
        }
    }
    void build(const char *s) {
        init();
        for (int i = 0; s[i]; i++)
            add(s[i], i + 1);
    }
    void dfs(Node *u, int idx, char path[]) {
        for (int i = 0; i < MAXC; i++) {
            if (u->next[i]) {
                path[idx] = toChar(i);
                path[idx + 1] = '\0';
                puts(path);
                dfs(u->next[i], idx + 1, path);
            }
        }
    }
}
```

```

        }
    }
    void print() {
        char s[1024];
        dfs(root, 0, s);
    }
} SAM;
int main() {
    char s[1024];
    while (scanf("%s", s) == 1) {
        SAM.build(s);
        SAM.print();
    }
    return 0;
}

```

7.9 Trie

```

int trie[MAXN * 31][2], node;
int tag[MAXN * 31];

void add(int x) {
    int now = 0;
    for (int i = 30; i >= 0; i--) {
        if (!trie[now][x
                     >> i & 1]) trie[now][x >> i & 1] = ++node;
        now = trie[now][x >> i & 1];
        tag[now]++;
    }
}
void del(int x) {
    int now = 0;
    for (int i = 30; i >= 0; i--) {
        now = trie[now][x >> i & 1];
        tag[now]--;
    }
}
int qry(int x) {
    int now = 0, res = 0;
    for (int i = 30; i >= 0; i--) {
        int id = (x >> i & 1) ^ 1;
        if (!tag[trie[now][id]]) id ^= 1;
        now = trie[now][id];
        res = res * 2 + id;
    }
    return res;
}

```

7.10 Z

```

void z_value(const char *s, int len, int *z) {
    z[0] = len;
    for (int i = 1, l = 0, r = 0; i < len; i++) {
        z[i] = i < r ? (i
                         - l + z[i - l] < z[l] ? z[i - l] : r - i) : 0;
        while (i
               + z[i] < len && s[i + z[i]] == s[z[i]]) ++z[i];
        if (i + z[i] > r) l = i, r = i + z[i];
    }
}

```

8 Others

8.1 Aliens

```

/*
實際上如果這邊根本是平的，那我們只要讓二分艘找到最
小的P讓他的切點不超過K，那就保證了這條F會貼在上面
ll mid = (l+r < 0 ? (l + r) / 2: (l + r + 1) / 2)
while(l < r){
    int m = (l + r) / 2;
    if(calc(m) <= K) r = m;
    else l = m + 1;
}
*/
#include <bits/stdc++.h>
#define F first
#define S second
#define int long long
using namespace std;

bool operator<(
    const pair<int, int> &a, const pair<int, int> &b) {
    return a.F < b.F or (a.F == b.F and a.S > b.S);
}
#define chmax(a, b) a = (a) < (b) ? (b) : (a)

```

```

int n, k;
int a[1000005];
pair<int, int> dp[1000005];
vector<int> last(100005, 0);

pair<int, int> DP(int penalty) {
    last.assign(100005, 0);
    pair<int, int> ans = {0, 0};
    int l = 0;
    for (int i = 1; i <= n; i++) {
        while (l < last[a[i]]) {
            l++;
            chmax(ans, dp[l]);
        }
        dp[i] = {ans.F + i - l - penalty, ans.S + 1};
        last[a[i]] = i;
    }
    while (l < n) {
        l++;
        chmax(ans, dp[l]);
    }
    return ans;
}

signed main() {
    ios_base::sync_with_stdio(0), cin.tie(0);
    cin >> n >> k;
    for (int i = 1; i <= n; i++) cin >> a[i];
    int l = -1, r = 2000000;
    while (l < r - 1) {
        int m = (l + r) / 2;
        pair<int, int> res = DP(m);
        if (res.S <= k) {
            r = m;
        } else
            l = m;
    }
    auto res = DP(r);
    cout << res.F + k * r << '\n';
}

```

8.2 Knapsack on Tree

```

#include <bits/stdc++.h>
#define F first
#define S second
#define pb push_back
#define all(x) begin(x), end(x)
#define LOCAL
#define HEHE freopen("in.txt", "r", stdin);
#define HEHE ios_base::sync_with_stdio(0), cin.tie(0);
#define using namespace std;

#define chmax(a, b) (a) = (a) < (b) ? (b) : (a)
#define chmin(a, b) (a) = (a) < (b) ? (a) : (b)

#define ll long long

#define FOR(i, a, b) for (int i = a; i <= b; i++)

int N, W, cur;
vector<int> w, v, sz;
vector<vector<int>> adj, dp;

void dfs(int x) {
    sz[x] = 1;
    for (int i : adj[x]) dfs(i), sz[x] += sz[i];
    cur++;
    // choose x
    FOR (i, w[x], W) {
        dp[cur][i] = dp[cur - 1][i - w[x]] + v[x];
    }
    // not choose x
    FOR (i, 0, W) {
        chmax(dp[cur][i], dp[cur - sz[x]][i]);
    }
}

signed main() {
    HEHE
    cin >> N >> W;
    adj.resize(N + 1);
    w.assign(N + 1, 0);
    v.assign(N + 1, 0);
    sz.assign(N + 1, 0);
}

```

```

dp.assign(N + 2, vector<int>(W + 1, 0));
FOR (i, 1, N) {
    int p; cin >> p;
    adj[p].pb(i);
}
FOR (i, 1, N) cin >> w[i];
FOR (i, 1, N) cin >> v[i];
dfs(0);
cout << dp[N + 1][W] << '\n';
}

```

8.3 Mo

```

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

const int N = 2e5 + 5, sqN = sqrt(N) + 5;
int a[N], ans[N], n, q, sz; // maybe need blk[sqN];

struct Query {
    int ql, qr, id;
    bool operator<(const Query& b) const {
        int aa = ql / sz, bb = b.ql / sz;
        if (aa != bb) return aa < bb;
        else return qr < b.qr;
    }
} Q[N];

void add(int x) {}
void sub(int x) {}
int qry(int k) {}

int main() {
    ios::sync_with_stdio(false), cin.tie(nullptr);
    cin >> n >> q, sz = sqrt(n);
    for (int i = 0; i < n; i++) cin >> a[i];
    for (int i = 0, ql, qr; i < q; i++)
        cin >> ql >> qr, Q[i] = {ql - 1, qr - 1, i};
    // Mo's algorithm
    sort(Q, Q + q); /* remember initialize arrays */
    int l = 0, r = -1;
    for (int i = 0; i < q; i++) {
        auto [ql, qr, k, id] = Q[i];
        while (r < qr) add(a[++r]);
        while (r > qr) sub(a[r--]);
        while (l < ql) sub(a[l++]);
        while (l > ql) add(a[--l]);
        ans[id] = qry(k);
    }
    for (int i = 0; i < q; i++) cout << ans[i] << '\n';
}

```

8.4 Mono Slope

```

struct Line{
    ll a, b;
    ll l = MIN, r = MAX;
    Line(ll a, ll b): a(a), b(b) {}
    ll operator()(ll x){
        return a * x + b;
    }
};

deque<Line> dq;

ll ceil(ll a, ll b){
    if(b < 0) a *= -1, b *= -1;
    if(a > 0) return (a + b - 1) / b;
    else return a / b;
}

ll intersect(Line a, Line b){
    return ceil(a.b - b.b, b.a - a.a);
}

void add(Line ln){
    while(!dq.empty()
        () && ln(dq.back().l) >= dq.back()(dq.back().l)){
        dq.pop();
    }
    if(dq.empty()){
        dq.eb(ln);
        return;
    }
    ll pos = intersect(ln, dq.back());
    if(pos > dq.back().r){
        if(dq.back().r != MAX){

```

```

            ln.l = dq.back().r + 1;
            dq.eb(ln);
        }
        return;
    }
    dq.back().r = pos - 1;
    ln.l = pos;
    dq.eb(ln);
}

ll query(ll x){
    while(dq.front().r < x) dq.pop();
    return dq.front()(x);
}

// O(n log^2 n)
#include <bits/stdc++.h>
using namespace std;
using ll = long long;
const int N = 1e5 + 5, M = 2e5 + 5;
int n, K, cnt, ans[N];
struct node {
    int x, y, z, v, ans, tag, id;
    node() { ans = tag = v = x = y = z = 0; }
    friend
        bool operator==(const node &a, const node &b) {
            return
                (a.x == b.x) && (a.y == b.y) && (a.z == b.z);
        }
} a[N], t[N];
bool cmp1(const node &a, const node &b) {
    if (a.x != b.x) return a.x < b.x;
    if (a.y != b.y) return a.y < b.y;
    return a.z < b.z;
}
bool cmp2(const node &a, const node &b) {
    if (a.y != b.y) return a.y < b.y;
    if (a.tag != b.tag) return a.tag < b.tag;
    return a.id < b.id;
}
#define lowbit(x) (x & -x)
int bit[M];
void add(int p, int x) {
    for (; p <= K; p += lowbit(p)) bit[p] += x;
}
int query(int p) {
    int ret = 0;
    for (; p; p -= lowbit(p)) ret += bit[p];
    return ret;
}
void CDQ(int l, int r) {
    if (l == r) return;
    int mid = (l + r) >> 1;
    CDQ(l, mid); CDQ(mid + 1, r);
    for (int i = l; i <= r; ++i) a[i].id = i;
    for (int i = l; i <= mid; ++i) a[i].tag = 0;
    for (int i = mid + 1; i <= r; ++i) a[i].tag = 1;
    sort(a + l, a + r + 1, cmp2);
    for (int i = l; i <= r; ++i) {
        if (!a[i].tag) add(a[i].z, a[i].v);
        else a[i].ans += query(a[i].z);
    }
    for (int i = l; i <= r; ++i)
        if (!a[i].tag) add(a[i].z, -a[i].v);
}
int main() {
    cin >> n >> K;
    for (int i = 1; i <= n; ++
        i) cin >> a[i].x >> a[i].y >> a[i].z, a[i].v = 1;
    sort(a + 1, a + n + 1, cmp1);
    cnt = 1;
    for (int i = 2; i <= n; ++i) {
        if (a[i] == a[cnt]) ++a[cnt].v;
        else a[+cnt] = a[i];
    }
    CDQ(1, cnt);
    // let ans[i] denote that the
    // number of (aj <= ai && bj <= bi && cj <= ci) for i != j
    for (int i = 1; i <=
        cnt; ++i) ans[a[i].ans + a[i].v - 1] += a[i].v;
    for (int i = 0; i < n; ++i) cout << ans[i] << '\n';
    return 0;
}

```

8.6 Xor Basis

```
int basis[20]
bool add(int x) {
    for (int i = 19; i >= 0; i--) {
        if (!(x >> i & 1)) continue;
        if (!basis[i]) {
            basis[i] = x;
            return true;
        }
        else x ^= basis[i];
    }
    return false;
}
// 維持 basis[i] 的最高位是 i
```


