

TEAM DEAD TEMPLATES

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1 data-structures

1.1 dsu

```
struct DSU {
    vector<int> parent, siz;
    void init(int n) {
        parent.resize(n);
        siz.resize(n);
        for (int i = 0; i < n; i++) {
            parent[i] = i;
            siz[i] = 1;
        }
    }
    int find(int x) {
        if (x == parent[x]) return x;
        return parent[x] = find(parent[x]);
    }
    void merge(int x, int y) {
        x = find(x);
        y = find(y);
        if (x == y) return;
        if (siz[x] < siz[y]) swap(x, y);
        parent[y] = x;
        siz[x] += siz[y];
    }
    int size(int x) { return siz[find(x)]; }
    bool same(int x, int y) { return find(x) == find(y); }
}
```

1.2 fenwick-tree

```
template <class T>
class BIT {
private:
    int size;
    vector<T> bit;
    vector<T> arr;

public:
    BIT(int size) : size(size), bit(size + 1), arr(size) {}

    /** Sets the value at index ind to val. */
    void set(int ind, int val) { add(ind, val - arr[ind]); }

    /** Adds val to the element at index ind. */
    void add(int ind, int val) {
        arr[ind] += val;
        ind++;
        for (; ind <= size; ind += ind & -ind) {
            bit[ind] += val;
        }
    }

    /** @return The sum of all values in [0, ind]. */
    T pref_sum(int ind) {
        ind++;
        T total = 0;
        for (; ind > 0; ind -= ind & -ind) {
            total += bit[ind];
        }
        return total;
    }
}
```

};

1.3 lazy-segment-tree

```
template <typename node_type, typename tag_type>
struct lazy_segtree {
    vector<node_type> tree;
    vector<tag_type> lazy;
    int n;
    template <typename Iter>
    void init(Iter first, Iter last, int nn = -1) {
        n = nn;
        if (n == -1) n = distance(first, last);
        tree.resize(4 * n);
        lazy.resize(4 * n);
        build_tree(0, 0, n - 1, first);
    }
    node_type query(int ql, int qr) { return query(0, 0, n - 1, ql, qr); }
    void update(int ql, int qr, tag_type const &val) {
        update(0, 0, n - 1, ql, qr, val);
    }

private:
    template <typename Iter>
    void build_tree(int id, int tl, int tr, Iter first) {
        if (tl == tr) {
            tree[id].init(tl, tr, *(first + tl));
            lazy[id].init(tl, tr);
            return;
        }
        int tm = (tl + tr) / 2;
        build_tree(2 * id + 1, tl, tm, first);
        build_tree(2 * id + 2, tm + 1, tr, first);
        tree[id] = node_type::merge(tree[2 * id + 1], tree[2 * id + 2]);
        lazy[id].init(tl, tr);
    }
    void push(int id, int tl, int tr) {
        if (tl != tr) {
            int tm = (tl + tr) / 2;
            tree[2 * id + 1].apply(tl, tm, lazy[id]);
            lazy[2 * id + 1].merge(lazy[id]);
            tree[2 * id + 2].apply(tm + 1, tr, lazy[id]);
            lazy[2 * id + 2].merge(lazy[id]);
        }
        lazy[id].reset();
    }
    node_type query(int id, int tl, int tr, int ql, int qr) {
        if (tl > qr || ql > tr) return node_type::phi();
        if (ql <= tl && tr <= qr) return tree[id];
        push(id, tl, tr);
        int tm = (tl + tr) / 2;
        return node_type::merge(query(2 * id + 1, tl, tm, ql, qr),
                                query(2 * id + 2, tm + 1, tr, ql, qr));
    }
    void update(int id, int tl, int tr, int ql, int qr, tag_type const &val) {
        if (tl > qr || ql > tr) return;
        if (ql <= tl && tr <= qr) {
            tree[id].apply(tl, tr, val);
            lazy[id].merge(val);
        }
    }
}
```

```

    return;
}
push(id, tl, tr);
int tm = (tl + tr) / 2;
update(2 * id + 1, tl, tm, ql, qr, val);
update(2 * id + 2, tm + 1, tr, ql, qr, val);
tree[id] = node_type::merge(tree[2 * id + 1],
    tree[2 * id + 2]);
}
};
struct tag {
    ll inc;
    void reset() { inc = 0; }
    void merge(tag const &other) { inc += other.inc; }
    void init(int tl, int tr) {}
};
struct node {
    static node phi() { return {0LL}; }
    static node merge(node const &a, node const &b) {
        return {a.data + b.data}; }
    ll data;
    void apply(ll tl, ll tr, tag const &t) { data += (tr
        - tl + 1) * t.inc; }
    template <typename T>
    void init(ll tl, ll tr, T &ddata) {
        this->data = ddata;
    }
};

```

1.4 segment-tree-beats

```

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

const int N = 2e5 + 9;

using ll = long long;

struct SGTBeats {
    const ll inf = 1e18;
    int n, n0;
    ll max_v[4 * N], smax_v[4 * N], max_c[4 * N];
    ll min_v[4 * N], smin_v[4 * N], min_c[4 * N];
    ll sum[4 * N];
    ll len[4 * N], ladd[4 * N], lval[4 * N];

    void update_node_max(int k, ll x) {
        sum[k] += (x - max_v[k]) * max_c[k];

        if (max_v[k] == min_v[k]) {
            max_v[k] = min_v[k] = x;
        } else if (max_v[k] == smin_v[k]) {
            max_v[k] = smin_v[k] = x;
        } else {
            max_v[k] = x;
        }

        if (lval[k] != inf && x < lval[k]) {
            lval[k] = x;
        }
    }

    void update_node_min(int k, ll x) {
        sum[k] += (x - min_v[k]) * min_c[k];

        if (max_v[k] == min_v[k]) {

```

```

            max_v[k] = min_v[k] = x;
        } else if (smax_v[k] == min_v[k]) {
            min_v[k] = smax_v[k] = x;
        } else {
            min_v[k] = x;
        }

        if (lval[k] != inf && lval[k] < x) {
            lval[k] = x;
        }
    }

    void push(int k) {
        if (n0 - 1 <= k) return;
        if (lval[k] != inf) {
            updateall(2 * k + 1, lval[k]);
            updateall(2 * k + 2, lval[k]);
            lval[k] = inf;
            return;
        }
        if (ladd[k] != 0) {
            addall(2 * k + 1, ladd[k]);
            addall(2 * k + 2, ladd[k]);
            ladd[k] = 0;
        }
        if (max_v[k] < max_v[2 * k + 1]) {
            update_node_max(2 * k + 1, max_v[k]);
        }
        if (min_v[2 * k + 1] < min_v[k]) {
            update_node_min(2 * k + 1, min_v[k]);
        }

        if (max_v[k] < max_v[2 * k + 2]) {
            update_node_max(2 * k + 2, max_v[k]);
        }
        if (min_v[2 * k + 2] < min_v[k]) {
            update_node_min(2 * k + 2, min_v[k]);
        }
    }

    void update(int k) {
        sum[k] = sum[2 * k + 1] + sum[2 * k + 2];

        if (max_v[2 * k + 1] < max_v[2 * k + 2]) {
            max_v[k] = max_v[2 * k + 2];
            max_c[k] = max_c[2 * k + 2];
            smax_v[k] = max(max_v[2 * k + 1], smax_v[2 * k +
                2]);
        } else if (max_v[2 * k + 1] > max_v[2 * k + 2]) {
            max_v[k] = max_v[2 * k + 1];
            max_c[k] = max_c[2 * k + 1];
            smax_v[k] = max(smax_v[2 * k + 1], max_v[2 * k +
                2]);
        } else {
            max_v[k] = max_v[2 * k + 1];
            max_c[k] = max_c[2 * k + 1] + max_c[2 * k + 2];
            smax_v[k] = max(smax_v[2 * k + 1], smax_v[2 * k +
                2]);
        }

        if (min_v[2 * k + 1] < min_v[2 * k + 2]) {
            min_v[k] = min_v[2 * k + 1];
            min_c[k] = min_c[2 * k + 1];
            smin_v[k] = min(smin_v[2 * k + 1], min_v[2 * k +
                2]);
        } else if (min_v[2 * k + 1] > min_v[2 * k + 2]) {
            min_v[k] = min_v[2 * k + 2];
            min_c[k] = min_c[2 * k + 2];

```

```

    smin_v[k] = min(min_v[2 * k + 1], smin_v[2 * k + 2]);
} else {
    min_v[k] = min_v[2 * k + 1];
    min_c[k] = min_c[2 * k + 1] + min_c[2 * k + 2];
    smin_v[k] = min(smin_v[2 * k + 1], smin_v[2 * k + 2]);
}
}
void _update_min(ll x, int a, int b, int k, int l,
    int r) {
    if (b <= l || r <= a || max_v[k] <= x) {
        return;
    }
    if (a <= l && r <= b && smax_v[k] < x) {
        update_node_max(k, x);
        return;
    }
    push(k);
    _update_min(x, a, b, 2 * k + 1, l, (l + r) / 2);
    _update_min(x, a, b, 2 * k + 2, (l + r) / 2, r);
    update(k);
}
void _update_max(ll x, int a, int b, int k, int l,
    int r) {
    if (b <= l || r <= a || x <= min_v[k]) {
        return;
    }
    if (a <= l && r <= b && x < smin_v[k]) {
        update_node_min(k, x);
        return;
    }
    push(k);
    _update_max(x, a, b, 2 * k + 1, l, (l + r) / 2);
    _update_max(x, a, b, 2 * k + 2, (l + r) / 2, r);
    update(k);
}
void addall(int k, ll x) {
    max_v[k] += x;
    if (smax_v[k] != -inf) smax_v[k] += x;
    min_v[k] += x;
    if (smin_v[k] != inf) smin_v[k] += x;

    sum[k] += len[k] * x;
    if (lval[k] != inf) {
        lval[k] += x;
    } else {
        ladd[k] += x;
    }
}
void updateall(int k, ll x) {
    max_v[k] = x; smax_v[k] = -inf;
    min_v[k] = x; smin_v[k] = inf;
    max_c[k] = min_c[k] = len[k];

    sum[k] = x * len[k];
    lval[k] = x; ladd[k] = 0;
}
void _add_val(ll x, int a, int b, int k, int l, int
    r) {
    if (b <= l || r <= a) {
        return;
    }
    if (a <= l && r <= b) {
        addall(k, x);
        return;
    }
}

```

```

    push(k);
    _add_val(x, a, b, 2 * k + 1, l, (l + r) / 2);
    _add_val(x, a, b, 2 * k + 2, (l + r) / 2, r);
    update(k);
}
void _update_val(ll x, int a, int b, int k, int l,
    int r) {
    if (b <= l || r <= a) {
        return;
    }
    if (a <= l && r <= b) {
        updateall(k, x);
        return;
    }
    push(k);
    _update_val(x, a, b, 2 * k + 1, l, (l + r) / 2);
    _update_val(x, a, b, 2 * k + 2, (l + r) / 2, r);
    update(k);
}
ll _query_max(int a, int b, int k, int l, int r) {
    if (b <= l || r <= a) {
        return -inf;
    }
    if (a <= l && r <= b) {
        return max_v[k];
    }
    push(k);
    ll lv = _query_max(a, b, 2 * k + 1, l, (l + r) / 2);
    ll rv = _query_max(a, b, 2 * k + 2, (l + r) / 2, r);
    return max(lv, rv);
}
ll _query_min(int a, int b, int k, int l, int r) {
    if (b <= l || r <= a) {
        return inf;
    }
    if (a <= l && r <= b) {
        return min_v[k];
    }
    push(k);
    ll lv = _query_min(a, b, 2 * k + 1, l, (l + r) / 2);
    ll rv = _query_min(a, b, 2 * k + 2, (l + r) / 2, r);
    return min(lv, rv);
}
ll _query_sum(int a, int b, int k, int l, int r) {
    if (b <= l || r <= a) {
        return 0;
    }
    if (a <= l && r <= b) {
        return sum[k];
    }
    push(k);
    ll lv = _query_sum(a, b, 2 * k + 1, l, (l + r) / 2);
    ll rv = _query_sum(a, b, 2 * k + 2, (l + r) / 2, r);
    return lv + rv;
}
SGTBeats(int n, ll *a) : n(n) {
    n0 = 1;
    while (n0 < n) n0 <<= 1;
    for (int i = 0; i < 2 * n0; ++i) ladd[i] = 0,
        lval[i] = inf;
    len[0] = n0;
    for (int i = 0; i < n0 - 1; ++i) len[2 * i + 1] =
        len[2 * i + 2] = (len[i] >> 1);
}

```

```

for (int i = 0; i < n; ++i) {
    max_v[n0 - 1 + i] = min_v[n0 - 1 + i] = sum[n0 -
        1 + i] = (a != nullptr ? a[i] : 0);
    smax_v[n0 - 1 + i] = -inf;
    smin_v[n0 - 1 + i] = inf;
    max_c[n0 - 1 + i] = min_c[n0 - 1 + i] = 1;
}
for (int i = n; i < n0; ++i) {
    max_v[n0 - 1 + i] = smax_v[n0 - 1 + i] = -inf;
    min_v[n0 - 1 + i] = smin_v[n0 - 1 + i] = inf;
    max_c[n0 - 1 + i] = min_c[n0 - 1 + i] = 0;
}
for (int i = n0 - 2; i >= 0; i--) {
    update(i);
}
}

// all queries are performed on [l, r) segment (right
// exclusive)
// 0 indexed

// range minimize query
void update_min(int a, int b, ll x) {
    _update_min(x, a, b, 0, 0, n0);
}

// range maximize query
void update_max(int a, int b, ll x) {
    _update_max(x, a, b, 0, 0, n0);
}

// range add query
void add_val(int a, int b, ll x) {
    _add_val(x, a, b, 0, 0, n0);
}

// range update query
void update_val(int a, int b, ll x) {
    _update_val(x, a, b, 0, 0, n0);
}

// range minimum query
ll query_max(int a, int b) {
    return _query_max(a, b, 0, 0, n0);
}

// range maximum query
ll query_min(int a, int b) {
    return _query_min(a, b, 0, 0, n0);
}

// range sum query
ll query_sum(int a, int b) {
    return _query_sum(a, b, 0, 0, n0);
}
};

ll a[N];
int32_t main() {
    ios_base::sync_with_stdio(0);
    cin.tie(0);
    int n, q; cin >> n >> q;
    for (int i = 0; i < n; i++) {
        cin >> a[i];
    }
    SGTBeats t(n, a);
    while (q--) {
        int ty, l, r; cin >> ty >> l >> r;
        ll x; if (ty < 3) cin >> x;
        if (ty == 0) {
            t.update_min(l, r, x);
        }
    }
}

```

```

else if (ty == 1) {
    t.update_max(l, r, x);
}
else if (ty == 2) {
    t.add_val(l, r, x);
}
else {
    cout << t.query_sum(l, r) << '\n';
}
}
return 0;
}
//
https://judge.yosupo.jp/problem/range\_chmin\_chmax\_add\_range

```

1.5 segment-tree

```

template <typename T, typename CombineT>
struct SegmentTree {
    vector<T> tree;
    CombineT combine;
    T defaultValue;
    ll n;

    void init(ll n, T val) {
        tree.resize(4 * n);
        this->n = n;
        defaultValue = val;
        build_tree(1, 0, n - 1);
    }

    template <typename Itr>
    void init(Itr begin, Itr end) {
        n = distance(begin, end);
        tree.resize(4 * n);

        build_tree(1, 0, n - 1, begin);
    }

    void build_tree(ll id, ll tl, ll tr) {
        if (tl == tr) {
            tree[id] = defaultValue;
            return;
        }
        ll tm = (tl + tr) / 2;
        build_tree(id * 2, tl, tm);
        build_tree(id * 2 + 1, tm + 1, tr);
        tree[id] = combine(tree[id * 2], tree[id * 2 + 1]);
    }

    template <typename Itr>
    void build_tree(ll id, ll tl, ll tr, Itr begin) {
        if (tl == tr) {
            tree[id] = *(begin + tl);
            return;
        }
        ll tm = (tl + tr) / 2;
        build_tree(id * 2, tl, tm, begin);
        build_tree(id * 2 + 1, tm + 1, tr, begin);
        tree[id] = combine(tree[id * 2], tree[id * 2 + 1]);
    }

    T query(ll id, ll tl, ll tr, ll ql, ll qr) {
        if (ql > tr || tl > qr) return defaultValue;
        if (ql <= tl && tr <= qr) return tree[id];
    }
}

```

```

    ll tm = (tl + tr) / 2;
    return combine(query(id * 2, tl, tm, ql, qr),
                   query(id * 2 + 1, tm + 1, tr, ql, qr));
}

T query(ll l, ll r) { return query(1, 0, n - 1, l, r); }

void update(ll id, ll tl, ll tr, ll p, T x) {
    if (tl == tr) {
        tree[id] = x;
        return;
    }
    ll tm = (tl + tr) / 2;
    if (p <= tm)
        update(id * 2, tl, tm, p, x);
    else
        update(id * 2 + 1, tm + 1, tr, p, x);
    tree[id] = combine(tree[id * 2], tree[id * 2 + 1]);
}

void update(ll p, T x) { update(1, 0, n - 1, p, x); }
};

```

1.6 sparse-table

```

struct min_op {
    ll operator()(ll a, ll b) { return min(a, b); }
};
struct max_op {
    ll operator()(ll a, ll b) { return max(a, b); }
};
struct gcd_op {
    ll operator()(ll a, ll b) { return __gcd(a, b); }
};
template <typename OperationT>
struct sparse_table {
    vector<vector<ll>> m;
    OperationT op;
    template <typename Itr>
    void init(Itr begin, Itr end) {
        ll sz = end - begin;
        ll lg = 63 - __builtin_clzll(sz);
        m.assign(sz, vector<ll>(lg + 1));
        for (ll j = 0; j <= lg; ++j) {
            ll len = (1 << j);
            for (ll i = 0; i + len - 1 < sz; ++i) {
                if (len == 1) {
                    m[i][j] = *(begin + i);
                } else {
                    m[i][j] = op(m[i][j - 1], m[i + (1 << (j - 1))][j - 1]);
                }
            }
        }
    }
    ll query(ll L, ll R) {
        ll j = 63 - __builtin_clzll((R - L + 1));
        return op(m[L][j], m[R + 1 - (1 << j)][j]);
    }
};

```

2 graph

2.1 bellaman-ford

```

const int N = 3e5 + 9;
struct st {
    int a, b, cost;
} e[N];
const int INF = 2e9;
int32_t main() {
    int n, m;
    cin >> n >> m;
    for(int i = 0; i < m; i++) cin >> e[i].a >> e[i].b >> e[i].cost;
    int s;
    cin >> s; //is there any negative cycle which is reachable from s?
    vector<int> d(n, INF); //for finding any cycle(not necessarily from s) set d[i] = 0 for all i
    d[s] = 0;
    vector<int> p(n, -1);
    int x;
    for (int i=0; i<n; ++i) {
        x = -1;
        for (int j=0; j<m; ++j) {
            if (d[e[j].a] < INF) {
                if (d[e[j].b] > d[e[j].a] + e[j].cost) {
                    d[e[j].b] = max(-INF, d[e[j].a] + e[j].cost); //for overflow
                    p[e[j].b] = e[j].a;
                    x = e[j].b;
                }
            }
        }
    }
    if (x == -1) cout << "No negative cycle from "<<s;
    else {
        int y = x; //x can be on any cycle or reachable from some cycle
        for (int i=0; i<n; ++i) y = p[y];

        vector<int> path;
        for (int cur=y; ; cur=p[cur]) {
            path.push_back(cur);
            if (cur == y && path.size() > 1) break;
        }
        reverse(path.begin(), path.end());

        cout << "Negative cycle: ";
        for (int i=0; i<path.size(); ++i) cout << path[i] << ' ';
    }
    return 0;
}

```

2.2 floyd-warshall

```

// d is the adjacency matrix
int d[N][N];

for (int k = 1; k <= n; ++k) {
    for (int i = 1; i <= n; ++i) {
        for (int j = 1; j <= n; ++j) {
            d[i][j] = min(d[i][j], d[i][k] + d[k][j]);
        }
    }
}

```

```

    }
}

```

2.3 SCC

```

vector<vector<int>> adj, adj_rev;
vector<bool> used;
vector<int> order, component;

void dfs1(int v) {
    used[v] = true;

    for (auto u : adj[v])
        if (!used[u]) dfs1(u);

    order.push_back(v);
}

void dfs2(int v) {
    used[v] = true;
    component.push_back(v);

    for (auto u : adj_rev[v])
        if (!used[u]) dfs2(u);
}

int main() {
    int n;
    // ... read n ...

    for (;;) {
        int a, b;
        // ... read next directed edge (a,b) ...
        adj[a].push_back(b);
        adj_rev[b].push_back(a);
    }

    used.assign(n, false);

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

    used.assign(n, false);
    reverse(order.begin(), order.end());

    for (auto v : order)
        if (!used[v]) {
            dfs2(v);

            // ... processing next component ...

            component.clear();
        }

    // Condensed Graph
    vector<int> roots(n, 0);
    vector<int> root_nodes;
    vector<vector<int>> adj_scc(n);

    for (auto v : order)
        if (!used[v]) {
            dfs2(v);

            int root = component.front();
            for (auto u : component) roots[u] = root;

```

```

        root_nodes.push_back(root);

        component.clear();
    }

    for (int v = 0; v < n; v++)
        for (auto u : adj[v]) {
            int root_v = roots[v], root_u = roots[u];

            if (root_u != root_v)
                adj_scc[root_v].push_back(root_u);
        }
}

```

3 misc

3.1 bitwise-tricks

```

// iterating over subsets
for (int x = mask;; x = (x - 1) & mask) {
    // Code here...
    if (x == 0) break;
}

```

3.2 cppt

```

#include <bits/stdc++.h>
using namespace std;
#define all(x) begin(x), end(x)
#define OUT(T) cout << "Case #" << T << ": "
#ifdef _DEBUG
#define endl '\n'
#endif
#ifdef _DEBUG
void dbg_out() { cerr << endl; }
template <typename Head, typename... Tail>
void dbg_out(Head H, Tail... T) {
    cerr << ' ' << H;
    dbg_out(T...);
}
#define dbg(...) cerr << "(" << #__VA_ARGS__ << "):",
    dbg_out(__VA_ARGS__)
#else
#define dbg(...)
#endif
#define ckmin(x, y) x = min((x), (y))
#define ckmax(x, y) x = max((x), (y))

// clang-format off
template <typename T> ostream &operator<<(ostream &out,
    const vector<T> &v) { for (const auto &x : v) out
    << x << ' '; return out; }
template <typename T> istream &operator>>(istream &in,
    vector<T> &v) { for (auto &x : v) in >> x; return
    in; }
// clang-format on

using ll = long long;
using lld = long double;
using pll = pair<ll, ll>;
using pii = pair<int, int>;

void solve(ll _t) {}

```



```
int main() {
    ios_base::sync_with_stdio(false), cin.tie(NULL);

    ll T = 1;
    cin >> T;
    for (ll t = 1; t <= T; ++t) solve(t);
}
```

3.3 ordered-set

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
template <typename T, typename ComparatorFn = less<T>>
using ordered_set = tree<T, null_type, ComparatorFn,
    rb_tree_tag,
    tree_order_statistics_node_update>;
```

4 number-theory

4.1 crt

```
using T = __int128;
// ax + by = __gcd(a, b)
// returns __gcd(a, b)
T extended_euclid(T a, T b, T &x, T &y) {
    T xx = y = 0;
    T yy = x = 1;
    while (b) {
        T q = a / b;
        T t = b; b = a % b; a = t;
        t = xx; xx = x - q * xx; x = t;
        t = yy; yy = y - q * yy; y = t;
    }
    return a;
}
// finds x such that x % m1 = a1, x % m2 = a2. m1 and
// m2 may not be coprime
// here, x is unique modulo m = lcm(m1, m2). returns
// (x, m). on failure, m = -1.
pair<T, T> CRT(T a1, T m1, T a2, T m2) {
    T p, q;
    T g = extended_euclid(m1, m2, p, q);
    if (a1 % g != a2 % g) return make_pair(0, -1);
    T m = m1 / g * m2;
    p = (p % m + m) % m;
    q = (q % m + m) % m;
    return make_pair((p * a2 % m * (m1 / g) % m + q * a1
        % m * (m2 / g) % m) % m, m);
}
```

4.2 euler-totient-function

```
// phi(n) = # of integers in [1, n] that are relatively
// prime to n
// phi(p) = p - 1, where p is prime
// phi(p^k) = p^k - p^(k-1) = p^k * (1 - 1/p) for
// prime p;
void phi_1_to_n(int n) {
    vector<int> phi(n + 1);
```

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

for (int i = 2; i <= n; i++) {
    if (phi[i] == i) {
        for (int j = i; j <= n; j += i) phi[j] -= phi[j]
            / i;
    }
}
```

4.3 extended-euclid

```
using ll = long long;
ll extended_euclid(ll a, ll b, ll &x, ll &y) {
    if (b == 0) {
        x = 1;
        y = 0;
        return a;
    }
    ll x1, y1;
    ll d = extended_euclid(b, a % b, x1, y1);
    x = y1;
    y = x1 - y1 * (a / b);
    return d;
}
ll inverse(ll a, ll m) {
    ll x, y;
    ll g = extended_euclid(a, m, x, y);
    if (g != 1) return -1;
    return (x % m + m) % m;
}
```

4.4 modular-int

```
const ll MOD = 1e9 + 7;
ll binexp(ll a, ll b, ll p = MOD) {
    if (b < 0) return 0;
    ll res = 1;
    while (b > 0) {
        if (b & 1) res = (res * a) % p;
        a = (a * a) % p;
        b >>= 1;
    }
    return res;
}

inline ll modinv(ll x, ll p = MOD) { return binexp(x, p
    - 2, p); }
template <ll mod>
struct mi_ {
    ll value;
    mi_() = default;
    mi_(ll x) : value(x % mod) {}
    mi_(const mi_ &m) : value(m.value % mod) {}
    mi_ &operator=(const mi_ &m) {
        value = m.value;
        return *this;
    }
    ll inverse_value() const { return modinv(value, mod);
    }
    mi_ &operator+=(const mi_ &m) {
        value = (value + m.value) % mod;
        return *this;
    }
}
```

```

}
mi_ &operator+=(const mi_ &m) {
    value = (mod + value - m.value) % mod;
    return *this;
}
mi_ &operator*=(const mi_ &m) {
    value = (value * m.value) % mod;
    return *this;
}
mi_ &operator/=(const mi_ &m) {
    value = (value * m.inverse_value()) % mod;
    return *this;
}
mi_ &operator++() {
    value++;
    value %= mod;
    return *this;
}
mi_ &operator--() {
    value--;
    value %= mod;
    return *this;
}
mi_ operator*(const mi_ &b) { return mi_(value *
    b.value); }
mi_ operator*(ll b) { return mi_(value * b); }
mi_ operator-(const mi_ &b) { return mi_(mod + value
    - b.value); }
mi_ operator-(ll b) { return mi_(mod + value - b); }
mi_ operator+(const mi_ &b) { return mi_(value +
    b.value); }
mi_ operator+(ll b) { return mi_(value + b); }
mi_ operator/(const mi_ &b) { return mi_(value *
    modinv(b.value, mod)); }
mi_ operator/(ll b) { return mi_(value * modinv(b,
    mod)); }
};
template <ll mod>
ostream &operator<<(ostream &out, const mi_<mod> &m) {
    out << m.value % mod;
    return out;
}
template <ll mod>
istream &operator>>(istream &in, mi_<mod> &m) {
    ll x;
    in >> x;
    m.value = (x % mod);
    return in;
}
using mi = mi_<MOD>;
vector<mi> factorial;
void init_factorial() {
    factorial.resize(1000005);
    factorial[0] = factorial[1] = 1;
    for (ll i = 2; i < 1000005; ++i) {
        factorial[i] = (factorial[i - 1] * i);
    }
}
inline mi choose(const mi &a, const mi &b) {
    if (a.value < b.value) return 0;
    return factorial[a.value] /
        (factorial[b.value] * factorial[(a.value -
            b.value)]);
}

```

4.5 polard-rho

```

using ll = long long;
namespace PollardRho {
    mt19937
        rnd(chrono::steady_clock::now().time_since_epoch().count)
    const int P = 1e6 + 9;
    ll seq[P];
    int primes[P], spf[P];
    inline ll add_mod(ll x, ll y, ll m) {
        return (x += y) < m ? x : x - m;
    }
    inline ll mul_mod(ll x, ll y, ll m) {
        ll res = __int128(x) * y % m;
        return res;
        // ll res = x * y - (ll)((long double)x * y / m +
        //     0.5) * m;
        // return res < 0 ? res + m : res;
    }
    inline ll pow_mod(ll x, ll n, ll m) {
        ll res = 1 % m;
        for (; n; n >>= 1) {
            if (n & 1) res = mul_mod(res, x, m);
            x = mul_mod(x, x, m);
        }
        return res;
    }
    // 0(it * (logn)^3), it = number of rounds performed
    inline bool miller_rabin(ll n) {
        if (n <= 2 || (n & 1 ^ 1)) return (n == 2);
        if (n < P) return spf[n] == n;
        ll c, d, s = 0, r = n - 1;
        for (; !(r & 1); r >>= 1, s++) {}
        // each iteration is a round
        for (int i = 0; primes[i] < n && primes[i] < 32;
            i++) {
            c = pow_mod(primes[i], r, n);
            for (int j = 0; j < s; j++) {
                d = mul_mod(c, c, n);
                if (d == 1 && c != 1 && c != (n - 1)) return
                    false;
                c = d;
            }
            if (c != 1) return false;
        }
        return true;
    }
    void init() {
        int cnt = 0;
        for (int i = 2; i < P; i++) {
            if (!spf[i]) primes[cnt++] = spf[i] = i;
            for (int j = 0, k; (k = i * primes[j]) < P; j++) {
                spf[k] = primes[j];
                if (spf[i] == spf[k]) break;
            }
        }
    }
    // returns 0(n^(1/4))
    ll pollard_rho(ll n) {
        while (1) {
            ll x = rnd() % n, y = x, c = rnd() % n, u = 1, v,
                t = 0;
            ll *px = seq, *py = seq;
            while (1) {
                *py++ = y = add_mod(mul_mod(y, y, n), c, n);
                *py++ = y = add_mod(mul_mod(y, y, n), c, n);
                if ((x = *px++) == y) break;
            }
        }
    }
}

```

```

    v = u;
    u = mul_mod(u, abs(y - x), n);
    if (!u) return __gcd(v, n);
    if (++t == 32) {
        t = 0;
        if ((u = __gcd(u, n)) > 1 && u < n) return u;
    }
}
if (t && (u = __gcd(u, n)) > 1 && u < n) return u;
}
}
vector<ll> factorize(ll n) {
    if (n == 1) return vector<ll>();
    if (miller_rabin(n)) return vector<ll> {n};
    vector<ll> v, w;
    while (n > 1 && n < P) {
        v.push_back(spf[n]);
        n /= spf[n];
    }
    if (n >= P) {
        ll x = pollard_rho(n);
        v = factorize(x);
        w = factorize(n / x);
        v.insert(v.end(), w.begin(), w.end());
    }
    return v;
}
}
}

```

4.6 sieve

```

struct sieve_t {
    sieve_t(int n, bool gen_primes = false, bool
        gen_sieve = false) {
        is_prime.assign(n + 1, true);
        is_prime[0] = is_prime[1] = false;
        for (int i = 2; i * i <= n; ++i) {
            for (int j = i * i; j <= n; j += i)
                is_prime[j] = false;
        }
        if (gen_primes) {
            for (int i = 2; i <= n; ++i) {
                if (is_prime[i])
                    primes.push_back(i);
            }
        }
        if (gen_sieve) {
            sieve.assign(n + 1, -1);
            for (int i = 2; i <= n; ++i) {
                if (is_prime[i]) {
                    sieve[i] = i;
                    if ((ll)i * i <= n) {
                        for (int j = i * i; j <= n; j += i) {
                            if (sieve[j] == -1)
                                sieve[j] = i;
                        }
                    }
                }
            }
        }
    }
}
// requires gen_fact; works only upto sz;
vector<int> fast_factorize(int k) {
    vector<int> res;
    while (k > 1) {

```

```

        ll p = sieve[k];
        res.push_back(p);
        k /= p;
    }
    return res;
}
// requires gen_primes; works upto sz*sz;
vector<int> factorize(int k) {
    vector<int> res;
    for (int p : primes) {
        if (p * p > k)
            break;
        while (k % p == 0) {
            k /= p;
            res.push_back(p);
        }
    }
    if (k > 1)
        res.push_back(k);
    return res;
}
vector<bool> is_prime;
vector<int> primes;
vector<int> sieve;
};

```

5 strings

5.1 kmp

```

#include <bits/stdc++.h>
using namespace std;
// pi[i] = longest proper prefix of s[0..i] which is
// also a suffix;
// online algorithm;
vector<int> prefix_function(string const& s) {
    int n = s.length();
    vector<int> pi(n);
    for (int i = 1; i < n; ++i) {
        int j = pi[i - 1];
        while (j > 0 && s[i] != s[j]) {
            j = pi[j - 1];
        }
        if (s[i] == s[j]) j++;
        pi[i] = j;
    }
}
// Applications:
// finding occurrences: Concat 's # t' and check in
// where pi[i] = |S|
// counting prefixes;
vector<int> prefix_occurrences(vector<int> const& pi,
    int n) {
    vector<int> ans(n + 1);
    for (int i = 0; i < n; i++) ans[pi[i]]++;
    for (int i = n - 1; i > 0; i--) ans[pi[i - 1]] +=
        ans[i];
    for (int i = 0; i <= n; i++) ans[i]++;
    return ans;
}
// compression, if k = n - pi[n-1], divides n then 'k'
// is smallest
// unit to compress the string 's';
// aut[i][j] = automaton going from state 'i' with
// character 'j';

```

```

void compute_automaton(string s, vector<vector<int>>&
    aut) {
    s += '#';
    int n = s.size();
    vector<int> pi = prefix_function(s);
    aut.assign(n, vector<int>(26));
    for (int i = 0; i < n; i++) {
        for (int c = 0; c < 26; c++) {
            if (i > 0 && 'a' + c != s[i])
                aut[i][c] = aut[pi[i - 1]][c];
            else
                aut[i][c] = i + ('a' + c == s[i]);
        }
    }
}

```

6 tree

6.1 binary-lifting

```

struct binary_lift {
    vector<vector<ll>> children;
    vector<ll> depth;
    const ll LOG = 18;
    void init(vector<vector<ll>> &adj) {
        ll n = adj.size();
        depth.resize(n);
        children.assign(n, vector<ll>(LOG + 1));
        function<void(ll, ll, ll)> dfs = [&](ll u, ll p, ll
            d) {
            depth[u] = d;
            children[u][0] = p;
            for (ll i = 1; i <= LOG; ++i) {
                children[u][i] = children[children[u][i - 1]][i
                    - 1];
            }
            for (ll v : adj[u]) {
                if (v != p)
                    dfs(v, u, d + 1);
            }
        };
        dfs(0, 0, 0);
    }
    ll lift_node(ll n, ll d) {
        for (ll i = LOG; i >= 0; --i) {
            if (d & (1 << i))
                n = children[n][i];
        }
        return n;
    }
    ll lca(ll u, ll v) {
        if (depth[u] < depth[v])
            swap(u, v);
        u = lift_node(u, depth[u] - depth[v]);
        if (u == v)
            return u;
        for (ll i = LOG; i >= 0; --i) {
            if (children[u][i] != children[v][i]) {
                u = children[u][i];
                v = children[v][i];
            }
        }
        return children[u][0];
    }
}

```

```

ll dist(ll u, ll v) { return depth[u] + depth[v] - 2
    * depth[lca(u, v)]; }
};

```

6.2 euler-tour

```

struct euler_tour {
    vector<ll> in, out;
    ll timer = 0;
    void init(vector<vector<ll>> &adj) {
        ll n = adj.size();
        in.resize(n);
        out.resize(n);
        function<void(ll, ll)> dfs = [&](ll u, ll p) {
            in[u] = timer++;
            for (ll v : adj[u]) {
                if (v != p)
                    dfs(v, u);
            }
            out[u] = timer++;
        };
        dfs(0, 0);
    }
    bool is_ancestor(ll u, ll v) { return in[u] <= in[v]
        && out[u] >= out[v]; }
};

```

6.3 tree-isomorphism

```

const int N = 3e5 + 9, mod = 1e9 + 97;
template <const int32_t MOD>
struct modint {
    int32_t value;
    modint() = default;
    modint(int32_t value_) : value(value_) {}
    inline modint<MOD> operator + (modint<MOD> other)
        const { int32_t c = this->value + other.value;
            return modint<MOD>(c >= MOD ? c - MOD : c); }
    inline modint<MOD> operator - (modint<MOD> other)
        const { int32_t c = this->value - other.value;
            return modint<MOD>(c < 0 ? c + MOD : c); }
    inline modint<MOD> operator * (modint<MOD> other)
        const { int32_t c = (int64_t)this->value *
            other.value % MOD; return modint<MOD>(c < 0 ? c +
            MOD : c); }
    inline modint<MOD> & operator += (modint<MOD> other)
        { this->value += other.value; if (this->value >=
            MOD) this->value -= MOD; return *this; }
    inline modint<MOD> & operator -= (modint<MOD> other)
        { this->value -= other.value; if (this->value <
            0) this->value += MOD; return *this; }
    inline modint<MOD> & operator *= (modint<MOD> other)
        { this->value = (int64_t)this->value *
            other.value % MOD; if (this->value < 0)
            this->value += MOD; return *this; }
    inline modint<MOD> operator - () const { return
        modint<MOD>(this->value ? MOD - this->value : 0); }
    modint<MOD> pow(uint64_t k) const { modint<MOD> x =
        *this, y = 1; for (; k; k >>= 1) { if (k & 1) y
        *= x; x *= x; } return y; }
    modint<MOD> inv() const { return pow(MOD - 2); } //
    MOD must be a prime

```

```

inline modint<MOD> operator / (modint<MOD> other)
    const { return *this * other.inv(); }
inline modint<MOD> operator /= (modint<MOD> other) {
    return *this *= other.inv(); }
inline bool operator == (modint<MOD> other) const {
    return value == other.value; }
inline bool operator != (modint<MOD> other) const {
    return value != other.value; }
inline bool operator < (modint<MOD> other) const {
    return value < other.value; }
inline bool operator > (modint<MOD> other) const {
    return value > other.value; }
};

template <int32_t MOD> modint<MOD> operator * (int64_t
    value, modint<MOD> n) { return modint<MOD>(value)
    * n; }
template <int32_t MOD> modint<MOD> operator * (int32_t
    value, modint<MOD> n) { return modint<MOD>(value %
    MOD) * n; }
template <int32_t MOD> istream & operator >> (istream &
    in, modint<MOD> &n) { return in >> n.value; }
template <int32_t MOD> ostream & operator << (ostream &
    out, modint<MOD> n) { return out << n.value; }

using mint = modint<mod>;

mint pw[N];
const mint P = 998244353, Q = 1e9 + 33, R = 99999989;
const int base = 10;
struct Tree {
    int n;
    vector<vector<int>> g;
    Tree() {}
    Tree(int _n) : n(_n) {
        g.resize(n + 1);
    }
    void add_edge(int u, int v) {
        g[u].push_back(v);
        g[v].push_back(u);
    }
    vector<int> bfs(int s) {
        queue<int> q;
        vector<int> d(n + 1, n * 2);
        d[0] = -1;
        q.push(s);
        d[s] = 0;
        while(!q.empty()) {
            int u = q.front();
            q.pop();
            for(auto v : g[u]) if(d[u] + 1 < d[v]) {
                d[v] = d[u] + 1;
                q.push(v);
            }
        }
        return d;
    }
    vector<int> get_centers() {
        auto du = bfs(1);
        int v = max_element(du.begin(), du.end()) -
            du.begin();
        auto dv = bfs(v);
        int u = max_element(dv.begin(), dv.end()) -
            dv.begin();
        du = bfs(u);
        vector<int> ans;
        for(int i = 1; i <= n; i++) if(du[i] + dv[i] ==
            du[v] && du[i] >= du[v] / 2 && dv[i] >= du[v] /

```

```

2) {
    ans.push_back(i);
}
return ans;
}

mint yo(int u, int pre = 0) {
    vector<mint> nw;
    for(auto v : g[u]) if(v != pre) nw.push_back(yo(v,
        u));
    mint ans = 0;
    for(auto x : nw) {
        ans = ans + P.pow(x.value);
    }
    ans = ans * Q + R;
    return ans;
}

bool iso(Tree &t) {
    auto a = get_centers();
    auto b = t.get_centers();
    for(auto x : a) for(auto y : b) if(yo(x) ==
        t.yo(y)) return 1;
    return 0;
}
};

```

6.4 tree-lifting

```

/*
 * Does all the binary lifting tasks in the same
 * time complexity but uses only O(n) memory;
 */
struct tree_lifting {
    vector<int> dep, jmp, fa;
    int n;
    void add_leaf(int cur, int par) {
        fa[cur] = par;
        dep[cur] = 1 + dep[par];
        if (dep[par] - dep[jmp[par]] == dep[jmp[par]] -
            dep[jmp[jmp[par]]]) {
            jmp[cur] = jmp[jmp[par]];
        } else {
            jmp[cur] = par;
        }
    }
    void dfs(int cur, int par, vector<vector<int>> &adj) {
        add_leaf(cur, par);
        for (int it : adj[cur]) {
            if (it == par)
                continue;
            dfs(it, cur, adj);
        }
    }
    void init(int nn) {
        dep.resize(nn), jmp.resize(nn), fa.resize(nn);
        this->n = nn;
    }
    int lift(int cur, int k) {
        int new_depth = max(dep[cur] - k, 0);
        while (dep[cur] > new_depth) {
            if (dep[jmp[cur]] >= new_depth)
                cur = jmp[cur];
            else
                cur = fa[cur];
        }
        return cur;
    }
};

```

```
}  
int lca(int u, int v) {  
    if (dep[u] > dep[v])  
        swap(u, v);  
    v = lift(v, dep[v] - dep[u]);  
    while (u != v) {  
        if (jmp[v] != jmp[u]) {  
            u = jmp[u];  
            v = jmp[v];  
        } else {  
            u = fa[u];  
            v = fa[v];  
        }  
    }  
    return u;  
}  
int dist(int u, int v) { return dep[u] + dep[v] - 2 *  
    dep[lca(u, v)]; }  
};
```
