ECNU ICPC

Team Reference Document

F0RE1GNERS

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Contents

1 First Thing First

1.1 Header

```
#include <bits/stdc++.h>
using namespace std;
using LL = long long;
#define FOR(i, x, y) for (decay<decltype(y)>::type i = (x), _##i = (y); i < _##i; ++i)
#define FORD(i, x, y) for (decay<decltype(x)>::type i = (x), _##i = (y); i > _##i; --i)
#ifdef zerol
#define dbg(x...) do { cout << "\033[32;1m" << #x << " -> "; err(x); } while (0)
void err() { cout << "\033[39;0m" << endl; }
template<template<typename...> class T, typename t, typename... A>
void err(T<t> a, A... x) { for (auto v: a) cout << v << ' '; err(x...); }
template<typename T, typename... A>
void err(T a, A... x) { cout << a << ' '; err(x...); }
#else
#define dbg(...)
#endif
```

1.2 55kai

```
inline char nc() {
    static char buf[100000], *p1 = buf, *p2 = buf;
    return p1 == p2 && (p2 = (p1 = buf) + fread(buf, 1, 100000, stdin), p1 == p2) ? EOF : *p1++;
}
template <typename T>
bool rn(T& v) {
    static char ch;
    while (ch != EOF && !isdigit(ch)) ch = nc();
    if (ch == EOF) return false;
    for (v = 0; isdigit(ch); ch = nc())
        v = v * 10 + ch - '0';
    return true;
}

template <typename T>
void o(T p) {
    static int stk[70], tp;
    if (p == 0) { putchar('0'); return; }
    if (p < 0) { p = -p; putchar('-'); }
    while (p) stk[++tp] = p % 10, p /= 10;
    while (tp) putchar(stk[tp--] + '0');
}
```

2 Data Structure

2.1 RMQ

```
int f[maxn][maxn][10][10];
inline int highbit(int x) { return 31 - __builtin_clz(x); }
inline int calc(int x, int y, int xx, int yy, int p, int q) {
    return max(
        max(f[x][y][p][q], f[xx - (1 << p) + 1][yy - (1 << q) + 1][p][q]),
        max(f[xx - (1 << p) + 1][y][p][q], f[x][yy - (1 << q) + 1][p][q])
    );
```

```
}
void init() {
    FOR (x, 0, highbit(n) + 1)
    FOR (y, 0, highbit(m) + 1)
        FOR (i, 0, n - (1 << x) + 1)
        FOR (j, 0, m - (1 << y) + 1) {
            if (!x && !y) { f[i][j][x
                ][y] = a[i][j];
                continue; }
            f[i][j][x][y] = calc(
                i, j,
                i + (1 << x) - 1, j +
                    (1 << y) - 1,
                max(x - 1, 0), max(y -
                    1, 0)
            );
        }
}
inline int get_max(int x, int y, int
    xx, int yy) {
    return calc(x, y, xx, yy, highbit(
        xx - x + 1), highbit(yy - y +
        1));
}

struct RMQ {
    int f[22][M];
    inline int highbit(int x) { return
        31 - __builtin_clz(x); }
    void init(int* v, int n) {
        FOR (i, 0, n) f[0][i] = v[i];
        FOR (x, 1, highbit(n) + 1)
            FOR (i, 0, n - (1 << x) +
                1)
                f[x][i] = min(f[x -
                    1][i], f[x - 1][i +
                    (1 << (x - 1))]);
    }
    int get_min(int l, int r) {
        assert(l <= r);
        int t = highbit(r - l + 1);
        return min(f[t][l], f[t][r -
            (1 << t) + 1]);
    }
} rmq;
```

2.2 Segment Tree Beats

```
namespace R {
#define lson o * 2, l, (l + r) / 2
#define rson o * 2 + 1, (l + r) / 2 +
    1, r
    int m1[N], m2[N], cm1[N];
    LL sum[N];
    void up(int o) {
        int lc = o * 2, rc = lc + 1;
        m1[o] = max(m1[lc], m1[rc]);
        sum[o] = sum[lc] + sum[rc];
        if (m1[lc] == m1[rc]) {
            cm1[o] = cm1[lc] + cm1[rc
                ];
            m2[o] = max(m2[lc], m2[rc
                ]);
        } else {
            cm1[o] = m1[lc] > m1[rc] ?
                cm1[lc] : cm1[rc];
            m2[o] = max(min(m1[lc], m1
                [rc]), max(m2[lc], m2[
                rc]));
        }
    }
    void mod(int o, int x) {
        if (x >= m1[o]) return;
        assert(x > m2[o]);
        sum[o] -= 1LL * (m1[o] - x) *
            cm1[o];
        m1[o] = x;
    }
    void down(int o) {
        int lc = o * 2, rc = lc + 1;
        mod(lc, m1[o]); mod(rc, m1[o])
            ;
    }
    void build(int o, int l, int r) {
        if (l == r) { int t; read(t);
            sum[o] = m1[o] = t; m2[o] =
            -INF; cm1[o] = 1; }
        else { build(lson); build(rson
            ); up(o); }
    }
    void update(int ql, int qr, int x,
        int o, int l, int r) {
        if (r < ql || qr < l || m1[o]
            <= x) return;
        if (ql <= l && r <= qr && m2[o
            ] < x) { mod(o, x); return;
            }
        down(o);
        update(ql, qr, x, lson);
            update(ql, qr, x, rson);
        up(o);
    }
    int qmax(int ql, int qr, int o,
        int l, int r) {
        if (r < ql || qr < l) return -
            INF;
        if (ql <= l && r <= qr) return
             m1[o];
        down(o);
        return max(qmax(ql, qr, lson),
             qmax(ql, qr, rson));
    }
    LL qsum(int ql, int qr, int o, int
         l, int r) {
        if (r < ql || qr < l) return
            0;
        if (ql <= l && r <= qr) return
             sum[o];
        down(o);
        return qsum(ql, qr, lson) +
            qsum(ql, qr, rson);
    }
}
```

2.3 Segment Tree

```
// set + add

struct IntervalTree {
#define ls o * 2, l, m
#define rs o * 2 + 1, m + 1, r
    static const LL M = maxn * 4, RS =
        1E18 - 1;
    LL addv[M], setv[M], minv[M], maxv
        [M], sumv[M];
    void init() {
        memset(addv, 0, sizeof addv);
        fill(setv, setv + M, RS);
        memset(minv, 0, sizeof minv);
        memset(maxv, 0, sizeof maxv);
```

```
    memset(sumv, 0, sizeof sumv);
}
void maintain(LL o, LL l, LL r) {
    if (l < r) {
        LL lc = o * 2, rc = o * 2 + 1;
        sumv[o] = sumv[lc] + sumv[rc];
        minv[o] = min(minv[lc], minv[rc]);
        maxv[o] = max(maxv[lc], maxv[rc]);
    } else sumv[o] = minv[o] = maxv[o] = 0;
    if (setv[o] != RS) { minv[o] = maxv[o] = setv[o]; sumv[o] = setv[o] * (r - l + 1); }
    if (addv[o]) { minv[o] += addv[o]; maxv[o] += addv[o]; sumv[o] += addv[o] * (r - l + 1); }
}
void build(LL o, LL l, LL r) {
    if (l == r) addv[o] = a[l];
    else {
        LL m = (l + r) / 2;
        build(ls); build(rs);
    }
    maintain(o, l, r);
}
void pushdown(LL o) {
    LL lc = o * 2, rc = o * 2 + 1;
    if (setv[o] != RS) {
        setv[lc] = setv[rc] = setv[o];
        addv[lc] = addv[rc] = 0;
        setv[o] = RS;
    }
    if (addv[o]) {
        addv[lc] += addv[o]; addv[rc] += addv[o];
        addv[o] = 0;
    }
}
void update(LL p, LL q, LL o, LL l, LL r, LL v, LL op) {
        if (p <= r && l <= q)
        if (p <= l && r <= q) {
            if (op == 2) { setv[o] = v; addv[o] = 0; }
            else addv[o] += v;
        } else {
            pushdown(o);
            LL m = (l + r) / 2;
            update(p, q, ls, v, op); update(p, q, rs, v, op);
        }
        maintain(o, l, r);
    }
    void query(LL p, LL q, LL o, LL l, LL r, LL add, LL& ssum, LL& smin, LL& smax) {
        if (p > r || l > q) return;
        if (setv[o] != RS) {
            LL v = setv[o] + add + addv[o];
            ssum += v * (min(r, q) - max(l, p) + 1);
            smin = min(smin, v);
            smax = max(smax, v);
        } else if (p <= l && r <= q) {
            ssum += sumv[o] + add * (r - l + 1);
            smin = min(smin, minv[o] + add);
            smax = max(smax, maxv[o] + add);
        } else {
            LL m = (l + r) / 2;
            query(p, q, ls, add + addv[o], ssum, smin, smax);
            query(p, q, rs, add + addv[o], ssum, smin, smax);
        }
    }
} IT;

// persistent

namespace tree {
#define mid ((l + r) >> 1)
#define lson ql, qr, l, mid
#define rson ql, qr, mid + 1, r
    struct P {
        LL add, sum;
        int ls, rs;
    } tr[maxn * 45 * 2];
    int sz = 1;
    int N(LL add, int l, int r, int ls, int rs) {
        tr[sz] = {add, tr[ls].sum + tr[rs].sum + add * (len[r] - len[l - 1]), ls, rs};
        return sz++;
    }
    int update(int o, int ql, int qr, int l, int r, LL add) {
        if (ql > r || l > qr) return o;
        const P& t = tr[o];
        if (ql <= l && r <= qr) return N(add + t.add, l, r, t.ls, t.rs);
        return N(t.add, l, r, update(t.ls, lson, add), update(t.rs, rson, add));
    }
    LL query(int o, int ql, int qr, int l, int r, LL add = 0) {
        if (ql > r || l > qr) return 0;
        const P& t = tr[o];
        if (ql <= l && r <= qr) return add * (len[r] - len[l - 1]) + t.sum;
        return query(t.ls, lson, add + t.add) + query(t.rs, rson, add + t.add);
    }
}
```

2.4 K-D Tree

```
// global variable pruning
// visit L/R with more potential
namespace kd {
    const int K = 2, inf = 1E9, M = N;
```

```cpp
const double lim = 0.7;
struct P {
    int d[K], l[K], r[K], sz, val;
    LL sum;
    P *ls, *rs;
    P* up() {
        sz = ls->sz + rs->sz + 1;
        sum = ls->sum + rs->sum +
            val;
        FOR (i, 0, K) {
            l[i] = min(d[i], min(
                ls->l[i], rs->l[i])
                );
            r[i] = max(d[i], max(
                ls->r[i], rs->r[i])
                );
        }
        return this;
    }
} pool[M], *null = new P, *pit =
    pool;
static P *tmp[M], **pt;
void init() {
    null->ls = null->rs = null;
    FOR (i, 0, K) null->l[i] = inf
        , null->r[i] = -inf;
    null->sum = null->val = 0;
    null->sz = 0;
}

P* build(P** l, P** r, int d = 0)
    { // [l, r)
    if (d == K) d = 0;
    if (l >= r) return null;
    P** m = l + (r - l) / 2;
        assert(l <= m && m < r);
    nth_element(l, m, r, [&](const
        P* a, const P* b){
        return a->d[d] < b->d[d];
    });
    P* o = *m;
    o->ls = build(l, m, d + 1); o
        ->rs = build(m + 1, r, d +
        1);
    return o->up();
}
P* Build() {
    pt = tmp; FOR (it, pool, pit)
        *pt++ = it;
    return build(tmp, pt);
}
inline bool inside(int p[], int q
    [], int l[], int r[]) {
    FOR (i, 0, K) if (r[i] < q[i]
        || p[i] < l[i]) return
        false;
    return true;
}
LL query(P* o, int l[], int r[]) {
    if (o == null) return 0;
    FOR (i, 0, K) if (o->r[i] < l[
        i] || r[i] < o->l[i])
        return 0;
    if (inside(o->l, o->r, l, r))
        return o->sum;
    return query(o->ls, l, r) +
        query(o->rs, l, r) +
            (inside(o->d, o->d, l,
                r) ? o->val : 0);
}
void dfs(P* o) {
    if (o == null) return;
    *pt++ = o; dfs(o->ls); dfs(o->
        rs);
}
P* ins(P* o, P* x, int d = 0) {
    if (d == K) d = 0;
    if (o == null) return x->up();
    P*& oo = x->d[d] <= o->d[d] ?
        o->ls : o->rs;
    if (oo->sz > o->sz * lim) {
        pt = tmp; dfs(o); *pt++ =
            x;
        return build(tmp, pt, d);
    }
    oo = ins(oo, x, d + 1);
    return o->up();
}
}
```

2.5 STL+

```cpp
// priority_queue
// binary_heap_tag
// pairing_heap_tag: support editing
// thin_heap_tag: fast when increasing
    , can't join
#include <ext/pb_ds/priority_queue.hpp>
using namespace __gnu_pbds;

typedef __gnu_pbds::priority_queue<LL,
    less<LL>, pairing_heap_tag> PQ;
__gnu_pbds::priority_queue<int, cmp,
    pairing_heap_tag>::point_iterator
    it;
PQ pq, pq2;

int main() {
    auto it = pq.push(2);
    pq.push(3);
    assert(pq.top() == 3);
    pq.modify(it, 4);
    assert(pq.top() == 4);
    pq2.push(5);
    pq.join(pq2);
    assert(pq.top() == 5);
}


// BBT

// ov_tree_tag
// rb_tree_tag
// splay_tree_tag

// mapped: null_type or
    null_mapped_type (old) is null
// Node_Update should be
    tree_order_statistics_node_update
    to use find_by_order & order_of_key
// find_by_order: find the element
    with order+1 (0-based)
// order_of_key: number of elements lt
    r_key
// support join & split

#include <ext/pb_ds/assoc_container.
    hpp>
using namespace __gnu_pbds;
```

```cpp
using Tree = tree<int, null_type, less<int>, rb_tree_tag, tree_order_statistics_node_update>;
Tree t;

// Persistent BBT

#include <ext/rope>
using namespace __gnu_cxx;
rope<int> s;

int main() {
    FOR (i, 0, 5) s.push_back(i); // 0 1 2 3 4
    s.replace(1, 2, s); // 0 (0 1 2 3 4) 3 4
    auto ss = s.substr(2, 2); // 1 2
    s.erase(2, 2); // 0 1 4
    s.insert(2, s); // equal to s.replace(2, 0, s)
    assert(s[2] == s.at(2)); // 2
}

// Hash Table

#include<ext/pb_ds/assoc_container.hpp>
#include<ext/pb_ds/hash_policy.hpp>
using namespace __gnu_pbds;

gp_hash_table<int, int> mp;
cc_hash_table<int, int> mp;
```

2.6 BIT

```cpp
namespace bit {
    LL c[M];
    inline int lowbit(int x) { return x & -x; }
    void add(int x, LL v) {
        for (; x < M; x += lowbit(x))
            c[x] += v;
    }
    LL sum(int x) {
        LL ret = 0;
        for (; x > 0; x -= lowbit(x))
            ret += c[x];
        return ret;
    }
    int kth(LL k) {
        int p = 0;
        for (int lim = 1 << 20; lim; lim /= 2)
            if (p + lim < M && c[p + lim] < k) {
                p += lim;
                k -= c[p];
            }
        return p + 1;
    }
}
namespace bit {
    int c[maxn], cc[maxn];
    inline int lowbit(int x) { return x & -x; }
    void add(int x, int v) {
        for (int i = x; i <= n; i += lowbit(i)) {
            c[i] += v; cc[i] += x * v;
        }
    }
    void add(int l, int r, int v) { add(l, v); add(r + 1, -v); }
    int sum(int x) {
        int ret = 0;
        for (int i = x; i > 0; i -= lowbit(i))
            ret += (x + 1) * c[i] - cc[i];
        return ret;
    }
    int sum(int l, int r) { return sum(r) - sum(l - 1); }
}
namespace bit {
    LL c[N], cc[N], ccc[N];
    inline LL lowbit(LL x) { return x & -x; }
    void add(LL x, LL v) {
        for (LL i = x; i < N; i += lowbit(i)) {
            c[i] = (c[i] + v) % MOD;
            cc[i] = (cc[i] + x * v) % MOD;
            ccc[i] = (ccc[i] + x * x % MOD * v) % MOD;
        }
    }
    void add(LL l, LL r, LL v) { add(l, v); add(r + 1, -v); }
    LL sum(LL x) {
        static LL INV2 = (MOD + 1) / 2;
        LL ret = 0;
        for (LL i = x; i > 0; i -= lowbit(i))
            ret += (x + 1) * (x + 2) % MOD * c[i] % MOD
                - (2 * x + 3) * cc[i] % MOD
                + ccc[i];
        return ret % MOD * INV2 % MOD;
    }
    LL sum(LL l, LL r) { return sum(r) - sum(l - 1); }
}
```

2.7 Trie

```cpp
namespace trie {
    const int M = 31;
    int ch[N * M][2], sz;
    void init() { memset(ch, 0, sizeof ch); sz = 2; }
    void ins(LL x) {
        int u = 1;
        FORD (i, M, -1) {
            bool b = x & (1LL << i);
            if (!ch[u][b]) ch[u][b] = sz++;
            u = ch[u][b];
        }
    }
}

// persistent
// !!! sz = 1

struct P { int w, ls, rs; };
P tr[M] = {{0, 0, 0}};
```

```
int sz;

int _new(int w, int ls, int rs) { tr[
    sz] = {w, ls, rs}; return sz++; }
int ins(int oo, int v, int d = 30) {
    P& o = tr[oo];
    if (d == -1) return _new(o.w + 1,
        0, 0);
    bool u = v & (1 << d);
    return _new(o.w + 1, u == 0 ? ins(
        o.ls, v, d - 1) : o.ls, u == 1
        ? ins(o.rs, v, d - 1) : o.rs);
}
int query(int pp, int qq, int v, int d
    = 30) {
    if (d == -1) return 0;
    bool u = v & (1 << d);
    P &p = tr[pp], &q = tr[qq];
    int lw = tr[q.ls].w - tr[p.ls].w;
    int rw = tr[q.rs].w - tr[p.rs].w;

    int ret = 0;
    if (u == 0) {
        if (rw) { ret += 1 << d; ret
            += query(p.rs, q.rs, v, d -
            1); }
        else ret += query(p.ls, q.ls,
            v, d - 1);
    } else {
        if (lw) { ret += 1 << d; ret
            += query(p.ls, q.ls, v, d -
            1); }
        else ret += query(p.rs, q.rs,
            v, d - 1);
    }
    return ret;
}
```

2.8 Treap

```
// set
namespace treap {
    const int M = maxn * 17;
    extern struct P* const null;
    struct P {
        P *ls, *rs;
        int v, sz;
        unsigned rd;
        P(int v): ls(null), rs(null),
            v(v), sz(1), rd(rnd()) {}
        P(): sz(0) {}

        P* up() { sz = ls->sz + rs->sz
            + 1; return this; }
        int lower(int v) {
            if (this == null) return
                0;
            return this->v >= v ? ls->
                lower(v) : rs->lower(v)
                 + ls->sz + 1;
        }
        int upper(int v) {
            if (this == null) return
                0;
            return this->v > v ? ls->
                upper(v) : rs->upper(v)
                 + ls->sz + 1;
        }
    } *const null = new P, pool[M], *
        pit = pool;

    P* merge(P* l, P* r) {
        if (l == null) return r; if (r
            == null) return l;
        if (l->rd < r->rd) { l->rs =
            merge(l->rs, r); return l->
            up(); }
        else { r->ls = merge(l, r->ls)
            ; return r->up(); }
    }

    void split(P* o, int rk, P*& l, P
        *& r) {
        if (o == null) { l = r = null;
             return; }
        if (o->ls->sz >= rk) { split(o
            ->ls, rk, l, o->ls); r = o
            ->up(); }
        else { split(o->rs, rk - o->ls
            ->sz - 1, o->rs, r); l = o
            ->up(); }
    }
}
```

```
// persistent set
namespace treap {
    const int M = maxn * 17 * 12;
    extern struct P* const null, *pit;
    struct P {
        P *ls, *rs;
        int v, sz;
        LL sum;
        P(P* ls, P* rs, int v): ls(ls)
            , rs(rs), v(v), sz(ls->sz +
            rs->sz + 1),

        P() {}

        void* operator new(size_t _) {
            return pit++; }
        template<typename T>
        int rk(int v, T&& cmp) {
            if (this == null) return
                0;
            return cmp(this->v, v) ?
                ls->rk(v, cmp) : rs->rk
                (v, cmp) + ls->sz + 1;
        }
        int lower(int v) { return rk(v
            , greater_equal<int>()); }
        int upper(int v) { return rk(v
            , greater<int>()); }
```

```
} pool[M], *pit = pool, *const
  null = new P;
P* merge(P* l, P* r) {
  if (l == null) return r; if (r
    == null) return l;
  if (rnd() % (l->sz + r->sz) <
    l->sz) return new P{l->ls,
    merge(l->rs, r), l->v};
  else return new P{merge(l, r->
    ls), r->rs, r->v};
}
void split(P* o, int rk, P*& l, P
  *& r) {
  if (o == null) { l = r = null;
    return; }
  if (o->ls->sz >= rk) { split(o
    ->ls, rk, l, r); r = new P{
    r, o->rs, o->v}; }
  else { split(o->rs, rk - o->ls
    ->sz - 1, l, r); l = new P{
    o->ls, l, o->v}; }
}
}
// persistent set with pushdown
int now;
namespace Treap {
  const int M = 10000000;
  extern struct P* const null, *pit;
  struct P {
    P *ls, *rs;
    int sz, time;
    LL cnt, sc, pos, add;
    bool rev;

    P* up() { sz = ls->sz + rs->sz
      + 1; sc = ls->sc + rs->sc
      + cnt; return this; } //
      MOD
    P* check() {
      if (time == now) return
        this;
      P* t = new(pit++) P; *t =
        *this; t->time = now;
        return t;
    };
    P* _do_rev() { rev ^= 1; add
```

```
      *= -1; pos *= -1; swap(ls,
      rs); return this; } // MOD
    P* _do_add(LL v) { add += v;
      pos += v; return this; } //
      MOD
    P* do_rev() { if (this == null
      ) return this; return check
      ()->_do_rev(); } // FIX &
      MOD
    P* do_add(LL v) { if (this ==
      null) return this; return
      check()->_do_add(v); } //
      FIX & MOD
    P* _down() { // MOD
      if (rev) { ls = ls->do_rev
        (); rs = rs->do_rev();
        rev = 0; }
      if (add) { ls = ls->do_add
        (add); rs = rs->do_add(
        add); add = 0; }
      return this;
    }
    P* down() { return check()->
      _down(); } // FIX & MOD
    void _split(LL p, P*& l, P*& r
      ) { // MOD
      if (pos >= p) { ls->split(
        p, l, r); ls = r; r =
        up(); }
      else          { rs->split(
        p, l, r); rs = l; l =
        up(); }
    }
    void split(LL p, P*& l, P*& r)
      { // FIX & MOD
      if (this == null) l = r =
        null;
      else down()->_split(p, l,
        r);
    }
  } pool[M], *pit = pool, *const
    null = new P;
  P* merge(P* a, P* b) {
    if (a == null) return b; if (b
      == null) return a;
    if (rand() % (a->sz + b->sz) <
```

```
      a->sz) { a = a->down(); a
      ->rs = merge(a->rs, b);
      return a->up(); }
    else

      { b = b->down(); b->ls =
      merge(a, b->ls); return b->
      up(); }
  }
}
// sequence with add, sum
namespace treap {
  const int M = 8E5 + 100;
  extern struct P*const null;
  struct P {
    P *ls, *rs;
    int sz, val, add, sum;
    P(int v, P* ls = null, P* rs =
      null): ls(ls), rs(rs), sz
      (1), val(v), add(0), sum(v)
      {}
    P(): sz(0), val(0), add(0),
      sum(0) {}

    P* up() {
      assert(this != null);
      sz = ls->sz + rs->sz + 1;
      sum = ls->sum + rs->sum +
        val + add * sz;
      return this;
    }
    void upd(int v) {
      if (this == null) return;
      add += v;
      sum += sz * v;
    }
    P* down() {
      if (add) {
        ls->upd(add); rs->upd(
          add);
        val += add;
        add = 0;
      }
      return this;
    }
```

```
    P* select(int rk) {
      if (rk == ls->sz + 1)
        return this;
      return ls->sz >= rk ? ls->
        select(rk) : rs->select
        (rk - ls->sz - 1);
    }
} pool[M], *pit = pool, *const
  null = new P, *rt = null;

P* merge(P* a, P* b) {
  if (a == null) return b->up();
  if (b == null) return a->up();
  if (rand() % (a->sz + b->sz) <
    a->sz) {
    a->down()->rs = merge(a->
      rs, b);
    return a->up();
  } else {
    b->down()->ls = merge(a, b
      ->ls);
    return b->up();
  }
}

void split(P* o, int rk, P*& l, P
  *& r) {
  if (o == null) { l = r = null;
    return; }
  o->down();
  if (o->ls->sz >= rk) {
    split(o->ls, rk, l, o->ls)
      ;
    r = o->up();
  } else {
    split(o->rs, rk - o->ls->
      sz - 1, o->rs, r);
    l = o->up();
  }
}

inline void insert(int k, int v) {
  P *l, *r;
  split(rt, k - 1, l, r);
  rt = merge(merge(l, new (pit
    ++) P(v)), r);
}

inline void erase(int k) {
  P *l, *r, *_, *t;
  split(rt, k - 1, l, t);
  split(t, 1, _, r);
  rt = merge(l, r);
}

P* build(int l, int r, int* a) {
  if (l > r) return null;
  if (l == r) return new(pit++)
    P(a[l]);
  int m = (l + r) / 2;
  return (new(pit++) P(a[m],
    build(l, m - 1, a), build(m
    + 1, r, a)))->up();
}
};
// persistent sequence
namespace treap {
  struct P;
  extern P*const null;
  P* N(P* ls, P* rs, LL v, bool fill
    );
  struct P {
    P *const ls, *const rs;
    const int sz, v;
    const LL sum;
    bool fill;
    int cnt;

    void split(int k, P*& l, P*& r
      ) {
      if (this == null) { l = r
        = null; return; }
      if (ls->sz >= k) {
        ls->split(k, l, r);
        r = N(r, rs, v, fill);
      } else {
        rs->split(k - ls->sz -
          fill, l, r);
        l = N(ls, l, v, fill);
      }
    }
  } *const null = new P{0, 0, 0, 0,
    0, 0, 1};

  P* N(P* ls, P* rs, LL v, bool fill
    ) {
    ls->cnt++; rs->cnt++;
    return new P{ls, rs, ls->sz +
      rs->sz + fill, v, ls->sum +
      rs->sum + v, fill, 1};
  }

  P* merge(P* a, P* b) {
    if (a == null) return b;
    if (b == null) return a;
    if (rand() % (a->sz + b->sz) <
      a->sz)
      return N(a->ls, merge(a->
        rs, b), a->v, a->fill);
    else
      return N(merge(a, b->ls),
        b->rs, b->v, b->fill);
  }

  void go(P* o, int x, int y, P*& l,
    P*& m, P*& r) {
    o->split(y, l, r);
    l->split(x - 1, l, m);
  }
}
```

2.9 Cartesian Tree

```
void build() {
  static int s[N], last;
  int p = 0;
  FOR (x, 1, n + 1) {
    last = 0;
    while (p && val[s[p - 1]] >
      val[x]) last = s[--p];
    if (p) G[s[p - 1]][1] = x;
    if (last) G[x][0] = last;
    s[p++] = x;
  }
  rt = s[0];
}
```

2.10 LCT

```cpp
// do not forget down when findint L/R most son
// make_root if not sure

namespace lct {
    extern struct P *const null;
    const int M = N;
    struct P {
        P *fa, *ls, *rs;
        int v, maxv;
        bool rev;

        bool has_fa() { return fa->ls == this || fa->rs == this; }
        bool d() { return fa->ls == this; }
        P*& c(bool x) { return x ? ls : rs; }
        void do_rev() {
            if (this == null) return;
            rev ^= 1;
            swap(ls, rs);
        }
        P* up() {
            maxv = max(v, max(ls->maxv, rs->maxv));
            return this;
        }
        void down() {
            if (rev) {
                rev = 0;
                ls->do_rev(); rs->do_rev();
            }
        }
        void all_down() { if (has_fa()) fa->all_down(); down(); }
    } *const null = new P{0, 0, 0, 0, 0, 0}, pool[M], *pit = pool;

    void rot(P* o) {
        bool dd = o->d();
        P *f = o->fa, *t = o->c(!dd);
        if (f->has_fa()) f->fa->c(f->d()) = o; o->fa = f->fa;
        if (t != null) t->fa = f; f->c(dd) = t;
        o->c(!dd) = f->up(); f->fa = o;
    }
    void splay(P* o) {
        o->all_down();
        while (o->has_fa()) {
            if (o->fa->has_fa())
                rot(o->d() ^ o->fa->d() ? o : o->fa);
            rot(o);
        }
        o->up();
    }
    void access(P* u, P* v = null) {
        if (u == null) return;
        splay(u); u->rs = v;
        access(u->up()->fa, u);
    }
    void make_root(P* o) {
        access(o); splay(o); o->do_rev();
    }
    void split(P* o, P* u) {
        make_root(o); access(u); splay(u);
    }
    void link(P* u, P* v) {
        make_root(u); u->fa = v;
    }
    void cut(P* u, P* v) {
        split(u, v);
        u->fa = v->ls = null; v->up();
    }
    bool adj(P* u, P* v) {
        split(u, v);
        return v->ls == u && u->ls == null && u->rs == null;
    }
    bool linked(P* u, P* v) {
        split(u, v);
        return u == v || u->fa != null;
    }
    P* findrt(P* o) {
        access(o); splay(o);
        while (o->ls != null) o = o->ls;
        return o;
    }
    P* findfa(P* rt, P* u) {
        split(rt, u);
        u = u->ls;
        while (u->rs != null) {
            u = u->rs;
            u->down();
        }
        return u;
    }
}
// maintain subtree size
P* up() {
    sz = ls->sz + rs->sz + _sz + 1;
    return this;
}
void access(P* u, P* v = null) {
    if (u == null) return;
    splay(u);
    u->_sz += u->rs->sz - v->sz;
    u->rs = v;
    access(u->up()->fa, u);
}
void link(P* u, P* v) {
    split(u, v);
    u->fa = v; v->_sz += u->sz;
    v->up();
}

// ////////////////////
// latest spanning tree
// ////////////////////
namespace lct {
    extern struct P* null;
    struct P {
        P *fa, *ls, *rs;
        int v;
        P *minp;
        bool rev;

        bool has_fa() { return fa->ls
```

```
        == this || fa->rs == this;
    }
    bool d() { return fa->ls == this; }
    P*& c(bool x) { return x ? ls : rs; }
    void do_rev() { if (this == null) return; rev ^= 1; swap(ls, rs); }

    P* up() {
        minp = this;
        if (minp->v > ls->minp->v)
            minp = ls->minp;
        if (minp->v > rs->minp->v)
            minp = rs->minp;
        return this;
    }
    void down() { if (rev) { rev = 0; ls->do_rev(); rs->do_rev(); }}
    void all_down() { if (has_fa()) fa->all_down(); down(); }
} *null = new P{0, 0, 0, INF, 0, 0}, pool[maxm], *pit = pool;
void rot(P* o) {
    bool dd = o->d();
    P *f = o->fa, *t = o->c(!dd);
    if (f->has_fa()) f->fa->c(f->d()) = o; o->fa = f->fa;
    if (t != null) t->fa = f; f->c(dd) = t;
    o->c(!dd) = f->up(); f->fa = o;
}
void splay(P* o) {
    o->all_down();
    while (o->has_fa()) {
        if (o->fa->has_fa()) rot(o->d() ^ o->fa->d() ? o : o->fa);
        rot(o);
    }
    o->up();
}
void access(P* u, P* v = null) {
    if (u == null) return;
    splay(u); u->rs = v;
    access(u->up()->fa, u);
}
void make_root(P* o) { access(o); splay(o); o->do_rev(); }
void split(P* u, P* v) { make_root(u); access(v); splay(v); }
bool linked(P* u, P* v) { split(u, v); return u == v || u->fa != null; }
void link(P* u, P* v) { make_root(u); u->fa = v; }
void cut(P* u, P* v) { split(u, v); u->fa = v->ls = null; v->up(); }
}

using namespace lct;
int n, m;
P *p[maxn];
struct Q {
    int tp, u, v, l, r;
};
vector<Q> q;

int main() {
    null->minp = null;
    cin >> n >> m;
    FOR (i, 1, n + 1) p[i] = new (pit++) P{null, null, null, INF, p[i], 0};
    int clk = 0;
    map<pair<int, int>, int> mp;
    FOR (_, 0, m) {
        int tp, u, v; scanf("%d%d%d", &tp, &u, &v);
        if (u > v) swap(u, v);
        if (tp == 0) mp.insert({{u, v}, clk});
        else if (tp == 1) {
            auto it = mp.find({u, v});
            assert(it != mp.end());
            q.push_back({1, u, v, it->second, clk});
            mp.erase(it);
        } else q.push_back({0, u, v, clk, clk});
        ++clk;
    }
    for (auto& x: mp) q.push_back({1, x.first.first, x.first.second, x.second, clk});
    sort(q.begin(), q.end(), [](const Q& a, const Q& b)->bool { return a.l < b.l; });
    map<P*, int> mp2;
    FOR (i, 0, q.size()) {
        Q& cur = q[i];
        int u = cur.u, v = cur.v;
        if (cur.tp == 0) {
            if (!linked(p[u], p[v]))
                puts("N");
            else puts(p[v]->minp->v >= cur.r ? "Y" : "N");
            continue;
        }
        if (linked(p[u], p[v])) {
            P* t = p[v]->minp;
            if (t->v > cur.r) continue;
            Q& old = q[mp2[t]];
            cut(p[old.u], t); cut(p[old.v], t);
        }
        P* t = new (pit++) P {null, null, null, cur.r, t, 0};
        mp2[t] = i;
        link(t, p[u]); link(t, p[v]);
    }
}
```

2.11 Mo's Algorithm On Tree

```
struct Q {
    int u, v, idx;
    bool operator < (const Q& b) const {
        const Q& a = *this;
        return blk[a.u] < blk[b.u] || (blk[a.u] == blk[b.u] && in[a.v] < in[b.v]);
```

```
    }
};

void dfs(int u = 1, int d = 0) {
    static int S[maxn], sz = 0,
        blk_cnt = 0, clk = 0;
    in[u] = clk++;
    dep[u] = d;
    int btm = sz;
    for (int v: G[u]) {
        if (v == fa[u]) continue;
        fa[v] = u;
        dfs(v, d + 1);
        if (sz - btm >= B) {
            while (sz > btm) blk[S[--
                sz]] = blk_cnt;
            ++blk_cnt;
        }
    }
    S[sz++] = u;
    if (u == 1) while (sz) blk[S[--sz
        ]] = blk_cnt - 1;
}

void flip(int k) {
    dbg(k);
    if (vis[k]) {
        // ...
    } else {
        // ...
    }
    vis[k] ^= 1;
}

void go(int& k) {
    if (bug == -1) {
        if (vis[k] && !vis[fa[k]]) bug
            = k;
        if (!vis[k] && vis[fa[k]]) bug
            = fa[k];
    }
    flip(k);
    k = fa[k];
}

void mv(int a, int b) {
    bug = -1;
    if (vis[b]) bug = b;
    if (dep[a] < dep[b]) swap(a, b);
    while (dep[a] > dep[b]) go(a);
    while (a != b) {
        go(a); go(b);
    }
    go(a); go(bug);
}

for (Q& q: query) {
    mv(u, q.u); u = q.u;
    mv(v, q.v); v = q.v;
    ans[q.idx] = Ans;
}
```

2.12 CDQ's Divide and Conquer

```
const int maxn = 2E5 + 100;
struct P {
    int x, y;
    int* f;
    bool d1, d2;
} a[maxn], b[maxn], c[maxn];
int f[maxn];

void go2(int l, int r) {
    if (l + 1 == r) return;
    int m = (l + r) >> 1;
    go2(l, m); go2(m, r);
    FOR (i, l, m) b[i].d2 = 0;
    FOR (i, m, r) b[i].d2 = 1;
    merge(b + l, b + m, b + m, b + r,
        c + l, [](const P& a, const P&
        b)->bool {
            if (a.y != b.y) return a.y
                < b.y;
            return a.d2 > b.d2;
        });
    int mx = -1;
    FOR (i, l, r) {
        if (c[i].d1 && c[i].d2) *c[i].
            f = max(*c[i].f, mx + 1);
        if (!c[i].d1 && !c[i].d2) mx =
            max(mx, *c[i].f);
    }
    FOR (i, l, r) b[i] = c[i];
}

void go1(int l, int r) { // [l, r)
    if (l + 1 == r) return;
    int m = (l + r) >> 1;
    go1(l, m);
    FOR (i, l, m) a[i].d1 = 0;
    FOR (i, m, r) a[i].d1 = 1;
    copy(a + l, a + r, b + l);
    sort(b + l, b + r, [](const P& a,
        const P& b)->bool {
            if (a.x != b.x) return a.x
                < b.x;
            return a.d1 > b.d1;
        });
    go2(l, r);
    go1(m, r);
}
```

2.13 Persistent Segment Tree

```
namespace tree {
#define mid ((l + r) >> 1)
#define lson l, mid
#define rson mid + 1, r
    const int MAGIC = M * 30;
    struct P {
        int sum, ls, rs;
    } tr[MAGIC] = {{0, 0, 0}};
    int sz = 1;
    int N(int sum, int ls, int rs) {
        if (sz == MAGIC) assert(0);
        tr[sz] = {sum, ls, rs};
        return sz++;
    }
    int ins(int o, int x, int v, int l
        = 1, int r = ls) {
        if (x < l || x > r) return o;
        const P& t = tr[o];
        if (l == r) return N(t.sum + v
            , 0, 0);
        return N(t.sum + v, ins(t.ls,
            x, v, lson), ins(t.rs, x, v
            , rson));
    }
    int query(int o, int ql, int qr,
        int l = 1, int r = ls) {
```

```
        if (ql > r || l > qr) return 0;
        const P& t = tr[o];
        if (ql <= l && r <= qr) return t.sum;
        return query(t.ls, ql, qr, lson) + query(t.rs, ql, qr, rson);
    }
}
// kth
int query(int pp, int qq, int l, int r, int k) { // (pp, qq]
    if (l == r) return l;
    const P &p = tr[pp], &q = tr[qq];
    int w = tr[q.ls].w - tr[p.ls].w;
    if (k <= w) return query(p.ls, q.ls, lson, k);
    else return query(p.rs, q.rs, rson, k - w);
}

//////////////////////
// with bit
//////////////////////

typedef vector<int> VI;
struct TREE {
#define mid ((l + r) >> 1)
#define lson l, mid
#define rson mid + 1, r
    struct P {
        int w, ls, rs;
    } tr[maxn * 20 * 20];
    int sz = 1;
    TREE() { tr[0] = {0, 0, 0}; }
    int N(int w, int ls, int rs) {
        tr[sz] = {w, ls, rs};
        return sz++;
    }
    int add(int tt, int l, int r, int x, int d) {
        if (x < l || r < x) return tt;
        const P& t = tr[tt];
        if (l == r) return N(t.w + d, 0, 0);
        return N(t.w + d, add(t.ls, lson, x, d), add(t.rs, rson, x, d));
    }
    int ls_sum(const VI& rt) {
        int ret = 0;
        FOR (i, 0, rt.size())
            ret += tr[tr[rt[i]].ls].w;
        return ret;
    }
    inline void ls(VI& rt) { transform(rt.begin(), rt.end(), rt.begin(), [&](int x)->int{ return tr[x].ls; }); }
    inline void rs(VI& rt) { transform(rt.begin(), rt.end(), rt.begin(), [&](int x)->int{ return tr[x].rs; }); }
    int query(VI& p, VI& q, int l, int r, int k) {
        if (l == r) return l;
        int w = ls_sum(q) - ls_sum(p);
        if (k <= w) {
            ls(p); ls(q);
            return query(p, q, lson, k);
        }
        else {
            rs(p); rs(q);
            return query(p, q, rson, k - w);
        }
    }
} tree;
struct BIT {
    int root[maxn];
    void init() { memset(root, 0, sizeof root); }
    inline int lowbit(int x) { return x & -x; }
    void update(int p, int x, int d) {
        for (int i = p; i <= m; i += lowbit(i))
            root[i] = tree.add(root[i], 1, m, x, d);
    }
    int query(int l, int r, int k) {
        VI p, q;
        for (int i = l - 1; i > 0; i -= lowbit(i)) p.push_back(root[i]);
        for (int i = r; i > 0; i -= lowbit(i)) q.push_back(root[i]);
        return tree.query(p, q, 1, m, k);
    }
} bit;

void init() {
    m = 10000;
    tree.sz = 1;
    bit.init();
    FOR (i, 1, m + 1)
        bit.update(i, a[i], 1);
}
```

2.14 Persistent Union Find

```
namespace uf {
    int fa[maxn], sz[maxn];
    int undo[maxn], top;
    void init() { memset(fa, -1, sizeof fa); memset(sz, 0, sizeof sz); top = 0; }
    int findset(int x) { while (fa[x] != -1) x = fa[x]; return x; }
    bool join(int x, int y) {
        x = findset(x); y = findset(y);
        if (x == y) return false;
        if (sz[x] > sz[y]) swap(x, y);
        undo[top++] = x;
        fa[x] = y;
        sz[y] += sz[x] + 1;
        return true;
    }
    inline int checkpoint() { return top; }
    void rewind(int t) {
        while (top > t) {
            int x = undo[--top];
            sz[fa[x]] -= sz[x] + 1;
```

```
            fa[x] = -1;
        }
    }
}
```

3 Math

3.1 Multiplication, Powers

```
LL mul(LL u, LL v, LL p) {
    return (u * v - LL((long double) u * v / p) * p + p) % p;
}
LL mul(LL u, LL v, LL p) { // better constant
    LL t = u * v - LL((long double) u * v / p) * p;
    return t < 0 ? t + p : t;
}
LL bin(LL x, LL n, LL MOD) {
    n %= (MOD - 1); // if MOD is prime
    LL ret = MOD != 1;
    for (x %= MOD; n; n >>= 1, x = mul(x, x, MOD))
        if (n & 1) ret = mul(ret, x, MOD);
    return ret;
}
```

3.2 Matrix Power

```
struct Mat {
    static const LL M = 2;
    LL v[M][M];
    Mat() { memset(v, 0, sizeof v); }
    void eye() { FOR (i, 0, M) v[i][i] = 1; }
    LL* operator [] (LL x) { return v[x]; }
    const LL* operator [] (LL x) const { return v[x]; }
    Mat operator * (const Mat& B) {
        const Mat& A = *this;
        Mat ret;
        FOR (k, 0, M)
            FOR (i, 0, M) if (A[i][k])
                FOR (j, 0, M)
                    ret[i][j] = (ret[i][j] + A[i][k] * B[k][j]) % MOD;
        return ret;
    }
    Mat pow(LL n) const {
        Mat A = *this, ret; ret.eye();
        for (; n; n >>= 1, A = A * A)
            if (n & 1) ret = ret * A;
        return ret;
    }
    Mat operator + (const Mat& B) {
        const Mat& A = *this;
        Mat ret;
        FOR (i, 0, M)
            FOR (j, 0, M)
                ret[i][j] = (A[i][j] + B[i][j]) % MOD;
        return ret;
    }
    void prt() const {
        FOR (i, 0, M)
            FOR (j, 0, M)
                printf("%lld%c", (*this)[i][j], j == M - 1 ? '\n' : ' ');
    }
};
```

3.3 Sieve

```
const LL p_max = 1E5 + 100;
LL phi[p_max];
void get_phi() {
    phi[1] = 1;
    static bool vis[p_max];
    static LL prime[p_max], p_sz, d;
    FOR (i, 2, p_max) {
        if (!vis[i]) {
            prime[p_sz++] = i;
            phi[i] = i - 1;
        }
        for (LL j = 0; j < p_sz && (d = i * prime[j]) < p_max; ++j) {
            vis[d] = 1;
            if (i % prime[j] == 0) {
                phi[d] = phi[i] * prime[j];
                break;
            }
            else phi[d] = phi[i] * (prime[j] - 1);
        }
    }
}
// mobius
const LL p_max = 1E5 + 100;
LL mu[p_max];
void get_mu() {
    mu[1] = 1;
    static bool vis[p_max];
    static LL prime[p_max], p_sz, d;
    mu[1] = 1;
    FOR (i, 2, p_max) {
        if (!vis[i]) {
            prime[p_sz++] = i;
            mu[i] = -1;
        }
        for (LL j = 0; j < p_sz && (d = i * prime[j]) < p_max; ++j) {
            vis[d] = 1;
            if (i % prime[j] == 0) {
                mu[d] = 0;
                break;
            }
            else mu[d] = -mu[i];
        }
    }
}
// min_25
namespace min25 {
    const int M = 1E6 + 100;
    LL B, N;
    // g(x)
    inline LL pg(LL x) { return 1; }
    inline LL ph(LL x) { return x % MOD; }
    // Sum[g(i),{x,2,x}]
    inline LL psg(LL x) { return x % MOD - 1; }
```

```
inline LL psh(LL x) {
    static LL inv2 = (MOD + 1) / 2;
    x = x % MOD;
    return x * (x + 1) % MOD * inv2 % MOD - 1;
}
// f(pp=p^k)
inline LL fpk(LL p, LL e, LL pp) {
    return (pp - pp / p) % MOD; }
// f(p) = fgh(g(p), h(p))
inline LL fgh(LL g, LL h) { return h - g; }

LL pr[M], pc, sg[M], sh[M];
void get_prime(LL n) {
    static bool vis[M]; pc = 0;
    FOR (i, 2, n + 1) {
        if (!vis[i]) {
            pr[pc++] = i;
            sg[pc] = (sg[pc - 1] + pg(i)) % MOD;
            sh[pc] = (sh[pc - 1] + ph(i)) % MOD;
        }
        FOR (j, 0, pc) {
            if (pr[j] * i > n) break;
            vis[pr[j] * i] = 1;
            if (i % pr[j] == 0) break;
        }
    }
}
LL w[M];
LL id1[M], id2[M], h[M], g[M];
inline LL id(LL x) { return x <= B ? id1[x] : id2[N / x]; }
LL go(LL x, LL k) {
    if (x <= 1 || (k >= 0 && pr[k] > x)) return 0;
    LL t = id(x);
    LL ans = fgh((g[t] - sg[k + 1]), (h[t] - sh[k + 1]));
    FOR (i, k + 1, pc) {
        LL p = pr[i];
        if (p * p > x) break;
        ans -= fgh(pg(p), ph(p));
        for (LL pp = p, e = 1; pp <= x; ++e, pp = pp * p)
            ans += fpk(p, e, pp) * (1 + go(x / pp, i)) % MOD;
    }
    return ans % MOD;
}
LL solve(LL _N) {
    N = _N;
    B = sqrt(N + 0.5);
    get_prime(B);
    int sz = 0;
    for (LL l = 1, v, r; l <= N; l = r + 1) {
        v = N / l; r = N / v;
        w[sz] = v; g[sz] = psg(v); h[sz] = psh(v);
        if (v <= B) id1[v] = sz;
        else id2[r] = sz;
        sz++;
    }
    FOR (k, 0, pc) {
        LL p = pr[k];
        FOR (i, 0, sz) {
            LL v = w[i]; if (p * p > v) break;
            LL t = id(v / p);
            g[i] = (g[i] - (g[t] - sg[k]) * pg(p)) % MOD;
            h[i] = (h[i] - (h[t] - sh[k]) * ph(p)) % MOD;
        }
    }
    return (go(N, -1) % MOD + MOD + 1) % MOD;
}
}
// see cheatsheet for instructions
namespace dujiao {
    const int M = 5E6;
    LL f[M] = {0, 1};
    void init() {
        static bool vis[M];
        static LL pr[M], p_sz, d;
        FOR (i, 2, M) {
            if (!vis[i]) { pr[p_sz++] = i; f[i] = -1; }
            FOR (j, 0, p_sz) {
                if ((d = pr[j] * i) >= M) break;
                vis[d] = 1;
                if (i % pr[j] == 0) {
                    f[d] = 0;
                    break;
                } else f[d] = -f[i];
            }
        }
        FOR (i, 2, M) f[i] += f[i - 1];
    }
    inline LL s_fg(LL n) { return 1; }
    inline LL s_g(LL n) { return n; }

    LL N, rd[M];
    bool vis[M];
    LL go(LL n) {
        if (n < M) return f[n];
        LL id = N / n;
        if (vis[id]) return rd[id];
        vis[id] = true;
        LL& ret = rd[id] = s_fg(n);
        for (LL l = 2, v, r; l <= n; l = r + 1) {
            v = n / l; r = n / v;
            ret -= (s_g(r) - s_g(l - 1)) * go(v);
        }
        return ret;
    }
    LL solve(LL n) {
        N = n;
        memset(vis, 0, sizeof vis);
        return go(n);
    }
}
```

3.4 Prime Test

```
bool checkQ(LL a, LL n) {
    if (n == 2 || a >= n) return 1;
    if (n == 1 || !(n & 1)) return 0;
    LL d = n - 1;
    while (!(d & 1)) d >>= 1;
    LL t = bin(a, d, n); // usually needs mul-on-LL
    while (d != n - 1 && t != 1 && t != n - 1) {
        t = mul(t, t, n);
        d <<= 1;
    }
    return t == n - 1 || d & 1;
}
bool primeQ(LL n) {
    static vector<LL> t = {2, 325, 9375, 28178, 450775, 9780504, 1795265022};
    if (n <= 1) return false;
    for (LL k: t) if (!checkQ(k, n)) return false;
    return true;
}
```

3.5 Pollard-Rho

```
mt19937 mt(time(0));
LL pollard_rho(LL n, LL c) {
    LL x = uniform_int_distribution<LL>(1, n - 1)(mt), y = x;
    auto f = [&](LL v) { LL t = mul(v, v, n) + c; return t < n ? t : t - n; };
    while (1) {
        x = f(x); y = f(f(y));
        if (x == y) return n;
        LL d = gcd(abs(x - y), n);
        if (d != 1) return d;
    }
}
LL fac[100], fcnt;
void get_fac(LL n, LL cc = 19260817) {
    if (n == 4) { fac[fcnt++] = 2; fac[fcnt++] = 2; return; }
    if (primeQ(n)) { fac[fcnt++] = n; return; }
    LL p = n;
    while (p == n) p = pollard_rho(n, --cc);
    get_fac(p); get_fac(n / p);
}
```

3.6 Berlekamp-Massey

```
namespace BerlekampMassey {
    inline void up(LL& a, LL b) { (a += b) %= MOD; }
    V mul(const V&a, const V& b, const V& m, int k) {
        V r; r.resize(2 * k - 1);
        FOR (i, 0, k) FOR (j, 0, k) up(r[i + j], a[i] * b[j]);
        FORD (i, k - 2, -1) {
            FOR (j, 0, k) up(r[i + j], r[i + k] * m[j]);
            r.pop_back();
        }
        return r;
    }
    V pow(LL n, const V& m) {
        int k = (int) m.size() - 1;
        assert (m[k] == -1 || m[k] == MOD - 1);
        V r(k), x(k); r[0] = x[1] = 1;
        for (; n; n >>= 1, x = mul(x, x, m, k))
            if (n & 1) r = mul(x, r, m, k);
        return r;
    }
    LL go(const V& a, const V& x, LL n) {
        // a: (-1, a1, a2, ..., ak).reverse
        // x: x1, x2, ..., xk
        // x[n] = sum[a[i]*x[n-i],{i,1,k}]
        int k = (int) a.size() - 1;
        if (n <= k) return x[n - 1];
        if (a.size() == 2) return x[0] * bin(a[0], n - 1, MOD) % MOD;
        V r = pow(n - 1, a);
        LL ans = 0;
        FOR (i, 0, k) up(ans, r[i] * x[i]);
        return (ans + MOD) % MOD;
    }
    V BM(const V& x) {
        V a = {-1}, b = {233}, t;
        FOR (i, 1, x.size()) {
            b.push_back(0);
            LL d = 0, la = a.size(), lb = b.size();
            FOR (j, 0, la) up(d, a[j] * x[i - la + 1 + j]);
            if (d == 0) continue;
            t.clear(); for (auto& v: b) t.push_back(d * v % MOD);
            FOR (_, 0, la - lb) t.push_back(0);
            lb = max(la, lb);
            FOR (j, 0, la) up(t[lb - 1 - j], a[la - 1 - j]);
            if (lb > la) {
                b.swap(a);
                LL inv = -get_inv(d, MOD);
                for (auto& v: b) v = v * inv % MOD;
            }
            a.swap(t);
        }
        for (auto& v: a) up(v, MOD);
        return a;
    }
}
```

3.7 Extended Euclidean

```
LL ex_gcd(LL a, LL b, LL &x, LL &y) {
    if (b == 0) { x = 1; y = 0; return a; }
    LL ret = ex_gcd(b, a % b, y, x);
    y -= a / b * x;
    return ret;
}
////////////////////////////////
inline int ctz(LL x) { return __builtin_ctzll(x); }
```

```
LL gcd(LL a, LL b) {
    if (!a) return b; if (!b) return a;
    int t = ctz(a | b);
    a >>= ctz(a);
    do {
        b >>= ctz(b);
        if (a > b) swap(a, b);
        b -= a;
    } while (b);
    return a << t;
}
```

3.8 Inverse

```
// if p is prime
inline LL get_inv(LL x, LL p) { return bin(x, p - 2, p); }
// if p is not prime
LL get_inv(LL a, LL M) {
    static LL x, y;
    assert(exgcd(a, M, x, y) == 1);
    return (x % M + M) % M;
}
////////////////////////
LL inv[N];
void inv_init(LL n, LL p) {
    inv[1] = 1;
    FOR (i, 2, n)
        inv[i] = (p - p / i) * inv[p % i] % p;
}
////////////////////////
LL invf[M], fac[M] = {1};
void fac_inv_init(LL n, LL p) {
    FOR (i, 1, n)
        fac[i] = i * fac[i - 1] % p;
    invf[n - 1] = bin(fac[n - 1], p - 2, p);
    FORD (i, n - 2, -1)
        invf[i] = invf[i + 1] * (i + 1) % p;
}
```

3.9 Binomial Numbers

```
inline LL C(LL n, LL m) { // n >= m >= 0
    return n < m || m < 0 ? 0 : fac[n] * invf[m] % MOD * invf[n - m] % MOD;
}
// The following code reverses n and m
LL C(LL n, LL m) { // m >= n >= 0
    if (m - n < n) n = m - n;
    if (n < 0) return 0;
    LL ret = 1;
    FOR (i, 1, n + 1)
        ret = ret * (m - n + i) % MOD * bin(i, MOD - 2, MOD) % MOD;
    return ret;
}
LL Lucas(LL n, LL m) { // m >= n >= 0
    return m ? C(n % MOD, m % MOD) * Lucas(n / MOD, m / MOD) % MOD : 1;
}
// precalculations
LL C[M][M];
void init_C(int n) {
    FOR (i, 0, n) {
        C[i][0] = C[i][i] = 1;
        FOR (j, 1, i)
            C[i][j] = (C[i - 1][j] + C[i - 1][j - 1]) % MOD;
    }
}
```

3.10 NTT, FFT, FWT

```
// NTT
LL wn[N << 2], rev[N << 2];
int NTT_init(int n_) {
    int step = 0; int n = 1;
    for ( ; n < n_; n <<= 1) ++step;
    FOR (i, 1, n)
        rev[i] = (rev[i >> 1] >> 1) | ((i & 1) << (step - 1));
    int g = bin(G, (MOD - 1) / n, MOD);
    wn[0] = 1;
    for (int i = 1; i <= n; ++i)
        wn[i] = wn[i - 1] * g % MOD;
    return n;
}
void NTT(LL a[], int n, int f) {
    FOR (i, 0, n) if (i < rev[i])
        std::swap(a[i], a[rev[i]]);
    for (int k = 1; k < n; k <<= 1) {
        for (int i = 0; i < n; i += (k << 1)) {
            int t = n / (k << 1);
            FOR (j, 0, k) {
                LL w = f == 1 ? wn[t * j] : wn[n - t * j];
                LL x = a[i + j];
                LL y = a[i + j + k] * w % MOD;
                a[i + j] = (x + y) % MOD;
                a[i + j + k] = (x - y + MOD) % MOD;
            }
        }
    }
    if (f == -1) {
        LL ninv = get_inv(n, MOD);
        FOR (i, 0, n)
            a[i] = a[i] * ninv % MOD;
    }
}
// FFT
// n needs to be power of 2
typedef double LD;
const LD PI = acos(-1);
struct C {
    LD r, i;
    C(LD r = 0, LD i = 0): r(r), i(i) {}
};
C operator + (const C& a, const C& b) {
    return C(a.r + b.r, a.i + b.i);
}
C operator - (const C& a, const C& b) {
    return C(a.r - b.r, a.i - b.i);
}
```

```
C operator * (const C& a, const C& b)
    {
     return C(a.r * b.r - a.i * b.i, a.r * b.i + a.i * b.r);
}
void FFT(C x[], int n, int p) {
    for (int i = 0, t = 0; i < n; ++i)
        {
        if (i > t) swap(x[i], x[t]);
        for (int j = n >> 1; (t ^= j) < j; j >>= 1);
    }
    for (int h = 2; h <= n; h <<= 1) {
        C wn(cos(p * 2 * PI / h), sin(p * 2 * PI / h));
        for (int i = 0; i < n; i += h)
            {
            C w(1, 0), u;
            for (int j = i, k = h >> 1; j < i + k; ++j) {
                u = x[j + k] * w;
                x[j + k] = x[j] - u;
                x[j] = x[j] + u;
                w = w * wn;
            }
        }
    }
    if (p == -1)
        FOR (i, 0, n)
            x[i].r /= n;
}
void conv(C a[], C b[], int n) {
    FFT(a, n, 1);
    FFT(b, n, 1);
    FOR (i, 0, n)
        a[i] = a[i] * b[i];
    FFT(a, n, -1);
}

// FWT
// C_k = \sum_{i \oplus j=k} A_i B_j
template<typename T>
void fwt(LL a[], int n, T f) {
    for (int d = 1; d < n; d *= 2)
        for (int i = 0, t = d * 2; i < n; i += t)
            FOR (j, 0, d)
                f(a[i + j], a[i + j + d]);
}

void AND(LL& a, LL& b) { a += b; }
void OR(LL& a, LL& b) { b += a; }
void XOR (LL& a, LL& b) {
    LL x = a, y = b;
    a = (x + y) % MOD;
    b = (x - y + MOD) % MOD;
}
void rAND(LL& a, LL& b) { a -= b; }
void rOR(LL& a, LL& b) { b -= a; }
void rXOR(LL& a, LL& b) {
    static LL INV2 = (MOD + 1) / 2;
    LL x = a, y = b;
    a = (x + y) * INV2 % MOD;
    b = (x - y + MOD) * INV2 % MOD;
}

/*
FWT subset convolution
a[popcount(x)][x] = A[x]
b[popcount(x)][x] = B[x]
fwt(a[i]) fwt(b[i])
c[i + j][x] += a[i][x] * b[j][x]
rfwt(c[i])
ans[x] = c[popcount(x)][x]
*/
```

3.11 Simpson's Numerical Integration

```
LD simpson(LD l, LD r) {
    LD c = (l + r) / 2;
    return (f(l) + 4 * f(c) + f(r)) * (r - l) / 6;
}

LD asr(LD l, LD r, LD eps, LD S) {
    LD m = (l + r) / 2;
    LD L = simpson(l, m), R = simpson(m, r);
    if (fabs(L + R - S) < 15 * eps)
        return L + R + (L + R - S) / 15;
    return asr(l, m, eps / 2, L) + asr(m, r, eps / 2, R);
}

LD asr(LD l, LD r, LD eps) { return asr(l, r, eps, simpson(l, r)); }
```

3.12 Gauss Elimination

```
// n equations, m variables
// a is an n x (m + 1) augmented matrix
// free is an indicator of free variable
// return the number of free variables, -1 for "404"
int n, m;
LD a[maxn][maxn], x[maxn];
bool free_x[maxn];
inline int sgn(LD x) { return (x > eps) - (x < -eps); }
int gauss(LD a[maxn][maxn], int n, int m) {
  memset(free_x, 1, sizeof free_x);
    memset(x, 0, sizeof x);
  int r = 0, c = 0;
  while (r < n && c < m) {
    int m_r = r;
    FOR (i, r + 1, n)
      if (fabs(a[i][c]) > fabs(a[m_r][c])) m_r = i;
    if (m_r != r)
      FOR (j, c, m + 1)
        swap(a[r][j], a[m_r][j]);
    if (!sgn(a[r][c])) {
      a[r][c] = 0; ++c;
      continue;
    }
    FOR (i, r + 1, n)
      if (a[i][c]) {
        LD t = a[i][c] / a[r][c];
        FOR (j, c, m + 1) a[i][j] -= a[r][j] * t;
      }
    ++r; ++c;
  }
  FOR (i, r, n)
    if (sgn(a[i][m])) return -1;
```

```
  if (r < m) {
    FORD (i, r - 1, -1) {
      int f_cnt = 0, k = -1;
      FOR (j, 0, m)
        if (sgn(a[i][j]) && free_x[j])
        {
          ++f_cnt; k = j;
        }
      if(f_cnt > 0) continue;
      LD s = a[i][m];
      FOR (j, 0, m)
        if (j != k) s -= a[i][j] * x[j];
      x[k] = s / a[i][k];
      free_x[k] = 0;
    }
    return m - r;
  }
  FORD (i, m - 1, -1) {
    LD s = a[i][m];
    FOR (j, i + 1, m)
      s -= a[i][j] * x[j];
    x[i] = s / a[i][i];
  }
  return 0;
}
```

3.13 Factor Decomposition

```
LL factor[30], f_sz, factor_exp[30];
void get_factor(LL x) {
    f_sz = 0;
    LL t = sqrt(x + 0.5);
    for (LL i = 0; pr[i] <= t; ++i)
        if (x % pr[i] == 0) {
            factor_exp[f_sz] = 0;
            while (x % pr[i] == 0) {
                x /= pr[i];
                ++factor_exp[f_sz];
            }
            factor[f_sz++] = pr[i];
        }
    if (x > 1) {
        factor_exp[f_sz] = 1;
        factor[f_sz++] = x;
    }
}
```

3.14 Primitive Root

```
LL find_smallest_primitive_root(LL p)
    {
    // p should be a prime
    get_factor(p - 1);
    FOR (i, 2, p) {
        bool flag = true;
        FOR (j, 0, f_sz)
            if (bin(i, (p - 1) / factor[j], p) == 1) {
                flag = false;
                break;
            }
        if (flag) return i;
    }
    assert(0); return -1;
}
```

3.15 Quadratic Residue

```
LL q1, q2, w;
struct P { // x + y * sqrt(w)
    LL x, y;
};
P pmul(const P& a, const P& b, LL p) {
    P res;
    res.x = (a.x * b.x + a.y * b.y % p * w) % p;
    res.y = (a.x * b.y + a.y * b.x) % p;
    return res;
}
P bin(P x, LL n, LL MOD) {
    P ret = {1, 0};
    for (; n; n >>= 1, x = pmul(x, x, MOD))
        if (n & 1) ret = pmul(ret, x, MOD);
    return ret;
}
LL Legendre(LL a, LL p) { return bin(a, (p - 1) >> 1, p); }
LL equation_solve(LL b, LL p) {
    if (p == 2) return 1;
    if ((Legendre(b, p) + 1) % p == 0)
        return -1;
    LL a;
    while (true) {
        a = rand() % p;
        w = ((a * a - b) % p + p) % p;
        if ((Legendre(w, p) + 1) % p == 0)
            break;
    }
    return bin({a, 1}, (p + 1) >> 1, p).x;
}
// Given a and prime p, find x such that x*x=a(mod p)
int main() {
    LL a, p; cin >> a >> p;
    a = a % p;
    LL x = equation_solve(a, p);
    if (x == -1) {
        puts("No root");
    } else {
        LL y = p - x;
        if (x == y) cout << x << endl;
        else cout << min(x, y) << " "
            << max(x, y) << endl;
    }
}
```

3.16 Chinese Remainder Theorem

```
LL CRT(LL *m, LL *r, LL n) {
    if (!n) return 0;
    LL M = m[0], R = r[0], x, y, d;
    FOR (i, 1, n) {
        d = ex_gcd(M, m[i], x, y);
        if ((r[i] - R) % d) return -1;
        x = (r[i] - R) / d * x % (m[i] / d);
        R += x * M;
        M = M / d * m[i];
        R %= M;
    }
    return R >= 0 ? R : R + M;
}
```

3.17 Bernoulli Numbers

```
namespace Bernoulli {
    LL inv[M] = {-1, 1};
    LL C[M][M];
    void init();
    LL B[M] = {1};
    void init() {
        inv_init(M, MOD);
        init_C(M);
        FOR (i, 1, M - 1) {
            LL& s = B[i] = 0;
            FOR (j, 0, i)
                s += C[i + 1][j] * B[j] % MOD;
            s = (s % MOD * -inv[i + 1] % MOD + MOD) % MOD;
        }
    }
    LL p[M] = {1};
    LL go(LL n, LL k) {
        n %= MOD;
        if (k == 0) return n;
        FOR (i, 1, k + 2)
            p[i] = p[i - 1] * (n + 1) % MOD;
        LL ret = 0;
        FOR (i, 1, k + 2)
            ret += C[k + 1][i] * B[k + 1 - i] % MOD * p[i] % MOD;
        ret = ret % MOD * inv[k + 1] % MOD;
        return ret;
    }
}
```

3.18 Simplex Method

```
// x = 0 should satisfy the constraints
// initialize v to be 0
// n is dimension of vector, m is number of constraints
// min{ b x } / max { c x }
// A x >= c   / A x <= b
// x >= 0
namespace lp {
    int n, m;
    double a[M][N], b[M], c[N], v;

    void pivot(int l, int e) {
        b[l] /= a[l][e];
        FOR (j, 0, n) if (j != e) a[l][j] /= a[l][e];
        a[l][e] = 1 / a[l][e];

        FOR (i, 0, m)
            if (i != l && fabs(a[i][e]) > 0) {
                b[i] -= a[i][e] * b[l];
                FOR (j, 0, n)
                    if (j != e) a[i][j] -= a[i][e] * a[l][j];
                a[i][e] = -a[i][e] * a[l][e];
            }
        v += c[e] * b[l];
        FOR (j, 0, n) if (j != e) c[j] -= c[e] * a[l][j];
        c[e] = -c[e] * a[l][e];
    }
    double simplex() {
        while (1) {
            v = 0;
            int e = -1, l = -1;
            FOR (i, 0, n) if (c[i] > eps) { e = i; break; }
            if (e == -1) return v;
            double t = INF;
            FOR (i, 0, m)
                if (a[i][e] > eps && t > b[i] / a[i][e]) {
                    t = b[i] / a[i][e];
                    l = i;
                }
            if (l == -1) return INF;
            pivot(l, e);
        }
    }
}
```

3.19 BSGS

```
// p is a prime
LL BSGS(LL a, LL b, LL p) { // a^x = b (mod p)
    a %= p;
    if (!a && !b) return 1;
    if (!a) return -1;
    static map<LL, LL> mp; mp.clear();
    LL m = sqrt(p + 1.5);
    LL v = 1;
    FOR (i, 1, m + 1) {
        v = v * a % p;
        mp[v * b % p] = i;
    }
    LL vv = v;
    FOR (i, 1, m + 1) {
        auto it = mp.find(vv);
        if (it != mp.end()) return i * m - it->second;
        vv = vv * v % p;
    }
    return -1;
}
// p can be not a prime
LL exBSGS(LL a, LL b, LL p) { // a^x = b (mod p)
    a %= p; b %= p;
    if (a == 0) return b > 1 ? -1 : b == 0 && p != 1;
    LL c = 0, q = 1;
    while (1) {
        LL g = __gcd(a, p);
        if (g == 1) break;
        if (b == 1) return c;
        if (b % g) return -1;
        ++c; b /= g; p /= g; q = a / g * q % p;
    }
    static map<LL, LL> mp; mp.clear();
    LL m = sqrt(p + 1.5);
    LL v = 1;
    FOR (i, 1, m + 1) {
        v = v * a % p;
        mp[v * b % p] = i;
    }
```

```
    FOR (i, 1, m + 1) {
        q = q * v % p;
        auto it = mp.find(q);
        if (it != mp.end()) return i *
            m - it->second + c;
    }
    return -1;
}
```

4 Graph Theory

4.1 LCA

```
void dfs(int u, int fa) {
    pa[u][0] = fa; dep[u] = dep[fa] +
        1;
    FOR (i, 1, SP) pa[u][i] = pa[pa[u
        ][i - 1]][i - 1];
    for (int& v: G[u]) {
        if (v == fa) continue;
        dfs(v, u);
    }
}
int lca(int u, int v) {
    if (dep[u] < dep[v]) swap(u, v);
    int t = dep[u] - dep[v];
    FOR (i, 0, SP) if (t & (1 << i)) u
        = pa[u][i];
    FORD (i, SP - 1, -1) {
        int uu = pa[u][i], vv = pa[v][
            i];
        if (uu != vv) { u = uu; v = vv
            ; }
    }
    return u == v ? u : pa[u][0];
}
```

4.2 Maximum Flow

```
struct E {
    int to, cp;
    E(int to, int cp): to(to), cp(cp)
        {}
};

struct Dinic {
    static const int M = 1E5 * 5;
    int m, s, t;
    vector<E> edges;
    vector<int> G[M];
    int d[M];
    int cur[M];
    void init(int n, int s, int t) {
        this->s = s; this->t = t;
        for (int i = 0; i <= n; i++) G
            [i].clear();
        edges.clear(); m = 0;
    }
    void addedge(int u, int v, int cap
        ) {
        edges.emplace_back(v, cap);
        edges.emplace_back(u, 0);
        G[u].push_back(m++);
        G[v].push_back(m++);
    }
    bool BFS() {
        memset(d, 0, sizeof d);
        queue<int> Q;
        Q.push(s); d[s] = 1;
        while (!Q.empty()) {
            int x = Q.front(); Q.pop()
                ;
            for (int& i: G[x]) {
                E &e = edges[i];
                if (!d[e.to] && e.cp >
                    0) {
                    d[e.to] = d[x] +
                        1;
                    Q.push(e.to);
                }
            }
        }
        return d[t];
    }
    int DFS(int u, int cp) {
        if (u == t || !cp) return cp;
        int tmp = cp, f;
        for (int& i = cur[u]; i < G[u
            ].size(); i++) {
            E& e = edges[G[u][i]];
            if (d[u] + 1 == d[e.to]) {
                f = DFS(e.to, min(cp,
                    e.cp));
                e.cp -= f;
                edges[G[u][i] ^ 1].cp
                    += f;
                cp -= f;
                if (!cp) break;
            }
        }
        return tmp - cp;
    }
    int go() {
        int flow = 0;
        while (BFS()) {
            memset(cur, 0, sizeof cur)
                ;
            flow += DFS(s, INF);
        }
        return flow;
    }
} DC;
```

4.3 Minimum Cost Maximum Flow

```
struct E {
    int from, to, cp, v;
    E() {}
    E(int f, int t, int cp, int v) :
        from(f), to(t), cp(cp), v(v) {}
};

struct MCMF {
    int n, m, s, t;
    vector<E> edges;
    vector<int> G[maxn];
    bool inq[maxn];
    int d[maxn]; // shortest path
    int p[maxn]; // the last edge id
        of the path from s to i
    int a[maxn]; // least remaining
        capacity from s to i
    void init(int _n, int _s, int _t)
        {}
    void addedge(int from, int to, int
        cap, int cost) {
        edges.emplace_back(from, to,
            cap, cost);
        edges.emplace_back(to, from,
            0, -cost);
        G[from].push_back(m++);
        G[to].push_back(m++);
```

```
}
bool BellmanFord(int &flow, int &cost) {
    FOR (i, 0, n + 1) d[i] = INF;
    memset(inq, 0, sizeof inq);
    d[s] = 0, a[s] = INF, inq[s] = true;
    queue<int> Q; Q.push(s);
    while (!Q.empty()) {
        int u = Q.front(); Q.pop();
        inq[u] = false;
        for (int& idx: G[u]) {
            E &e = edges[idx];
            if (e.cp && d[e.to] > d[u] + e.v) {
                d[e.to] = d[u] + e.v;
                p[e.to] = idx;
                a[e.to] = min(a[u], e.cp);
                if (!inq[e.to]) {
                    Q.push(e.to);
                    inq[e.to] = true;
                }
            }
        }
    }
    if (d[t] == INF) return false;
    flow += a[t];
    cost += a[t] * d[t];
    int u = t;
    while (u != s) {
        edges[p[u]].cp -= a[t];
        edges[p[u] ^ 1].cp += a[t];
        u = edges[p[u]].from;
    }
    return true;
}

int go() {
    int flow = 0, cost = 0;
    while (BellmanFord(flow, cost));
    return cost;
}
} MM;
```

4.4 Path Intersection on Trees

```
int intersection(int x, int y, int xx, int yy) {
    int t[4] = {lca(x, xx), lca(x, yy), lca(y, xx), lca(y, yy)};
    sort(t, t + 4);
    int r = lca(x, y), rr = lca(xx, yy);
    if (dep[t[0]] < min(dep[r], dep[rr]) || dep[t[2]] < max(dep[r], dep[rr]))
        return 0;
    int tt = lca(t[2], t[3]);
    int ret = 1 + dep[t[2]] + dep[t[3]] - dep[tt] * 2;
    return ret;
}
```

4.5 Centroid Decomposition (Divide-Conquer)

```
int get_rt(int u) {
    static int q[N], fa[N], sz[N], mx[N];
    int p = 0, cur = -1;
    q[p++] = u; fa[u] = -1;
    while (++cur < p) {
        u = q[cur]; mx[u] = 0; sz[u] = 1;
        for (int& v: G[u])
            if (!vis[v] && v != fa[u]) fa[q[p++] = v] = u;
    }
    FORD (i, p - 1, -1) {
        u = q[i];
        mx[u] = max(mx[u], p - sz[u]);
        if (mx[u] * 2 <= p) return u;
        sz[fa[u]] += sz[u];
        mx[fa[u]] = max(mx[fa[u]], sz[u]);
    }
    assert(0);
}

void dfs(int u) {
    u = get_rt(u);
    vis[u] = true;
    get_dep(u, -1, 0);
    // ...
    for (E& e: G[u]) {
        int v = e.to;
        if (vis[v]) continue;
        // ...
        dfs(v);
    }
}

// ///////////////////////////
// dynamic divide and conquer
// ///////////////////////////
const int maxn = 15E4 + 100, INF = 1E9;
struct E {
    int to, d;
};
vector<E> G[maxn];
int n, Q, w[maxn];
LL A, ans;

bool vis[maxn];
int sz[maxn];

int get_rt(int u) {
    static int q[N], fa[N], sz[N], mx[N];
    int p = 0, cur = -1;
    q[p++] = u; fa[u] = -1;
    while (++cur < p) {
        u = q[cur]; mx[u] = 0; sz[u] = 1;
        for (int& v: G[u])
            if (!vis[v] && v != fa[u])
                fa[q[p++] = v] = u;
    }
    FORD (i, p - 1, -1) {
        u = q[i];
        mx[u] = max(mx[u], p - sz[u]);
        if (mx[u] * 2 <= p) return u;
```

```
        sz[fa[u]] += sz[u];
        mx[fa[u]] = max(mx[fa[u]], sz[
            u]);
    }
    assert(0);
}

int dep[maxn], md[maxn];
void get_dep(int u, int fa, int d) {
    dep[u] = d; md[u] = 0;
    for (E& e: G[u]) {
        int v = e.to;
        if (vis[v] || v == fa)
            continue;
        get_dep(v, u, d + e.d);
        md[u] = max(md[u], md[v] + 1);
    }
}

struct P {
    int w;
    LL s;
};
using VP = vector<P>;
struct R {
    VP *rt, *rt2;
    int dep;
};
VP pool[maxn << 1], *pit = pool;
vector<R> tr[maxn];

void go(int u, int fa, VP* rt, VP* rt2
    ) {
    tr[u].push_back({rt, rt2, dep[u]})
        ;
    for (E& e: G[u]) {
        int v = e.to;
        if (v == fa || vis[v])
            continue;
        go(v, u, rt, rt2);
    }
}

void dfs(int u) {
    u = get_rt(u);
    vis[u] = true;
    get_dep(u, -1, 0);
    VP* rt = pit++; tr[u].push_back({
        rt, nullptr, 0});
    for (E& e: G[u]) {
        int v = e.to;
        if (vis[v]) continue;
        go(v, u, rt, pit++);
        dfs(v);
    }
}

bool cmp(const P& a, const P& b) {
    return a.w < b.w; }

LL query(VP& p, int d, int l, int r) {
    l = lower_bound(p.begin(), p.end()
        , P{l, -1}, cmp) - p.begin();
    r = upper_bound(p.begin(), p.end()
        , P{r, -1}, cmp) - p.begin() -
        1;
    return p[r].s - p[l - 1].s + 1LL *
        (r - l + 1) * d;
}

int main() {
    cin >> n >> Q >> A;
    FOR (i, 1, n + 1) scanf("%d", &w[i
        ]);
    FOR (_, 1, n) {
        int u, v, d; scanf("%d%d%d", &
            u, &v, &d);
        G[u].push_back({v, d}); G[v].
            push_back({u, d});
    }
    dfs(1);
    FOR (i, 1, n + 1)
        for (R& x: tr[i]) {
            x.rt->push_back({w[i], x.
                dep});
            if (x.rt2) x.rt2->
                push_back({w[i], x.dep
                });
        }
    FOR (it, pool, pit) {
        it->push_back({-INF, 0});
        sort(it->begin(), it->end(),
            cmp);
        FOR (i, 1, it->size())
            (*it)[i].s += (*it)[i -
                1].s;
    }
    while (Q--) {
        int u; LL a, b; scanf("%d%lld%
            lld", &u, &a, &b);
        a = (a + ans) % A; b = (b +
            ans) % A;
        int l = min(a, b), r = max(a,
            b);
        ans = 0;
        for (R& x: tr[u]) {
            ans += query(*(x.rt), x.
                dep, l, r);
            if (x.rt2) ans -= query(*(
                x.rt2), x.dep, l, r);
        }
        printf("%lld\n", ans);
    }
}
```

4.6 Heavy-light Decomposition

```
// clear clk
// usage: hld::predfs(1, 1); hld::dfs
    (1, 1);
int fa[N], dep[N], idx[N], out[N],
    ridx[N];
namespace hld {
    int sz[N], son[N], top[N], clk;
    void predfs(int u, int d) {
        dep[u] = d; sz[u] = 1;
        int& maxs = son[u] = -1;
        for (int& v: G[u]) {
            if (v == fa[u]) continue;
            fa[v] = u;
            predfs(v, d + 1);
            sz[u] += sz[v];
            if (maxs == -1 || sz[v] >
                sz[maxs]) maxs = v;
        }
    }
    void dfs(int u, int tp) {
        top[u] = tp; idx[u] = ++clk;
            ridx[clk] = u;
```

```
    if (son[u] != -1) dfs(son[u], tp);
    for (int& v: G[u])
        if (v != fa[u] && v != son[u]) dfs(v, v);
    out[u] = clk;
}
template<typename T>
int go(int u, int v, T&& f = [](int, int) {}) {
    int uu = top[u], vv = top[v];
    while (uu != vv) {
        if (dep[uu] < dep[vv]) {
            swap(uu, vv); swap(u, v);
        }
        f(idx[uu], idx[u]);
        u = fa[uu]; uu = top[u];
    }
    if (dep[u] < dep[v]) swap(u, v);
    // choose one
    // f(idx[v], idx[u]);
    // if (u != v) f(idx[v] + 1, idx[u]);
    return v;
}
int up(int u, int d) {
    while (d) {
        if (dep[u] - dep[top[u]] < d) {
            d -= dep[u] - dep[top[u]];
            u = top[u];
        } else return ridx[idx[u] - d];
        u = fa[u]; --d;
    }
    return u;
}
int finds(int u, int rt) { // find u in which sub-tree of rt
    while (top[u] != top[rt]) {
        u = top[u];
        if (fa[u] == rt) return u;
        u = fa[u];
    }
    return ridx[idx[rt] + 1];
  }
}
```

4.7 Bipartite Matching

```
struct MaxMatch {
    int n;
    vector<int> G[maxn];
    int vis[maxn], left[maxn], clk;

    void init(int n) {
        this->n = n;
        FOR (i, 0, n + 1) G[i].clear();
        memset(left, -1, sizeof left);
        memset(vis, -1, sizeof vis);
    }

    bool dfs(int u) {
        for (int v: G[u])
            if (vis[v] != clk) {
                vis[v] = clk;
                if (left[v] == -1 || dfs(left[v])) {
                    left[v] = u;
                    return true;
                }
            }
        return false;
    }

    int match() {
        int ret = 0;
        for (clk = 0; clk <= n; ++clk)
            if (dfs(clk)) ++ret;
        return ret;
    }
} MM;

/////////////////////
// max weight: KM
/////////////////////
namespace R {
    const int maxn = 300 + 10;
    int n, m;
    int left[maxn], L[maxn], R[maxn];
    int w[maxn][maxn], slack[maxn];
    bool visL[maxn], visR[maxn];

    bool dfs(int u) {
        visL[u] = true;
        FOR (v, 0, m) {
            if (visR[v]) continue;
            int t = L[u] + R[v] - w[u][v];
            if (t == 0) {
                visR[v] = true;
                if (left[v] == -1 || dfs(left[v])) {
                    left[v] = u;
                    return true;
                }
            } else slack[v] = min(slack[v], t);
        }
        return false;
    }

    int go() {
        memset(left, -1, sizeof left);
        memset(R, 0, sizeof R);
        memset(L, 0, sizeof L);
        FOR (i, 0, n)
            FOR (j, 0, m)
                L[i] = max(L[i], w[i][j]);

        FOR (i, 0, n) {
            memset(slack, 0x3f, sizeof slack);
            while (1) {
                memset(visL, 0, sizeof visL); memset(visR, 0, sizeof visR);
                if (dfs(i)) break;
                int d = 0x3f3f3f3f;
                FOR (j, 0, m) if (!visR[j]) d = min(d, slack[j]);
                FOR (j, 0, n) if (visL[j]) L[j] -= d;
                FOR (j, 0, m) if (visR
```

```
                [j]) R[j] += d;
                else slack[j] -= d;
            }
        }
        int ret = 0;
        FOR (i, 0, m) if (left[i] !=
            -1) ret += w[left[i]][i];
        return ret;
    }
}
```

4.8 Virtual Tree

```
void go(vector<int>& V, int& k) {
    int u = V[k]; f[u] = 0;
    dbg(u, k);
    for (auto& e: G[u]) {
        int v = e.to;
        if (v == pa[u][0]) continue;
        while (k + 1 < V.size()) {
            int to = V[k + 1];
            if (in[to] <= out[v]) {
                go(V, ++k);
                if (key[to]) f[u] += w
                    [to];
                else f[u] += min(f[to
                    ], (LL)w[to]);
            } else break;
        }
    }
    dbg(u, f[u]);
}
inline bool cmp(int a, int b) { return
    in[a] < in[b]; }
LL solve(vector<int>& V) {
    static vector<int> a; a.clear();
    for (int& x: V) a.push_back(x);
    sort(a.begin(), a.end(), cmp);
    FOR (i, 1, a.size())
        a.push_back(lca(a[i], a[i -
            1]));
    a.push_back(1);
    sort(a.begin(), a.end(), cmp);
    a.erase(unique(a.begin(), a.end())
        , a.end());
    dbg(a);
    int tmp; go(a, tmp = 0);
    return f[1];
}
```

4.9 Euler Tour

```
int S[N << 1], top;
Edge edges[N << 1];
set<int> G[N];

void DFS(int u) {
    S[top++] = u;
    for (int eid: G[u]) {
        int v = edges[eid].get_other(u
            );
        G[u].erase(eid);
        G[v].erase(eid);
        DFS(v);
        return;
    }
}
void fleury(int start) {
    int u = start;
    top = 0; path.clear();
    S[top++] = u;
    while (top) {
        u = S[--top];
        if (!G[u].empty())
            DFS(u);
        else path.push_back(u);
    }
}
```

4.10 SCC, 2-SAT

```
int n, m;
vector<int> G[N], rG[N], vs;
int used[N], cmp[N];

void add_edge(int from, int to) {
    G[from].push_back(to);
    rG[to].push_back(from);
}

void dfs(int v) {
    used[v] = true;
    for (int u: G[v]) {
        if (!used[u])
            dfs(u);
    }
    vs.push_back(v);
}

void rdfs(int v, int k) {
    used[v] = true;
    cmp[v] = k;
    for (int u: rG[v])
        if (!used[u])
            rdfs(u, k);
}

int scc() {
    memset(used, 0, sizeof(used));
    vs.clear();
    for (int v = 0; v < n; ++v)
        if (!used[v]) dfs(v);
    memset(used, 0, sizeof(used));
    int k = 0;
    for (int i = (int) vs.size() - 1;
        i >= 0; --i)
        if (!used[vs[i]]) rdfs(vs[i],
            k++);
    return k;
}

int main() {
    cin >> n >> m;
    n *= 2;
    for (int i = 0; i < m; ++i) {
        int a, b; cin >> a >> b;
        add_edge(a - 1, (b - 1) ^ 1);
        add_edge(b - 1, (a - 1) ^ 1);
    }
    scc();
    for (int i = 0; i < n; i += 2) {
        if (cmp[i] == cmp[i + 1]) {
            puts("NIE");
            return 0;
        }
    }
    for (int i = 0; i < n; i += 2) {
        if (cmp[i] > cmp[i + 1])
            printf("%d\n", i + 1);
        else printf("%d\n", i + 2);
```

```
    }
}
```

4.11 Topological Sort

```
vector<int> toporder(int n) {
    vector<int> orders;
    queue<int> q;
    for (int i = 0; i < n; i++)
        if (!deg[i]) {
            q.push(i);
            orders.push_back(i);
        }
    while (!q.empty()) {
        int u = q.front(); q.pop();
        for (int v: G[u])
            if (!--deg[v]) {
                q.push(v);
                orders.push_back(v);
            }
    }
    return orders;
}
```

4.12 General Matching

```
// O(n^3)
vector<int> G[N];
int fa[N], mt[N], pre[N], mk[N];
int lca_clk, lca_mk[N];
pair<int, int> ce[N];
void connect(int u, int v) {
    mt[u] = v;
    mt[v] = u;
}
int find(int x) { return x == fa[x] ?
    x : fa[x] = find(fa[x]); }
void flip(int s, int u) {
    if (s == u) return;
    if (mk[u] == 2) {
        int v1 = ce[u].first, v2 = ce[
            u].second;
        flip(mt[u], v1);
        flip(s, v2);
        connect(v1, v2);
    } else {
        flip(s, pre[mt[u]]);
        connect(pre[mt[u]], mt[u]);
    }
}
int get_lca(int u, int v) {
    lca_clk++;
    for (u = find(u), v = find(v); ; u
        = find(pre[u]), v = find(pre[v
        ])) {
        if (u && lca_mk[u] == lca_clk)
            return u;
        lca_mk[u] = lca_clk;
        if (v && lca_mk[v] == lca_clk)
            return v;
        lca_mk[v] = lca_clk;
    }
}
void access(int u, int p, const pair<
    int, int>& c, vector<int>& q) {
    for (u = find(u); u != p; u = find
        (pre[u])) {
        if (mk[u] == 2) {
            ce[u] = c;
            q.push_back(u);
        }
        fa[find(u)] = find(p);
    }
}
bool aug(int s) {
    fill(mk, mk + n + 1, 0);
    fill(pre, pre + n + 1, 0);
    iota(fa, fa + n + 1, 0);
        vector<int> q = {s};
        mk[s] = 1;
    int t = 0;
    for (int t = 0; t < (int) q.size()
        ; ++t) {
        // q size can be changed
        int u = q[t];
        for (int &v: G[u]) {
            if (find(v) == find(u))
                continue;
            if (!mk[v] && !mt[v]) {
                flip(s, u);
                connect(u, v);
                return true;
            } else if (!mk[v]) {
                int w = mt[v];
                mk[v] = 2; mk[w] = 1;
                pre[w] = v; pre[v] = u
                    ;
                q.push_back(w);
            } else if (mk[find(v)] ==
                1) {
                int p = get_lca(u, v);
                access(u, p, {u, v}, q
                    );
                access(v, p, {v, u}, q
                    );
            }
        }
    }
    return false;
}

int match() {
    fill(mt + 1, mt + n + 1, 0);
    lca_clk = 0;
    int ans = 0;
    FOR (i, 1, n + 1)
        if (!mt[i]) ans += aug(i);
    return ans;
}
```

4.13 Tarjan

```
 // articulation points
// note that the graph might be
    disconnected
int dfn[N], low[N], clk;
void init() { clk = 0; memset(dfn, 0,
    sizeof dfn); }
void tarjan(int u, int fa) {
    low[u] = dfn[u] = ++clk;
    int cc = fa != -1;
    for (int& v: G[u]) {
        if (v == fa) continue;
        if (!dfn[v]) {
            tarjan(v, u);
            low[u] = min(low[u], low[v
                ]);
            cc += low[v] >= dfn[u];
        } else low[u] = min(low[u],
            dfn[v]);
```

```
    }
    if (cc > 1) // ...
}

// bridge
// note that the graph might have multiple edges or be disconnected
int dfn[N], low[N], clk;
void init() { memset(dfn, 0, sizeof dfn); clk = 0; }
void tarjan(int u, int fa) {
    low[u] = dfn[u] = ++clk;
    int _fst = 0;
    for (E& e: G[u]) {
        int v = e.to; if (v == fa && ++_fst == 1) continue;
        if (!dfn[v]) {
            tarjan(v, u);
            if (low[v] > dfn[u]) // ...
            low[u] = min(low[u], low[v]);
        } else low[u] = min(low[u], dfn[v]);
    }
}

// scc
int low[N], dfn[N], clk, B, bl[N];
vector<int> bcc[N];
void init() { B = clk = 0; memset(dfn, 0, sizeof dfn); }
void tarjan(int u) {
    static int st[N], p;
    static bool in[N];
    dfn[u] = low[u] = ++clk;
    st[p++] = u; in[u] = true;
    for (int& v: G[u]) {
        if (!dfn[v]) {
            tarjan(v);
            low[u] = min(low[u], low[v]);
        } else if (in[v]) low[u] = min(low[u], dfn[v]);
    }
    if (dfn[u] == low[u]) {
        while (1) {
            int x = st[--p]; in[x] = false;
            bl[x] = B; bcc[B].push_back(x);
            if (x == u) break;
        }
        ++B;
    }
}
```

4.14 Bi-connected Components, Block-cut Tree

```
// Array size should be 2 * N
// Single edge also counts as bi-connected comp
// Use |V| <= |E| to filter
struct E { int to, nxt; } e[N];
int hd[N], ecnt;
void addedge(int u, int v) {
    e[ecnt] = {v, hd[u]};
    hd[u] = ecnt++;
}
int low[N], dfn[N], clk, B, bno[N];
vector<int> bc[N], be[N];
bool vise[N];
void init() {
    memset(vise, 0, sizeof vise);
    memset(hd, -1, sizeof hd);
    memset(dfn, 0, sizeof dfn);
    memset(bno, -1, sizeof bno);
    B = clk = ecnt = 0;
}

void tarjan(int u, int feid) {
    static int st[N], p;
    static auto add = [&](int x) {
        if (bno[x] != B) { bno[x] = B; bc[B].push_back(x); }
    };
    low[u] = dfn[u] = ++clk;
    for (int i = hd[u]; ~i; i = e[i].nxt) {
        if ((feid ^ i) == 1) continue;
        if (!vise[i]) { st[p++] = i; vise[i] = vise[i ^ 1] = true; }
        int v = e[i].to;
        if (!dfn[v]) {
            tarjan(v, i);
            low[u] = min(low[u], low[v]);
            if (low[v] >= dfn[u]) {
                bc[B].clear(); be[B].clear();
                while (1) {
                    int eid = st[--p];
                    add(e[eid].to); add(e[eid ^ 1].to);
                    be[B].push_back(eid);
                    if ((eid ^ i) <= 1) break;
                }
                ++B;
            }
        } else low[u] = min(low[u], dfn[v]);
    }
}

//////////////////////////
// block-cut tree
// cactus -> block-cut tree
// N >= |E| * 2
//////////////////////////

vector<int> G[N];
int nn;

struct E { int to, nxt; };
namespace C {
    E e[N * 2];
    int hd[N], ecnt;
    void addedge(int u, int v) {
        e[ecnt] = {v, hd[u]};
        hd[u] = ecnt++;
    }
    int idx[N], clk, fa[N];
    bool ring[N];
```

```cpp
void init() { ecnt = 0; memset(hd,
    -1, sizeof hd); clk = 0; }
void dfs(int u, int feid) {
    idx[u] = ++clk;
    for (int i = hd[u]; ~i; i = e[
        i].nxt) {
        if ((i ^ feid) == 1)
            continue;
        int v = e[i].to;
        if (!idx[v]) {
            fa[v] = u; ring[u] =
                false;
            dfs(v, i);
            if (!ring[u]) { G[u].
                push_back(v); G[v].
                push_back(u); }
        } else if (idx[v] < idx[u
            ]) {
            ++nn;
            G[nn].push_back(v); G[
                v].push_back(nn);
                // put the root of
                the cycle in the
                front
            for (int x = u; x != v
                ; x = fa[x]) {
                ring[x] = true;
                G[nn].push_back(x)
                    ; G[x].
                    push_back(nn);
            }
            ring[v] = true;
        }
    }
}
}
```

4.15 Minimum Directed Spanning Tree

```cpp
// edges will be modified
vector<E> edges;
int in[N], id[N], pre[N], vis[N];
// a copy of n is needed
LL zl_tree(int rt, int n) {
    LL ans = 0;
    int v, _n = n;
    while (1) {
        fill(in, in + n, INF);
        for (E &e: edges) {
            if (e.u != e.v && e.w < in
                [e.v]) {
                pre[e.v] = e.u;
                in[e.v] = e.w;
            }
        }
        FOR (i, 0, n) if (i != rt &&
            in[i] == INF) return -1;
        int tn = 0;
        fill(id, id + _n, -1); fill(
            vis, vis + _n, -1);
        in[rt] = 0;
        FOR (i, 0, n) {
            ans += in[v = i];
            while (vis[v] != i && id[v
                ] == -1 && v != rt) {
                vis[v] = i; v = pre[v
                    ];
            }
            if (v != rt && id[v] ==
                -1) {
                for (int u = pre[v]; u
                    != v; u = pre[u])
                    id[u] = tn;
                id[v] = tn++;
            }
        }
        if (tn == 0) break;
        FOR (i, 0, n) if (id[i] == -1)
            id[i] = tn++;
        for (int i = 0; i < (int)
            edges.size(); ) {
            auto &e = edges[i];
            v = e.v;
            e.u = id[e.u]; e.v = id[e.
                v];
            if (e.u != e.v) { e.w -=
                in[v]; i++; }
            else { swap(e, edges.back
                ()); edges.pop_back();
                }
        }
        n = tn; rt = id[rt];
}
    return ans;
}
```

4.16 Cycles

```cpp
// refer to cheatsheet for elaboration
LL cycle4() {
    LL ans = 0;
    iota(kth, kth + n + 1, 0);
    sort(kth, kth + n, [&](int x, int
        y) { return deg[x] < deg[y]; })
        ;
    FOR (i, 1, n + 1) rk[kth[i]] = i;
    FOR (u, 1, n + 1)
        for (int v: G[u])
            if (rk[v] > rk[u]) key[u].
                push_back(v);
    FOR (u, 1, n + 1) {
        for (int v: G[u])
            for (int w: key[v])
                if (rk[w] > rk[u]) ans
                    += cnt[w]++;
        for (int v: G[u])
            for (int w: key[v])
                if (rk[w] > rk[u]) --
                    cnt[w];
    }
    return ans;
}
int cycle3() {
    int ans = 0;
    for (E &e: edges) { deg[e.u]++;
        deg[e.v]++; }
    for (E &e: edges) {
        if (deg[e.u] < deg[e.v] || (
            deg[e.u] == deg[e.v] && e.u
             < e.v))
            G[e.u].push_back(e.v);
        else G[e.v].push_back(e.u);
    }
    FOR (x, 1, n + 1) {
        for (int y: G[x]) p[y] = x;
        for (int y: G[x]) for (int z:
            G[y]) if (p[z] == x) ans++;
    }
    return ans;
}
```

4.17 Dominator Tree

```
vector<int> G[N], rG[N];
vector<int> dt[N];

namespace tl{
    int fa[N], idx[N], clk, ridx[N];
    int c[N], best[N], semi[N], idom[N];
    void init(int n) {
        clk = 0;
        fill(c, c + n + 1, -1);
        FOR (i, 1, n + 1) dt[i].clear();
        FOR (i, 1, n + 1) semi[i] = best[i] = i;
        fill(idx, idx + n + 1, 0);
    }
    void dfs(int u) {
        idx[u] = ++clk; ridx[clk] = u;
        for (int& v: G[u]) if (!idx[v]) { fa[v] = u; dfs(v); }
    }
    int fix(int x) {
        if (c[x] == -1) return x;
        int &f = c[x], rt = fix(f);
        if (idx[semi[best[x]]] > idx[semi[best[f]]]) best[x] = best[f];
        return f = rt;
    }
    void go(int rt) {
        dfs(rt);
        FORD (i, clk, 1) {
            int x = ridx[i], mn = clk + 1;
            for (int& u: rG[x]) {
                if (!idx[u]) continue; // reaching all might not be possible
                fix(u); mn = min(mn, idx[semi[best[u]]]);
            }
            c[x] = fa[x];
            dt[semi[x] = ridx[mn]].push_back(x);
            x = ridx[i - 1];
            for (int& u: dt[x]) {
                fix(u);
                if (semi[best[u]] != x) idom[u] = best[u];
                else idom[u] = x;
            }
            dt[x].clear();
        }

        FOR (i, 2, clk + 1) {
            int u = ridx[i];
            if (idom[u] != semi[u]) idom[u] = idom[idom[u]];
            dt[idom[u]].push_back(u);
        }
    }
}
```

4.18 Global Minimum Cut

```
struct StoerWanger {
    LL n, vis[N];
    LL dist[N];
    LL g[N][N];

    void init(int nn, LL w[N][N]) {
        n = nn;
        FOR (i, 1, n + 1) FOR (j, 1, n + 1)
            g[i][j] = w[i][j];
        memset(dist, 0, sizeof(dist));
    }

    LL min_cut_phase(int clk, int &x, int &y) {
        int t;
        vis[t = 1] = clk;
        FOR (i, 1, n + 1) if (vis[i] != clk)
            dist[i] = g[1][i];
        FOR (i, 1, n) {
            x = t; t = 0;
            FOR (j, 1, n + 1)
                if (vis[j] != clk &&
                    (!t || dist[j] > dist[t]))
                    t = j;
            vis[t] = clk;
            FOR (j, 1, n + 1) if (vis[j] != clk)
                dist[j] += g[t][j];
        }
        y = t;
        return dist[t];
    }

    void merge(int x, int y) {
        if (x > y) swap(x, y);
        FOR (i, 1, n + 1)
            if (i != x && i != y) {
                g[i][x] += g[i][y];
                g[x][i] += g[i][y];
            }
        if (y == n) return;
        FOR (i, 1, n) if (i != y) {
            swap(g[i][y], g[i][n]);
            swap(g[y][i], g[n][i]);
        }
    }

    LL go() {
        LL ret = INF;
        memset(vis, 0, sizeof vis);
        for (int i = 1, x, y; n > 1; ++i, --n) {
            ret = min(ret, min_cut_phase(i, x, y));
            merge(x, y);
        }
        return ret;
    }
} sw;
```

5 Geometry

5.1 2D Basics

```
int sgn(LD x) { return fabs(x) < eps ? 0 : (x > 0 ? 1 : -1); }
struct L;
struct P;
typedef P V;
struct P {
    LD x, y;
    explicit P(LD x = 0, LD y = 0): x(x), y(y) {}
    explicit P(const L& l);
};
struct L {
    P s, t;
    L() {}
    L(P s, P t): s(s), t(t) {}
};

P operator + (const P& a, const P& b) { return P(a.x + b.x, a.y + b.y); }
P operator - (const P& a, const P& b) { return P(a.x - b.x, a.y - b.y); }
P operator * (const P& a, LD k) { return P(a.x * k, a.y * k); }
P operator / (const P& a, LD k) { return P(a.x / k, a.y / k); }
inline bool operator < (const P& a, const P& b) {
    return sgn(a.x - b.x) < 0 || (sgn(a.x - b.x) == 0 && sgn(a.y - b.y) < 0);
}
bool operator == (const P& a, const P& b) { return !sgn(a.x - b.x) && !sgn(a.y - b.y); }
P::P(const L& l) { *this = l.t - l.s; }
ostream &operator << (ostream &os, const P &p) {
    return (os << "(" << p.x << "," << p.y << ")");
}
istream &operator >> (istream &is, P &p) {
    return (is >> p.x >> p.y);
}
LD dist(const P& p) { return sqrt(p.x * p.x + p.y * p.y); }
LD dot(const V& a, const V& b) {
    return a.x * b.x + a.y * b.y; }
LD det(const V& a, const V& b) {
    return a.x * b.y - a.y * b.x; }
LD cross(const P& s, const P& t, const P& o = P()) { return det(s - o, t - o); }
```

5.2 Polar angle sort

```
int quad(P p) {
    int x = sgn(p.x), y = sgn(p.y);
    if (x > 0 && y >= 0) return 1;
    if (x <= 0 && y > 0) return 2;
    if (x < 0 && y <= 0) return 3;
    if (x >= 0 && y < 0) return 4;
    assert(0);
}

struct cmp_angle {
    P p;
    bool operator () (const P& a, const P& b) {
        int qa = quad(a - p), qb = quad(b - p);
        if (qa != qb) return qa < qb;
        // compare quad
        int d = sgn(cross(a, b, p));
        if (d) return d > 0;
        return dist(a - p) < dist(b - p);
    }
};
```

5.3 Segments, lines

```
bool parallel(const L& a, const L& b) {
    return !sgn(det(P(a), P(b)));
}
bool l_eq(const L& a, const L& b) {
    return parallel(a, b) && parallel(L(a.s, b.t), L(b.s, a.t));
}
// counter-clockwise r radius
P rotation(const P& p, const LD& r) {
    return P(p.x * cos(r) - p.y * sin(r), p.x * sin(r) + p.y * cos(r)); }
P RotateCCW90(const P& p) { return P(-p.y, p.x); }
P RotateCW90(const P& p) { return P(p.y, -p.x); }
V normal(const V& v) { return V(-v.y, v.x) / dist(v); }
// inclusive: <=0; exclusive: <0
bool p_on_seg(const P& p, const L& seg) {
    P a = seg.s, b = seg.t;
    return !sgn(det(p - a, b - a)) && sgn(dot(p - a, p - b)) <= 0;
}
LD dist_to_line(const P& p, const L& l) {
    return fabs(cross(l.s, l.t, p)) / dist(l);
}
LD dist_to_seg(const P& p, const L& l) {
    if (l.s == l.t) return dist(p - l);
    V vs = p - l.s, vt = p - l.t;
    if (sgn(dot(l, vs)) < 0) return dist(vs);
    else if (sgn(dot(l, vt)) > 0) return dist(vt);
    else return dist_to_line(p, l);
}

// make sure they have intersection in advance
P l_intersection(const L& a, const L& b) {
    LD s1 = det(P(a), b.s - a.s), s2 = det(P(a), b.t - a.s);
    return (b.s * s2 - b.t * s1) / (s2 - s1);
}
LD angle(const V& a, const V& b) {
    LD r = asin(fabs(det(a, b)) / dist(a) / dist(b));
    if (sgn(dot(a, b)) < 0) r = PI - r
```

```
        ;
    return r;
}
// 1: proper; 2: improper
int s_l_cross(const L& seg, const L&
    line) {
    int d1 = sgn(cross(line.s, line.t,
        seg.s));
    int d2 = sgn(cross(line.s, line.t,
        seg.t));
    if ((d1 ^ d2) == -2) return 1; //
        proper
    if (d1 == 0 || d2 == 0) return 2;
    return 0;
}
// 1: proper; 2: improper
int s_cross(const L& a, const L& b, P&
    p) {
    int d1 = sgn(cross(a.t, b.s, a.s))
        , d2 = sgn(cross(a.t, b.t, a.s)
        );
    int d3 = sgn(cross(b.t, a.s, b.s))
        , d4 = sgn(cross(b.t, a.t, b.s)
        );
    if ((d1 ^ d2) == -2 && (d3 ^ d4)
        == -2) { p = l_intersection(a,
        b); return 1; }
    if (!d1 && p_on_seg(b.s, a)) { p =
        b.s; return 2; }
    if (!d2 && p_on_seg(b.t, a)) { p =
        b.t; return 2; }
    if (!d3 && p_on_seg(a.s, b)) { p =
        a.s; return 2; }
    if (!d4 && p_on_seg(a.t, b)) { p =
        a.t; return 2; }
    return 0;
}
```

5.4 Polygons

```
typedef vector<P> S;

// 0 = outside, 1 = inside, -1 = on
    border
int inside(const S& s, const P& p) {
    int cnt = 0;
    FOR (i, 0, s.size()) {
        P a = s[i], b = s[nxt(i)];
        if (p_on_seg(p, L(a, b)))
            return -1;
        if (sgn(a.y - b.y) <= 0) swap(
            a, b);
        if (sgn(p.y - a.y) > 0)
            continue;
        if (sgn(p.y - b.y) <= 0)
            continue;
        cnt += sgn(cross(b, a, p)) >
            0;
    }
    return bool(cnt & 1);
}
// can be negative
LD polygon_area(const S& s) {
    LD ret = 0;
    FOR (i, 1, (LL)s.size() - 1)
        ret += cross(s[i], s[i + 1], s
            [0]);
    return ret / 2;
}
// duplicate points are not allowed
// s is subject to change
const int MAX_N = 1000;
S convex_hull(S& s) {
//     assert(s.size() >= 3);
    sort(s.begin(), s.end());
    S ret(MAX_N * 2);
    int sz = 0;
    FOR (i, 0, s.size()) {
        while (sz > 1 && sgn(cross(ret
            [sz - 1], s[i], ret[sz -
            2])) < 0) --sz;
        ret[sz++] = s[i];
    }
    int k = sz;
    FORD (i, (LL)s.size() - 2, -1) {
        while (sz > k && sgn(cross(ret
            [sz - 1], s[i], ret[sz -
            2])) < 0) --sz;
        ret[sz++] = s[i];
    }
    ret.resize(sz - (s.size() > 1));
    return ret;
}
// centroid
P ComputeCentroid(const vector<P> &p)
    {
    P c(0, 0);
    LD scale = 6.0 * polygon_area(p);
    for (unsigned i = 0; i < p.size();
         i++) {
        unsigned j = (i + 1) % p.size
            ();
        c = c + (p[i] + p[j]) * (p[i].
            x * p[j].y - p[j].x * p[i].
            y);
    }
    return c / scale;
}
// Rotating Calipers, find convex hull
    first
LD rotatingCalipers(vector<P>& qs) {
    int n = qs.size();
    if (n == 2)
        return dist(qs[0] - qs[1]);
    int i = 0, j = 0;
    FOR (k, 0, n) {
        if (!(qs[i] < qs[k])) i = k;
        if (qs[j] < qs[k]) j = k;
    }
    LD res = 0;
    int si = i, sj = j;
    while (i != sj || j != si) {
        res = max(res, dist(qs[i] - qs
            [j]));
        if (sgn(cross(qs[(i+1)%n] - qs
            [i], qs[(j+1)%n] - qs[j]))
            < 0)
             i = (i + 1) % n;
        else j = (j + 1) % n;
    }
    return res;
}
```

5.5 Half-plane intersection

```
struct LV {
    P p, v; LD ang;
    LV() {}
    LV(P s, P t): p(s), v(t - s) { ang
        = atan2(v.y, v.x); }
```

```
}; // [illegible]

bool operator < (const LV &a, const LV & b) { return a.ang < b.ang; }
bool on_left(const LV& l, const P& p) { return sgn(cross(l.v, p - l.p)) >= 0; }
P l_intersection(const LV& a, const LV & b) {
    P u = a.p - b.p; LD t = cross(b.v, u) / cross(a.v, b.v);
    return a.p + a.v * t;
}

S half_plane_intersection(vector<LV>& L) {
    int n = L.size(), fi, la;
    sort(L.begin(), L.end());
    vector<P> p(n); vector<LV> q(n);
    q[fi = la = 0] = L[0];
    FOR (i, 1, n) {
        while (fi < la && !on_left(L[i], p[la - 1])) la--;
        while (fi < la && !on_left(L[i], p[fi])) fi++;
        q[++la] = L[i];
        if (sgn(cross(q[la].v, q[la - 1].v)) == 0) {
            la--;
            if (on_left(q[la], L[i].p)) q[la] = L[i];
        }
        if (fi < la) p[la - 1] = l_intersection(q[la - 1], q[la]);
    }
    while (fi < la && !on_left(q[fi], p[la - 1])) la--;
    if (la - fi <= 1) return vector<P>();
    p[la] = l_intersection(q[la], q[fi]);
    return vector<P>(p.begin() + fi, p.begin() + la + 1);
}

S convex_intersection(const vector<P> &v1, const vector<P> &v2) {
    vector<LV> h; int n = v1.size(), m = v2.size();
    FOR (i, 0, n) h.push_back(LV(v1[i], v1[(i + 1) % n]));
    FOR (i, 0, m) h.push_back(LV(v2[i], v2[(i + 1) % m]));
    return half_plane_intersection(h);
}
```

5.6 Circles

```
struct C {
    P p; LD r;
    C(LD x = 0, LD y = 0, LD r = 0): p(x, y), r(r) {}
    C(P p, LD r): p(p), r(r) {}
};

P compute_circle_center(P a, P b, P c) {
    b = (a + b) / 2;
    c = (a + c) / 2;
    return l_intersection({b, b + RotateCW90(a - b)}, {c , c + RotateCW90(a - c)});
}

// intersections are clockwise subject to center
vector<P> c_l_intersection(const L& l, const C& c) {
    vector<P> ret;
    P b(l), a = l.s - c.p;
    LD x = dot(b, b), y = dot(a, b), z = dot(a, a) - c.r * c.r;
    LD D = y * y - x * z;
    if (sgn(D) < 0) return ret;
    ret.push_back(c.p + a + b * (-y + sqrt(D + eps)) / x);
    if (sgn(D) > 0) ret.push_back(c.p + a + b * (-y - sqrt(D)) / x);
    return ret;
}

vector<P> c_c_intersection(C a, C b) {
    vector<P> ret;
    LD d = dist(a.p - b.p);
    if (sgn(d) == 0 || sgn(d - (a.r + b.r)) > 0 || sgn(d + min(a.r, b.r) - max(a.r, b.r)) < 0)
        return ret;
    LD x = (d * d - b.r * b.r + a.r * a.r) / (2 * d);
    LD y = sqrt(a.r * a.r - x * x);
    P v = (b.p - a.p) / d;
    ret.push_back(a.p + v * x + RotateCCW90(v) * y);
    if (sgn(y) > 0) ret.push_back(a.p + v * x - RotateCCW90(v) * y);
    return ret;
}
// 1: inside, 2: internally tangent
// 3: intersect, 4: ext tangent 5: outside
int c_c_relation(const C& a, const C& v) {
    LD d = dist(a.p - v.p);
    if (sgn(d - a.r - v.r) > 0) return 5;
    if (sgn(d - a.r - v.r) == 0) return 4;
    LD l = fabs(a.r - v.r);
    if (sgn(d - l) > 0) return 3;
    if (sgn(d - l) == 0) return 2;
    if (sgn(d - l) < 0) return 1;
}

// circle triangle intersection
// abs might be needed
LD sector_area(const P& a, const P& b, LD r) {
    LD th = atan2(a.y, a.x) - atan2(b.y, b.x);
    while (th <= 0) th += 2 * PI;
    while (th > 2 * PI) th -= 2 * PI;
    th = min(th, 2 * PI - th);
    return r * r * th / 2;
}
LD c_tri_area(P a, P b, P center, LD r) {
    a = a - center; b = b - center;
```

```
    int ina = sgn(dist(a) - r) < 0,
        inb = sgn(dist(b) - r) < 0;
    // dbg(a, b, ina, inb);
    if (ina && inb) {
        return fabs(cross(a, b)) / 2;
    } else {
        auto p = c_l_intersection(L(a, b), C(0, 0, r));
        if (ina ^ inb) {
            auto cr = p_on_seg(p[0], L(a, b)) ? p[0] : p[1];
            if (ina) return sector_area(b, cr, r) + fabs(cross(a, cr)) / 2;
            else return sector_area(a, cr, r) + fabs(cross(b, cr)) / 2;
        } else {
            if ((int) p.size() == 2 && p_on_seg(p[0], L(a, b))) {
                if (dist(p[0] - a) > dist(p[1] - a)) swap(p[0], p[1]);
                return sector_area(a, p[0], r) + sector_area(p[1], b, r)
                    + fabs(cross(p[0], p[1])) / 2;
            } else return sector_area(a, b, r);
        }
    }
}
typedef vector<P> S;
LD c_poly_area(S poly, const C& c) {
    LD ret = 0; int n = poly.size();
    FOR (i, 0, n) {
        int t = sgn(cross(poly[i] - c.p, poly[(i + 1) % n] - c.p));
        if (t) ret += t * c_tri_area(poly[i], poly[(i + 1) % n], c.p, c.r);
    }
    return ret;
}
```

5.7 Circle Union

```
// version 1
// union O(n^3 log n)
struct CV {
    LD yl, yr, ym; C o; int type;
    CV() {}
    CV(LD yl, LD yr, LD ym, C c, int t)
        : yl(yl), yr(yr), ym(ym), type(t), o(c) {}
};
pair<LD, LD> c_point_eval(const C& c, LD x) {
    LD d = fabs(c.p.x - x), h = rt(sq(c.r) - sq(d));
    return {c.p.y - h, c.p.y + h};
}
pair<CV, CV> pairwise_curves(const C& c, LD xl, LD xr) {
    LD yl1, yl2, yr1, yr2, ym1, ym2;
    tie(yl1, yl2) = c_point_eval(c, xl);
    tie(ym1, ym2) = c_point_eval(c, (xl + xr) / 2);
    tie(yr1, yr2) = c_point_eval(c, xr);
    return {CV(yl1, yr1, ym1, c, 1), CV(yl2, yr2, ym2, c, -1)};
}
bool operator < (const CV& a, const CV& b) { return a.ym < b.ym; }
LD cv_area(const CV& v, LD xl, LD xr) {
    LD l = rt(sq(xr - xl) + sq(v.yr - v.yl));
    LD d = rt(sq(v.o.r) - sq(l / 2));
    LD ang = atan(l / d / 2);
    return ang * sq(v.o.r) - d * l / 2;
}
LD circle_union(const vector<C>& cs) {
    int n = cs.size();
    vector<LD> xs;
    FOR (i, 0, n) {
        xs.push_back(cs[i].p.x - cs[i].r);
        xs.push_back(cs[i].p.x);
        xs.push_back(cs[i].p.x + cs[i].r);
        FOR (j, i + 1, n) {
            auto pts = c_c_intersection(cs[i], cs[j]);
            for (auto& p: pts) xs.push_back(p.x);
        }
    }
    sort(xs.begin(), xs.end());
    xs.erase(unique(xs.begin(), xs.end(), [](LD x, LD y) { return sgn(x - y) == 0; }), xs.end());
    LD ans = 0;
    FOR (i, 0, (int) xs.size() - 1) {
        LD xl = xs[i], xr = xs[i + 1];
        vector<CV> intv;
        FOR (k, 0, n) {
            auto& c = cs[k];
            if (sgn(c.p.x - c.r - xl) <= 0 && sgn(c.p.x + c.r - xr) >= 0) {
                auto t = pairwise_curves(c, xl, xr);
                intv.push_back(t.first); intv.push_back(t.second);
            }
        }
        sort(intv.begin(), intv.end());

        vector<LD> areas(intv.size());
        FOR (i, 0, intv.size()) areas[i] = cv_area(intv[i], xl, xr);

        int cc = 0;
        FOR (i, 0, intv.size()) {
```

```
        if (cc > 0) {
          ans += (intv[i].yl - intv[i - 1].yl + intv[i].yr - intv[i - 1].yr) * (xr - xl) / 2;
          ans += intv[i - 1].type * areas[i - 1];
          ans -= intv[i].type * areas[i];
        }
        cc += intv[i].type;
      }
    }
    return ans;
}

// version 2 (k-cover, O(n^2 log n))
inline LD angle(const P &p) { return atan2(p.y, p.x); }

// Points on circle
// p is coordinates relative to c
struct CP {
  P p;
  LD a;
  int t;
  CP() {}
  CP(P p, LD a, int t) : p(p), a(a), t(t) {}
};
bool operator<(const CP &u, const CP &v) { return u.a < v.a; }
LD cv_area(LD r, const CP &q1, const CP &q2) {
  return (r * r * (q2.a - q1.a) - cross(q1.p, q2.p)) / 2;
}

LD ans[N];
void circle_union(const vector<C> &cs) {
  int n = cs.size();
  FOR(i, 0, n) {
    // same circle, only the first one counts
    bool ok = true;
    FOR(j, 0, i)
    if (sgn(cs[i].r - cs[j].r) == 0 && cs[i].p == cs[j].p) {
      ok = false;
      break;
    }
    if (!ok)
      continue;
    auto &c = cs[i];
    vector<CP> ev;
    int belong_to = 0;
    P bound = c.p + P(-c.r, 0);
    ev.emplace_back(bound, -PI, 0);
    ev.emplace_back(bound, PI, 0);
    FOR(j, 0, n) {
      if (i == j)
        continue;
      if (c_c_relation(c, cs[j]) <= 2) {
        if (sgn(cs[j].r - c.r) >= 0)
          // totally covered
          belong_to++;
        continue;
      }
      auto its = c_c_intersection(c, cs[j]);
      if (its.size() == 2) {
        P p = its[1] - c.p, q = its[0] - c.p;
        LD a = angle(p), b = angle(q);
        if (sgn(a - b) > 0) {
          ev.emplace_back(p, a, 1);
          ev.emplace_back(bound, PI, -1);
          ev.emplace_back(bound, -PI, 1);
          ev.emplace_back(q, b, -1);
        } else {
          ev.emplace_back(p, a, 1);
          ev.emplace_back(q, b, -1);
        }
      }
    }
    sort(ev.begin(), ev.end());
    int cc = ev[0].t;
    FOR(j, 1, ev.size()) {
      int t = cc + belong_to;
      ans[t] += cross(ev[j - 1].p + c.p, ev[j].p + c.p) / 2;
      ans[t] += cv_area(c.r, ev[j - 1], ev[j]);
      cc += ev[j].t;
    }
  }
}
```

5.8 Minimum Covering Circle

```
P compute_circle_center(P a, P b) {
  return (a + b) / 2; }
bool p_in_circle(const P& p, const C& c) {
  return sgn(dist(p - c.p) - c.r) <= 0;
}
C min_circle_cover(const vector<P> &in) {
  vector<P> a(in.begin(), in.end());
  dbg(a.size());
  random_shuffle(a.begin(), a.end());
  P c = a[0]; LD r = 0; int n = a.size();
  FOR (i, 1, n) if (!p_in_circle(a[i], {c, r})) {
    c = a[i]; r = 0;
    FOR (j, 0, i) if (!p_in_circle(a[j], {c, r})) {
      c = compute_circle_center(a[i], a[j]);
      r = dist(a[j] - c);
      FOR (k, 0, j) if (!p_in_circle(a[k], {c, r})) {
        c = compute_circle_center(a[i], a[j], a[k]);
        r = dist(a[k] - c);
      }
    }
  }
```

```
    return {c, r};
}
```

5.9 Circle Inversion

```
C inv(C c, const P& o) {
    LD d = dist(c.p - o);
    assert(sgn(d) != 0);
    LD a = 1 / (d - c.r);
    LD b = 1 / (d + c.r);
    c.r = (a - b) / 2 * R2;
    c.p = o + (c.p - o) * ((a + b) *
        R2 / 2 / d);
    return c;
}
```

5.10 3D Basics

```
struct P;
struct L;
typedef P V;
struct P {
    LD x, y, z;
    explicit P(LD x = 0, LD y = 0, LD
        z = 0): x(x), y(y), z(z) {}
    explicit P(const L& l);
};
struct L {
    P s, t;
    L() {}
    L(P s, P t): s(s), t(t) {}
};
struct F {
    P a, b, c;
    F() {}
    F(P a, P b, P c): a(a), b(b), c(c)
        {}
};
P operator + (const P& a, const P& b)
    { }
P operator - (const P& a, const P& b)
    { }
P operator * (const P& a, LD k) { }
P operator / (const P& a, LD k) { }
inline int operator < (const P& a,
    const P& b) {
    return sgn(a.x - b.x) < 0 || (sgn(
        a.x - b.x) == 0 && (sgn(a.y - b
        .y) < 0 ||
        (sgn(a.y - b.y) == 0 && sgn(a.z - b.z) < 0)));
}
bool operator == (const P& a, const P&
    b) { return !sgn(a.x - b.x) && !
    sgn(a.y - b.y) && !sgn(a.z - b.z);
    }
P::P(const L& l) { *this = l.t - l.s;
    }
ostream &operator << (ostream &os,
    const P &p) {
    return (os << "(" << p.x << "," <<
        p.y << "," << p.z << ")");
}
istream &operator >> (istream &is, P &
    p) {
    return (is >> p.x >> p.y >> p.z);
}
LD dist2(const P& p) { return p.x * p.
    x + p.y * p.y + p.z * p.z; }
LD dist(const P& p) { return sqrt(
    dist2(p)); }
LD dot(const V& a, const V& b) {
    return a.x * b.x + a.y * b.y + a.z
    * b.z; }
P cross(const P& v, const P& w) {
    return P(v.y * w.z - v.z * w.y, v.
        z * w.x - v.x * w.z, v.x * w.y
        - v.y * w.x);
}
LD mix(const V& a, const V& b, const V
    & c) { return dot(a, cross(b, c));
    }
// counter-clockwise r radius
// axis = 0 around axis x
// axis = 1 around axis y
// axis = 2 around axis z
P rotation(const P& p, const LD& r,
    int axis = 0) {
    if (axis == 0)
        return P(p.x, p.y * cos(r) - p
            .z * sin(r), p.y * sin(r) +
            p.z * cos(r));
    else if (axis == 1)
        return P(p.z * cos(r) - p.x *
            sin(r), p.y, p.z * sin(r) +
            p.x * cos(r));
    else if (axis == 2)
        return P(p.x * cos(r) - p.y *
            sin(r), p.x * sin(r) + p.y
            * cos(r), p.z);
}
// n is normal vector
// this is clockwise
```

```
P rotation(const P& p, const LD& r,
    const P& n) {
    LD c = cos(r), s = sin(r), x = n.x
      , y = n.y, z = n.z;
    return P((x * x * (1 - c) + c) * p
       .x + (x * y * (1 - c) + z * s)
       * p.y + (x * z * (1 - c) - y *
       s) * p.z,
             (x * y * (1 - c) - z * s)
               * p.x + (y * y * (1 -
               c) + c) * p.y + (y *
               z * (1 - c) + x * s) *
               p.z,
             (x * z * (1 - c) + y * s)
               * p.x + (y * z * (1 -
               c) - x * s) * p.y + (
               z * z * (1 - c) + c) *
               p.z);
}
```

5.11 3D Line, Face

```
// <= 0 inproper, < 0 proper
bool p_on_seg(const P& p, const L& seg
    ) {
    P a = seg.s, b = seg.t;
    return !sgn(dist2(cross(p - a, b -
        a))) && sgn(dot(p - a, p - b))
        <= 0;
}
LD dist_to_line(const P& p, const L& l
    ) {
    return dist(cross(l.s - p, l.t - p
       )) / dist(l);
}
LD dist_to_seg(const P& p, const L& l)
     {
    if (l.s == l.t) return dist(p - l.
       s);
    V vs = p - l.s, vt = p - l.t;
    if (sgn(dot(l, vs)) < 0) return
        dist(vs);
    else if (sgn(dot(l, vt)) > 0)
        return dist(vt);
    else return dist_to_line(p, l);
}
P norm(const F& f) { return cross(f.a
    - f.b, f.b - f.c); }
int p_on_plane(const F& f, const P& p)
     { return sgn(dot(norm(f), p - f.a)
    ) == 0; }
// if two points are on the opposite
    side of a line
// return 0 if points is on the line
// makes no sense if points and line
    are not coplanar
int opposite_side(const P& u, const P&
    v, const L& l) {
        return sgn(dot(cross(P(l), u -
           l.s), cross(P(l), v - l.s)
           )) < 0;
}

bool parallel(const L& a, const L& b)
    { return !sgn(dist2(cross(P(a), P(b
    )))); }
int s_intersect(const L& u, const L& v
    ) {
     return p_on_plane(F(u.s, u.t, v.s)
         , v.t) &&
            opposite_side(u.s, u.t, v)
                &&
            opposite_side(v.s, v.t, u);
}
```

5.12 3D Convex

```
struct FT {
    int a, b, c;
    FT() { }
    FT(int a, int b, int c) : a(a), b(
        b), c(c) { }
};

bool p_on_line(const P& p, const L& l)
     {
    return !sgn(dist2(cross(p - l.s, P
       (l))));
}

vector<F> convex_hull(vector<P> &p) {
    sort(p.begin(), p.end());
    p.erase(unique(p.begin(), p.end())
        , p.end());
    random_shuffle(p.begin(), p.end())
        ;
    vector<FT> face;
    FOR (i, 2, p.size()) {
        if (p_on_line(p[i], L(p[0], p
           [1]))) continue;
        swap(p[i], p[2]);
        FOR (j, i + 1, p.size())
            if (sgn(mix(p[1] - p[0], p
               [2] - p[1], p[j] - p
               [0]))) {
                swap(p[j], p[3]);
                face.emplace_back(0,
                    1, 2);
                face.emplace_back(0,
                    2, 1);
                goto found;
            }
    }
found:
    vector<vector<int>> mk(p.size(),
        vector<int>(p.size()));
    FOR (v, 3, p.size()) {
        vector<FT> tmp;
        FOR (i, 0, face.size()) {
            int a = face[i].a, b =
               face[i].b, c = face[i].
               c;
            if (sgn(mix(p[a] - p[v], p
               [b] - p[v], p[c] - p[v
               ])) < 0) {
                mk[a][b] = mk[b][a] =
                    v;
                mk[b][c] = mk[c][b] =
                    v;
                mk[c][a] = mk[a][c] =
                    v;
            } else tmp.push_back(face[
               i]);
        }
        face = tmp;
        FOR (i, 0, tmp.size()) {
            int a = face[i].a, b =
               face[i].b, c = face[i].
               c;
```

```
            if (mk[a][b] == v) face.
                emplace_back(b, a, v);
            if (mk[b][c] == v) face.
                emplace_back(c, b, v);
            if (mk[c][a] == v) face.
                emplace_back(a, c, v);
        }
    }
    vector<F> out;
    FOR (i, 0, face.size())
        out.emplace_back(p[face[i].a],
            p[face[i].b], p[face[i].c
            ]);
    return out;
}
```

6 String

6.1 Aho-Corasick Automation

```
const int N = 1e6 + 100, M = 26;
int mp(char ch) { return ch - 'a'; }
struct ACA {
    int ch[N][M], danger[N], fail[N];
    int sz;
    void init() {
        sz = 1;
        memset(ch[0], 0, sizeof ch[0])
            ;
        memset(danger, 0, sizeof
            danger);
    }
    void insert(const string &s, int m
        ) {
        int n = s.size(); int u = 0, c
            ;
        FOR (i, 0, n) {
            c = mp(s[i]);
            if (!ch[u][c]) {
                memset(ch[sz], 0,
                    sizeof ch[sz]);
                danger[sz] = 0; ch[u][
                    c] = sz++;
            }
            u = ch[u][c];
        }
        danger[u] |= 1 << m;
    }
    void build() {
        queue<int> Q;
        fail[0] = 0;
        for (int c = 0, u; c < M; c++)
            {
            u = ch[0][c];
            if (u) { Q.push(u); fail[u
                ] = 0; }
        }
        while (!Q.empty()) {
            int r = Q.front(); Q.pop()
                ;
            danger[r] |= danger[fail[r
                ]];
            for (int c = 0, u; c < M;
                c++) {
                u = ch[r][c];
                if (!u) {
                    ch[r][c] = ch[fail
                        [r]][c];
                    continue;
                }
                fail[u] = ch[fail[r]][
                    c];
                Q.push(u);
            }
        }
    }
} ac;

char s[N];
int main() {
    int n; scanf("%d", &n);
    ac.init();
    while (n--) {
        scanf("%s", s);
        ac.insert(s, 0);
    }
    ac.build();
    scanf("%s", s);
    int u = 0; n = strlen(s);
    FOR (i, 0, n) {
        u = ac.ch[u][mp(s[i])];
        if (ac.danger[u]) {
            puts("YES");
            return 0;
        }
    }
    puts("NO");
    return 0;
}
```

6.2 Hash

```
const int p1 = 1e9 + 7, p2 = 1e9 + 9;
ULL xp1[N], xp2[N], xp[N];
void init_xp() {
    xp1[0] = xp2[0] = xp[0] = 1;
    for (int i = 1; i < N; ++i) {
        xp1[i] = xp1[i - 1] * x % p1;
        xp2[i] = xp2[i - 1] * x % p2;
        xp[i] = xp[i - 1] * x;
    }
}
struct String {
    char s[N];
    int length, subsize;
    bool sorted;
    ULL h[N], hl[N];
    ULL hash() {
        length = strlen(s);
        ULL res1 = 0, res2 = 0;
        h[length] = 0;  // ATTENTION!
        for (int j = length - 1; j >=
            0; --j) {
        #ifdef ENABLE_DOUBLE_HASH
            res1 = (res1 * x + s[j]) %
                p1;
            res2 = (res2 * x + s[j]) %
                p2;
            h[j] = (res1 << 32) | res2
                ;
        #else
            res1 = res1 * x + s[j];
            h[j] = res1;
        #endif
            // printf("%llu\n", h[j]);
        }
        return h[0];
    }
    // hash of [left, right)
    ULL get_substring_hash(int left,
```

```
        int right) const {
        int len = right - left;
    #ifdef ENABLE_DOUBLE_HASH
        // get hash of s[left...right
            -1]
        unsigned int mask32 = ~(0u);
        ULL left1 = h[left] >> 32,
            right1 = h[right] >> 32;
        ULL left2 = h[left] & mask32,
            right2 = h[right] & mask32;
        return (((left1 - right1 * xp1
            [len] % p1 + p1) % p1) <<
            32) |
               (((left2 - right2 * xp2
                  [len] % p2 + p2) %
                  p2));
    #else
        return h[left] - h[right] * xp
            [len];
    #endif
    }
    void get_all_subs_hash(int sublen)
        {
        subsize = length - sublen + 1;
        for (int i = 0; i < subsize;
            ++i)
             hl[i] = get_substring_hash
                 (i, i + sublen);
        sorted = 0;
    }
    void sort_substring_hash() {
        sort(hl, hl + subsize);
        sorted = 1;
    }
    bool match(ULL key) const {
        if (!sorted) assert (0);
        if (!subsize) return false;
        return binary_search(hl, hl +
            subsize, key);
    }
    void init(const char *t) {
        length = strlen(t);
        strcpy(s, t);
    }
};
int LCP(const String &a, const String
    &b, int ai, int bi) {
    // Find LCP of a[ai...] and b[bi
        ...]
    int l = 0, r = min(a.length - ai,
        b.length - bi);
    while (l < r) {
        int mid = (l + r + 1) / 2;
        if (a.get_substring_hash(ai,
            ai + mid) == b.
            get_substring_hash(bi, bi +
             mid))
             l = mid;
        else r = mid - 1;
    }
    return l;
}
```

6.3 KMP

```
void get_pi(int a[], char s[], int n)
    {
    int j = a[0] = 0;
    FOR (i, 1, n) {
        while (j && s[i] != s[j]) j =
            a[j - 1];
        a[i] = j += s[i] == s[j];
    }
}
void get_z(int a[], char s[], int n) {
    int l = 0, r = 0; a[0] = n;
    FOR (i, 1, n) {
        a[i] = i > r ? 0 : min(r - i +
            1, a[i - l]);
        while (i + a[i] < n && s[a[i]]
            == s[i + a[i]]) ++a[i];
        if (i + a[i] - 1 > r) { l = i;
            r = i + a[i] - 1; }
    }
}
```

6.4 Manacher

```
int RL[N];
void manacher(int* a, int n) { // "abc
    " => "#a#b#a#"
    int r = 0, p = 0;
    FOR (i, 0, n) {
        if (i < r) RL[i] = min(RL[2 *
            p - i], r - i);
        else RL[i] = 1;
        while (i - RL[i] >= 0 && i +
            RL[i] < n && a[i - RL[i]]
            == a[i + RL[i]])
             RL[i]++;
        if (RL[i] + i - 1 > r) { r =
            RL[i] + i - 1; p = i; }
    }
    FOR (i, 0, n) --RL[i];
}
```

6.5 Palindrome Automation

```
// num: the number of palindrome
    suffixes of the prefix represented
    by the node
// cnt: the number of occurrences in
    string (should update to father
    before using)
namespace pam {
    int t[N][26], fa[N], len[N], rs[N
        ], cnt[N], num[N];
    int sz, n, last;
    int _new(int l) {
        memset(t[sz], 0, sizeof t[0]);
        len[sz] = l; cnt[sz] = num[sz]
            = 0;
        return sz++;
    }
    void init() {
        rs[n = sz = 0] = -1;
        last = _new(0);
        fa[last] = _new(-1);
    }
    int get_fa(int x) {
        while (rs[n - 1 - len[x]] !=
            rs[n]) x = fa[x];
        return x;
    }
    void ins(int ch) {
        rs[++n] = ch;
        int p = get_fa(last);
        if (!t[p][ch]) {
            int np = _new(len[p] + 2);
            num[np] = num[fa[np] = t[
```

```
            get_fa(fa[p])][ch]] + 1;
        t[p][ch] = np;
      }
      ++cnt[last = t[p][ch]];
    }
}
```

6.6 Suffix Array

```
struct SuffixArray {
    const int L;
    vector<vector<int> > P;
    vector<pair<pair<int, int>, int> > M;
    int s[N], sa[N], rank[N], height[N];
    // s: raw string
    // sa[i]=k: s[k...L-1] ranks i (0 based)
    // rank[i]=k: the rank of s[i...L-1] is k (0 based)
    // height[i] = lcp(sa[i-1], sa[i])
    SuffixArray(const string &raw_s) : L(raw_s.length()), P(1, vector<int>(L, 0)), M(L) {
        for (int i = 0; i < L; i++)
            P[0][i] = this->s[i] = int(raw_s[i]);
        for (int skip = 1, level = 1; skip < L; skip *= 2, level++) {
            P.push_back(vector<int>(L, 0));
            for (int i = 0; i < L; i++)
                M[i] = make_pair(make_pair(P[level - 1][i], i + skip < L ? P[level - 1][i + skip] : -1000), i);
            sort(M.begin(), M.end());
            for (int i = 0; i < L; i++)
                P[level][M[i].second] = (i > 0 && M[i].first == M[i - 1].first) ? P[level][M[i - 1].second] : i;
        }
        for (unsigned i = 0; i < P.back().size(); ++i) {
            rank[i] = P.back()[i];
            sa[rank[i]] = i;
        }
    }
    // This is a traditional way to calculate LCP
    void getHeight() {
        memset(height, 0, sizeof height);
        int k = 0;
        for (int i = 0; i < L; ++i) {
            if (rank[i] == 0) continue;
            if (k) k--;
            int j = sa[rank[i] - 1];
            while (i + k < L && j + k < L && s[i + k] == s[j + k]) ++k;
            height[rank[i]] = k;
        }
        rmq_init(height, L);
    }
    int f[N][Nlog];
    inline int highbit(int x) {
        return 31 - __builtin_clz(x);
    }
    int rmq_query(int x, int y) {
        int p = highbit(y - x + 1);
        return min(f[x][p], f[y - (1 << p) + 1][p]);
    }
    // arr has to be 0 based
    void rmq_init(int *arr, int length) {
        for (int x = 0; x <= highbit(length); ++x)
            for (int i = 0; i <= length - (1 << x); ++i) {
                if (!x) f[i][x] = arr[i];
                else f[i][x] = min(f[i][x - 1], f[i + (1 << (x - 1))][x - 1]);
            }
    }
#ifdef NEW
    // returns the length of the longest common prefix of s[i...L-1] and s[j...L-1]
    int LongestCommonPrefix(int i, int j) {
        int len = 0;
        if (i == j) return L - i;
        for (int k = (int) P.size() - 1; k >= 0 && i < L && j < L; k--) {
            if (P[k][i] == P[k][j]) {
                i += 1 << k;
                j += 1 << k;
                len += 1 << k;
            }
        }
        return len;
    }
#else
    int LongestCommonPrefix(int i, int j) {
        // getHeight() must be called first
        if (i == j) return L - i;
        if (i > j) swap(i, j);
        return rmq_query(i + 1, j);
    }
#endif
    int checkNonOverlappingSubstring(int K) {
        // check if there is two non-overlapping identical substring of length K
        int minsa = 0, maxsa = 0;
        for (int i = 0; i < L; ++i) {
            if (height[i] < K) {
                minsa = sa[i]; maxsa =
```

```
                sa[i];
        } else {
            minsa = min(minsa, sa[i]);
            maxsa = max(maxsa, sa[i]);
            if (maxsa - minsa >= K) return 1;
        }
    }
    return 0;
}
int checkBelongToDifferentSubstring(int K, int split) {
    int minsa = 0, maxsa = 0;
    for (int i = 0; i < L; ++i) {
        if (height[i] < K) {
            minsa = sa[i]; maxsa = sa[i];
        } else {
            minsa = min(minsa, sa[i]);
            maxsa = max(maxsa, sa[i]);
            if (maxsa > split && minsa < split) return 1;
        }
    }
    return 0;
}
} *S;
int main() {
    int sp = s.length();
    s += "*" + t;
    S = new SuffixArray(s);
    S->getHeight();
    int left = 0, right = sp;
    while (left < right) {
        // ...
        if (S->checkBelongToDifferentSubstring(mid, sp))
            // ...
    }
    printf("%d\n", left);
}
///////////////////////////////////
// rk [0..n-1] -> [1..n], sa/ht [1..n]
// s[i] > 0 && s[n] = 0
// b: normally as bucket
// c: normally as bucket1
// d: normally as bucket2
// f: normally as cntbuf
///////////////////////////////////
template<size_t size>
struct SuffixArray {
    bool t[size << 1];
    int b[size], c[size];
    int sa[size], rk[size], ht[size];
    inline bool isLMS(const int i, const bool *t) { return i > 0 && t[i] && !t[i - 1]; }
    template<class T>
    inline void inducedSort(T s, int *sa, const int n, const int M, const int bs,
                            bool *t, int *b, int *f, int *p) {
        fill(b, b + M, 0); fill(sa, sa + n, -1);
        FOR (i, 0, n) b[s[i]]++;
        f[0] = b[0];
        FOR (i, 1, M) f[i] = f[i - 1] + b[i];
        FORD (i, bs - 1, -1) sa[--f[s[p[i]]]] = p[i];
        FOR (i, 1, M) f[i] = f[i - 1] + b[i - 1];
        FOR (i, 0, n) if (sa[i] > 0 && !t[sa[i] - 1]) sa[f[s[sa[i] - 1]]++] = sa[i] - 1;
        f[0] = b[0];
        FOR (i, 1, M) f[i] = f[i - 1] + b[i];
        FORD (i, n - 1, -1) if (sa[i] > 0 && t[sa[i] - 1]) sa[--f[s[sa[i] - 1]]] = sa[i] - 1;
    }
    template<class T>
    inline void sais(T s, int *sa, int n, bool *t, int *b, int *c, int M) {
        int i, j, bs = 0, cnt = 0, p = -1, x, *r = b + M;
        t[n - 1] = 1;
        FORD (i, n - 2, -1) t[i] = s[i] < s[i + 1] || (s[i] == s[i + 1] && t[i + 1]);
        FOR (i, 1, n) if (t[i] && !t[i - 1]) c[bs++] = i;
        inducedSort(s, sa, n, M, bs, t, b, r, c);
        for (i = bs = 0; i < n; i++) if (isLMS(sa[i], t)) sa[bs++] = sa[i];
        FOR (i, bs, n) sa[i] = -1;
        FOR (i, 0, bs) {
            x = sa[i];
            for (j = 0; j < n; j++) {
                if (p == -1 || s[x + j] != s[p + j] || t[x + j] != t[p + j])
                    { cnt++, p = x; break; }
                else if (j > 0 && (isLMS(x + j, t) || isLMS(p + j, t)))
                    break;
            }
            x = (~x & 1 ? x >> 1 : x - 1 >> 1), sa[bs + x] = cnt - 1;
        }
        for (i = j = n - 1; i >= bs; i--) if (sa[i] >= 0) sa[j--] = sa[i];
        int *s1 = sa + n - bs, *d = c + bs;
        if (cnt < bs) sais(s1, sa, bs, t + n, b, c + bs, cnt);
        else FOR (i, 0, bs) sa[s1[i]] = i;
```

```
        FOR (i, 0, bs) d[i] = c[sa[i]];
        inducedSort(s, sa, n, M, bs, t, b, r, d);
    }
    template<typename T>
    inline void getHeight(T s, const int n, const int *sa) {
        for (int i = 0, k = 0; i < n; i++) {
            if (rk[i] == 0) k = 0;
            else {
                if (k > 0) k--;
                int j = sa[rk[i] - 1];
                while (i + k < n && j + k < n && s[i + k] == s[j + k]) k++;
            }
            ht[rk[i]] = k;
        }
    }
    template<class T>
    inline void init(T s, int n, int M) {
        sais(s, sa, ++n, t, b, c, M);
        for (int i = 1; i < n; i++) rk[sa[i]] = i;
        getHeight(s, n, sa);
    }
};
SuffixArray<N> sa;
int main() {
    int n = s.length();
    sa.init(s, n, 128);
    FOR (i, 1, n + 1) printf("%d%c", sa.sa[i] + 1, i == _i - 1 ? '\n' : ' ');
    FOR (i, 2, n + 1) printf("%d%c", sa.ht[i], i == _i - 1 ? '\n' : ' ');
}
```

6.7 Suffix Automation

```
namespace sam {
    const int M = N << 1;
    int t[M][26], len[M] = {-1}, fa[M], sz = 2, last = 1;
    void init() { memset(t, 0, (sz + 10) * sizeof t[0]); sz = 2; last = 1; }
    void ins(int ch) {
        int p = last, np = last = sz++;
        len[np] = len[p] + 1;
        for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
        if (!p) { fa[np] = 1; return; }
        int q = t[p][ch];
        if (len[p] + 1 == len[q]) fa[np] = q;
        else {
            int nq = sz++; len[nq] = len[p] + 1;
            memcpy(t[nq], t[q], sizeof t[0]);
            fa[nq] = fa[q];
            fa[np] = fa[q] = nq;
            for (; t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
        }
    }
    int c[M] = {1}, a[M];
    void rsort() {
        FOR (i, 1, sz) c[i] = 0;
        FOR (i, 1, sz) c[len[i]]++;
        FOR (i, 1, sz) c[i] += c[i - 1];
        FOR (i, 1, sz) a[--c[len[i]]] = i;
    }
}
// really-generalized sam
int t[M][26], len[M] = {-1}, fa[M], sz = 2, last = 1;
LL cnt[M][2];
void ins(int ch, int id) {
    int p = last, np = 0, nq = 0, q = -1;
    if (!t[p][ch]) {
        np = sz++;
        len[np] = len[p] + 1;
        for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
    }
    if (!p) fa[np] = 1;
    else {
        q = t[p][ch];
        if (len[p] + 1 == len[q]) fa[np] = q;
        else {
            nq = sz++; len[nq] = len[p] + 1;
            memcpy(t[nq], t[q], sizeof t[0]);
            fa[nq] = fa[q];
            fa[np] = fa[q] = nq;
            for (; t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
        }
    }
    last = np ? np : nq ? nq : q;
    cnt[last][id] = 1;
}
// lexicographical order
// rsort2 is not topo sort
void ins(int ch, int pp) {
    int p = last, np = last = sz++;
    len[np] = len[p] + 1; one[np] = pos[np] = pp;
    for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
    if (!p) { fa[np] = 1; return; }
    int q = t[p][ch];
    if (len[q] == len[p] + 1) fa[np] = q;
    else {
        int nq = sz++; len[nq] = len[p] + 1; one[nq] = one[q];
        memcpy(t[nq], t[q], sizeof t[0]);
        fa[nq] = fa[q];
        fa[q] = fa[np] = nq;
        for (; p && t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
    }
}
// lexicographical order
```

```cpp
// generalized sam
int up[M], c[256] = {2}, a[M];
void rsort2() {
    FOR (i, 1, 256) c[i] = 0;
    FOR (i, 2, sz) up[i] = s[one[i] +
        len[fa[i]]];
    FOR (i, 2, sz) c[up[i]]++;
    FOR (i, 1, 256) c[i] += c[i - 1];
    FOR (i, 2, sz) a[--c[up[i]]] = i;
    FOR (i, 2, sz) G[fa[a[i]]].
        push_back(a[i]);
}

int t[M][26], len[M] = {0}, fa[M], sz
    = 2, last = 1;
char* one[M];
void ins(int ch, char* pp) {
    int p = last, np = 0, nq = 0, q =
        -1;
    if (!t[p][ch]) {
        np = sz++; one[np] = pp;
        len[np] = len[p] + 1;
        for (; p && !t[p][ch]; p = fa[
            p]) t[p][ch] = np;
    }
    if (!p) fa[np] = 1;
    else {
        q = t[p][ch];
        if (len[p] + 1 == len[q]) fa[
            np] = q;
        else {
            nq = sz++; len[nq] = len[p
                ] + 1; one[nq] = one[q
                ];
            memcpy(t[nq], t[q], sizeof
                t[0]);
            fa[nq] = fa[q];
            fa[np] = fa[q] = nq;
            for (; t[p][ch] == q; p =
                fa[p]) t[p][ch] = nq;
        }
    }
    last = np ? np : nq ? nq : q;
}
int up[M], c[256] = {2}, aa[M];
vector<int> G[M];
void rsort() {
    FOR (i, 1, 256) c[i] = 0;
    FOR (i, 2, sz) up[i] = *(one[i] +
        len[fa[i]]);
    FOR (i, 2, sz) c[up[i]]++;
    FOR (i, 1, 256) c[i] += c[i - 1];
    FOR (i, 2, sz) aa[--c[up[i]]] = i;
    FOR (i, 2, sz) G[fa[aa[i]]].
        push_back(aa[i]);
}
// match
int u = 1, l = 0;
FOR (i, 0, strlen(s)) {
    int ch = s[i] - 'a';
    while (u && !t[u][ch]) { u = fa[u
        ]; l = len[u]; }
    ++l; u = t[u][ch];
    if (!u) u = 1;
    if (l) // do something...
}
// substring state
int get_state(int l, int r) {
    int u = rpos[r], s = r - l + 1;
    FORD (i, SP - 1, -1) if (len[pa[u
        ][i]] >= s) u = pa[u][i];
    return u;
}

// LCT-SAM
namespace lct_sam {
    extern struct P *const null;
    const int M = N;
    struct P {
        P *fa, *ls, *rs;
        int last;

        bool has_fa() { return fa->ls
            == this || fa->rs == this;
            }
        bool d() { return fa->ls ==
            this; }
        P*& c(bool x) { return x ? ls
            : rs; }
        P* up() { return this; }
        void down() {
            if (ls != null) ls->last =
                last;
            if (rs != null) rs->last =
                last;
        }
        void all_down() { if (has_fa()
            ) fa->all_down(); down(); }
    } *const null = new P{0, 0, 0, 0},
        pool[M], *pit = pool;
    P* G[N];
    int t[M][26], len[M] = {-1}, fa[M
        ], sz = 2, last = 1;

    void rot(P* o) {
        bool dd = o->d();
        P *f = o->fa, *t = o->c(!dd);
        if (f->has_fa()) f->fa->c(f->d
            ()) = o; o->fa = f->fa;
        if (t != null) t->fa = f; f->c
            (dd) = t;
        o->c(!dd) = f->up(); f->fa = o
            ;
    }
    void splay(P* o) {
        o->all_down();
        while (o->has_fa()) {
            if (o->fa->has_fa())
                rot(o->d() ^ o->fa->d
                    () ? o : o->fa);
            rot(o);
        }
        o->up();
    }
    void access(int last, P* u, P* v =
        null) {
        if (u == null) { v->last =
            last; return; }
        splay(u);
        P *t = u;
        while (t->ls != null) t = t->
            ls;
        int L = len[fa[t - pool]] + 1,
            R = len[u - pool];

        if (u->last) bit::add(u->last
            - R + 2, u->last - L + 2,
            1);
```

```
        else bit::add(1, 1, R - L + 1);
        bit::add(last - R + 2, last - L + 2, -1);

    u->rs = v;
    access(last, u->up()->fa, u);
}
void insert(P* u, P* v, P* t) {
    if (v != null) { splay(v); v->rs = null; }
    splay(u);
    u->fa = t; t->fa = v;
}

void ins(int ch, int pp) {
    int p = last, np = last = sz++;
    len[np] = len[p] + 1;
    for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
    if (!p) fa[np] = 1;
    else {
        int q = t[p][ch];
        if (len[p] + 1 == len[q]) { fa[np] = q; G[np]->fa = G[q]; }
        else {
            int nq = sz++; len[nq] = len[p] + 1;
            memcpy(t[nq], t[q], sizeof t[0]);
            insert(G[q], G[fa[q]], G[nq]);
            G[nq]->last = G[q]->last;
            fa[nq] = fa[q];
            fa[np] = fa[q] = nq;
            G[np]->fa = G[nq];
            for (; t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
        }
    }
    access(pp + 1, G[np]);
}

    void init() {
        ++pit;
        FOR (i, 1, N) {
            G[i] = pit++;
            G[i]->ls = G[i]->rs = G[i]->fa = null;
        }
        G[1] = null;
    }
}
```

7 Miscellaneous

7.1 Date

```
// Routines for performing computations on dates. In these
// routines, months are exprsesed as integers from 1 to 12, days
// are expressed as integers from 1 to 31, and
// years are expressed as 4-digit integers.
string dayOfWeek[] = {"Mo", "Tu", "We", "Th", "Fr", "Sa", "Su"};
// converts Gregorian date to integer (Julian day number)
int DateToInt (int m, int d, int y){
  return
    1461 * (y + 4800 + (m - 14) / 12) / 4 +
    367 * (m - 2 - (m - 14) / 12 * 12) / 12 -
    3 * ((y + 4900 + (m - 14) / 12) / 100) / 4 +
    d - 32075;
}
// converts integer (Julian day number) to Gregorian date: month/day/year
void IntToDate (int jd, int &m, int &d, int &y){
  int x, n, i, j;
  x = jd + 68569;
  n = 4 * x / 146097;
  x -= (146097 * n + 3) / 4;
  i = (4000 * (x + 1)) / 1461001;
  x -= 1461 * i / 4 - 31;
  j = 80 * x / 2447;
  d = x - 2447 * j / 80;
  x = j / 11;
  m = j + 2 - 12 * x;
  y = 100 * (n - 49) + i + x;
}
// converts integer (Julian day number) to day of week
string IntToDay (int jd){
  return dayOfWeek[jd % 7];
}
```

7.2 Subset Enumeration

```
// all proper subset
for (int s = (S - 1) & S; s; s = (s - 1) & S) {
    // ...
}

// subset of length k
template<typename T>
void subset(int k, int n, T&& f) {
    int t = (1 << k) - 1;
    while (t < 1 << n) {
        f(t);
        int x = t & -t, y = t + x;
        t = ((t & ~y) / x >> 1) | y;
    }
}
```

7.3 Digit DP

```
LL dfs(LL base, LL pos, LL len, LL s, bool limit) {
    if (pos == -1) return s ? base : 1;
    if (!limit && dp[base][pos][len][s] != -1) return dp[base][pos][len][s];
    LL ret = 0;
    LL ed = limit ? a[pos] : base - 1;
    FOR (i, 0, ed + 1) {
        tmp[pos] = i;
        if (len == pos)
            ret += dfs(base, pos - 1,
```

```
                len - (i == 0), s,
                limit && i == a[pos]);
        else if (s &&pos < (len + 1) /
            2)
            ret += dfs(base, pos - 1,
                len, tmp[len - pos] ==
                i, limit && i == a[pos
                ]);
        else
            ret += dfs(base, pos - 1,
                len, s, limit && i == a
                [pos]);
    }
    if (!limit) dp[base][pos][len][s]
        = ret;
    return ret;
}

LL solve(LL x, LL base) {
    LL sz = 0;
    while (x) {
        a[sz++] = x % base;
        x /= base;
    }
    return dfs(base, sz - 1, sz - 1,
        1, true);
}
```

7.4 Simulated Annealing

```
// Minimum Circle Cover
using LD = double;
const int N = 1E4 + 100;
int x[N], y[N], n;
LD eval(LD xx, LD yy) {
    LD r = 0;
    FOR (i, 0, n)
        r = max(r, sqrt(pow(xx - x[i],
            2) + pow(yy - y[i], 2)));
    return r;
}
mt19937 mt(time(0));
auto rd = bind(
    uniform_real_distribution<LD>(-1,
    1), mt);
int main() {
    int X, Y;
    while (cin >> X >> Y >> n) {
        FOR (i, 0, n) scanf("%d%d", &x
            [i], &y[i]);
        pair<LD, LD> ans;
        LD M = 1e9;
        FOR (_, 0, 100) {
            LD cur_x = X / 2.0, cur_y
                = Y / 2.0, T = max(X, Y
                );
            while (T > 1e-3) {
                LD best_ans = eval(
                    cur_x, cur_y);
                LD best_x = cur_x,
                    best_y = cur_y;
                FOR (___, 0, 20) {
                    LD nxt_x = cur_x +
                        rd() * T,
                        nxt_y = cur_y +
                        rd() * T;
                    LD nxt_ans = eval(
                        nxt_x, nxt_y);
                    if (nxt_ans <
                        best_ans) {
                        best_x = nxt_x
                            ; best_y =
                            nxt_y;
                        best_ans =
                            nxt_ans;
                    }
                }
                cur_x = best_x; cur_y
                    = best_y;
                T *= .9;
            }
            if (eval(cur_x, cur_y) < M
                ) {
                ans = {cur_x, cur_y};
                M = eval(cur_x,
                cur_y);
            }
        }
        printf("(%.1f,%.1f).\n%.1f\n",
            ans.first, ans.second,
            eval(ans.first, ans.second)
            );
    }
}
```

1 数学

1.1 杜教筛

求 $S(n)=\sum_{i=1}^{n} f(i)$，其中 f 是一个积性函数。

构造一个积性函数 g，那么由 $(f*g)(n)=\sum_{d|n} f(d)g(\frac{n}{d})$，得到 $f(n)=(f*g)(n)-\sum_{d|n,d<n} f(d)g(\frac{n}{d})$。

$$g(1)S(n) = \sum_{i=1}^{n}(f*g)(i)-\sum_{i=1}^{n}\sum_{d|i,d<i} f(d)g(\frac{n}{d}) \quad (1)$$
$$\overset{t=\frac{i}{d}}{=} \sum_{i=1}^{n}(f*g)(i)-\sum_{t=2}^{n} g(t)S(\lfloor\frac{n}{t}\rfloor) \quad (2)$$

当然，要能够由此计算 $S(n)$，会对 f,g 提出一些要求：

- $f*g$ 要能够快速求前缀和。
- g 要能够快速求分段和（前缀和）。
- 对于正常的积性函数 $g(1)=1$，所以不会有什么问题。

在预处理 $S(n)$ 前 $n^{\frac{2}{3}}$ 项的情况下复杂度是 $O(n^{\frac{2}{3}})$。

1.2 素性测试

- 前置：快速乘、快速幂
- int 范围内只需检查 2, 7, 61
- long long 范围 2，325，9375，28178，450775，9780504，1795265022
- 3E15 内 2, 2570940, 880937, 610386380, 4130785767
- 4E13 内 2, 2570940, 211991001, 3749873356
- http://miller-rabin.appspot.com/

1.3 扩展欧几里得

- 求 $ax+by=gcd(a,b)$ 的一组解
- 如果 a 和 b 互素，那么 x 是 a 在模 b 下的逆元
- 注意 x 和 y 可能是负数

1.4 类欧几里得

- $m=\lfloor\frac{an+b}{c}\rfloor$.
- $f(a,b,c,n)=\sum_{i=0}^{n}\lfloor\frac{ai+b}{c}\rfloor$：当 $a\ge c$ or $b\ge c$ 时，$f(a,b,c,n)=(\frac{a}{c})n(n+1)/2+(\frac{b}{c})(n+1)+f(a \bmod c, b \bmod c, c, n)$；否则 $f(a,b,c,n)=nm-f(c,c-b-1,a,m-1)$。
- $g(a,b,c,n)=\sum_{i=0}^{n} i\lfloor\frac{ai+b}{c}\rfloor$：当 $a\ge c$ or $b\ge c$ 时，$g(a,b,c,n)=(\frac{a}{c})n(n+1)(2n+1)/6+(\frac{b}{c})n(n+1)/2+g(a \bmod c, b \bmod c, c, n)$；否则 $g(a,b,c,n)=\frac{1}{2}(n(n+1)m-f(c,c-b-1,a,m-1)-h(c,c-b-1,a,m-1))$。
- $h(a,b,c,n)=\sum_{i=0}^{n}\lfloor\frac{ai+b}{c}\rfloor^2$：当 $a\ge c$ or $b\ge c$ 时，$h(a,b,c,n)=(\frac{a}{c})^2n(n+1)(2n+1)/6+(\frac{b}{c})^2(n+1)+(\frac{a}{c})(\frac{b}{c})n(n+1)+h(a \bmod c, b \bmod c, c, n)+2(\frac{a}{c})g(a \bmod c, b \bmod c, c, n)+2(\frac{b}{c})f(a \bmod c, b \bmod c, c, n)$；否则 $h(a,b,c,n)=nm(m+1)-2g(c,c-b-1,a,m-1)-2f(c,c-b-1,a,m-1)-f(a,b,c,n)$。

1.5 斯特灵数

- 第一类斯特灵数：绝对值是 n 个元素划分为 k 个环排列的方案数。$s(n,k)=s(n-1,k-1)+(n-1)s(n-1,k)$
- 第二类斯特灵数：n 个元素划分为 k 个等价类的方案数。$S(n,k)=S(n-1,k-1)+kS(n-1,k)$

1.6 一些数论公式

- 当 $x\ge\phi(p)$ 时有 $a^x\equiv a^{x \bmod \phi(p)+\phi(p)} \pmod p$
- $\mu^2(n)=\sum_{d^2|n}\mu(d)$
- $\sum_{d|n}\varphi(d)=n$
- $\sum_{d|n}2^{\omega(d)}=\sigma_0(n^2)$，其中 ω 是不同素因子个数
- $\sum_{d|n}\mu^2(d)=2^{\omega(d)}$

1.7 一些数论函数求和的例子

- $\sum_{i=1}^{n} i[gcd(i,n)=1]=\frac{n\varphi(n)+[n=1]}{2}$
- $\sum_{i=1}^{n}\sum_{j=1}^{m}[gcd(i,j)=x]=\sum_d\mu(d)\lfloor\frac{n}{dx}\rfloor\lfloor\frac{m}{dx}\rfloor$
- $\sum_{i=1}^{n}\sum_{j=1}^{m} gcd(i,j)=\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{d|gcd(i,j)}\varphi(d)=\sum_d\varphi(d)\lfloor\frac{n}{d}\rfloor\lfloor\frac{m}{d}\rfloor$
- $S(n)=\sum_{i=1}^{n}\mu(i)=1-\sum_{i=1}^{n}\sum_{d|i,d<i}\mu(d)\overset{t=\frac{i}{d}}{=}1-\sum_{t=2}^{n}S(\lfloor\frac{n}{t}\rfloor)$（利用 $[n=1]=\sum_{d|n}\mu(d)$）
- $S(n)=\sum_{i=1}^{n}\varphi(i)=\sum_{i=1}^{n} i-\sum_{i=1}^{n}\sum_{d|i,d<i}\varphi(i)\overset{t=\frac{i}{d}}{=}\frac{i(i+1)}{2}-\sum_{t=2}^{n}S(\frac{n}{t})$（利用 $n=\sum_{d|n}\varphi(d)$）
- $\sum_{i=1}^{n}\mu^2(i)=\sum_{i=1}^{n}\sum_{d^2|n}\mu(d)=\sum_{d=1}^{\lfloor\sqrt{n}\rfloor}\mu(d)\lfloor\frac{n}{d^2}\rfloor$
- $\sum_{i=1}^{n}\sum_{j=1}^{n} gcd^2(i,j)=\sum_d d^2\sum_t\mu(t)\lfloor\frac{n}{dt}\rfloor^2 \overset{x=dt}{=}\sum_x\lfloor\frac{n}{x}\rfloor^2\sum_{d|x}d^2\mu(\frac{t}{x})$
- $\sum_{i=1}^{n}\varphi(i)=\frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}[i\perp j]-1=\frac{1}{2}\sum_{i=1}^{n}\mu(i)\cdot\lfloor\frac{n}{i}\rfloor^2-1$

1.8 斐波那契数列性质

- $F_{a+b}=F_{a-1}\cdot F_b+F_a\cdot F_{b+1}$
- $F_1+F_3+\dots+F_{2n-1}=F_{2n}, F_2+F_4+\dots+F_{2n}=F_{2n+1}-1$
- $\sum_{i=1}^{n}F_i=F_{n+2}-1$
- $\sum_{i=1}^{n}F_i^2=F_n\cdot F_{n+1}$
- $F_n^2=(-1)^{n-1}+F_{n-1}\cdot F_{n+1}$
- $gcd(F_a,F_b)=F_{gcd(a,b)}$
- 模 n 周期（皮萨诺周期）
  - $\pi(p^k)=p^{k-1}\pi(p)$
  - $\pi(nm)=lcm(\pi(n),\pi(m)), \forall n\perp m$
  - $\pi(2)=3, \pi(5)=20$
  - $\forall p\equiv\pm1 \pmod{10}, \pi(p)|p-1$
  - $\forall p\equiv\pm2 \pmod 5, \pi(p)|2p+2$

1.9 常见生成函数

- $(1+ax)^n=\sum_{k=0}^{n}\binom{n}{k}a^kx^k$
- $\dfrac{1-x^{r+1}}{1-x}=\sum_{k=0}^{n}x^k$
- $\dfrac{1}{1-ax}=\sum_{k=0}^{\infty}a^kx^k$

- $\frac{1}{(1-x)^2} = \sum_{k=0}^{\infty}(k+1)x^k$
- $\frac{1}{(1-x)^n} = \sum_{k=0}^{\infty}\binom{n+k-1}{k}x^k$
- $e^x = \sum_{k=0}^{\infty}\frac{x^k}{k!}$
- $\ln(1+x) = \sum_{k=0}^{\infty}\frac{(-1)^{k+1}}{k}x^k$

1.10 佩尔方程

若一个丢番图方程具有以下的形式：$x^2-ny^2=1$。且 n 为正整数，则称此二元二次不定方程为**佩尔方程**。

若 n 是完全平方数，则这个方程式只有平凡解 $(\pm1,0)$（实际上对任意的 n，$(\pm1,0)$ 都是解)。对于其余情况，拉格朗日证明了佩尔方程总有非平凡解。而这些解可由 $\sqrt{n}$ 的连分数求出。

$$x=[a_0;a_1,a_2,a_3]=x=a_0+\cfrac{1}{a_1+\cfrac{1}{a_2+\cfrac{1}{a_3+\cfrac{1}{\ddots}}}}$$

设 $\frac{p_i}{q_i}$ 是 $\sqrt{n}$ 的连分数表示：$[a_0;a_1,a_2,a_3,\ldots]$ 的渐近分数列，由连分数理论知存在 i 使得 (p_i,q_i) 为佩尔方程的解。取其中最小的 i，将对应的 (p_i,q_i) 称为佩尔方程的基本解，或最小解，记作 (x_1,y_1)，则所有的解 (x_i,y_i) 可表示成如下形式：$x_i+y_i\sqrt{n}=(x_1+y_1\sqrt{n})^i$。或者由以下的递回关系式得到：

$x_{i+1}=x_1x_i+ny_1y_i$, $y_{i+1}=x_1y_i+y_1x_i$。

通常,佩尔方程结果的形式通常是 $a_n=ka_{n-1}-a_{n-2}$(a_{n-2} 前的系数通常是 -1)。暴力 / 凑出两个基础解之后加上一个 0，容易解出 k 并验证。

1.11 Burnside & Polya

$|X/G|=\frac{1}{|G|}\sum_{g\in G}|X^g|$。$X^g$ 是 g 下的不动点数量，也就是说有多少种东西用 g 作用之后可以保持不变。

$|Y^X/G|=\frac{1}{|G|}\sum_{g\in G}m^{c(g)}$。用 m 种颜色染色，然后对于某一种置换 g，有 $c(g)$ 个置换环，为了保证置换后颜色仍然相同，每个置换环必须染成同色。

1.12 皮克定理

$2S=2a+b-2$

- S 多边形面积
- a 多边形内部点数
- b 多边形边上点数

1.13 莫比乌斯反演

- $g(n)=\sum_{d|n}f(d)\Leftrightarrow f(n)=\sum_{d|n}\mu(d)g(\frac{n}{d})$
- $f(n)=\sum_{n|d}g(d)\Leftrightarrow g(n)=\sum_{n|d}\mu(\frac{d}{n})f(d)$

1.14 低阶等幂求和

- $\sum_{i=1}^{n}i^1=\frac{n(n+1)}{2}=\frac{1}{2}n^2+\frac{1}{2}n$
- $\sum_{i=1}^{n}i^2=\frac{n(n+1)(2n+1)}{6}=\frac{1}{3}n^3+\frac{1}{2}n^2+\frac{1}{6}n$
- $\sum_{i=1}^{n}i^3=\left[\frac{n(n+1)}{2}\right]^2=\frac{1}{4}n^4+\frac{1}{2}n^3+\frac{1}{4}n^2$
- $\sum_{i=1}^{n}i^4=\frac{n(n+1)(2n+1)(3n^2+3n-1)}{30}=\frac{1}{5}n^5+\frac{1}{2}n^4+\frac{1}{3}n^3-\frac{1}{30}n$
- $\sum_{i=1}^{n}i^5=\frac{n^2(n+1)^2(2n^2+2n-1)}{12}=\frac{1}{6}n^6+\frac{1}{2}n^5+\frac{5}{12}n^4-\frac{1}{12}n^2$

1.15 一些组合公式

- 错排公式：$D_1=0,D_2=1,D_n=(n-1)(D_{n-1}+D_{n-2})=n!(\frac{1}{2!}-\frac{1}{3!}+\cdots+(-1)^n\frac{1}{n!})=\lfloor\frac{n!}{e}+0.5\rfloor$
- 卡塔兰数（n 对括号合法方案数，n 个结点二叉树个数，$n\times n$ 方格中对角线下方的单调路径数，凸 $n+2$ 边形的三角形划分数，n 个元素的合法出栈序列数）：$C_n=\frac{1}{n+1}\binom{2n}{n}=\frac{(2n)!}{(n+1)!n!}$

1.16 伯努利数与等幂求和

$\sum_{i=0}^{n}i^k=\frac{1}{k+1}\sum_{i=0}^{k}\binom{k+1}{i}B_{k+1-i}(n+1)^i$。也可以 $\sum_{i=0}^{n}i^k=\frac{1}{k+1}\sum_{i=0}^{k}\binom{k+1}{i}B^+_{k+1-i}n^i$。区别在于 $B^+_1=1/2$。

1.17 数论分块

$f(i)=\lfloor\frac{n}{i}\rfloor=v$ 时 i 的取值范围是 $[l,r]$。

```
for (LL l = 1, v, r; l <= N; l = r + 1) {
    v = N / l; r = N / v;
}
```

1.18 博弈

- Nim 游戏：每轮从若干堆石子中的一堆取走若干颗。先手必胜条件为石子数量异或和非零。
- 阶梯 Nim 游戏：可以选择阶梯上某一堆中的若干颗向下推动一级，直到全部推下去。先手必胜条件是奇数阶梯的异或和非零（对于偶数阶梯的操作可以模仿)。
- Anti-SG：无法操作者胜。先手必胜的条件是：
  - SG 不为 0 且某个单一游戏的 SG 大于 1 。
  - SG 为 0 且没有单一游戏的 SG 大于 1。
- Every-SG：对所有单一游戏都要操作。先手必胜的条件是单一游戏中的最大 step 为奇数。
  - 对于终止状态 step 为 0
  - 对于 SG 为 0 的状态，step 是最大后继 step +1
  - 对于 SG 非 0 的状态，step 是最小后继 step +1
- 树上删边：叶子 SG 为 0，非叶子结点为所有子结点的 SG 值加 1 后的异或和。

尝试：

- 打表找规律
- 寻找一类必胜态（如对称局面）
- 直接博弈 dp

2 图论

2.1 带下界网络流

- 无源汇：$u \to v$ 边容量为 $[l, r]$，连容量 $r - l$，虚拟源点到 v 连 l，u 到虚拟汇点连 l。
- 有源汇：为了让流能循环使用，连 $T \to S$，容量 ∞。
- 最大流：跑完可行流后，加 $S' \to S$，$T \to T'$，最大流就是答案（$T \to S$ 的流量自动退回去了，这一部分就是下界部分的流量）。
- 最小流：T 到 S 的那条边的实际流量，减去删掉那条边后 T 到 S 的最大流。
- 网上说可能会减成负的，还要有限地供应 S 之后，再跑一遍 S 到 T 的。
- 费用流：必要的部分（下界以下的）不要钱，剩下的按照最大流。

2.2 二分图匹配

- 最小覆盖数 = 最大匹配数
- 最大独立集 = 顶点数 - 二分图匹配数
- DAG 最小路径覆盖数 = 结点数 - 拆点后二分图最大匹配数

2.3 差分约束

一个系统 n 个变量和 m 个约束条件组成，每个约束条件形如 $x_j - x_i \le b_k$。可以发现每个约束条件都形如最短路中的三角不等式 $d_u - d_v \le w_{u,v}$。因此连一条边 (i, j, b_k) 建图。

若要使得所有量两两的值最接近，源点到各点的距离初始成 0，跑最远路。

若要使得某一变量与其他变量的差尽可能大，则源点到各点距离初始化成 ∞，跑最短路。

2.4 三元环

将点分成度入小于 $\sqrt{m}$ 和超过 $\sqrt{m}$ 的两类。现求包含第一类点的三元环个数。由于边数较少，直接枚举两条边即可。由于一个点度数不超过 $\sqrt{m}$，所以一条边最多被枚举 $\sqrt{m}$ 次，复杂度 $O(m\sqrt{m})$。再求不包含第一类点的三元环个数，由于这样的点不超过 $\sqrt{m}$ 个，所以复杂度也是 $O(m\sqrt{m})$。

对于每条无向边 (u, v)，如果 $d_u < d_v$，那么连有向边 (u, v)，否则有向边 (v, u)。度数相等的按第二关键字判断。然后枚举每个点 x，假设 x 是三元组中度数最小的点，然后暴力往后面枚举两条边找到 y，判断 (x, y) 是否有边即可。复杂度也是 $O(m\sqrt{m})$。

2.5 四元环

考虑这样一个四元环，将答案统计在度数最大的点 b 上。考虑枚举点 u，然后枚举与其相邻的点 v，然后再枚举所有度数比 v 大的与 v 相邻的点，这些点显然都可能作为 b 点，我们维护一个计数器来计算之前 b 被枚举多少次，答案加上计数器的值，然后计数器加一。

枚举完 u 之后，我们用和枚举时一样的方法来清空计数器就好了。

任何一个点，与其直接相连的度数大于等于它的点最多只有 $\sqrt{2m}$ 个。所以复杂度 $O(m\sqrt{m})$。

2.6 支配树

- `semi[x]` 半必经点（就是 x 的祖先 z 中，能不经过 z 和 x 之间的树上的点而到达 x 的点中深度最小的）
- `idom[x]` 最近必经点（就是深度最大的根到 x 的必经点）

3 计算几何

3.1 k 次圆覆盖

一种是用竖线进行切分，然后对每一个切片分别计算。扫描线部分可以魔改，求各种东西。复杂度 $O(n^3 \log n)$。

复杂度 $O(n^2 \log n)$。原理是：认为所求部分是一个奇怪的多边形 + 若干弓形。然后对于每个圆分别求贡献的弓形，并累加多边形有向面积。可以魔改扫描线的部分，用于求周长、至少覆盖 k 次等等。内含、内切、同一个圆的情况，通常需要特殊处理。

3.2 三维凸包

增量法。先将所有的点打乱顺序，然后选择四个不共面的点组成一个四面体，如果找不到说明凸包不存在。然后遍历剩余的点，不断更新凸包。对遍历到的点做如下处理。

1. 如果点在凸包内，则不更新。
2. 如果点在凸包外，那么找到所有原凸包上所有分隔了对于这个点可见面和不可见面的边，以这样的边的两个点和新的点创建新的面加入凸包中。

4 随机素数表

42737, 46411, 50101, 52627, 54577, 191677, 194869, 210407, 221831, 241337, 578603, 625409, 713569, 788813, 862481, 2174729, 2326673, 2688877, 2779417, 3133583, 4489747, 6697841, 6791471, 6878533, 7883129, 9124553, 10415371, 11134633, 12214801, 15589333, 17148757, 17997457, 20278487, 27256133, 28678757, 38206199, 41337119, 47422547, 48543479, 52834961, 76993291, 85852231, 95217823, 108755593, 132972461, 171863609, 173629837, 176939899, 207808351, 227218703, 306112619, 311809637, 322711981, 330806107, 345593317, 345887293, 362838523, 373523729, 394207349, 409580177, 437359931, 483577261, 490845269, 512059357, 534387017, 698987533, 764016151, 906097321, 914067307, 954169327

适合哈希的素数：1572869, 3145739, 6291469, 12582917, 25165843, 50331653

NTT 素数表：$p = r2^k + 1$，原根是 g。3, 1, 1, 2; 5, 1, 2, 2; 17, 1, 4, 3; 97, 3, 5, 5; 193, 3, 6, 5; 257, 1, 8, 3; 7681, 15, 9, 17; 12289, 3, 12, 11; 40961, 5, 13, 3; 65537, 1, 16, 3; 786433, 3, 18, 10; 5767169, 11, 19, 3; 7340033, 7, 20, 3; 23068673, 11, 21, 3; 104857601, 25, 22, 3; 167772161, 5, 25, 3; 469762049, 7, 26, 3; 1004535809, 479, 21, 3; 2013265921, 15, 27, 31; 2281701377, 17, 27, 3; 3221225473, 3, 30, 5; 75161927681, 35, 31, 3; 77309411329, 9, 33, 7; 206158430209, 3, 36, 22; 2061584302081, 15, 37, 7; 2748779069441, 5, 39, 3; 6597069766657, 3, 41, 5; 39582418599937, 9, 42, 5; 79164837199873, 9, 43, 5; 263882790666241, 15, 44, 7; 1231453023109121, 35, 45, 3; 1337006139375617, 19, 46, 3; 3799912185593857, 27, 47, 5.

5 心态崩了

- `(int)v.size()`
- `1LL << k`
- 递归函数用全局或者 static 变量要小心
- 预处理组合数注意上限
- 想清楚到底是要 `multiset` 还是 `set`
- 提交之前看一下数据范围，测一下边界
- 数据结构注意数组大小（2 倍，4 倍）
- 字符串注意字符集
- 如果函数中使用了默认参数的话，注意调用时的参数个数
- 注意要读完
- 构造参数无法使用自己
- 树链剖分/dfs 序，初始化或者询问不要忘记 idx, ridx
- 排序时注意结构体的所有属性是不是考虑了
- 不要把 while 写成 if
- 不要把 int 开成 char
- 清零的时候全部用 0 到 $n+1$。
- 模意义下不要用除法
- 哈希不要自然溢出
- 最短路不要 SPFA，乖乖写 Dijkstra
- 上取整以及 GCD 小心负数
- mid 用 `l + (r - l) / 2` 可以避免溢出和负数的问题
- 小心模板自带的意料之外的隐式类型转换
- 求最优解时不要忘记更新当前最优解
- 图论问题一定要注意图不连通的问题
- 处理强制在线的时候 lastans 负数也要记得矫正
- 不要觉得编译器什么都能优化