

.bashrc	1	structures/fenwick_tree.h	8
.vimrc	1	structures/fenwick_tree_2d.h	8
template.cpp	1	structures/find_union.h	8
geometry/convex_hull.h	1	structures/hull_offline.h	9
geometry/convex_hull_dist.h	1	structures/hull_online.h	9
geometry/convex_hull_sum.h	1	structures/max_queue.h	9
geometry/halfplane_intersect.h	1	structures/pairing_heap.h	9
geometry/line2.h	2	structures/rmq.h	9
geometry/rmst.h	2	structures/segment_tree.h	10
geometry/segment2.h	2	structures/segment_tree_beats.h	10
geometry/vec2.h	3	structures/segment_tree_point.h	11
graphs/2sat.h	3	structures/treap.h	11
graphs/bellman_inequalities.h	3	structures/ext/hash_table.h	11
graphs/bridges_online.h	3	structures/ext/rope.h	11
graphs/dense_dfs.h	3	structures/ext/tree.h	11
graphs/edmonds_karp.h	3	structures/ext/trie.h	11
graphs/gomory_hu.h	4	text/aho_corasick.h	12
graphs/push_relabel.h	4	text/kmp.h	12
graphs/scc.h	4	text/kmr.h	12
graphs/turbo_matching.h	4	text/lcp.h	12
math/bit_gauss.h	5	text/lyndon_factorization.h	12
math/bit_matrix.h	5	text/main_lorentz.h	12
math/crt.h	5	text/manacher.h	12
math/discrete_logarithm.h	5	text/min_rotation.h	13
math/fft_complex.h	5	text/palindromic_tree.h	13
math/fft_mod.h	6	text/suffix_array_linear.h	13
math/fwht.h	6	text/suffix_automaton.h	13
math/ gauss.h	6	text/suffix_tree.h	14
math/miller_rabin.h	6	text/z_function.h	14
math/modinv_precompute.h	6	trees/centroid_decomp.h	14
math/modular.h	6	trees/heavy_light_decomp.h	14
math/modular64.h	7	trees/lca.h	15
math/montgomery.h	7	trees/link_cut_tree.h	15
math/nimber.h	7	util/arc_interval_cover.h	15
math/phi_large.h	7	util/bit_hacks.h	16
math/phi_precompute.h	7	util/bump_alloc.h	16
math/phi_prefix_sum.h	7	util/compress_vec.h	16
math/pi_large_precomp.h	7	util/inversion_vector.h	16
math/pollard_rho.h	8	util/longest_increasing_sub.h	16
math/polynomial_interp.h	8	util/max_rects.h	16
math/sieve.h	8	util/mo.h	16
math/sieve_factors.h	8	util/parallel_binsearch.h	16
math/sieve_segmented.h	8	util/radix_sort.h	16
structures/bitset_plus.h	8		

.bashrc

```
build() {
    g++ $@ -o $1.e -DLOC -std=c++11 \
        -Wall -Wextra -Wfatal-errors -Wshadow \
        -Wlogical-op -Wconversion -Wfloat-equal
}

b()( build $@ -O2 )

d()( build $@ -fsanitize=address,undefined \
    -D_GLIBCXX_DEBUG -g )

run()( $1 $2 && echo start && time ./ $2.e )

loo() {
    set -e; $1 $2; $1 $3
    for (;;){
        ./ $3.e > gen.in
        time ./ $2.e < gen.in > gen.out
    }
}

cmp() {
    set -e; $1 $2; $1 $3; $1 $4
    for (;;){
        ./ $4.e > gen.in;          echo -n 0
        ./ $2.e < gen.in > p1.out; echo -n 1
        ./ $3.e < gen.in > p2.out; echo -n 2
        diff p1.out p2.out;       echo -n Y
    }
}

# Other flags:
# -Wformat=2 -Wshift-overflow=2 -Wcast-qual
# -Wcast-align -Wduplicated-cond
# -D_GLIBCXX_DEBUG_PEDANTIC -D_FORTIFY_SOURCE=2
# -fno-sanitize-recover -fstack-protector
```

.vimrc

```
se ai aw cin cul ic is nocp nohls nu sc scs
se bg=dark sw=4 ts=4 so=7 ttm=9
sy on
```

template.cpp

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

using ll = long long;
using Vi = vector<int>;
using Pii = pair<int,int>;

#define mp make_pair
#define pb push_back
#define x first
#define y second

#define rep(i,b,e) for(int i=(b); i<(e); i++)
#define each(a,x) for(auto& a : (x))
#define all(x) (x).begin(), (x).end()
#define sz(x) int((x).size())

int main() {
    cin.sync_with_stdio(0); cin.tie(0);
    cout << fixed << setprecision(18);
    return 0;
}
```

```
}

// > Debug printer

#define tem template<class t,class u,class...w>
#define pri(x,y)tem auto operator<<(t& o,u a) \
    ->decltype(x,o) { o << y; return o; }

pri(a.print(), "{"; a.print(); o << "}")
pri(a.y, "(" << a.x << ", " << a.y << ")")

pri(all(a), "["; auto d=""; for (auto i : a)
    (o << d << i, d = ", "; o << "]")

void DD(...) {}
tem void DD(t s, u a, w... k) {
    for (int b = 44; *s && *s - b; cerr << *s++)
        b += ((*s == 41) - (*s == 40)) * 88;
    cerr << ": " << a << *s++; DD(s, k...);
}

tem vector<t> span(const t* a, u n) {
    return {a, a+n};
}

#ifdef LOC
#define deb(...) (DD("[, \b :] #__VA_ARGS__, \
    __LINE__, __VA_ARGS__), cerr << endl)
#else
#define deb(...)
#endif

#define DBP(...) void print() { \
    DD((__VA_ARGS__, __VA_ARGS__)); }

// > Utils

// #define _USE_MATH_DEFINES

// #pragma GCC optimize("Ofast,unroll-loops,
//                        no-stack-protector")
// #pragma GCC target("avx,tune=native")

// while (clock() < time*CLOCKS_PER_SEC)

// using namespace rel_ops;

// Return smallest k such that 2^k > n
// Undefined for n = 0!
int uplg(int n) { return 32-__builtin_clz(n); }
int uplg(ll n){ return 64-__builtin_clzll(n); }

// Compare with certain epsilon (branchless)
// Returns -1 if a < b; 1 if a > b; 0 if equal
// a and b are assumed equal if |a-b| <= eps
int cmp(double a, double b, double eps=1e-10) {
    return (a > b+eps) - (a+eps < b);
}

// > Randomization

// mt19937_64 rnd(chrono::steady_clock::now()
//     .time_since_epoch().count());

// To pick from [0;N-1]: rnd() % N
// To random shuffle: shuffle(all(vec), rnd)
```

geometry/convex_hull.h

```
#include "vec2.h"

// Translate points such that lower-left point
// is (0, 0). Returns old point location; O(n)
vec2 normPos(vector<vec2>& points) {
    auto q = points[0].yxPair();
    each(p, points) q = min(q, p.yxPair());
    vec2 ret{q.y, q.x};
    each(p, points) p = p-ret;
    return ret;
}

// Find convex hull of points; time: O(n lg n)
// Points are returned counter-clockwise.
vector<vec2> convexHull(vector<vec2> points) {
    vec2 pivot = normPos(points);
    sort(all(points));
    vector<vec2> hull;

    each(p, points) {
        while (sz(hull) >= 2) {
            vec2 a = hull.back() - hull[sz(hull)-2];
            vec2 b = p - hull.back();
            if (a.cross(b) > 0) break;
            hull.pop_back();
        }
        hull.pb(p);
    }

    // Translate back, optional
    each(p, hull) p = p+pivot;
    return hull;
}
```

geometry/convex_hull_dist.h

```
#include "vec2.h"

// Check if p is inside convex polygon. Hull
// must be given in counter-clockwise order.
// Returns 2 if inside, 1 if on border,
// 0 if outside; time: O(n)
int insideHull(vector<vec2>& hull, vec2 p) {
    int ret = 1;
    rep(i, 0, sz(hull)) {
        auto v = hull[(i+1)%sz(hull)] - hull[i];
        auto t = v.cross(p-hull[i]);
        ret = min(ret, cmp(t, 0)); // For doubles
        //ret = min(ret, (t>0) - (t<0)); // Ints
    }
    return int(max(ret+1, 0));
}
```

```
#include "segment2.h"
```

```
// Get distance from point to hull; time: O(n)
double hullDist(vector<vec2>& hull, vec2 p) {
    if (insideHull(hull, p)) return 0;
    double ret = 1e30;
    rep(i, 0, sz(hull)) {
        seg2 seg{hull[(i+1)%sz(hull)], hull[i]};
        ret = min(ret, seg.distTo(p));
    }
    return ret;
}
```

```
// Compare distance from point to hull
// with sqrt(d2); time: O(n)
// -1 if smaller, 0 if equal, 1 if greater
int cmpHullDist(vector<vec2>& hull,
    vec2 p, ll d2) {
    if (insideHull(hull,p)) return (d2<0)-(d2>0);
    int ret = 1;
    rep(i, 0, sz(hull)) {
        seg2 seg{hull[(i+1)%sz(hull)], hull[i]};
        ret = min(ret, seg.cmpDistTo(p, d2));
    }
    return ret;
}
```

geometry/convex_hull_sum.h

```
#include "vec2.h"

// Get edge sequence for given polygon
// starting from lower-left vertex; time: O(n)
// Returns start position.
vec2 edgeSeq(vector<vec2> points,
    vector<vec2>& edges) {
    int i = 0, n = sz(points);
    rep(j, 0, n) {
        if (points[i].yxPair()>points[j].yxPair())
            i = j;
    }
    rep(j, 0, n) edges.pb(points[(i+j+1)%n] -
        points[(i+j)%n]);
    return points[i];
}
```

```
// Minkowski sum of given convex polygons.
// Vertices are required to be in
// counter-clockwise order; time: O(n+m)
vector<vec2> hullSum(vector<vec2> A,
    vector<vec2> B) {
    vector<vec2> sum, e1, e2, es(sz(A) + sz(B));
    vec2 pivot = edgeSeq(A, e1) + edgeSeq(B, e2);
    merge(all(e1), all(e2), es.begin());

    sum.pb(pivot);
    each(e, es) sum.pb(sum.back() + e);
    sum.pop_back();
    return sum;
}
```

geometry/halfplane_intersect.h

```
#include "vec2.h"
#include "line2.h"

// Intersect given halfplanes and output
// hull vertices to out.
// Returns 0 if intersection is empty,
// 1 if intersection is non-empty and bounded,
// 2 if intersection is unbounded.
// Output vertices are valid ONLY IF
// intersection is non-empty and bounded.
// Works only with floating point vec2/line2.
// CURRENTLY DOESN'T WORK FOR NON-EMPTY
// AND UNBOUNDED CASES!
int intersectHalfPlanes(vector<line2> lines,
    vector<vec2>& out) {
    deque<line2> H;
    out.clear();
}
```

```

if (sz(lines) <= 1) return 2;

sort(all(lines), [](line2 a, line2 b) {
    int t = cmp(a.norm.angle(), b.norm.angle());
    return t ? t < 0 : cmp(a.off*b.norm.len(),
        b.off*a.norm.len()) < 0;
});

auto bad = [](line2 a, line2 b, line2 c) {
    if (cmp(a.norm.cross(c.norm), 0) <= 0)
        return false;
    vec2 p; assert(a.intersect(c, p));
    return b.side(p) <= 0;
};

each(e, lines) {
    if (!H.empty() &&
        !cmp(H.back().norm.angle(),
            e.norm.angle())) continue;
    while (sz(H) > 1 && bad(H[sz(H)-2],
        H.back(), e)) H.pop_back();
    while (sz(H) > 1 && bad(e, H[0], H[1]))
        H.pop_front();
    H.pb(e);
}

while (sz(H) > 2 && bad(H[sz(H)-2],
    H.back(), H[0])) H.pop_back();
while (sz(H) > 2 && bad(H.back(),
    H[0], H[1])) H.pop_front();

out.resize(sz(H));

rep(i, 0, sz(H)) {
    auto a = H[i], b = H[(i+1)%sz(H)];
    if (a.norm.cross(b.norm) <= 0)
        return cmp(a.off*b.norm.len(),
            -b.off*a.norm.len()) <= 0 ? 0 : 2;
    assert(a.intersect(b, out[i]));
}

rep(i, 0, sz(H)) {
    auto a = out[i], b = out[(i+1)%sz(H)];
    if (H[i].norm.perp().cross(b-a) <= 0)
        return 0;
}
return 1;
}

```

geometry/line2.h

```

#include "vec2.h"

// 2D line/halfplane structure
// PARTIALLY TESTED

// Base class of versions for ints and doubles
template<class T, class P, class S>
struct bline2 {
    // For lines: norm*point == off
    // For halfplanes: norm*point <= off
    // (i.e. normal vector points outside)
    P norm; // Normal vector [A; B]
    T off; // Offset (C parameter of equation)
    DBP(norm, off);

    // Line through 2 points; normal vector

```

```

// points to the right of ab vector
static S through(P a, P b) {
    return { (a-b).perp(), a.cross(b) };
}

// Parallel line through point
static S parallel(P a, S b) {
    return { b.norm, b.norm.dot(a) };
}

// Perpendicular line through point
static S perp(P a, S b) {
    return { b.norm.perp(), b.norm.cross(a) };
}

// Distance from point to line
double distTo(P a) {
    return fabs(norm.dot(a)-off) / norm.len();
}

// Version for integer coordinates (long long)
struct line2i : bline2<ll, vec2i, line2i> {
    line2i() : bline2<>{}, 0 {}
    line2i(vec2i n, ll c) : bline2{n, c} {}

    // Returns 0 if point a lies on the line,
    // 1 if on side where normal vector points,
    // -1 if on the other side.
    int side(vec2i a) {
        ll d = norm.dot(a);
        return (d > off) - (d < off);
    }
};

// Version for double coordinates
// Requires cmp() from template
struct line2d : bline2<double, vec2d, line2d> {
    line2d() : bline2<>{}, 0 {}
    line2d(vec2d n, double c) : bline2{n, c} {}

    // Returns 0 if point a lies on the line,
    // 1 if on side where normal vector points,
    // -1 if on the other side.
    int side(vec2d a) {
        return cmp(norm.dot(a), off);
    }

    // Intersect this line with line a, returns
    // true on success (false if parallel).
    // Intersection point is saved to 'out'.
    bool intersect(line2d a, vec2d& out) {
        double d = norm.cross(a.norm);
        if (cmp(d, 0) == 0) return false;
        out = (norm*a.off-a.norm*off).perp() / d;
        return true;
    }
};

using line2 = line2d;

```

geometry/rmst.h

```

#include "../structures/find_union.h"

// Rectilinear Minimum Spanning Tree
// (MST in Manhattan metric); time: O(n lg n)

```

```

// Returns MST weight. Outputs spanning tree
// to G, vertex indices match point indices.
// Edge in G is pair (target, weight).
ll rmst(vector<Pii>& points,
    vector<vector<Pii>>& G) {
    int n = sz(points);
    vector<pair<int, Pii>> edges;
    vector<Pii> close;
    Vi ord(n), merged(n);
    iota(all(ord), 0);

    function<void(int,int)> octant =
        [&](int begin, int end) {
            if (begin+1 >= end) return;

            int mid = (begin+end) / 2;
            octant(begin, mid);
            octant(mid, end);

            int j = mid;
            Pii best = {INT_MAX, -1};
            merged.clear();

            rep(i, begin, mid) {
                int v = ord[i];
                Pii p = points[v];

                while (j < end) {
                    int e = ord[j];
                    Pii q = points[e];
                    if (q.x-q.y > p.x-p.y) break;
                    best = min(best, make_pair(q.x+q.y, e));
                    merged.pb(e);
                    j++;
                }

                if (best.y != -1) {
                    int alt = best.x-p.x-p.y;
                    if (alt < close[v].x)
                        close[v] = {alt, best.y};
                }
                merged.pb(v);
            }

            while (j < end) merged.pb(ord[j++]);
            copy(all(merged), ord.begin()+begin);
        };

    rep(i, 0, 4) {
        rep(j, 0, 2) {
            sort(all(ord), [&](int l, int r) {
                return points[l] < points[r];
            });
            close.assign(n, {INT_MAX, -1});
            octant(0, n);
            rep(k, 0, n) {
                Pii p = close[k];
                if (p.y != -1) edges.pb({p.x, {k, p.y}});
                points[k].x += -1;
            }
        }
        each(p, points) p = {p.y, -p.x};
    }

    ll sum = 0;
    FAU fau(n);

```

```

sort(all(edges));
G.assign(n, {});

each(e, edges) if (fau.join(e.y.x, e.y.y)) {
    sum += e.x;
    G[e.y.x].pb({e.y.y, e.x});
    G[e.y.y].pb({e.y.x, e.x});
}
return sum;
}

```

geometry/segment2.h

```

#include "vec2.h"

// 2D segment structure; NOT HEAVILY TESTED

// Base class of versions for ints and doubles
template<class P, class S> struct bseg2 {
    P a, b; // Endpoints

    // Distance from segment to point
    double distTo(P p) const {
        if ((p-a).dot(b-a) < 0) return (p-a).len();
        if ((p-b).dot(a-b) < 0) return (p-b).len();
        return double(abs((p-a).cross(b-a)))
            / (b-a).len();
    }
};

// Version for integer coordinates (long long)
struct seg2i : bseg2<vec2i, seg2i> {
    seg2i() {}
    seg2i(vec2i c, vec2i d) : bseg2{c, d} {}

    // Check if segment contains point p
    bool contains(vec2i p) {
        return (a-p).dot(b-p) <= 0 &&
            (a-p).cross(b-p) == 0;
    }

    // Compare distance to p with sqrt(d2)
    // -1 if smaller, 0 if equal, 1 if greater
    int cmpDistTo(vec2i p, ll d2) const {
        if ((p-a).dot(b-a) < 0) {
            ll l = (p-a).len2();
            return (l > d2) - (l < d2);
        }
        if ((p-b).dot(a-b) < 0) {
            ll l = (p-b).len2();
            return (l > d2) - (l < d2);
        }
        ll c = abs((p-a).cross(b-a));
        d2 *= (b-a).len2();
        return (c*c > d2) - (c*c < d2);
    }
};

// Version for double coordinates
// Requires cmp() from template
struct seg2d : bseg2<vec2d, seg2d> {
    seg2d() {}
    seg2d(vec2d c, vec2d d) : bseg2{c, d} {}

    bool contains(vec2d p) {
        return cmp((a-p).dot(b-p), 0) <= 0 &&

```

```

        cmp((a-p).cross(b-p), 0) == 0;
    }
};

using seg2 = seg2d;

```

geometry/vec2.h

// 2D point/vector structure; PARTIALLY TESTED

```

// Base class of versions for ints and doubles
template<class T, class S> struct bvec2 {
    T x, y;
    S operator+(S r) const {return{x+r.x,y+r.y};}
    S operator-(S r) const {return{x-r.x,y-r.y};}
    S operator*(T r) const { return {x*r, y*r}; }
    S operator/(T r) const { return {x/r, y/r}; }

```

```

    T dot(S r) const { return x*r.x+y*r.y; }
    T cross(S r) const { return x*r.y-y*r.x; }
    T len2() const { return x*x + y*y; }
    double len() const { return sqrt(len2()); }
    S perp() const { return {-y,x}; } //90deg

```

```

pair<T, T> yxPair() const { return {y,x}; }

```

```

    double angle() const { //[0;2*PI] CCW from OX
        double a = atan2(y, x);
        return (a < 0 ? a+2*M_PI : a);
    }
};

```

// Version for integer coordinates (long long)

```

struct vec2i : bvec2<ll, vec2i> {
    vec2i() : bvec2{0, 0} {}
    vec2i(ll a, ll b) : bvec2{a, b} {}

```

```

    bool operator==(vec2i r) const {
        return x == r.x && y == r.y;
    }

```

```

    // Compare by angle, length if angles equal
    bool operator<(vec2i r) const {
        if (upper() != r.upper()) return upper();
        auto t = cross(r);
        return t > 0 || (!t && len2() < r.len2());
    }

```

```

    bool upper() const {
        return y > 0 || (y == 0 && x >= 0);
    }
};

```

// Version for double coordinates

// Requires cmp() from template

```

struct vec2d : bvec2<double, vec2d> {
    vec2d() : bvec2{0, 0} {}
    vec2d(double a, double b) : bvec2{a, b} {}

```

```

    vec2d unit() const { return *this/len(); }
    vec2d rotate(double a) const { // CCW
        return {x*cos(a) - y*sin(a),
                x*sin(a) + y*cos(a)};
    }

```

```

    bool operator==(vec2d r) const {
        return !cmp(x, r.x) && !cmp(y, r.y);
    }

```

```

    }

    // Compare by angle, length if angles equal
    bool operator<(vec2d r) const {
        int t = cmp(angle(), r.angle());
        return t < 0 || (!t && len2() < r.len2());
    }
};

```

using vec2 = vec2d;

graphs/2sat.h

```

// 2-SAT solver; time: O(n+m), space: O(n+m)
// Variables are indexed from 1 and
// negative indices represent negations!
// Usage: SAT2 sat(variable_count);
// (add constraints...)
// bool solution_found = sat.solve();
// sat[i] = value of i-th variable, 0 or 1
// (also indexed from 1!)
// (internally: positive = i*2-1, neg. = i*2-2)
struct SAT2 : Vi {
    vector<Vi> G;
    Vi order, flags;

```

```

    // Init n variables, you can add more later
    SAT2(int n = 0) : G(n*2) {}

```

```

    // Add new var and return its index
    int addVar() {
        G.resize(sz(G)+2); return sz(G)/2;
    }

```

```

    // Add (i => j) constraint
    void imply(int i, int j) {
        i = max(i*2-1, -i*2-2);
        j = max(j*2-1, -j*2-2);
        G[i].pb(j); G[j^1].pb(i^1);
    }

```

```

    // Add (i v j) constraint
    void either(int i, int j) { imply(-i, j); }

```

```

    // Constraint at most one true variable
    void atMostOne(Vi& vars) {
        int x = addVar();
        each(i, vars) {
            int y = addVar();
            imply(x, y); imply(i, -x); imply(i, y);
            x = y;
        }
    }

```

```

    // Solve and save assignments in `values`
    bool solve() { // O(n+m), Kosaraju is used
        assign(sz(G)/2+1, -1);
        flags.assign(sz(G), 0);
        rep(i, 0, sz(G)) dfs(i);
        while (!order.empty()) {
            if (!propag(order.back()^1, 1)) return 0;
            order.pop_back();
        }
        return 1;
    }

```

```

    void dfs(int i) {

```

```

        if (flags[i]) return;
        flags[i] = 1;
        each(e, G[i]) dfs(e);
        order.pb(i);
    }

    bool propag(int i, bool first) {
        if (!flags[i]) return 1;
        flags[i] = 0;
        if (at(i/2+1) >= 0) return first;
        at(i/2+1) = i&1;
        each(e, G[i]) if (!propag(e, 0)) return 0;
        return 1;
    }
};

```

graphs/bellman_inequalities.h

```

struct Ineq {
    ll a, b, c; // a - b >= c
};

// Solve system of inequalities of form a-b>=c
// using Bellman-Ford; time: O(n*m)
bool solveIneq(vector<Ineq>& edges,
               vector<ll>& vars) {
    rep(i, 0, sz(vars)) each(e, edges)
        vars[e.b] = min(vars[e.b], vars[e.a]-e.c);
    each(e, edges)
        if (vars[e.a]-e.c < vars[e.b]) return 0;
    return 1;
}

```

graphs/bridges_online.h

```

// Dynamic 2-edge connectivity queries
// Usage: Bridges bridges(vertex_count);
// - bridges.addEdge(u, v); - add edge (u, v)
// - bridges.cc[v] = connected component ID
// - bridges.bi(v) = 2-edge connected comp ID
struct Bridges {
    vector<Vi> G; // Spanning forest
    Vi cc, size, par, bp, seen;
    int cnt{0};

```

```

    // Initialize structure for n vertices; O(n)
    Bridges(int n = 0) : G(n), cc(n), size(n, 1),
                        par(n, -1), bp(n, -1),
                        seen(n) {}

    iota(all(cc), 0);
}

```

```

    // Add edge (u, v); time: amortized O(lg n)
    void addEdge(int u, int v) {
        if (cc[u] == cc[v]) {
            int r = lca(u, v);
            while ((v = root(v)) != r)
                v = bp[bi(v)] = par[v];
            while ((u = root(u)) != r)
                u = bp[bi(u)] = par[u];
        } else {
            G[u].pb(v); G[v].pb(u);
            if (size[cc[u]] > size[cc[v]]) swap(u,v);
            size[cc[v]] += size[cc[u]];
            dfs(u, v);
        }
    }
}

```

```

    // Get 2-edge connected component ID
    int bi(int v) { // amortized time: < O(lg n)
        return bp[v] == -1 ? v : bp[v] = bi(bp[v]);
    }

```

```

    int root(int v) {
        return par[v] == -1 || bi(par[v]) != bi(v)
            ? v : par[v] = root(par[v]);
    }

```

```

    void dfs(int v, int p) {
        par[v] = p; cc[v] = cc[p];
        each(e, G[v]) if (e != p) dfs(e, v);
    }

```

```

    int lca(int u, int v) { // Don't use this!
        for (cnt++; swap(u, v) if (u != -1) {
            if (seen[u] = root(u)) == cnt) return u;
            seen[u] = cnt; u = par[u];
        }
    }
};

```

graphs/dense_dfs.h

#include "../math/bit_matrix.h"

```

// DFS over adjacency matrix; time: O(n^2/64)
// G = graph, V = not visited vertices masks
// UNTESTED
struct DenseDFS {
    BitMatrix G, V; // space: O(n^2/64)

```

```

    DenseDFS(int n = 0) : G(n, n), V(1, n) {
        reset();
    }

```

```

    void reset() { each(x, V.M) x = -1; }
    void setVisited(int i) { V.set(0, i, 0); }
    bool isVisited(int i) { return !V(0, i); }

```

```

    // DFS step: func is called on each unvisited
    // neighbour of i. You need to manually call
    // setVisited(child) to mark it visited.
    template<class T> // Single step: O(n/64)
    void step(int i, T func) {
        ull* E = G.row(i);
        for (int w = 0; w < G.stride; ) {
            ull x = E[w] & V.row(0)[w];
            if (x) func((w<<6) | __builtin_ctzll(x));
            else w++;
        }
    }
};

```

graphs/edmonds_karp.h

```

using flow_t = int;
constexpr flow_t INF = 1e9+10;

```

```

// Edmonds-Karp algorithm for finding
// maximum flow in graph; time: O(V*E^2)
// NOT HEAVILY TESTED
struct MaxFlow {
    struct Edge {
        int dst, inv;

```

```

    flow_t flow, cap;
};

vector<vector<Edge>> G;
vector<flow_t> add;
Vi prev;

// Initialize for n vertices
MaxFlow(int n = 0) : G(n) {}

// Add new vertex
int addVert() {
    G.emplace_back(); return sz(G)-1;
}

// Add edge between u and v with capacity cap
// and reverse capacity rcap
void addEdge(int u, int v,
             flow_t cap, flow_t rcap = 0) {
    G[u].pb({ v, sz(G[v]), 0, cap });
    G[v].pb({ u, sz(G[u])-1, 0, rcap });
}

// Compute maximum flow from src to dst.
// Flow values can be found in edges,
// vertices with `add` >= 0 belong to
// cut component containing `s`.
flow_t maxFlow(int src, int dst) {
    flow_t f = 0;
    each(v, G) each(e, v) e.flow = 0;

    do {
        queue<int> Q;
        Q.push(src);
        prev.assign(sz(G), -1);
        add.assign(sz(G), -1);
        add[src] = INF;

        while (!Q.empty()) {
            int i = Q.front();
            flow_t m = add[i];
            Q.pop();

            if (i == dst) {
                while (i != src) {
                    auto& e = G[i][prev[i]];
                    e.flow -= m;
                    G[e.dst][e.inv].flow += m;
                    i = e.dst;
                }
                f += m;
                break;
            }

            each(e, G[i]) if (add[e.dst] < 0) {
                if (e.flow < e.cap) {
                    Q.push(e.dst);
                    prev[e.dst] = e.inv;
                    add[e.dst] = min(m, e.cap-e.flow);
                }
            }
        } while (prev[dst] != -1);

    } return f;
}

```

```

// Get if v belongs to cut component with src
bool cutSide(int v) {
    return add[v] >= 0;
}
};

```

graphs/gomory_hu.h

```

#include "edmonds_karp.h"
// #include "push_relabel.h" // if you need

struct Edge {
    int a, b; // vertices
    flow_t w; // weight
};

// Build Gomory-Hu tree; time: O(n*maxflow)
// Gomory-Hu tree encodes minimum cuts between
// all pairs of vertices: mincut for u and v
// is equal to minimum on path from u and v
// in Gomory-Hu tree. n is vertex count.
// Returns vector of Gomory-Hu tree edges.
vector<Edge> gomoryHu(vector<Edge>& edges,
                     int n) {
    MaxFlow flow(n);
    each(e, edges) flow.addEdge(e.a, e.b, e.w, e.w);

    vector<Edge> ret(n-1);
    rep(i, 1, n) ret[i-1] = {i, 0, 0};

    rep(i, 1, n) {
        ret[i-1].w = flow.maxFlow(i, ret[i-1].b);
        rep(j, i+1, n)
            if (ret[j-1].b == ret[i-1].b &&
                flow.cutSide(j)) ret[j-1].b = i;
    }

    return ret;
}

```

graphs/push_relabel.h

```

using flow_t = int;
constexpr flow_t INF = 1e9+10;

// Push-relabel algorithm with global relabel
// heuristic for finding maximum flow; O(V^3),
// but very fast in practice.
// Preflow is not converted to flow!
struct MaxFlow {
    struct Vert {
        int head{0}, cur{0}, label;
        flow_t excess;
    };

    struct Edge {
        int dst, nxt;
        flow_t avail, cap;
    };

    vector<Vert> V;
    vector<Edge> E;
    queue<int> que, bfs;

    // Initialize for n vertices
    MaxFlow(int n = 0) {

```

```

        V.assign(n, {});
        E.resize(2);
    }

    // Add new vertex
    int addVert() {
        V.emplace_back();
        return sz(V)-1;
    }

    // Add edge between u and v with capacity cap
    // and reverse capacity rcap
    void addEdge(int u, int v,
                 flow_t cap, flow_t rcap = 0) {
        E.pb({ v, V[u].head, 0, cap });
        E.pb({ u, V[v].head, 0, rcap });
        V[u].head = sz(E)-2;
        V[v].head = sz(E)-1;
    }

    void push(int v, int e) {
        flow_t f = min(V[v].excess, E[e].avail);
        E[e].avail -= f;
        E[e^1].avail += f;
        V[v].excess -= f;
        if ((V[E[e].dst].excess += f) == f)
            que.push(E[e].dst);
    }

    // Compute maximum flow from src to dst
    flow_t maxFlow(int src, int dst) {
        each(v, V) v.excess = v.label = v.cur = 0;
        each(e, E) e.avail = max(e.cap, flow_t(0));

        int cnt, n = cnt = V[src].label = sz(V);
        V[src].excess = INF;
        for (int e = V[src].head; e; e = E[e].nxt)
            push(src, e);

        for (; !que.empty(); que.pop()) {
            if (cnt >= n/2) {
                each(v, V) v.label = n;
                V[dst].label = 0;
                bfs.push(dst);
                cnt = 0;

                for (; !bfs.empty(); bfs.pop()) {
                    auto& v = V[bfs.front()];
                    for (int e=v.head; e; e = E[e].nxt) {
                        int x = E[e].dst;
                        if (E[e^1].avail &&
                            V[x].label > v.label+1) {
                            V[x].label = v.label+1;
                            bfs.push(x);
                        }
                    }
                }
            }

            int v = que.front(), &l = V[v].label;
            if (v == dst) continue;

            while (V[v].excess && l < n) {
                if (!V[v].cur) {
                    l = n;
                    for (int e=V[v].head; e; e=E[e].nxt){

```

```

                        if (E[e].avail)
                            l = min(l, V[E[e].dst].label+1);
                    }
                    V[v].cur = V[v].head;
                    cnt++;
                }

                int e = V[v].cur;
                V[v].cur = E[e].nxt;
                if (E[e].avail &&
                    l == V[E[e].dst].label+1) push(v, e);
            }
        }

        return V[dst].excess;
    }

    // Get if v belongs to cut component with src
    bool cutSide(int v) {
        return V[v].label >= sz(V);
    }
};

```

graphs/scc.h

```

// Tarjan's SCC algorithm; time: O(n+m)
// Usage: SCC scc(graph);
// scc[v] = index of SCC for vertex v
// scc.comps[i] = vertices of i-th SCC
struct SCC : Vi {
    vector<Vi> comps;
    Vi S;
    int cnt{0};

    SCC() {}

    SCC(vector<Vi>& G : Vi(sz(G), -1), S(sz(G)) {
        rep(i, 0, sz(G)) if (!S[i]) dfs(G, i);
    }

    int dfs(vector<Vi>& G, int v) {
        int low = S[v] = ++cnt, t = -1;
        S.pb(v);

        each(e, G[v]) if (at(e) < 0)
            low = min(low, S[e] ?: dfs(G, e));

        if (low == S[v]) {
            comps.emplace_back();
            for (; t != v; S.pop_back()) {
                at(t = S.back()) = sz(comps) - 1;
                comps.back().pb(t);
            }
        }

        return low;
    }
};

```

graphs/turbo_matching.h

```

// Find maximum bipartite matching; time: ?
// G must be bipartite graph!
// Returns matching size (edge count).
// match[v] = vert matched to v or -1
int matching(vector<Vi>& G, Vi& match) {
    vector<bool> seen;

```



```
int n = 0, k = 1;
match.assign(sz(G), -1);

function<int(int)> dfs = [&](int i) {
    if (seen[i]) return 0;
    seen[i] = 1;
    each(e, G[i]) {
        if (match[e] < 0 || dfs(match[e])) {
            match[i] = e; match[e] = i;
            return 1;
        }
    }
    return 0;
};

while (k) {
    seen.assign(sz(G), 0);
    k = 0;
    rep(i, 0, sz(G)) if (match[i] < 0)
        k += dfs(i);
    n += k;
}
return n;
}

// Convert maximum matching to vertex cover
// time: O(n+m)
Vi vertexCover(vector<Vi>& G, Vi& match) {
    Vi ret, col(sz(G)), seen(sz(G));

    function<void(int, int)> dfs =
        [&](int i, int c) {
            if (col[i]) return;
            col[i] = c+1;
            each(e, G[i]) dfs(e, !c);
        };

    function<void(int)> aug = [&](int i) {
        if (seen[i] || col[i] != 1) return;
        seen[i] = 1;
        each(e, G[i]) seen[e] = 1, aug(match[e]);
    };

    rep(i, 0, sz(G)) dfs(i, 0);
    rep(i, 0, sz(G)) if (match[i] < 0) aug(i);
    rep(i, 0, sz(G))
        if (seen[i] == col[i]-1) ret.pb(i);
    return ret;
}
```

math/bit_gauss.h

constexpr int MAX_COLS = 2048;

// Solve system of linear equations over \mathbb{Z}_2
// time: $O(n^2 \cdot m/W)$, where W is word size
// - A - extended matrix, rows are equations,
// columns are variables,
// m -th column is equation result
// ($A[i][j]$ - i -th row and j -th column)
// - ans - output for variables values
// - m - variable count
// Returns 0 if no solutions found, 1 if one,
// 2 if more than 1 solution exist.

```
int bitGauss(vector<bitset<MAX_COLS>>& A,
             vector<bool>& ans, int m) {
    Vi col;
```

```
ans.assign(m, 0);

rep(i, 0, sz(A)) {
    int c = int(A[i]._Find_first());
    if (c >= m) {
        if (c == m) return 0;
        continue;
    }

    rep(k, i+1, sz(A)) if (A[k][c]) A[k]^=A[i];
    swap(A[i], A[sz(col)]);
    col.pb(c);
}

for (int i = sz(col); i--;) if (A[i][m]) {
    ans[col[i]] = 1;
    rep(k, 0, i) if (A[k][col[i]]) A[k][m].flip();
}

return sz(col) < m ? 2 : 1;
}
```

math/bit_matrix.h

```
using ull = uint64_t;

// Matrix over  $\mathbb{Z}_2$  (bits and xor)
// UNTESTED and UNFINISHED
struct BitMatrix {
    vector<ull> M;
    int rows, cols, stride;

    BitMatrix(int n = 0, int m = 0) {
        rows = n; cols = m;
        stride = (m+63)/64;
        M.resize(n*stride);
    }

    ull* row(int i) { return &M[i*stride]; }

    bool operator()(int i, int j) {
        return (row(i)[j/64] >> (j%64)) & 1;
    }

    void set(int i, int j, bool val) {
        ull &w = row(i)[j/64], m = 1 << (j%64);
        if (val) w |= m;
        else w &= ~m;
    }
};
```

math/crt.h

```
using Pll = pair<ll, ll>;

ll egcd(ll a, ll b, ll& x, ll& y) {
    if (!a) return x=0, y=1, b;
    ll d = egcd(b%a, a, y, x);
    x -= b/a*y;
    return d;
}

// Chinese Remainder Theorem; time:  $O(\lg \text{lcm})$   

// Solves  $x = a.x \pmod{a.y}$ ,  $x = b.x \pmod{b.y}$   

// Returns pair  $(x \pmod{\text{lcm}}, \text{lcm}(a.y, b.y))$   

// or  $(-1, -1)$  if there's no solution.  

// WARNING:  $a.x$  and  $b.x$  are assumed to be
```

```
// in  $[0; a.y)$  and  $[0; b.y)$  respectively.
// Works properly if  $\text{lcm}(a.y, b.y) < 2^{63}$ .
Pll crt(Pll a, Pll b) {
    if (a.y < b.y) swap(a, b);
    ll x, y, g = egcd(a.y, b.y, x, y);
    ll c = b.x-a.x, d = b.y/g, p = a.y*d;
    if (c % g) return {-1, -1};
    ll s = (a.x + c/g*x % d * a.y) % p;
    return {s < 0 ? s+p : s, p};
}
```

math/discrete_logarithm.h

```
#include "../modular.h"

// Baby-step giant-step algorithm;  $O(\sqrt{p})$   

// Finds smallest  $x$  such that  $a^x = b \pmod{p}$   

// or returns -1 if there's no solution.
ll dlog(ll a, ll b, ll p) {
    int m = int(min(ll(sqrt(p))+2, p-1));
    unordered_map<ll, int> small;
    ll t = 1;

    rep(i, 0, m) {
        int& k = small[t];
        if (!k) k = i+1;
        t = t*a % p;
    }

    t = modInv(t, p);

    rep(i, 0, m) {
        int j = small[b];
        if (j) return i*m + j - 1;
        b = b*t % p;
    }

    return -1;
}
```

math/fft_complex.h

```
using dbl = double;
using cmpl = complex<dbl>;

// Default std::complex multiplication is slow.
// You can use this to achieve small speedup.
cmpl operator*(cmpl a, cmpl b) {
    dbl ax = real(a), ay = imag(a);
    dbl bx = real(b), by = imag(b);
    return {ax*bx-ay*by, ax*by+ay*bx};
}

cmpl operator==(cmpl& a, cmpl b) {return a==b;}

// Compute DFT over complex numbers;  $O(n \lg n)$   

// Input size must be power of 2!
void fft(vector<cmpl>& a) {
    static vector<cmpl> w(2, 1);
    int n = sz(a);

    for (int k = sz(w); k < n; k *= 2) {
        w.resize(n);
        rep(i, 0, k) w[k+i] = exp(cmpl(0, M_PI*i/k));
    }

    Vi rev(n);
```

```
rep(i, 0, n) rev[i] = (rev[i/2] | i%2*n) / 2;
rep(i, 0, n) if (i < rev[i]) swap(a[i], a[rev[i]]);

for (int k = 1; k < n; k *= 2) {
    for (int i=0; i < n; i += k*2) rep(j, 0, k) {
        auto d = a[i+j+k] * w[j+k];
        a[i+j+k] = a[i+j] - d;
        a[i+j] += d;
    }
}

// Convolve complex-valued a and b,
// store result in a; time:  $O(n \lg n)$ , 3x FFT
void convolve(vector<cmpl>& a, vector<cmpl> b) {
    int len = sz(a) + sz(b) - 1;
    int n = 1 << (32 - __builtin_clz(len));
    a.resize(n); b.resize(n);
    fft(a); fft(b);
    rep(i, 0, n) a[i] *= b[i] / dbl(n);
    reverse(a.begin()+1, a.end());
    fft(a);
    a.resize(len);
}

// Convolve real-valued a and b, returns result
// time:  $O(n \lg n)$ , 2x FFT
// Rounding to integers is safe as long as
//  $(\max_{\text{coeff}}^2) * n \log_2(n) < 9 \cdot 10^{14}$ 
// (in practice  $10^{16}$  or higher).
vector<dbl> convolve(vector<dbl>& a,
                    vector<dbl>& b) {
    int len = sz(a) + sz(b) - 1;
    int n = 1 << (32 - __builtin_clz(len));

    vector<cmpl> in(n), out(n);
    rep(i, 0, sz(a)) in[i].real(a[i]);
    rep(i, 0, sz(b)) in[i].imag(b[i]);

    fft(in);
    each(x, in) x *= x;
    rep(i, 0, n) out[i] = in[-i&(n-1)]-conj(in[i]);
    fft(out);

    vector<dbl> ret(len);
    rep(i, 0, len) ret[i] = imag(out[i]) / (n*4);
    return ret;
}

constexpr ll MOD = 1e9+7;

// High precision convolution of integer-valued
// a and b mod MOD; time:  $O(n \lg n)$ , 4x FFT
// Input is expected to be in range  $[0; \text{MOD})$ !
// Rounding is safe if  $\text{MOD} * n \log_2(n) < 9 \cdot 10^{14}$ 
// (in practice  $10^{16}$  or higher).
vector<ll> convMod(vector<ll>& a,
                  vector<ll>& b) {
    vector<ll> ret(sz(a) + sz(b) - 1);
    int n = 1 << (32 - __builtin_clz(sz(ret)));
    ll cut = ll(sqrt(MOD))+1;

    vector<cmpl> c(n), d(n), g(n), f(n);

    rep(i, 0, sz(a))
        c[i] = {dbl(a[i]/cut), dbl(a[i]%cut)};
```

```
rep(i, 0, sz(b))
    d[i] = {dbl(b[i]/cut), dbl(b[i]%cut)};

fft(c); fft(d);

rep(i, 0, n) {
    int j = -i & (n-1);
    f[j] = (c[i]+conj(c[j])) * d[i] / (n*2.0);
    g[j] =
        (c[i]-conj(c[j])) * d[i] / cmpl(0, n*2);
}

fft(f); fft(g);

rep(i, 0, sz(ret)) {
    ll t = llround(real(f[i])) % MOD * cut;
    t += llround(imag(f[i]));
    t = (t + llround(real(g[i]))) % MOD * cut;
    t = (t + llround(imag(g[i]))) % MOD;
    ret[i] = (t < 0 ? t+MOD : t);
}

return ret;
}
```

math/fft_mod.h

// Number Theoretic Transform (NTT)
 // For functions below you can choose 2 params:
 // 1. M - prime modulus that MUST BE of form
 // a*2^k+1, computation is done in \mathbb{Z}_M
 // 2. R - generator of \mathbb{Z}_M

// Modulus often seen on Codeforces:
 // M = (119<<23)+1, R = 62; M is 998244353

// Parameters for ll computation with CRT:
 // M = (479<<21)+1, R = 62; M is > 10^9
 // M = (483<<21)+1, R = 62; M is > 10^9

```
ll modPow(ll a, ll e, ll m) {
    ll t = 1 % m;
    while (e) {
        if (e % 2) t = t*a % m;
        e /= 2; a = a*a % m;
    }
    return t;
}
```

// Compute DFT over \mathbb{Z}_M with generator R.
 // Input size must be power of 2; $O(n \lg n)$
 // Input is expected to be in range $[0; \text{MOD})$!
 // dit == true <=> inverse transform * 2^n
 // (without normalization)

```
template<ll M, ll R, bool dit>
void ntt(vector<ll>& a) {
    static vector<ll> w(2, 1);
    int n = sz(a);

    for (int k = sz(w); k < n; k *= 2) {
        w.resize(n, 1);
        ll c = modPow(R, M/2/k, M);
        if (dit) c = modPow(c, M-2, M);
        rep(i, k+1, k*2) w[i] = w[i-1]*c % M;
    }

    for (int t = 1; t < n; t *= 2) {
```

```
int k = (dit ? t : n/t/2);
for (int i=0; i < n; i += k*2) rep(j, 0, k) {
    ll &c = a[i+j], &d = a[i+j+k];
    ll e = w[j+k], f = d;
    d = (dit ? c - (f*f*e%M) : (c-f)*e % M);
    if (d < 0) d += M;
    if ((c += f) >= M) c -= M;
}
}

// Convolve a and b mod M (R is generator),
// store result in a; time:  $O(n \lg n)$ , 3x NTT
// Input is expected to be in range  $[0; \text{MOD})$ !
template<ll M = (119<<23)+1, ll R = 62>
void convolve(vector<ll>& a, vector<ll> b) {
    int len = sz(a) + sz(b) - 1;
    int n = 1 << (32 - __builtin_clz(len));
    ll t = modPow(n, M-2, M);
    a.resize(n); b.resize(n);
    ntt<M, R, 0>(a); ntt<M, R, 0>(b);
    rep(i, 0, n) a[i] = a[i]*b[i] % M * t % M;
    ntt<M, R, 1>(a);
    a.resize(len);
}
```

```
ll egcd(ll a, ll b, ll& x, ll& y) {
    if (!a) return x=0, y=1, b;
    ll d = egcd(b%a, a, y, x);
    x -= b/a*y;
    return d;
}
```

// Convolve a and b with 64-bit output,
 // store result in a; time: $O(n \lg n)$, 6x NTT
 // Input is expected to be non-negative!
 void convLong(vector<ll>& a, vector<ll> b) {
 const ll M1 = (479<<21)+1, M2 = (483<<21)+1;
 const ll MOD = M1*M2, R = 62;

```
vector<ll> c = a, d = b;
each(k, a) k %= M1; each(k, b) k %= M1;
each(k, c) k %= M2; each(k, d) k %= M2;
```

```
convolve<M1, R>(a, b);
convolve<M2, R>(c, d);
```

```
ll x, y; egcd(M1, M2, x, y);
```

```
rep(i, 0, sz(a)) {
    a[i] += (c[i]-a[i])*x % M2 * M1;
    if ((a[i] %= MOD) < 0) a[i] += MOD;
}
}
```

math/fwht.h

// Fast Walsh-Hadamard Transform; $O(n \lg n)$
 // Input must be power of 2!
 // Uncommented version is for XOR.
 // OR version is equivalent to sum-over-subsets
 // (Zeta transform, inverse is Moebius).
 // AND version is same as sum-over-supersets.
 // TESTED ON RANDS
 template<bool inv, class T>
 void fwht(vector<T>& b) {
 for (int s = 1; s < sz(b); s *= 2) {

```
for (int i = 0; i < sz(b); i += s*2) {
    rep(j, i, i+s) {
        auto &x = b[j], &y = b[j+s];
        tie(x, y) =
            mp(x+y, x-y); //XOR
        // inv ? mp(x-y, y) : mp(x+y, y); //AND
        // inv ? mp(x, y-x) : mp(x, x+y); //OR
    }
}

// ONLY FOR XOR:
if (inv) each(e, b) e /= sz(b);
}

// Compute convolution of a and b such that
// ans[i#j] += a[i]*b[j], where # is OR, AND
// or XOR, depending on FWHT version.
// Stores result in a; time:  $O(n \lg n)$ 
// Both arrays must be of same size = 2^n!
template<class T>
void bitConv(vector<T>& a, vector<T> b) {
    fwht<0>(a);
    fwht<0>(b);
    rep(i, 0, sz(a)) a[i] *= b[i];
    fwht<1>(a);
}
```

math/gauss.h

// Solve system of linear equations; $O(n^2*m)$
 // - A - extended matrix, rows are equations,
 // columns are variables,
 // m-th column is equation result
 // (A[i][j] - i-th row and j-th column)
 // - ans - output for variables values
 // - m - variable count
 // Returns 0 if no solutions found, 1 if one,
 // 2 if more than 1 solution exist.
 int gauss(vector<vector<double>>& A,
 vector<double>& ans, int m) {
 Vi col;
 ans.assign(m, 0);

```
rep(i, 0, sz(A)) {
    int c = 0;
    while (c <= m && !cmp(A[i][c], 0)) c++;
    // For Zp:
    //while (c <= m && !A[i][c].x) c++;
```

```
if (c >= m) {
    if (c == m) return 0;
    continue;
}
```

```
rep(k, i+1, sz(A)) {
    auto mult = A[k][c] / A[i][c];
    rep(j, 0, m+1) A[k][j] -= A[i][j]*mult;
}
```

```
swap(A[i], A[sz(col)]);
col.pb(c);
}
```

```
for (int i = sz(col); i--;) {
    ans[col[i]] = A[i][m] / A[i][col[i]];
    rep(k, 0, i)
```

```
A[k][m] -= ans[col[i]] * A[k][col[i]];
}

return sz(col) < m ? 2 : 1;
}
```

math/miller_rabin.h

```
#include "modular64.h"

// Miller-Rabin primality test
// time  $O(k*\lg^2 n)$ , where k = number of bases

// Deterministic for  $p \leq 10^9$ 
// constexpr ll BASES[] = {
//     336781006125, 9639812373923155
// };

// Deterministic for  $p \leq 2^64$ 
constexpr ll BASES[] = {
    2, 325, 9375, 28178, 450775, 9780504, 1795265022
};
```

```
bool isPrime(ll p) {
    if (p == 2) return true;
    if (p <= 1 || p%2 == 0) return false;
```

```
ll d = p-1, times = 0;
while (d%2 == 0) d /= 2, times++;
```

```
each(a, BASES) if (a%p) {
    // ll a = rand() % (p-1) + 1;
    ll b = modPow(a%p, d, p);
    if (b == 1 || b == p-1) continue;

    rep(i, 1, times) {
        b = modMul(b, b, p);
        if (b == p-1) break;
    }
```

```
if (b != p-1) return false;
}
```

```
return true;
}
```

math/modinv_precompute.h

constexpr ll MOD = 234567899;
 vector<ll> modInv(MOD); // You can lower size

// Precompute modular inverses; time: $O(\text{MOD})$
 void initModInv() {
 modInv[1] = 1;
 rep(i, 2, sz(modInv)) modInv[i] =
 (MOD - (MOD/i) * modInv[MOD%i]) % MOD;
 }

math/modular.h

// Big prime number, about $2*10^9$
 constexpr int MOD = 15*(1<<27)+1;

 ll modInv(ll a, ll m) { // $a^{(-1)} \bmod m$
 if (a == 1) return 1;
 return ((a - modInv(m%a, a))*m + 1) / a;
 }

```

11 modPow(11 a, 11 e, 11 m) { // a^e mod m
11 t = 1 % m;
    while (e) {
        if (e % 2) t = t*a % m;
        e /= 2; a = a*a % m;
    }
    return t;
}

// Wrapper for modular arithmetic
struct Zp {
11 x; // Contained value, in range [0;MOD-1]
Zp() : x(0) {}
Zp(11 a) : x(a%MOD) { if (x < 0) x += MOD; }

#define OP(c,d) Zp& operator c##=(Zp r) { \
    x = x d; return *this; } \
    Zp operator c(Zp r) const { \
        Zp t = *this; return t c##= r; }

OP(+, +r.x - MOD*(x+r.x >= MOD));
OP(-, -r.x + MOD*(x-r.x < 0));
OP(*, *r.x % MOD);
OP(/, *r.inv().x % MOD);

// For composite modulus use modInv, not pow
Zp inv() const { return pow(MOD-2); }
Zp pow(11 e) const { return modPow(x,e,MOD); }
void print() { cerr << x; } // For deb()
};

// Extended Euclidean Algorithm
11 egcd(11 a, 11 b, 11& x, 11& y) {
    if (!a) return x=0, y=1, b;
    11 d = egcd(b%a, a, y, x);
    x -= b/a*y;
    return d;
}

```

math/modular64.h

// Modular arithmetic for modulus < 2^62

```

11 modAdd(11 x, 11 y, 11 m) {
    x += y;
    return x < m ? x : x-m;
}

11 modSub(11 x, 11 y, 11 m) {
    x -= y;
    return x >= 0 ? x : x+m;
}

```

// About 4x slower than normal modulo

```

11 modMul(11 a, 11 b, 11 m) {
    11 c = 11((long double)a * b / m);
    11 r = (a*b - c*m) % m;
    return r < 0 ? r+m : r;
}

```

```

11 modPow(11 x, 11 e, 11 m) {
    11 t = 1;
    while (e) {
        if (e & 1) t = modMul(t, x, m);
        e >>= 1;
        x = modMul(x, x, m);
    }
}

```

```

}
return t;
}

```

math/montgomery.h

#include "modular.h"

// Montgomery modular multiplication
// MOD < MG_MULT, gcd(MG_MULT, MOD) must be 1
// Don't use if modulo is constexpr; UNTESTED

```

constexpr 11 MG_SHIFT = 32;
constexpr 11 MG_MULT = 1LL << MG_SHIFT;
constexpr 11 MG_MASK = MG_MULT - 1;
const 11 MG_INV = MG_MULT-modInv(MOD, MG_MULT);

```

// Convert to Montgomery form
11 MG(11 x) { return (x*MG_MULT) % MOD; }

// Montgomery reduction
// redc(mg * mg) = Montgomery-form product
11 redc(11 x) {
 11 q = (x * MG_INV) & MG_MASK;
 x = (x + q*MOD) >> MG_SHIFT;
 return (x >= MOD ? x-MOD : x);
}

math/nimber.h

// Nimbers are defined as sizes of Nim heaps.
// Operations on nimbers are defined as:
// a+b = mex({a'+b : a' < a} u {a+b' : b' < b})
// ab = mex({a'b+ab'+a'b' : a' < a, b' < b})
// Nimbers smaller than M = 2^2^k form a field.
// Addition is equivalent to xor, meanwhile
// multiplication can be evaluated
// in O(lg^2 M) after precomputing.

```

using ull = uint64_t;
ull nbuf[64][64]; // Nim-products for 2^i * 2^j

```

```

// Multiply nimbers; time: O(lg^2 M)
// WARNING: Call initNimMul() before using.
ull nimMul(ull a, ull b) {
    ull ret = 0;
    for (ull s = a; s; s &= (s-1))
        for (ull t = b; t; t &= (t-1))
            ret ^= nbuf[__builtin_ctzll(s)]
                [__builtin_ctzll(t)];
    return ret;
}

```

// Initialize nim-products lookup table

```

void initNimMul() {
    rep(i, 0, 64)
        nbuf[i][0] = nbuf[0][i] = 1ull << i;
    rep(b, 1, 64) rep(a, 1, b+1) {
        int i = 1 << (63 - __builtin_clzll(a));
        int j = 1 << (63 - __builtin_clzll(b));
        ull t = nbuf[a-i][b-j];
        if (i < j)
            t = nimMul(t, 1ull << i) << j;
        else
            t = nimMul(t, 1ull << (i-1)) ^ (t << i);
        nbuf[a][b] = nbuf[b][a] = t;
    }
}

```

```

}

// Compute a^e under nim arithmetic; O(lg^3 M)
// WARNING: Call initNimMul() before using.
ull nimPow(ull a, ull e) {
    ull t = 1;
    while (e) {
        if (e % 2) t = nimMul(t, a);
        e /= 2; a = nimMul(a, a);
    }
    return t;
}

```

// Compute inverse of a in 2^64 nim-field;
// time: O(lg^3 M)
// WARNING: Call initNimMul() before using.
ull nimInv(ull a) {
 return nimPow(a, ull(-2));
}

// If you need to multiply many nimbers by
// the same value you can use this to speedup.
// WARNING: Call initNimMul() before using.
struct NimMult {
 ull M[64] = {0};

 // Initialize lookup; time: O(lg^2 M)
 NimMult(ull a) {
 for (ull t=a; t; t &= (t-1)) rep(i, 0, 64)
 M[i] ^= nbuf[__builtin_ctzll(t)][i];
 }

// Multiply by b; time: O(lg M)
ull operator()(ull b) {
 ull ret = 0;
 for (ull t = b; t; t &= (t-1))
 ret ^= M[__builtin_ctzll(t)];
 return ret;
}

math/phi_large.h

#include "pollard_rho.h"

```

// Compute Euler's totient of large numbers
// time: O(n^(1/4)) <- factorization
11 phi(11 n) {
    each(p, factorize(n)) n = n / p.x * (p.x-1);
    return n;
}

```

math/phi_precompute.h

Vi phi(1e7+1);

```

// Precompute Euler's totients; time: O(n lg n)
void calcPhi() {
    iota(all(phi), 0);
    rep(i, 2, sz(phi)) if (phi[i] == i)
        for (int j = i; j < sz(phi); j += i)
            phi[j] = phi[j] / i * (i-1);
}

```

math/phi_prefix_sum.h

#include "phi_precompute.h"

```

vector<ll> phiSum; // [k] = sum from 0 to k-1

// Precompute Euler's totient prefix sums
// for small values; time: O(n lg n)
void calcPhiSum() {
    calcPhi();
    phiSum.resize(sz(phi)+1);
    rep(i, 0, sz(phi))
        phiSum[i+1] = phiSum[i] + phi[i];
}

```

// Get prefix sum of phi(0) + ... + phi(n-1).
// WARNING: Call calcPhiSum first!
// For n > 4*10^9, answer will overflow.
// If you wish to get answer mod M use
// commented lines.
11 getPhiSum(11 n) { // time: O(n^(2/3))
 static unordered_map<ll, ll> big;
 if (n < sz(phiSum)) return phiSum[n];
 if (big.count(--n)) return big[n];

```

    11 ret = n*(n+1)/2;
    // 11 ret = (n%2 ? n%M * ((n+1)/2 % M)
    //           : n/2%M * (n%M+1) % M;

    for (11 s, i = 2; i <= n; i = s+1) {
        s = n / (n/i);
        ret -= (s-i+1) * getPhiSum(n/i+1);
        // ret -= (s-i+1)%M * getPhiSum(n/i+1) % M;
    }

    // ret = (ret%M + M) % M;
    return big[n] = ret;
}

```

math/pi_large_precomp.h

#include "sieve.h"

// Count primes in given interval
// using precomputed table.
// Set MAX_P to sqrt(MAX_N) and run sieve()!
// Precomputed table will contain N_BUCKETS
// elements - check source size limit.

```

constexpr 11 MAX_N = 1e11+1;
constexpr 11 N_BUCKETS = 10000;
constexpr 11 BUCKET_SIZE = (MAX_N/N_BUCKETS)+1;
constexpr 11 precomputed[] = { /* ... */ };

```

```

11 sieveRange(11 from, 11 to) {
    bitset<BUCKET_SIZE> elems;
    from = max(from, 2LL);
    to = max(from, to);
    each(p, primesList) {
        11 c = max((from+p-1) / p, 2LL);
        for (11 i = c*p; i < to; i += p)
            elems.set(i-from);
    }
    return to-from-elems.count();
}

```

// Run once on local computer to precompute
// table. Takes about 10 minutes for n = 1e11.
// Sanity check (for default params):
// 664579, 606028, 587253, 575795, ...
void localPrecompute() {


```
for (ll i = 0; i < MAX_N; i += BUCKET_SIZE) {
    ll to = min(i+BUCKET_SIZE, MAX_N);
    cout << sieveRange(i, to) << ', ' << flush;
}
cout << endl;
}

// Count primes in [from;to) using table.
// O(N_BUCKETS + BUCKET_SIZE*lg lg n + sqrt(n))
ll countPrimes(ll from, ll to) {
    ll bFrom = from/BUCKET_SIZE+1,
        bTo = to/BUCKET_SIZE;
    if (bFrom > bTo) return sieveRange(from, to);
    ll ret = accumulate(precomputed+bFrom,
                        precomputed+bTo, 0);
    ret += sieveRange(from, bFrom*BUCKET_SIZE);
    ret += sieveRange(bTo*BUCKET_SIZE, to);
    return ret;
}
```

math/pollard_rho.h

```
#include "modular64.h"
#include "miller_rabin.h"
```

```
using Factor = pair<ll, int>;
```

```
void rho(vector<ll>& out, ll n) {
    if (n <= 1) return;
    if (isPrime(n)) out.pb(n);
    else if (n%2 == 0) rho(out, 2), rho(out, n/2);
    else for (ll a = 2;; a++) {
        ll x = 2, y = 2, d = 1;
        while (d == 1) {
            x = modAdd(modMul(x, x, n), a, n);
            y = modAdd(modMul(y, y, n), a, n);
            y = modAdd(modMul(y, y, n), a, n);
            d = __gcd(abs(x-y), n);
        }
        if (d != n) {
            rho(out, d);
            rho(out, n/d);
            return;
        }
    }
}
```

// Pollard's rho factorization algorithm

// Las Vegas version; time: $n^{1/4}$

// Returns pairs (prime, power), sorted

```
vector<Factor> factorize(ll n) {
    vector<Factor> ret;
    vector<ll> raw;
    rho(raw, n);
    sort(all(raw));
    each(f, raw) {
        if (ret.empty() || ret.back().x != f)
            ret.pb({ f, 1 });
        else
            ret.back().y++;
    }
    return ret;
}
```

math/polynomial_interp.h

```
// Interpolates set of points (i, vec[i])
// and returns it evaluated at x; time:  $O(n^2)$ 
```

```
// TODO: Improve to linear time
template<typename T>
T polyExtend(vector<T>& vec, T x) {
    T ret = 0;
    rep(i, 0, sz(vec)) {
        T a = vec[i], b = 1;
        rep(j, 0, sz(vec)) if (i != j) {
            a *= x-j; b *= i-j;
        }
        ret += a/b;
    }
    return ret;
}
```

math/sieve.h

```
constexpr int MAX_P = 1e6;
bitset<MAX_P+1> primes;
Vi primesList;
```

// Erathostenes sieve; time: $O(n \lg \lg n)$

```
void sieve() {
    primes.set();
    primes.reset(0);
    primes.reset(1);
```

```
    for (int i = 2; i*i <= MAX_P; i++)
        if (primes[i])
            for (int j = i*i; j <= MAX_P; j += i)
                primes.reset(j);
```

```
    rep(i, 0, MAX_P+1) if (primes[i])
        primesList.pb(i);
}
```

math/sieve_factors.h

```
constexpr int MAX_P = 1e6;
Vi factor(MAX_P+1);
```

// Erathostenes sieve with saving smallest
// factor for each number; time: $O(n \lg \lg n)$

```
void sieve() {
    for (int i = 2; i*i <= MAX_P; i++)
        if (!factor[i])
            for (int j = i*i; j <= MAX_P; j += i)
                if (!factor[j])
                    factor[j] = i;
```

```
    rep(i, 0, MAX_P+1) if (!factor[i]) factor[i] = i;
}
```

// Factorize $n \leq MAX_P$; time: $O(\lg n)$

// Returns pairs (prime, power), sorted

```
vector<Pii> factorize(ll n) {
    vector<Pii> ret;
    while (n > 1) {
        int f = factor[n];
        if (ret.empty() || ret.back().x != f)
            ret.pb({ f, 1 });
        else
            ret.back().y++;
        n /= f;
    }
    return ret;
}
```

math/sieve_segmented.h

```
constexpr int MAX_P = 1e9;
bitset<MAX_P/2+1> primes; // Only odd numbers
```

// Cache-friendly Erathostenes sieve
// ~1.5s on Intel Core i5 for MAX_P = 10^9
// Memory usage: MAX_P/16 bytes

```
void sieve() {
    constexpr int SEG_SIZE = 1<<18;
    int pSqrt = int(sqrt(MAX_P)+0.5);
    vector<Pii> dels;
    primes.set();
    primes.reset(0);
```

```
    for (int i = 3; i <= pSqrt; i += 2) {
        if (primes[i/2]) {
            int j;
            for (j = i*i; j <= pSqrt; j += i*2)
                primes.reset(j/2);
            dels.pb({ i, j/2 });
        }
    }
```

```
    for (int seg = pSqrt/2;
        seg <= sz(primes); seg += SEG_SIZE) {
        int lim = min(seg+SEG_SIZE, sz(primes));
        each(d, dels) for (; d.y < lim; d.y += d.x)
            primes.reset(d.y);
    }
```

```
bool isPrime(int x) {
    return x == 2 || (x%2 && primes[x/2]);
}
```

structures/bitset_plus.h

// Undocumented std::bitset features:
// - _Find_first() - returns first bit = 1 or N
// - _Find_next(i) - returns first bit = 1
// after i-th bit
// or N if not found

// Bitwise operations for vector<bool>
// UNTESTED

```
#define OP(x) vector<bool>& operator x##=( \
    vector<bool>& l, const vector<bool>& r) { \
    assert(sz(l) == sz(r)); \
    auto a = l.begin(); auto b = r.begin(); \
    while (a<l.end()) *a._M_p++ x##= *b._M_p++; \
    return l; }
OP(&)OP(!)OP(^)
```

structures/fenwick_tree.h

// Fenwick tree (BIT tree); space: $O(n)$
// Default version: prefix sums

```
struct Fenwick {
    using T = int;
    static const T ID = 0;
    T f(T a, T b) { return a+b; }
```

```
    vector<T> s;
    Fenwick(int n = 0) : s(n, ID) {}
```

```
    // A[i] = f(A[i], v); time:  $O(\lg n)$ 
    void modify(int i, T v) {
```

```
        for (; i < sz(s); i |= i+1) s[i]=f(s[i],v);
    }
```

// Get f(A[0], ..., A[i-1]); time: $O(\lg n)$
T query(int i) {
 T v = ID;
 for (; i > 0; i &= i-1) v = f(v, s[i-1]);
 return v;
}

// Find smallest i such that
// f(A[0], ..., A[i-1]) >= val; time: $O(\lg n)$
// Prefixes must have non-decreasing values.

```
int lowerBound(T val) {
    if (val <= ID) return 0;
    int i = -1, mask = 1;
    while (mask <= sz(s)) mask *= 2;
    T off = ID;
```

```
    while (mask /= 2) {
        int k = mask+i;
        if (k < sz(s)) {
            T x = f(off, s[k]);
            if (val > x) i=k, off=x;
        }
    }
    return i+2;
}
```

```
};
```

structures/fenwick_tree_2d.h

*// Fenwick tree 2D (BIT tree 2D); space: $O(n*m)$*
// Default version: prefix sums 2D
// Change s to hashmap for $O(q \lg^2 n)$ memory

```
struct Fenwick2D {
    using T = int;
    static constexpr T ID = 0;
    T f(T a, T b) { return a+b; }
```

```
    vector<T> s;
    int w, h;
```

```
    Fenwick2D(int n = 0, int m = 0)
        : s(n*m, ID), w(n), h(m) {}
```

// A[i, j] = f(A[i, j], v); time: $O(\lg^2 n)$

```
void modify(int i, int j, T v) {
    for (; i < w; i |= i+1)
        for (int k = j; k < h; k |= k+1)
            s[i*h+k] = f(s[i*h+k], v);
}
```

// Query prefix; time: $O(\lg^2 n)$
T query(int i, int j) {
 T v = ID;
 for (; i>0; i&=i-1)
 for (int k = j; k > 0; k &= k-1)
 v = f(v, s[i*h+k-h-1]);
 return v;
}

```
};
```

structures/find_union.h

```
// Disjoint set data structure; space: O(n)
// Operations work in amortized O(alfa(n))
struct FAU {
    Vi G;
    FAU(int n = 0) : G(n, -1) {}

    // Get size of set containing i
    int size(int i) { return -G[find(i)]; }

    // Find representative of set containing i
    int find(int i) {
        return G[i] < 0 ? i : G[i] = find(G[i]);
    }

    // Union sets containing i and j
    bool join(int i, int j) {
        i = find(i); j = find(j);
        if (i == j) return 0;
        if (G[i] > G[j]) swap(i, j);
        G[i] += G[j]; G[j] = i;
        return 1;
    }
};
```

structures/hull_offline.h

```
constexpr ll INF = 2e18;
// constexpr double INF = 1e30;
// constexpr double EPS = 1e-9;

// MAX of linear functions; space: O(n)
// Use if you add lines in increasing `a` order
// Default uncommented version is for int64
struct Hull {
    using T = ll; // Or change to double

    struct Line {
        T a, b, end;
        T intersect(const Line& r) const {
            // Version for double:
            //if (r.a-a < EPS) return b>r.b?INF:-INF;
            //return (b-r.b) / (r.a-a);
            if (a==r.a) return b > r.b ? INF : -INF;
            ll u = b-r.b, d = r.a-a;
            return u/d + ((u^d) >= 0 || !(u^d));
        }
    };

    vector<Line> S;
    Hull() { S.pb({ 0, -INF, INF }); }

    // Insert f(x) = ax+b; time: amortized O(1)
    void push(T a, T b) {
        Line l{a, b, INF};
        while (true) {
            T e = S.back().end=S.back().intersect(l);
            if (sz(S) < 2 || S[sz(S)-2].end < e)
                break;
            S.pop_back();
        }
        S.pb(l);
    }

    // Query max(f(x) for each f): time: O(lg n)
    T query(T x) {
        auto t = *upper_bound(all(S), x,
            [](int l, const Line& r) {
```

```
        return l < r.end;
    });
    return t.a*x + t.b;
};
```

structures/hull_online.h

```
constexpr ll INF = 2e18;

// MAX of linear functions online; space: O(n)
struct Hull {
    static bool modeQ; // Toggles operator< mode

    struct Line {
        mutable ll a, b, end;

        ll intersect(const Line& r) const {
            if (a==r.a) return b > r.b ? INF : -INF;
            ll u = b-r.b, d = r.a-a;
            return u/d + ((u^d) >= 0 || !(u^d));
        }

        bool operator<(const Line& r) const {
            return modeQ ? end < r.end : a < r.a;
        }
    };

    multiset<Line> S;
    Hull() { S.insert({ 0, -INF, INF }); }

    // Updates segment end
    bool update(multiset<Line>::iterator it) {
        auto cur = it++; cur->end = INF;
        if (it == S.end()) return false;
        cur->end = cur->intersect(*it);
        return cur->end >= it->end;
    }

    // Insert f(x) = ax+b; time: O(lg n)
    void insert(ll a, ll b) {
        auto it = S.insert({ a, b, INF });
        while (update(it)) it = --S.erase(++it);
        rep(i, 0, 2)
            while (it != S.begin() && update(--it))
                update(it = --S.erase(++it));
    }

    // Query max(f(x) for each f): time: O(lg n)
    ll query(ll x) {
        modeQ = 1;
        auto l = *S.upper_bound({ 0, 0, x });
        modeQ = 0;
        return l.a*x + l.b;
    }
};
```

bool Hull::modeQ = false;

structures/max_queue.h

```
// Queue with max query on contained elements
struct MaxQueue {
    using T = int;
    deque<T> Q, M;

    // Add v to the back; time: amortized O(1)
```

```
void push(T v) {
    while (!M.empty() && M.back() < v)
        M.pop_back();
    M.pb(v); Q.pb(v);
}

// Pop from the front; time: O(1)
void pop() {
    if (M.front() == Q.front()) M.pop_front();
    Q.pop_front();
}

// Get max element value; time: O(1)
T max() const { return M.front(); }
};
```

structures/pairing_heap.h

```
// Pairing heap implementation; space O(n)
// Elements are stored in vector for faster
// allocation. It's MINIMUM queue.
// Allows to merge heaps in O(1)
template<class T, class Cmp = less<T>>
struct PHeap {
    struct Node {
        T val;
        int child{-1}, next{-1}, prev{-1};

        Node(T x = T()) : val(x) {}
    };

    using Vnode = vector<Node>;
    Vnode& M;
    int root{-1};

    int unlink(int& i) {
        if (i >= 0) M[i].prev = -1;
        int x = i; i = -1;
        return x;
    }

    void link(int host, int& i, int val) {
        if (i >= 0) M[i].prev = -1;
        i = val;
        if (i >= 0) M[i].prev = host;
    }

    int merge(int l, int r) {
        if (l < 0) return r;
        if (r < 0) return l;
        if (Cmp()(M[l].val, M[r].val)) swap(l, r);

        link(l, M[l].next, unlink(M[r].child));
        link(r, M[r].child, l);
        return r;
    }

    int mergePairs(int v) {
        if (v < 0 || M[v].next < 0) return v;
        int v2 = unlink(M[v].next);
        int v3 = unlink(M[v2].next);
        return merge(merge(v, v2), mergePairs(v3));
    }
};
```

// ---

// Initialize heap with given node storage

```
// Just declare 1 Vnode and pass it to heaps
PHeap(Vnode& mem) : M(mem) {}

// Add given key to heap, returns index; O(1)
int push(const T& x) {
    int index = sz(M);
    M.emplace_back(x);
    root = merge(root, index);
    return index;
}

// Change key of i to smaller value; O(1)
void decrease(int i, T val) {
    assert(!Cmp()(M[i].val, val));
    M[i].val = val;

    int prev = M[i].prev;
    if (prev < 0) return;

    auto& p = M[prev];
    link(prev, (p.child == i ? p.child
        : p.next), unlink(M[i].next));

    root = merge(root, i);
}

bool empty() { return root < 0; }
const T& top() { return M[root].val; }

// Merge with other heap. Must use same vec.
void merge(PHeap& r) { // time: O(1)
    assert(&M == &r.M);
    root = merge(root, r.root); r.root = -1;
}

// Remove min element; time: O(lg n)
void pop() {
    root = mergePairs(unlink(M[root].child));
}

};

structures/rmq.h

// Range Minimum Query; space: O(n lg n)
struct RMQ {
    using T = int;
    static constexpr T ID = INT_MAX;
    T f(T a, T b) { return min(a, b); }

    vector<vector<T>>> s;

    // Initialize RMQ structure; time: O(n lg n)
    RMQ(const vector<T>& vec = {}) {
        s = {vec};
        for (int h = 1; h <= sz(vec); h *= 2) {
            s.emplace_back();
            auto& prev = s[sz(s)-2];
            rep(i, 0, sz(vec)-h*2+1)
                s.back().pb(f(prev[i], prev[i+h]));
        }

        // Query f[s[b], ... ,s[e-1]); time: O(1)
        T query(int b, int e) {
            if (b >= e) return ID;
            int k = 31 - __builtin_clz(e-b);
            return f(s[k][b], s[k][e - (1<<k)]);
        }
    }
};
```

```

}
};

structures/segment_tree.h
// Optionally dynamic segment tree with lazy
// propagation. Configure by modifying:
// - T - data type for updates (stored type)
// - ID - neutral element for extra
// - Node - details in comments
struct SegmentTree {
    using T = int;
    static constexpr T ID = 0; // +
    // static constexpr T ID = INT_MIN; // max/=

    struct Node {
        T extra{ID}; // Lazy propagated value
        // Aggregates: sum, max, count of max
        T sum{0}, great{INT_MIN}, nGreat{0};

        // Initialize node with default value x
        void init(T x, int size) {
            sum = x*size; great = x; nGreat = size;
        }

        // Merge with node R on the right
        void merge(const Node& R) {
            if (great < R.great) nGreat = R.nGreat;
            else if (great == R.great) nGreat += R.nGreat;

            sum += R.sum;
            great = max(great, R.great);
        }

        // + version
        // Apply modification to node, return
        // value to be applied to node on right
        T apply(T x, int size) {
            extra += x;
            sum += x*size;
            great += x;
            return x;
        }

        // MAX
        // T apply(T x, int size) {
        //     if (great <= x) nGreat = size;
        //     extra = max(extra, x);
        //     great = max(great, x);
        //     // sum doesn't work here
        //     return x;
        // }

        // =
        // T apply(T x, int size) {
        //     extra = x;
        //     sum = x*size;
        //     great = x;
        //     nGreat = size;
        //     return x;
        // }
    };

    vector<Node> V;
    int len;
    // vector<array<int, 3>> links; // [DYNAMIC]
    // T defVal; // [DYNAMIC]

```

```

SegmentTree(int n=0, T def=ID) {init(n,def);}

void init(int n, T def) {
    for (len = 1; len < n; len *= 2);

    // [STATIC] version
    V.assign(len*2, {});
    rep(i, len, len+n) V[i].init(def, 1);
    for (int i = len-1; i > 0; i--) update(i);

    // [DYNAMIC] version
    // defVal = def;
    // links.assign(2, {-1, -1, len});
    // V.assign(2, {});
    // V[1].init(def, len);
}

// [STATIC] version
int getChild(int i, int j) { return i*2+j; }

// [DYNAMIC] version
// int getChild(int i, int j) {
//     if (links[i][j] < 0) {
//         int size = links[i][2] / 2;
//         links[i][j] = sz(V);
//         links.push_back({-1, -1, size});
//         V.emplace_back();
//         V.back().init(defVal, size);
//     }
//     return links[i][j];
// }

int L(int i) { return getChild(i, 0); }
int R(int i) { return getChild(i, 1); }

void update(int i) {
    int a = L(i), b = R(i);
    V[i] = {};
    V[i].merge(V[a]);
    V[i].merge(V[b]);
}

void push(int i, int size) {
    T e = V[i].extra;
    if (e != ID) {
        e = V[L(i)].apply(e, size/2);
        V[R(i)].apply(e, size/2);
        V[i].extra = ID;
    }
}

// Modify [vBegin;end) with x; time: O(lg n)
T modify(int vBegin, int vEnd, T x,
        int i = 1,
        int begin = 0, int end = -1) {
    if (end < 0) end = len;
    if (vEnd <= begin || end <= vBegin)
        return x;

    if (vBegin <= begin && end <= vEnd) {
        return V[i].apply(x, end-begin);
    }

    int mid = (begin + end) / 2;
    push(i, end-begin);

```

```

    x = modify(vBegin, vEnd, x, L(i), begin, mid);
    x = modify(vBegin, vEnd, x, R(i), mid, end);
    update(i);
    return x;
}

// Query [vBegin;vEnd]; time: O(lg n)
// Returns base nodes merged together
Node query(int vBegin, int vEnd, int i = 1,
          int begin = 0, int end = -1) {
    if (end < 0) end = len;
    if (vEnd <= begin || end <= vBegin)
        return {};
    if (vBegin <= begin && end <= vEnd)
        return V[i];

    int mid = (begin + end) / 2;
    push(i, end-begin);
    Node x = query(vBegin, vEnd, L(i), begin, mid);
    x.merge(query(vBegin, vEnd, R(i), mid, end));
    return x;
}

// TODO: generalize?
// Find longest suffix of given interval
// such that max value is smaller than val.
// Returns suffix begin index; time: O(lg n)
T search(int vBegin, int vEnd, int val,
        int i=1, int begin=0, int end=-1) {
    if (end < 0) end = len;
    if (vEnd <= begin || end <= vBegin)
        return begin;

    if (vBegin <= begin && end <= vEnd) {
        if (V[i].great < val) return begin;
        if (begin+1 == end) return end;
    }

    int mid = (begin+end) / 2;
    push(i, end-begin);

    int ind = search(vBegin, vEnd, val,
                  R(i), mid, end);
    if (ind > mid) return ind;
    return search(vBegin, vEnd, val,
                L(i), begin, mid);
}

```

structures/segment_tree_beats.h

```

constexpr ll INF = 1e18;

// Segment tree with min/+ update and
// sum/max query; time: amortized O(n lg^2 n)
// or O(n lg n) if not using + operation
struct SegmentTree {
    using T = ll;
    vector<T> sum, plus, max1, max2, cnt1;
    int len;

    SegmentTree(int n = 0) {
        for (len = 1; len < n; len *= 2);
        sum.resize(len*2);
        plus.resize(len*2);
        max1.resize(len*2);
        max2.assign(len*2, -INF);
    }

    cnt1.assign(len*2, 1);
    for (int i = len-1; i > 0; i--) update(i);

    void apply(int i, T m, T p, int size) {
        plus[i] += p; sum[i] += p*size;
        max1[i] += p; max2[i] += p;
        if (m < max1[i]) {
            sum[i] -= (max1[i]-m)*cnt1[i];
            max1[i] = m;
        }
    }

    void update(int i) {
        int a = i*2, b = i*2+1;
        sum[i] = sum[a] + sum[b];
        plus[i] = 0;
        max1[i] = max1[a];
        max2[i] = max2[a];
        cnt1[i] = cnt1[a];

        if (max1[b] > max1[i]) {
            max2[i] = max1[i];
            max1[i] = max1[b];
            cnt1[i] = cnt1[b];
        } else if (max1[b] == max1[i]) {
            cnt1[i] += cnt1[b];
        } else if (max1[b] > max2[i]) {
            max2[i] = max1[b];
        }
        max2[i] = max(max2[i], max2[b]);
    }

    void push(int i, int s) {
        rep(j, 0, 2)
            apply(i*2+j, max1[i], plus[i], s/2);
        plus[i] = 0;
    }

    // Apply min with x on [vBegin;vEnd]
    // time: amortized O(lg n) or O(lg^2 n)
    void setMin(int vBegin, int vEnd, T x,
            int i = 1,
            int begin = 0, int end = -1) {
        if (end < 0) end = len;
        if (vEnd <= begin || end <= vBegin ||
            max1[i] < x) return;

        if (begin >= vBegin && end <= vEnd &&
            max2[i] < x)
            return apply(i, x, 0, end-begin);

        int mid = (begin+end) / 2;
        push(i, end-begin);
        setMin(vBegin, vEnd, x, i*2, begin, mid);
        setMin(vBegin, vEnd, x, i*2+1, mid, end);
        update(i);
    }

    // Add x on [vBegin;vEnd]; time: O(lg n)
    void add(int vBegin, int vEnd, T x,
            int i = 1,
            int begin = 0, int end = -1) {
        if (end < 0) end = len;
        if (vEnd <= begin || end <= vBegin) return;
        if (begin >= vBegin && end <= vEnd)

```

```

    return apply(i, INF, x, end-begin);

    int mid = (begin+end) / 2;
    push(i, end-begin);
    add(vBegin, vEnd, x, i*2, begin, mid);
    add(vBegin, vEnd, x, i*2+1, mid, end);
    update(i);
}

// Query sum of [vBegin;vEnd]; time: O(lg n)
T getSum(int vBegin, int vEnd, int i = 1,
         int begin = 0, int end = -1) {
    if (end < 0) end = len;
    if (vEnd<=begin || end<=vBegin) return 0;
    if (vBegin <= begin && end <= vEnd)
        return sum[i];
    int mid = (begin+end) / 2;
    push(i, end-begin);
    return getSum(vBegin, vEnd, i*2, begin, mid) +
        getSum(vBegin, vEnd, i*2+1, mid, end);
}

// Query max of [vBegin;vEnd]; time: O(lg n)
T getMax(int vBegin, int vEnd, int i = 1,
         int begin = 0, int end = -1) {
    if (end < 0) end = len;
    if (vEnd <= begin || end <= vBegin)
        return -INF;
    if (vBegin <= begin && end <= vEnd)
        return max[i];
    int mid = (begin+end) / 2;
    push(i, end-begin);
    return max(
        getMax(vBegin, vEnd, i*2, begin, mid),
        getMax(vBegin, vEnd, i*2+1, mid, end)
    );
}
};

```

structures/segment_tree_point.h

```

// Segment tree (point, interval)
// Configure by modifying:
// - T - stored data type
// - ID - neutral element for query operation
// - merge(a, b) - combine results
struct SegmentTree {
    using T = int;
    static constexpr T ID = INT_MIN;
    static T merge(T a, T b) { return max(a,b); }

    vector<T> V;
    int len;

    SegmentTree(int n = 0, T def = ID) {
        for (len = 1; len < n; len *= 2);
        V.resize(len*2, ID);
        rep(i, 0, n) V[len+i] = def;
        for (int i = len-1; i > 0; i--)
            V[i] = merge(V[i*2], V[i*2+1]);
    }

    void set(int i, T val) {
        V[i+=len] = val;
        while ((i/=2) > 0)
            V[i] = merge(V[i*2], V[i*2+1]);
    }
}

```

```

T query(int begin, int end) {
    begin += len; end += len-1;
    if (begin > end) return ID;
    if (begin == end) return V[begin];
    T x = merge(V[begin], V[end]);

    while (begin/2 < end/2) {
        if (~begin&1) x = merge(x, V[begin^1]);
        if (end&1) x = merge(x, V[end^1]);
        begin /= 2; end /= 2;
    }
    return x;
}
};

```

constexpr SegmentTree::T SegmentTree::ID;

structures/treap.h

```

// "Set" of implicit keyed treaps; space: O(n)
// Nodes are keyed by their indices in array
// of all nodes. Treap key is key of its root.
// "Node x" means "node with key x".
// "Treap x" means "treap with key x".
// Key -1 is "null".
// Put any additional data in Node struct.
struct Treap {
    struct Node {
        // E[0] = left child, E[1] = right child
        // weight = node random weight (for treap)
        // size = subtree size, par = parent node
        int E[2] = {-1, -1}, weight{rand()};
        int size{1}, par{-1};
        bool flip{0}; // Is interval reversed?
    };

    vector<Node> G; // Array of all nodes

    // Initialize structure for n nodes
    // with keys 0, ..., n-1; time: O(n)
    // Each node is separate treap,
    // use join() to make sequence.
    Treap(int n = 0) : G(n) {}

    // Create new treap (a single node),
    // returns its key; time: O(1)
    int make() {
        G.emplace_back(); return sz(G)-1;
    }

    // Get size of node x subtree. x can be -1.
    int size(int x) { // time: O(1)
        return (x >= 0 ? G[x].size : 0);
    }

    // Propagate down data (flip flag etc).
    // x can be -1; time: O(1)
    void push(int x) {
        if (x >= 0 && G[x].flip) {
            G[x].flip = 0;
            swap(G[x].E[0], G[x].E[1]);
            each(e, G[x].E) if (e==0) G[e].flip ^= 1;
        } // + any other lazy operations
    }

    // Update aggregates of node x.

```

```

// x can be -1; time: O(1)
void update(int x) {
    if (x >= 0) {
        int& s = G[x].size = 1;
        G[x].par = -1;
        each(e, G[x].E) if (e >= 0) {
            s += G[e].size;
            G[e].par = x;
        }
    } // + any other aggregates
}

// Split treap x into treaps l and r
// such that l contains first i elements
// and r the remaining ones.
// x, l, r can be -1; time: ~O(lg n)
void split(int x, int& l, int& r, int i) {
    push(x); l = r = -1;
    if (x < 0) return;
    int key = size(G[x].E[0]);
    if (i <= key) {
        split(G[x].E[0], l, G[x].E[0], i);
        r = x;
    } else {
        split(G[x].E[1], G[x].E[1], r, i-key-1);
        l = x;
    }
    update(x);
}

// Join treaps l and r into one treap
// such that elements of l are before
// elements of r. Returns new treap.
// l, r and returned value can be -1.
int join(int l, int r) { // time: ~O(lg n)
    push(l); push(r);
    if (l < 0 || r < 0) return max(l, r);

    if (G[l].weight < G[r].weight) {
        G[l].E[1] = join(G[l].E[1], r);
        update(l);
        return l;
    }

    G[r].E[0] = join(l, G[r].E[0]);
    update(r);
    return r;
}

// Find i-th node in treap x.
// Returns its key or -1 if not found.
// x can be -1; time: ~O(lg n)
int find(int x, int i) {
    while (x >= 0) {
        push(x);
        int key = size(G[x].E[0]);
        if (key == i) return x;
        x = G[x].E[key < i];
        if (key < i) i -= key+1;
    }
    return -1;
}

// Get key of treap containing node x
// (key of treap root). x can be -1.
int root(int x) { // time: ~O(lg n)

```

```

while (G[x].par >= 0) x = G[x].par;
return x;
}

// Get position of node x in its treap.
// x is assumed to NOT be -1; time: ~O(lg n)
int index(int x) {
    int p, i = size(G[x].E[G[x].flip]);
    while ((p = G[x].par) >= 0) {
        if (G[p].E[1] == x) i+=size(G[p].E[0])+1;
        if (G[p].flip) i = G[p].size-i-1;
        x = p;
    }
    return i;
}

// Reverse interval [l;r] in treap x.
// Returns new key of treap; time: ~O(lg n)
int reverse(int x, int l, int r) {
    int a, b, c;
    split(x, b, c, r);
    split(b, a, b, l);
    if (b >= 0) G[b].flip ^= 1;
    return join(join(a, b), c);
}
};

```

structures/ext/hash_table.h

```

#include <ext/pb_ds/assoc_container.hpp>
using namespace __gnu_pbds;
// gp_hash_table<K, V> = faster unordered_set

// Anti-anti-hash
const size_t HXOR = mt19937_64(time(0))();
template<class T> struct SafeHash {
    size_t operator()(const T& x) const {
        return hash<T>() (x ^ T(HXOR));
    }
};

```

structures/ext/rope.h

```

#include <ext/rope>
using namespace __gnu_cxx;
// rope<T> = implicit cartesian tree

```

structures/ext/tree.h

```

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

template<class T, class Cmp = less<T>>
using ordered_set = tree<
    T, null_type, Cmp, rb_tree_tag,
    tree_order_statistics_node_update
>;

// Standard set functions and:
// t.order_of_key(key) - index of first >= key
// t.find_by_order(i) - find i-th element
// t1.join(t2) - assuming t1<t2 merge t2 to t1

```

structures/ext/trie.h

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

using pref_trie = trie<
    string, null_type,
    trie_string_access_traits<>, pat_trie_tag,
    trie_prefix_search_node_update
>;
```

text/aho_corasick.h

```
constexpr char AMIN = 'a'; // Smallest letter
constexpr int ALPHA = 26; // Alphabet size

// Aho-Corasick algorithm for linear-time
// multiple pattern matching.
// Add patterns using add(), then call build().
struct Aho {
    vector<array<int, ALPHA>> nxt{1};
    Vi suf = {-1}, accLink = {-1};
    vector<Vi> accept{1};

    // Add string with given ID to structure
    // Returns index of accepting node
    int add(const string& str, int id) {
        int i = 0;
        each(c, str) {
            if (!nxt[i][c-AMIN]) {
                nxt[i][c-AMIN] = sz(nxt);
                nxt.pb({}); suf.pb(-1);
                accLink.pb(1); accept.pb({});
            }
            i = nxt[i][c-AMIN];
        }
        accept[i].pb(id);
        return i;
    }

    // Build automata; time: O(V*ALPHA)
    void build() {
        queue<int> que;
        each(e, nxt[0]) if (e) {
            suf[e] = 0; que.push(e);
        }
        while (!que.empty()) {
            int i = que.front(), s = suf[i], j = 0;
            que.pop();
            each(e, nxt[i]) {
                if (e) que.push(e);
                (e ? suf[e] : e) = nxt[s][j++];
            }
            accLink[i] = (accept[s].empty() ?
                accLink[s] : s);
        }
    }

    // Append `c` to state `i`
    int next(int i, char c) {
        return nxt[i][c-AMIN];
    }

    // Call `f` for each pattern accepted
    // when in state `i` with its ID as argument.
    // Return true from `f` to terminate early.
    // Calls are in decreasing length order.
    template<class F> void accepted(int i, F f) {
```

```
while (i != -1) {
    each(a, accept[i]) if (f(a)) return;
    i = accLink[i];
}
};

text/kmp.h
// Computes prefsuf array; time: O(n)
// ps[i] = max prefsuf of [0;i]; ps[0] := -1
template<class T> Vi kmp(const T& str) {
    Vi ps; ps.pb(-1);
    each(x, str) {
        int k = ps.back();
        while (k >= 0 && str[k] != x) k = ps[k];
        ps.pb(k+1);
    }
    return ps;
}

// Finds occurrences of pat in vec; time: O(n)
// Returns starting indices of matches.
template<class T>
Vi match(const T& str, T pat) {
    int n = sz(pat);
    pat.pb(-1); // SET TO SOME UNUSED CHARACTER
    pat.insert(pat.end(), all(str));
    Vi ret, ps = kmp(pat);
    rep(i, 0, sz(ps)) {
        if (ps[i] == n) ret.pb(i-2*n-1);
    }
    return ret;
}

text/kmr.h
// KMR algorithm for O(1) lexicographical
// comparison of substrings.
struct KMR {
    vector<Vi> ids;

    KMR() {}

    // Initialize structure; time: O(n lg^2 n)
    // You can change str type to Vi freely.
    KMR(const string& str) {
        ids.clear();
        ids.pb(Vi(all(str)));

        for (int h = 1; h <= sz(str); h *= 2) {
            vector<pair<Pii, int>> tmp;

            rep(j, 0, sz(str)) {
                int a = ids.back()[j], b = -1;
                if (j+h < sz(str)) b = ids.back()[j+h];
                tmp.pb({a, b}, j);
            }

            sort(all(tmp));
            ids.emplace_back(sz(tmp));

            int n = 0;
            rep(j, 0, sz(tmp)) {
                if (j > 0 && tmp[j-1].x != tmp[j].x)
                    n++;
                ids.back()[tmp[j].y] = n;
            }
        }
    }
};
```

```
    }
}

// Get representative of [begin;end); O(1)
Pii get(int begin, int end) {
    if (begin >= end) return {0, 0};
    int k = 31 - __builtin_clz(end-begin);
    return {ids[k][begin], ids[k][end-(1<<k)]};
}

// Compare [b1;e1) with [b2;e2); O(1)
// Returns -1 if <, 0 if ==, 1 if >
int cmp(int b1, int e1, int b2, int e2) {
    int l1 = e1-b1, l2 = e2-b2;
    int l = min(l1, l2);
    Pii x = get(b1, b1+l), y = get(b2, b2+l);

    if (x == y) return (l1 > l2) - (l1 < l2);
    return (x > y) - (x < y);
}

// Compute suffix array of string; O(n)
Vi sufArray() {
    Vi sufs(sz(ids.back()));
    rep(i, 0, sz(ids.back()))
        sufs[ids.back()[i]] = i;
    return sufs;
}

text/lcp.h
// Compute Longest Common Prefix array for
// given string and it's suffix array; O(n)
// In order to compute suffix array use kmr.h
// or suffix_array_linear.h
template<class T>
Vi lcpArray(const T& str, const Vi& sufs) {
    int n = sz(str), k = 0;
    Vi pos(n), lcp(n-1);
    rep(i, 0, n) pos[sufs[i]] = i;
    rep(i, 0, n) {
        if (pos[i] < n-1) {
            int j = sufs[pos[i]+1];
            while (i+k < n && j+k < n &&
                str[i+k] == str[j+k]) k++;
            lcp[pos[i]] = k;
        }
        if (k > 0) k--;
    }
    return lcp;
}

text/lyndon_factorization.h
// Compute Lyndon factorization for s; O(n)
// Word is simple iff it's strictly smaller
// than any of it's nontrivial suffixes.
// Lyndon factorization is division of string
// into non-increasing simple words.
// It is unique.
vector<string> duval(const string& s) {
    int n = sz(s), i = 0;
    vector<string> ret;
    while (i < n) {
        int j = i+1, k = i;
```

```
while (j < n && s[k] <= s[j])
    k = (s[k] < s[j] ? i : k+1), j++;
while (i <= k)
    ret.pb(s.substr(i, j-k)), i += j-k;
}
return ret;
}

text/main_lorentz.h
#include "z_function.h"

struct Sqr {
    int begin, end, len;
};

// Main-Lorentz algorithm for finding
// all squares in given word; time: O(n lg n)
// Results are in compressed form:
// (b, e, l) means that for each b <= i < e
// there is square at position i of size 2l.
// Each square is present in only one interval.
vector<Sqr> lorentz(const string& s) {
    int n = sz(s);
    if (n <= 1) return {};
    auto a = s.substr(0, n/2), b = s.substr(n/2);

    auto ans = lorentz(a);
    each(p, lorentz(b))
        ans.pb({p.begin+n/2, p.end+n/2, p.len});

    string ra(a.rbegin(), a.rend());
    string rb(b.rbegin(), b.rend());

    rep(j, 0, 2) {
        Vi z1 = prefPref(ra), z2 = prefPref(b+a);
        z1.pb(0); z2.pb(0);

        rep(c, 0, sz(a)) {
            int l = sz(a)-c;
            int x = c - min(l-1, z1[l]);
            int y = c - max(l-z2[sz(b)+c], j);
            if (x > y) continue;

            if (j)
                ans.pb({n-y-l*2, n-x-l*2+1, l});
            else
                ans.pb({x, y+1, l});
        }

        a.swap(rb);
        b.swap(ra);
    }

    return ans;
}

text/manacher.h
// Manacher algorithm; time: O(n)
// Finds largest radiuses for palindromes:
// r[2*i] = for center at i (single letter = 1)
// r[2*i+1] = for center between i and i+1
template<class T> Vi manacher(const T& str) {
    int n = sz(str)*2, c = 0, e = 1;
    Vi r(n, 1);
    auto get = [&](int i) { return i%2 ? 0 :
```



```
(i >= 0 && i < n ? str[i/2] : i); });

rep(i, 0, n) {
    if (i < e) r[i] = min(r[c*2-i], e-i);
    while (get(i-r[i]) == get(i+r[i])) r[i]++;
    if (i+r[i] > e) c = i, e = i+r[i]-1;
}

rep(i, 0, n) r[i] /= 2;
return r;
}
```

text/min_rotation.h

```
// Find lexicographically smallest
// rotation of s; time: O(n)
// Returns index where shifted word starts.
// You can use std::rotate to get the word:
// rotate(s.begin(), v.begin()+minRotation(v),
//        v.end());
int minRotation(string s) {
    int a = 0, n = sz(s); s += s;
    rep(b, 0, n) rep(i, 0, n) {
        if (a+i == b || s[a+i] < s[b+i]) {
            b += max(0, i-1); break;
        }
        if (s[a+i] > s[b+i]) {
            a = b; break;
        }
    }
    return a;
}
```

text/palindromic_tree.h

```
constexpr int ALPHA = 26; // Set alphabet size
```

```
// Tree of all palindromes in string,
// constructed online by appending letters.
// space: O(n*ALPHA); time: O(n)
// Code marked with [EXT] is extension for
// calculating minimal palindrome partition
// in O(n lg n). Can also be modified for
// similar dynamic programmings.
struct PalTree {
    Vi txt; // Text for which tree is built

    // Node 0 = empty palindrome (root of even)
    // Node 1 = "-1" palindrome (root of odd)
    Vi len{0, -1}; // Lengths of palindromes
    Vi link{1, 0}; // Suffix palindrome links
    // Edges to next palindromes
    vector<array<int, ALPHA>> to{ {}, {} };
    int last{0}; // Current node (max suffix pal)
```

```
Vi diff{0, 0}; // len[i]-len[link[i]] [EXT]
Vi slink{0, 0}; // Serial links [EXT]
Vi series{0, 0}; // Series DP answer [EXT]
Vi ans{0}; // DP answer for prefix[EXT]
```

```
int ext(int i) {
    while (len[i]+2 > sz(txt) ||
           txt[sz(txt)-len[i]-2] != txt.back())
        i = link[i];
    return i;
}
```

```
// Append letter from [0;ALPHA); time: O(1)
// (or O(lg n) if [EXT] is enabled)
void add(int x) {
    txt.pb(x);
    last = ext(last);

    if (!to[last][x]) {
        len.pb(len[last]+2);
        link.pb(to[ext(link[last])][x]);
        to[last][x] = sz(to);
        to.emplace_back();

        // [EXT]
        diff.pb(len.back() - len[link.back()]);
        slink.pb(diff.back() == diff[link.back()]
                 ? slink[link.back()] : link.back());
        series.pb(0);
        // [/EXT]
    }
    last = to[last][x];

    // [EXT]
    ans.pb(INT_MAX);
    for (int i=last; len[i] > 0; i=slink[i]) {
        series[i] = ans[sz(ans) - len[slink[i]]
                       - diff[i] - 1];
        if (diff[i] == diff[link[i]])
            series[i] = min(series[i],
                           series[link[i]]);
        // If you want only even palindromes
        // set ans only for sz(txt)%2 == 0
        ans.back() = min(ans.back(), series[i]+1);
    }
    // [/EXT]
}
};
```

text/suffix_array_linear.h

```
#include "../util/radix_sort.h"
```

```
// KS algorithm for suffix array; time: O(n)
// Input values are assumed to be in [1;k]
Vi sufArray(Vi str, int k) {
    int n = sz(str);
    Vi suf(n);
    str.resize(n+15);
```

```
if (n < 15) {
    iota(all(suf), 0);
    rep(j, 0, n) countSort(suf,
        [&](int i) { return str[i+n-j-1]; }, k);
    return suf;
}
```

```
// Compute triples codes
Vi tmp, code(n+2);
rep(i, 0, n) if (i % 3) tmp.pb(i);
```

```
rep(j, 0, 3) countSort(tmp,
    [&](int i) { return str[i-j+2]; }, k);
```

```
int mc = 0, j = -1;
```

```
each(i, tmp) {
    code[i] = mc += (j == -1 ||
                    str[i] != str[j] ||
```

```
    str[i+1] != str[j+1] ||
    str[i+2] != str[j+2]);
    j = i;
}
```

```
// Compute suffix array of 2/3
tmp.clear();
for (int i=1; i < n; i += 3) tmp.pb(code[i]);
tmp.pb(0);
for (int i=2; i < n; i += 3) tmp.pb(code[i]);
tmp = sufArray(move(tmp), mc);
```

```
// Compute partial suffix arrays
Vi third;
int th = (n+4) / 3;
if (n%3 == 1) third.pb(n-1);
```

```
rep(i, 1, sz(tmp)) {
    int e = tmp[i];
    tmp[i-1] = (e < th ? e*3+1 : (e-th)*3+2);
    code[tmp[i-1]] = i;
    if (e < th) third.pb(e*3);
}
```

```
tmp.pop_back();
countSort(third,
    [&](int i) { return str[i]; }, k);
```

```
// Merge suffix arrays
merge(all(third), all(tmp), suf.begin(),
    [&](int l, int r) {
        while (l%3 == 0 || r%3 == 0) {
            if (str[l] != str[r])
                return str[l] < str[r];
            l++; r++;
        }
        return code[l] < code[r];
    });
```

```
return suf;
}
```

```
// KS algorithm for suffix array; time: O(n)
Vi sufArray(const string& str) {
    return sufArray(Vi(all(str)), 255);
}
```

text/suffix_automaton.h

```
constexpr char AMIN = 'a'; // Smallest letter
constexpr int ALPHA = 26; // Set alphabet size
```

```
// Suffix automaton - minimal DFA that
// recognizes all suffixes of given string
// (and encodes all substrings);
// space: O(n*ALPHA); time: O(n)
// Paths from root are equivalent to substrings
// Extensions:
// - [OCC] - count occurrences of substrings
// - [PATHS] - count paths from node
struct SufDFA {
```

```
    // State v represents endpos-equivalence
    // class that contains words of all lengths
    // between link[len[v]]+1 and len[v].
    // len[v] = longest word of equivalence class
    // link[v] = link to state of longest suffix
    // in other equivalence class
```

```
// to[v][c] = automaton edge c from v
Vi len{0}, link{-1};
vector<array<int, ALPHA>> to{ {} };
int last{0}; // Current node (whole word)
```

```
vector<Vi> inSufs; // [OCC] Suffix-link tree
Vi cnt{0}; // [OCC] Occurrence count
vector<ll> paths; // [PATHS] Out-path count
```

```
SufDFA() {}
```

```
// Build suffix automaton for given string
// and compute extended stuff; time: O(n)
SufDFA(const string& s) {
    each(c, s) add(c);
    finish();
}
```

```
// Append letter to the back
void add(char c) {
    int v = last, x = c-AMIN;
    last = sz(len);
    len.pb(len[v]+1);
    link.pb(0);
    to.pb({});
    cnt.pb(1); // [OCC]
```

```
while (v != -1 && !to[v][x]) {
    to[v][x] = last;
    v = link[v];
}
```

```
if (v != -1) {
    int q = to[v][x];
    if (len[v]+1 == len[q]) {
        link[last] = q;
    } else {
        len.pb(len[v]+1);
        link.pb(link[q]);
        to.pb(to[q]);
        cnt.pb(0); // [OCC]
        link[last] = link[q] = sz(len)-1;
        while (v != -1 && to[v][x] == q) {
            to[v][x] = link[q];
            v = link[v];
        }
    }
}
```

```
}
```

```
// Compute some additional stuff (offline)
```

```
void finish() {
    // [OCC]
    inSufs.resize(sz(len));
    rep(i, 1, sz(link)) inSufs[link[i]].pb(i);
    dfsSufs(0);
    // [/OCC]
```

```
    // [PATHS]
    paths.assign(sz(len), 0);
    dfs(0);
    // [/PATHS]
}
```

```
// Only for [OCC]
void dfsSufs(int v) {
```

```

    each(e, inSufs[v]) {
        dfsSufs(e);
        cnt[v] += cnt[e];
    }
}

// Only for [PATHS]
void dfs(int v) {
    if (paths[v]) return;
    paths[v] = 1;
    each(e, to[v]) if (e) {
        dfs(e);
        paths[v] += paths[e];
    }
}

// Go using edge `c` from state `i`.
// Returns 0 if edge doesn't exist.
int next(int i, char c) {
    return to[i][c-AMIN];
}

// Get lexicographically k-th substring
// of represented string; time: O(|substr|)
// Empty string has index 0.
// Requires [PATHS] extension.
string lex(ll k) {
    string s;
    int v = 0;
    while (k--) rep(i, 0, ALPHA) {
        int e = to[v][i];
        if (e) {
            if (k < paths[e]) {
                s.pb(char(AMIN+i));
                v = e;
                break;
            }
            k -= paths[e];
        }
    }
    return s;
}
};

```

text/suffix_tree.h

```

// Ukkonen's algorithm for online suffix tree
// construction; space: O(n*ALPHA); time: O(n)
// Real tree nodes are called dedicated nodes.
// "Nodes" lying on compressed edges are called
// implicit nodes and are represented
// as pairs (lower node, label index).
// Labels are represented as intervals [L;R)
// which refer to substrings [L;R) of txt.
// Leaves have labels of form [L;infinity),
// use getR to get current right endpoint.
// Suffix links are valid only for internal
// nodes (non-leaves).
struct SufTree {
    Vi txt; // Text for which tree is built
    // to[v][c] = edge with label starting with c
    // from node v
    vector<array<int, ALPHA>> to[{}];
    Vi L[0], R[0]; // Parent edge label endpoints
    Vi par[0]; // Parent link
    Vi link[0]; // Suffix link
    Pii cur[0, 0]; // Current state
};

```

```

// Get current right end of node label
int getR(int i) { return min(R[i], sz(txt)); }

// Follow edge `e` of implicit node `s`.
// Returns (-1, -1) if there is no edge.
Pii next(Pii s, int e) {
    if (s.y < getR(s.x))
        return txt[s.y] == e ? mp(s.x, s.y+1)
        : mp(-1, -1);
    e = to[s.x][e];
    return e ? mp(e, L[e]+1) : mp(-1, -1);
}

// Create dedicated node for implicit node
// and all its suffixes
int split(Pii s) {
    if (s.y == R[s.x]) return s.x;

    int t = sz(to); to.pb({});
    to[t][txt[s.y]] = s.x;
    L.pb(L[s.x]);
    R.pb(R[s.x] = s.y);
    par.pb(par[s.x]);
    par[s.x] = to[par[t]][txt[L[t]]] = t;
    link.pb(-1);

    int v = link[par[t]], l = L[t] + !par[t];
    while (l < R[t]) {
        v = to[v][txt[l]];
        l += getR(v) - L[v];
    }

    v = split({v, getR(v)-l+R[t]});
    link[t] = v;
    return t;
}

// Append letter from [0;ALPHA) to the back
void add(int x) { // amortized time: O(1)
    Pii t; txt.pb(x);
    while ((t = next(cur, x)).x == -1) {
        int m = split(cur);
        to[m][x] = sz(to);
        to.pb({});
        par.pb(m);
        L.pb(sz(txt)-1);
        R.pb(INT_MAX);
        link.pb(-1);
        cur = {link[m], getR(link[m])};
        if (!m) return;
    }
    cur = t;
}
};

```

text/z_function.h

```

// Computes Z function array; time: O(n)
// zf[i] = max common prefix of str and str[i:]
template<class T> Vi prefPref(const T& str) {
    int n = sz(str), b = 0, e = 1;
    Vi zf(n);
    rep(i, 1, n) {
        if (i < e) zf[i] = min(zf[i-b], e-i);
        while (i+zf[i] < n &&
            str[zf[i]] == str[i+zf[i]]) zf[i]++;
    }
};

```

```

    if (i+zf[i] > e) b = i, e = i+zf[i];
}
zf[0] = n;
return zf;
}

```

trees/centroid_decomp.h

```

// Centroid decomposition; space: O(n lg n)
// UNTESTED
struct CentroidTree {
    // child[v] = children of v in centroid tree
    // par[v] = parent of v in centroid tree
    // (-1 for root)
    // depth[v] = depth of v in centroid tree
    // (0 for root)
    // ind[v][i] = index of vertex v in i-th
    // centroid subtree from root
    // size[v] = size of centroid subtree of v
    // subtree[v] = list of vertices
    // in centroid subtree of v
    // dists[v] = distances from v to vertices
    // in its centroid subtree
    // (in the order of subtree[v])
    // neigh[v] = neighbours of v
    // in its centroid subtree
    // dir[v][i] = index of centroid neighbour
    // that is first vertex on path
    // from centroid v to i-th vertex
    // of centroid subtree
    // (-1 for centroid)
    vector<Vi> child, ind, dists, subtree,
        neigh, dir;
    Vi par, depth, size;
    int root; // Root centroid

    CentroidTree() {}

    CentroidTree(vector<Vi>& G)
        : child(sz(G)), ind(sz(G)), dists(sz(G)),
        subtree(sz(G)), neigh(sz(G)),
        dir(sz(G)), par(sz(G), -2),
        depth(sz(G)), size(sz(G)) {
        root = decomp(G, 0, 0);
    }

    int dfs(vector<Vi>& G, int v, int p) {
        size[v] = 1;
        each(e, G[v]) if (e != p && par[e] == -2)
            size[v] += dfs(G, e, v);
        return size[v];
    }

    void layer(vector<Vi>& G, int v,
        int p, int c, int d) {
        ind[v].pb(sz(subtree[c]));
        subtree[c].pb(v);
        dists[c].pb(d);
        dir[c].pb(sz(neigh[c])-1);
        each(e, G[v]) if (e != p && par[e] == -2) {
            if (v == c) neigh[c].pb(e);
            layer(G, e, v, c, d+1);
        }
    }

    int decomp(vector<Vi>& G, int v, int d) {
        int p = -1, s = dfs(G, v, -1);
    }
};

```

```

bool ok = 1;
while (ok) {
    ok = 0;
    each(e, G[v]) {
        if (e != p && par[e] == -2 &&
            size[e] > s/2) {
            p = v; v = e; ok = 1;
            break;
        }
    }
}

par[v] = -1;
size[v] = s;
depth[v] = d;
layer(G, v, -1, v, 0);

each(e, G[v]) if (par[e] == -2) {
    int j = decomp(G, e, d+1);
    child[v].pb(j);
    par[j] = v;
}
return v;
}
};

```

trees/heavylight_decomp.h

```

#include "../structures/segment_tree_point.h"

// Heavy-Light Decomposition of tree
// with subtree query support; space: O(n)
struct HLD {
    // Subtree of v = [pos[v]; pos[v]+size[v])
    // Chain with v = [chBegin[v]; chEnd[v])
    Vi par; // Vertex parent
    Vi size; // Vertex subtree size
    Vi depth; // Vertex distance to root
    Vi pos; // Vertex position in "HLD" order
    Vi chBegin; // Begin of chain with vertex
    Vi chEnd; // End of chain with vertex
    Vi order; // "HLD" preorder of vertices
    SegmentTree tree; // Verts are in HLD order

    HLD() {}

    // Initialize structure for tree G
    // and given root; time: O(n lg n)
    // MODIFIES ORDER OF EDGES IN G!
    HLD(vector<Vi>& G, int root)
        : par(sz(G)), size(sz(G)),
        depth(sz(G)), pos(sz(G)),
        chBegin(sz(G)), chEnd(sz(G)) {
        dfs(G, root, -1);
        decomp(G, root, -1, 0);
        tree = {sz(order)};
    }

    void dfs(vector<Vi>& G, int v, int p) {
        par[v] = p;
        size[v] = 1;
        depth[v] = p < 0 ? 0 : depth[p]+1;

        int& fs = G[v][0];
        if (fs == p) swap(fs, G[v].back());

        each(e, G[v]) if (e != p) {
    }
};

```

```

    dfs(G, e, v);
    size[v] += size[e];
    if (size[e] > size[fs]) swap(e, fs);
}

void decomp(vector<Vi>& G,
            int v, int p, int chb) {
    pos[v] = sz(order);
    chBegin[v] = chb;
    chEnd[v] = pos[v]+1;
    order.pb(v);

    each(e, G[v]) if (e != p) {
        if (e == G[v][0]) {
            decomp(G, e, v, chb);
            chEnd[v] = chEnd[e];
        } else {
            decomp(G, e, v, sz(order));
        }
    }

    // Get root of chain containing v
    int chRoot(int v) {return order[chBegin[v]];}

    // Level Ancestor Query; time: O(lg n)
    int laq(int v, int level) {
        while (true) {
            int k = pos[v] - depth[v] + level;
            if (k >= chBegin[v]) return order[k];
            v = par[chRoot(v)];
        }
    }

    // Lowest Common Ancestor; time: O(lg n)
    int lca(int a, int b) {
        while (chBegin[a] != chBegin[b]) {
            int ha = chRoot(a), hb = chRoot(b);
            if (depth[ha] > depth[hb]) a = par[ha];
            else b = par[hb];
        }
        return depth[a] < depth[b] ? a : b;
    }

    // Call func(chBegin, chEnd) on each path
    // segment; time: O(lg n * time of func)
    template<class T>
    void iterPath(int a, int b, T func) {
        while (chBegin[a] != chBegin[b]) {
            int ha = chRoot(a), hb = chRoot(b);
            if (depth[ha] > depth[hb]) {
                func(chBegin[a], pos[a]+1);
                a = par[ha];
            } else {
                func(chBegin[b], pos[b]+1);
                b = par[hb];
            }
        }

        if (pos[a] > pos[b]) swap(a, b);
        // Remove +1 from pos[a]+1 for vertices
        // queries (with +1 -> edges).
        func(pos[a]+1, pos[b]+1);
    }
}

```

```

// Query path between a and b; O(lg^2 n)
SegmentTree::T queryPath(int a, int b) {
    auto ret = SegmentTree::ID;
    iterPath(a, b, [&](int i, int j) {
        ret = SegmentTree::merge(ret,
            tree.query(i, j));
    });
    return ret;
}

// Query subtree of v; time: O(lg n)
SegmentTree::T querySubtree(int v) {
    return tree.query(pos[v], pos[v]+size[v]);
}

```

trees/lca.h

```

// LAQ and LCA using jump pointers
// space: O(n lg n)

struct LCA {
    vector<Vi> jumps;
    Vi level, pre, post;
    int cnt{0}, depth;

    LCA() {}

    // Initialize structure for tree G
    // and root r; time: O(n lg n)
    LCA(vector<Vi>& G, int root)
        : jumps(sz(G)), level(sz(G)),
          pre(sz(G)), post(sz(G)) {
        dfs(G, root, root);
        depth = int(log2(sz(G))) + 2;
        rep(j, 0, depth) each(v, jumps)
            v.pb(jumps[v[j]][j]);
    }

    void dfs(vector<Vi>& G, int v, int p) {
        level[v] = p == v ? 0 : level[p]+1;
        jumps[v].pb(p);
        pre[v] = ++cnt;
        each(e, G[v]) if (e != p) dfs(G, e, v);
        post[v] = ++cnt;
    }

    // Check if a is ancestor of b; time: O(1)
    bool isAncestor(int a, int b) {
        return pre[a] <= pre[b] &&
            post[b] <= post[a];
    }

    // Lowest Common Ancestor; time: O(lg n)
    int operator()(int a, int b) {
        for (int j = depth; j--;)
            if (!isAncestor(jumps[a][j], b))
                a = jumps[a][j];
        return isAncestor(a, b) ? a : jumps[a][0];
    }

    // Level Ancestor Query; time: O(lg n)
    int laq(int a, int lvl) {
        for (int j = depth; j--;)
            if (lvl <= level[jumps[a][j]])
                a = jumps[a][j];
        return a;
    }
}

```

```

}

// Get distance from a to b; time: O(lg n)
int distance(int a, int b) {
    return level[a] + level[b] -
        level[operator()(a, b)]*2;
}

};

```

trees/link_cut_tree.h

```

// Link/cut tree; space: O(n)
// Represents forest of (un)rooted trees.
struct LinkCutTree {
    vector<array<int, 2>> child;
    Vi par, prev, flip;

    // Initialize structure for n vertices; O(n)
    // At first there's no edges.
    LinkCutTree(int n = 0)
        : child(n, {-1, -1}), par(n, -1),
          prev(n, -1), flip(n, -1) {}

    void auxLink(int p, int i, int ch) {
        child[p][i] = ch;
        if (ch >= 0) par[ch] = p;
    }

    void push(int x) {
        if (x >= 0 && flip[x]) {
            flip[x] = 0;
            swap(child[x][0], child[x][1]);
            each(e, child[x]) if (e>=0) flip[e] ^= 1;
        }
    }

    void rot(int p, int i) {
        int x = child[p][i], g = par[x] = par[p];
        if (g >= 0) child[g][child[g][1] == p] = x;
        auxLink(p, i, child[x][!i]);
        auxLink(x, !i, p);
        swap(prev[x], prev[p]);
    }

    void splay(int x) {
        while (par[x] >= 0) {
            int p = par[x], g = par[p];
            push(g); push(p); push(x);
            bool f = (child[p][1] == x);

            if (g >= 0) {
                if (child[g][f] == p) { // zig-zig
                    rot(g, f); rot(p, f);
                } else { // zig-zag
                    rot(p, f); rot(g, !f);
                }
            } else { // zig
                rot(p, f);
            }
        }
        push(x);
    }
}

```

```

void access(int x) {
    while (true) {
        splay(x);
        int p = prev[x];
    }
}

```

```

    if (p < 0) break;

    prev[x] = -1;
    splay(p);

    int r = child[p][1];
    if (r >= 0) swap(par[r], prev[r]);
    auxLink(p, 1, x);
}

void makeRoot(int x) {
    access(x);
    int& l = child[x][0];
    if (l >= 0) {
        swap(par[l], prev[l]);
        flip[l] ^= 1;
        l = -1;
    }
}

// Find representative of tree containing x
int find(int x) { // time: amortized O(lg n)
    access(x);
    while (child[x][0] >= 0)
        push(x = child[x][0]);
    splay(x);
    return x;
}

// Add edge x-y; time: amortized O(lg n)
void link(int x, int y) {
    makeRoot(x); prev[x] = y;
}

// Remove edge x-y; time: amortized O(lg n)
void cut(int x, int y) {
    makeRoot(x); access(y);
    par[x] = child[y][0] = -1;
}
}

```

util/arc_interval_cover.h

```

using dbl = double;

// Find size of smallest set of points
// such that each arc contains at least one
// of them; time: O(n lg n)
int arcCover(vector<pair<dbl, dbl>>& inters,
             int n = sz(inters)) {
    rep(i, 0, n) {
        auto& e = inters[i];
        e.x = fmod(e.x, wrap);
        e.y = fmod(e.y, wrap);
        if (e.x < 0) e.x += wrap, e.y += wrap;
        if (e.x > e.y) e.x += wrap;
        inters.pb({e.x+wrap, e.y+wrap});
    }

    Vi nxt(n);
    deque<dbl> que;
    dbl r = wrap*4;
    sort(all(inters));
}

```

```
for (int i = n*2-1; i--;) {
    r = min(x, inters[i].y);
    que.push_front(inters[i].x);
    while (!que.empty() && que.back() > r)
        que.pop_back();
    if (i < n) nxt[i] = i+sz(que);
}

int a = 0, b = 0;
do {
    a = nxt[a] % n;
    b = nxt[nxt[b]%n] % n;
} while (a != b);

int ans = 0;
while (b < a+n) {
    b += nxt[b%n] - b%n;
    ans++;
}
return ans;
}
```

util/bit_hacks.h

```
// __builtin_popcount - count number of 1 bits
// __builtin_clz - count most significant 0s
// __builtin_ctz - count least significant 0s
// __builtin_ffs - like ctz, but indexed from 1
// returns 0 for 0
// For ll version add ll to name
```

```
using ull = uint64_t;
```

```
#define T64(s,up) \
for (ull i=0; i<64; i+=s*2) \
for (ull j = i; j < i+s; j++) { \
    ull a = (M[j] >> s) & up; \
    ull b = (M[j+s] & up) << s; \
    M[j] = (M[j] & up) | b; \
    M[j+s] = (M[j+s] & (up<<s)) | a; \
}
```

```
// Transpose 64x64 bit matrix
void transpose64(array<ull, 64>& M) {
    T64(1, 0x5555555555555555);
    T64(2, 0x3333333333333333);
    T64(4, 0xF0F0F0F0F0F0F0F0);
    T64(8, 0xFF00FF00FF00FF00);
    T64(16, 0xFFFF0000FFFF);
    T64(32, 0xFFFFFFFFFLL);
}
```

```
// Lexicographically next mask with same
// amount of ones.
int nextSubset(int v) {
    int t = v | (v - 1);
    return (t + 1) | (((~t & -~t) - 1) >>
        (__builtin_ctz(v) + 1));
}
```

util/bump_alloc.h

```
// Allocator, which doesn't free memory.
```

```
char mem[400<<20]; // Set memory limit
size_t nMem;
```

```
void* operator new(size_t n) {
    nMem += n; return &mem[nMem-n];
}
void operator delete(void*) {}
```

util/compress_vec.h

```
// Compress integers to range [0;n) while
// preserving their order; time: O(n lg n)
// Returns mapping: compressed -> original
Vi compressVec(vector<int*>& vec) {
    sort(all(vec),
        [](int* l, int* r) { return *l < *r; });
    Vi old;
    each(e, vec) {
        if (old.empty() || old.back() != *e)
            old.pb(*e);
        *e = sz(old)-1;
    }
    return old;
}
```

util/inversion_vector.h

```
// Get inversion vector for sequence of
// numbers in [0;n); ret[i] = count of numbers
// smaller than perm[i] to the left; O(n lg n)
Vi encodeInversions(Vi perm) {
    Vi odd, ret(sz(perm));
    int cont = 1;

    while (cont) {
        odd.assign(sz(perm)+1, 0);
        cont = 0;

        rep(i, 0, sz(perm)) {
            if (perm[i] % 2) odd[perm[i]]++;
            else ret[i] += odd[perm[i]+1];
            cont += perm[i] /= 2;
        }
    }
    return ret;
}
```

```
// Count inversions in sequence of numbers
// in [0;n); time: O(n lg n)
ll countInversions(Vi perm) {
    ll ret = 0, cont = 1;
    Vi odd;

    while (cont) {
        odd.assign(sz(perm)+1, 0);
        cont = 0;

        rep(i, 0, sz(perm)) {
            if (perm[i] % 2) odd[perm[i]]++;
            else ret += odd[perm[i]+1];
            cont += perm[i] /= 2;
        }
    }
    return ret;
}
```

util/longest_increasing_sub.h

```
// Longest Increasing Subsequence; O(n lg n)
int lis(const Vi& seq) {
```

```
Vi dp(sz(seq), INT_MAX);
each(c, seq) *lower_bound(all(dp), c) = c;
return int(lower_bound(all(dp), INT_MAX)
    - dp.begin());
}
```

util/max_rects.h

```
struct MaxRect {
    // begin = first column of rectangle
    // end = first column after rectangle
    // hei = height of rectangle
    // touch = columns of height hei inside
    int begin, end, hei;
    Vi touch; // sorted increasing
};

// Given consecutive column heights find
// all inclusion-wise maximal rectangles
// contained in "drawing" of columns; time O(n)
vector<MaxRect> getMaxRects(Vi hei) {
    hei.insert(hei.begin(), -1);
    hei.pb(-1);
    Vi reach(sz(hei), sz(hei)-1);
    vector<MaxRect> ans;

    for (int i = sz(hei)-1; --i;) {
        int j = i+1, k = i;
        while (hei[j] > hei[i]) j = reach[j];
        reach[i] = j;

        while (hei[k] > hei[i-1]) {
            ans.pb({ i-1, 0, hei[k], {} });
            auto& rect = ans.back();

            while (hei[k] == rect.hei) {
                rect.touch.pb(k-1);
                k = reach[k];
            }
            rect.end = k-1;
        }
    }
    return ans;
}
```

util/mo.h

```
// Modified MO's queries sorting algorithm,
// slightly better results than standard.
// Allows to process q queries in O(n*sqrt(q))

struct Query {
    int begin, end;
};

// Get point index on Hilbert curve
ll hilbert(int x, int y, int s, ll c = 0) {
    if (s <= 1) return c;
    s /= 2; c *= 4;
    if (y < s)
        return hilbert(x&(s-1), y, s, c+(x>=s)+1);
    if (x < s)
        return hilbert(2*s-y-1, s-x-1, s, c);
    return hilbert(y-s, x-s, s, c+3);
}

// Get good order of queries; time: O(n lg n)
```

```
Vi moOrder(vector<Query>& queries, int maxN) {
    int s = 1;
    while (s < maxN) s *= 2;

    vector<ll> ord;
    each(q, queries)
        ord.pb(hilbert(q.begin, q.end, s));

    Vi ret(sz(ord));
    iota(all(ret), 0);
    sort(all(ret), [&](int l, int r) {
        return ord[l] < ord[r];
    });
    return ret;
}
```

util/parallel_binsearch.h

```
// Run `count` binary searches on [begin;end),
// `cmp` arguments:
// 1) vector<Pii>& - pairs (value, index)
//    which are queries if value of index is
//    greater or equal to value,
//    sorted by value
// 2) vector<bool>& - true at index i means
//    value of i-th query is >= queried value
// Returns vector of found values.
// Time: O((n+c) lg n), where c is cmp time.
template<class T>
Vi multiBS(int begin,int end,int count,T cmp) {
    vector<Pii> ranges(count, {begin, end});
    vector<Pii> queries(count);
    vector<bool> answers(count);

    rep(i,0,count) queries[i]={(begin+end)/2,i};

    for (int k = uplg(end-begin); k > 0; k--) {
        int last = 0, j = 0;
        cmp(queries, answers);

        rep(i, 0, sz(queries)) {
            Pii &q = queries[i], &r = ranges[q.y];
            if (q.x != last) last = q.x, j = i;

            (answers[i] ? r.x : r.y) = q.x;
            q.x = (r.x+r.y) / 2;

            if (!answers[i])
                swap(queries[i], queries[j++]);
        }

        Vi ret;
        each(p, ranges) ret.pb(p.x);
        return ret;
    }
}
```

util/radix_sort.h

```
// Stable countingsort; time: O(k+sz(vec))
// See example usage in radixSort for pairs.
template<class F>
void countSort(Vi& vec, F key, int k) {
    static Vi buf, cnt;
    vec.swap(buf);
    vec.resize(sz(buf));
    cnt.assign(k+1, 0);
```

```

each(e, buf) cnt[key(e)]++;
rep(i, 1, k+1) cnt[i] += cnt[i-1];
for (int i = sz(vec)-1; i >= 0; i--)
    vec[--cnt[key(buf[i])]] = buf[i];
}

// Compute order of elems, k is max key; O(n)
Vi radixSort(const vector<pii>& elems, int k) {
    Vi order(sz(elems));
    iota(all(order), 0);
    countSort(order,
        [&](int i) { return elems[i].y; }, k);
    countSort(order,
        [&](int i) { return elems[i].x; }, k);
    return order;
}

```