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## 1 Basic

### 1.1 vimrc

```
set nu rnu cin ts=4 sw=4 autoread hls
sy on
map<leader>b :w<bar>!g++ -std=c++17 '%' -
    DKEV -fsanitize=undefined -o /tmp/.
    run<CR>
map<leader>r :w<bar>!cat 01.in && echo "
    ---" && /tmp/.run < 01.in<CR>
map<leader>i :!/tmp/.run<CR>
map<leader>c I//<Esc>
map<leader>y :%y+<CR>
map<leader>l :%d<bar>0r ~/t.cpp<CR>
```

### 1.2 Default code

```
#include <bits/stdc++.h>
using namespace std;
using i64 = long long;
using ll = long long;
#define SZ(v) ((v).size())
#define pb emplace_back
#define AI(i) begin(i), end(i)
#define X first
#define Y second
template<class T> bool chmin(T &a, T b) {
    return b < a && (a = b, true); }
template<class T> bool chmax(T &a, T b) {
    return a < b && (a = b, true); }
#ifdef KEV
#define DE(args...) kout("[ " + string(#
    args) + " ] = ", args)
void kout() { cerr << endl; }
template<class T, class ...U> void kout(T
    a, U ...b) { cerr << a << ' ', kout
    (b...); }
template<class T> void debug(T l, T r) {
    while (l != r) cerr << *l << " \n"[
        next(l)==r], ++l; }
#else
#define DE(...) 0
#define debug(...) 0
#endif
int main() {
    cin.tie(nullptr)->sync_with_stdio(false);
    return 0;
}
```

### 1.3 Fast Integer Input

```
char buf[1 << 16], *p1 = buf, *p2 = buf;
char get() {
    if (p1 == p2) {
        p1 = buf;
        p2 = p1 + fread(buf, 1, sizeof(buf),
            stdin);
    }
    if (p1 == p2)
        return -1;
    return *p1++;
}
char readChar() {
    char c = get();
    while (isspace(c))
        c = get();
    return c;
}
int readInt() {
    int x = 0;
    char c = get();
    while (!isdigit(c))
        c = get();
    while (isdigit(c)) {
```

```
x = 10 * x + c - '0';
c = get();
}
return x;
}
```

### 1.4 Pragma optimization

```
#pragma GCC optimize("Ofast", "no-stack-
    protector", "no-math-errno", "unroll
    -loops")
#pragma GCC target("sse,sse2,sse3,ssse3,
    sse4,sse4.2,popcnt,abm,mmx,avx,tune=
    native,arch=core-avx2,tune=core-avx2
    ")
#pragma GCC ivdep
```

## 2 Flows, Matching

### 2.1 Flow

```
template <typename F>
struct Flow {
    static constexpr F INF = numeric_limits
        <F>::max() / 2;
    struct Edge {
        int to;
        F cap;
        Edge(int to, F cap) : to(to), cap(cap)
        {}
    };
    int n;
    vector<Edge> e;
    vector<vector<int>> adj;
    vector<int> cur, h;
    Flow(int n) : n(n), adj(n) {}
    bool bfs(int s, int t) {
        h.assign(n, -1);
        queue<int> q;
        h[s] = 0;
        q.push(s);
        while (!q.empty()) {
            int u = q.front();
            q.pop();
            for (int i : adj[u]) {
                auto [v, c] = e[i];
                if (c > 0 && h[v] == -1) {
                    h[v] = h[u] + 1;
                    if (v == t) { return true; }
                    q.push(v);
                }
            }
        }
        return false;
    }
    F dfs(int u, int t, F f) {
        if (u == t) { return f; }
        F r = f;
        for (int &i = cur[u]; i < int(adj[u].
            size()); i++) {
            int j = adj[u][i];
            auto [v, c] = e[j];
            if (c > 0 && h[v] == h[u] + 1) {
                F a = dfs(v, t, min(r, c));
                e[j].cap -= a;
                e[j ^ 1].cap += a;
                r -= a;
                if (r == 0) { return f; }
            }
        }
        return f - r;
    }
    // can be bidirectional
    void addEdge(int u, int v, F cf = INF,
        F cb = 0) {
        adj[u].push_back(e.size(), e.
            emplace_back(v, cf));
        adj[v].push_back(e.size(), e.
            emplace_back(u, cb));
    }
    F maxFlow(int s, int t) {
        F ans = 0;
        while (bfs(s, t)) {
            cur.assign(n, 0);
            ans += dfs(s, t, INF);
        }
    }
}
```

```

    }
    return ans;
}
// do max flow first
vector<int> minCut() {
    vector<int> res(n);
    for (int i = 0; i < n; i++) { res[i]
        = h[i] != -1; }
    return res;
}
};

```

## 2.2 MCMF

```

template <class Flow, class Cost>
struct MinCostMaxFlow {
public:
    static constexpr Flow flowINF =
        numeric_limits<Flow>::max();
    static constexpr Cost costINF =
        numeric_limits<Cost>::max();
    MinCostMaxFlow() {}
    MinCostMaxFlow(int n) : n(n), g(n) {}
    int addEdge(int u, int v, Flow cap,
        Cost cost) {
        int m = int(pos.size());
        pos.push_back({u, int(g[u].size())});
        g[u].push_back({v, int(g[v].size()),
            cap, cost});
        g[v].push_back({u, int(g[u].size()) -
            1, 0, -cost});
        return m;
    }
    struct edge {
        int u, v;
        Flow cap, flow;
        Cost cost;
    };
    edge getEdge(int i) {
        auto _e = g[pos[i].first][pos[i].
            second];
        auto _re = g[_e.v][_e.rev];
        return {pos[i].first, _e.v, _e.cap +
            _re.cap, _re.cap, _e.cost};
    }
    vector<edge> edges() {
        int m = int(pos.size());
        vector<edge> result(m);
        for (int i = 0; i < m; i++) { result[
            i] = getEdge(i); }
        return result;
    }
    pair<Flow, Cost> maxFlow(int s, int t,
        Flow flow_limit = flowINF) {
        return slope(s, t, flow_limit).
            back();
    }
    vector<pair<Flow, Cost>> slope(int s,
        int t, Flow flow_limit = flowINF)
    {
        vector<Cost> dual(n, 0), dis(n);
        vector<int> pv(n), pe(n), vis(n);
        auto dualRef = [&]() {
            fill(dis.begin(), dis.end(),
                costINF);
            fill(pv.begin(), pv.end(), -1);
            fill(pe.begin(), pe.end(), -1);
            fill(vis.begin(), vis.end(), false);
        };
        struct Q {
            Cost key;
            int u;
            bool operator<(Q o) const {
                return key > o.key;
            }
        };
        priority_queue<Q> h;
        dis[s] = 0;
        h.push({0, s});
        while (!h.empty()) {
            int u = h.top().u;
            h.pop();
            if (vis[u]) { continue; }
            vis[u] = true;
            if (u == t) { break; }
            for (int i = 0; i < int(g[u].size())
                ; i++) {
                auto e = g[u][i];

```

```

                if (vis[e.v] || e.cap == 0)
                    continue;
                Cost cost = e.cost - dual[e.v]
                    + dual[u];
                if (dis[e.v] - dis[u] > cost) {
                    dis[e.v] = dis[u] + cost;
                    pv[e.v] = u;
                    pe[e.v] = i;
                    h.push({dis[e.v], e.v});
                }
            }
        }
        if (!vis[t]) { return false; }
        for (int v = 0; v < n; v++) {
            if (!vis[v]) continue;
            dual[v] -= dis[t] - dis[v];
        }
        return true;
    };
    Flow flow = 0;
    Cost cost = 0, prevCost = -1;
    vector<pair<Flow, Cost>> result;
    result.push_back({flow, cost});
    while (flow < flow_limit) {
        if (!dualRef()) break;
        Flow c = flow_limit - flow;
        for (int v = t; v != s; v = pv[v]) {
            {
                c = min(c, g[pv[v]][pe[v]].cap);
            }
            for (int v = t; v != s; v = pv[v]) {
                {
                    auto& e = g[pv[v]][pe[v]];
                    e.cap -= c;
                    g[v][e.rev].cap += c;
                }
            }
            Cost d = -dual[s];
            flow += c;
            cost += c * d;
            if (prevCost == d) { result.
                pop_back(); }
            result.push_back({flow, cost});
            prevCost = cost;
        }
        return result;
    }
private:
    int n;
    struct _edge {
        int v, rev;
        Flow cap;
        Cost cost;
    };
    vector<pair<int, int>> pos;
    vector<vector<_edge>> g;
};

```

## 2.3 GomoryHu Tree

```

auto gomory(int n, vector<array<int, 3>>
    e) {
    Flow<int, int> mf(n);
    for (auto [u, v, c] : e) { mf.addEdge(u,
        v, c, c); }
    vector<array<int, 3>> res;
    vector<int> p(n);
    for (int i = 1; i < n; i++) {
        for (int j = 0; j < int(e.size()); j
            ++ ) { mf.e[j][0] = mf.e[j]
                << 1 | 1].cap = e[j][2]; }
        int f = mf.maxFlow(i, p[i]);
        auto cut = mf.minCut();
        for (int j = i + 1; j < n; j++) { if
            (cut[i] == cut[j] && p[i] == p[j]
                ) { p[j] = i; } }
        res.push_back({f, i, p[i]});
    }
    return res;
}

```

## 2.4 Global Minimum Cut

```

// O(V ^ 3)
template <typename F>
struct GlobalMinCut {
    static constexpr int INF =
        numeric_limits<F>::max() / 2;

```

```

    int n;
    vector<int> vis, wei;
    vector<vector<int>> adj;
    GlobalMinCut(int n) : n(n), vis(n), wei
        (n), adj(n, vector<int>(n)) {}
    void addEdge(int u, int v, int w) {
        adj[u][v] += w;
        adj[v][u] += w;
    }
    int solve() {
        int sz = n;
        int res = INF, x = -1, y = -1;
        auto search = [&]() {
            fill(vis.begin(), vis.begin() + sz,
                0);
            fill(wei.begin(), wei.begin() + sz,
                0);
            x = y = -1;
            int mx, cur;
            for (int i = 0; i < sz; i++) {
                mx = -1, cur = 0;
                for (int j = 0; j < sz; j++) {
                    if (wei[j] > mx) {
                        mx = wei[j], cur = j;
                    }
                }
                vis[cur] = 1, wei[cur] = -1;
                x = y;
                y = cur;
                for (int j = 0; j < sz; j++) {
                    if (!vis[j]) {
                        wei[j] += adj[cur][j];
                    }
                }
            }
            return mx;
        };
        while (sz > 1) {
            res = min(res, search());
            for (int i = 0; i < sz; i++) {
                adj[x][i] += adj[y][i];
                adj[i][x] = adj[x][i];
            }
            for (int i = 0; i < sz; i++) {
                adj[y][i] = adj[sz - 1][i];
                adj[i][y] = adj[i][sz - 1];
            }
            sz--;
        }
        return res;
    }
};

```

## 2.5 Bipartite Matching

```

struct BipartiteMatching {
    int n, m;
    vector<vector<int>> adj;
    vector<int> l, r, dis, cur;
    BipartiteMatching(int n, int m) : n(n),
        m(m), adj(n), l(n, -1), r(m, -1),
        dis(n), cur(n) {}
    void addEdge(int u, int v) { adj[u].
        push_back(v); }
    void bfs() {
        vector<int> q;
        for (int u = 0; u < n; u++) {
            if (l[u] == -1) {
                q.push_back(u), dis[u] = 0;
            } else {
                dis[u] = -1;
            }
        }
        for (int i = 0; i < int(q.size()); i
            ++ ) {
            int u = q[i];
            for (auto v : adj[u]) {
                if (r[v] != -1 && dis[r[v]] ==
                    -1) {
                    dis[r[v]] = dis[u] + 1;
                    q.push_back(r[v]);
                }
            }
        }
    }
    bool dfs(int u) {

```

```

for (int &i = cur[u]; i < int(adj[u].
    size()); i++) {
    int v = adj[u][i];
    if (r[v] == -1 || dis[r[v]] == dis[
        u] + 1 && dfs(r[v])) {
        l[u] = v, r[v] = u;
        return true;
    }
}
return false;
}
int maxMatching() {
    int match = 0;
    while (true) {
        bfs();
        fill(cur.begin(), cur.end(), 0);
        int cnt = 0;
        for (int u = 0; u < n; u++) {
            if (l[u] == -1) {
                cnt += dfs(u);
            }
        }
        if (cnt == 0) {
            break;
        }
        match += cnt;
    }
    return match;
}
auto minVertexCover() {
    vector<int> L, R;
    for (int u = 0; u < n; u++) {
        if (dis[u] == -1) {
            L.push_back(u);
        } else if (l[u] != -1) {
            R.push_back(l[u]);
        }
    }
    return pair(L, R);
}
};

```

## 2.6 GeneralMatching

```

struct GeneralMatching {
    int n;
    vector<vector<int>> adj;
    vector<int> match;
    GeneralMatching(int n) : n(n), adj(n),
        match(n, -1) {}
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
    int maxMatching() {
        vector<int> vis(n), link(n), f(n),
            dep(n);
        auto find = [&](int u) {
            while (f[u] != u) { u = f[u] = f[f[
                u]]; }
            return u;
        };
        auto lca = [&](int u, int v) {
            u = find(u);
            v = find(v);
            while (u != v) {
                if (dep[u] < dep[v]) { swap(u, v)
                    ; }
                u = find(link[match[u]]);
            }
            return u;
        };
        queue<int> q;
        auto blossom = [&](int u, int v, int
            p) {
            while (find(u) != p) {
                link[u] = v;
                v = match[u];
                if (vis[v] == 0) {
                    vis[v] = 1;
                    q.push(v);
                }
                f[u] = f[v] = p;
                u = link[v];
            }
        };
        auto augment = [&](int u) {

```

```

while (!q.empty()) { q.pop(); }
iota(f.begin(), f.end(), 0);
fill(vis.begin(), vis.end(), -1);
q.push(u), vis[u] = 1, dep[u] = 0;
while (!q.empty()) {
    int u = q.front();
    q.pop();
    for (auto v : adj[u]) {
        if (vis[v] == -1) {
            vis[v] = 0;
            link[v] = u;
            dep[v] = dep[u] + 1;
            if (match[v] == -1) {
                for (int x = v, y = u, tmp;
                    y != -1; x = tmp, y =
                        x == -1 ? -1 : link[x]
                ) {
                    tmp = match[y], match[x]
                        = y, match[y] = x;
                }
                return true;
            }
            q.push(match[v]), vis[match[v]]
                = 1, dep[match[v]] =
                    dep[u] + 2;
        } else if (vis[v] == 1 && find(
            v) != find(u)) {
            int p = lca(u, v);
            blossom(u, v, p), blossom(v,
                u, p);
        }
    }
    return false;
};
int res = 0;
for (int u = 0; u < n; u++) { if (
    match[u] == -1) { res += augment
        (u); } }
return res;
}
};

```

## 2.7 Kuhn Munkres

```

// need perfect matching or not : w
// initialize with -INF / 0
template <typename Cost>
struct KM {
    static constexpr Cost INF =
        numeric_limits<Cost>::max() / 2;
    int n;
    vector<Cost> hl, hr, slk;
    vector<int> l, r, pre, vl, vr;
    queue<int> q;
    vector<vector<Cost>> w;
    KM(int n) : n(n), hl(n), hr(n), slk(n),
        l(n, -1), r(n, -1), pre(n), vl(n),
        vr(n), w(n, vector<Cost>(n, -INF)) {}
    bool check(int x) {
        vl[x] = true;
        if (l[x] != -1) {
            q.push(l[x]);
            return vr[l[x]] == true;
        }
        while (x != -1) { swap(x, r[l[x] =
            pre[x]]); }
        return false;
    }
    void bfs(int s) {
        fill(slk.begin(), slk.end(), INF);
        fill(vl.begin(), vl.end(), false);
        fill(vr.begin(), vr.end(), false);
        q = {};
        q.push(s);
        vr[s] = true;
        while (true) {
            Cost d;
            while (!q.empty()) {
                int y = q.front();
                q.pop();
                for (int x = 0; x < n; ++x) {
                    if (!vl[x] && slk[x] >= (d = hl
                        [x] + hr[y] - w[x][y])) {
                        pre[x] = y;
                        if (d != 0) {

```

```

slk[x] = d;
} else if (!check(x)) {
    return;
}
}
d = INF;
for (int x = 0; x < n; ++x) { if (!
    vl[x] && d > slk[x]) { d = slk
        [x]; } }
for (int x = 0; x < n; ++x) {
    if (vl[x]) {
        hl[x] += d;
    } else {
        slk[x] -= d;
    }
    if (vr[x]) { hr[x] -= d; }
}
for (int x = 0; x < n; ++x) { if (!
    vl[x] && !slk[x] && !check(x))
    { return; } }
}
void addEdge(int u, int v, Cost x) { w[
    u][v] = max(w[u][v], x); }
Cost solve() {
    for (int i = 0; i < n; ++i) { hl[i] =
        *max_element(w[i].begin(), w[i]
            .end()); }
    for (int i = 0; i < n; ++i) { bfs(i);
    }
    Cost res = 0;
    for (int i = 0; i < n; ++i) { res +=
        w[i][l[i]]; }
    return res;
}
};

```

## 2.8 Flow Models

- Maximum/Minimum flow with lower bound / Circulation problem
  - Construct super source  $S$  and sink  $T$ .
  - For each edge  $(x, y, l, u)$ , connect  $x \rightarrow y$  with capacity  $u - l$ .
  - For each vertex  $v$ , denote by  $in(v)$  the difference between the sum of incoming lower bounds and the sum of outgoing lower bounds.
  - If  $in(v) > 0$ , connect  $S \rightarrow v$  with capacity  $in(v)$ , otherwise, connect  $v \rightarrow T$  with capacity  $-in(v)$ .
    - To maximize, connect  $t \rightarrow s$  with capacity  $\infty$  (skip this in circulation problem), and let  $f$  be the maximum flow from  $S$  to  $T$ . If  $f \neq \sum_{v \in V, in(v) > 0} in(v)$ , there's no solution. Otherwise, the maximum flow from  $s$  to  $t$  is the answer.
    - To minimize, let  $f$  be the maximum flow from  $S$  to  $T$ . Connect  $t \rightarrow s$  with capacity  $\infty$  and let the flow from  $S$  to  $T$  be  $f'$ . If  $f + f' \neq \sum_{v \in V, in(v) > 0} in(v)$ , there's no solution. Otherwise,  $f'$  is the answer.
  - The solution of each edge  $e$  is  $l_e + f_e$ , where  $f_e$  corresponds to the flow of edge  $e$  on the graph.
- Construct minimum vertex cover from maximum matching  $M$  on bipartite graph  $(X, Y)$ 
  - Redirect every edge:  $y \rightarrow x$  if  $(x, y) \in M$ ,  $x \rightarrow y$  otherwise.
  - DFS from unmatched vertices in  $X$ .
  - $x \in X$  is chosen iff  $x$  is unvisited.
  - $y \in Y$  is chosen iff  $y$  is visited.
- Minimum cost cyclic flow
  - Construct super source  $S$  and sink  $T$ .
  - For each edge  $(x, y, c)$ , connect  $x \rightarrow y$  with  $(cost, cap) = (c, 1)$  if  $c > 0$ , otherwise connect  $y \rightarrow x$  with  $(cost, cap) = (-c, 1)$ .
  - For each edge with  $c < 0$ , sum these cost as  $K$ , then increase  $d(y)$  by 1, decrease  $d(x)$  by 1.
  - For each vertex  $v$  with  $d(v) > 0$ , connect  $S \rightarrow v$  with  $(cost, cap) = (0, d(v))$ .

5. For each vertex  $v$  with  $d(v) < 0$ , connect  $v \rightarrow T$  with  $(cost, cap) = (0, -d(v))$
  6. Flow from  $S$  to  $T$ , the answer is the cost of the flow  $C + K$
- Maximum density induced subgraph
    1. Binary search on answer, suppose we're checking answer  $T$
    2. Construct a max flow model, let  $K$  be the sum of all weights
    3. Connect source  $s \rightarrow v$ ,  $v \in G$  with capacity  $K$
    4. For each edge  $(u, v, w)$  in  $G$ , connect  $u \rightarrow v$  and  $v \rightarrow u$  with capacity  $w$
    5. For  $v \in G$ , connect it with sink  $v \rightarrow t$  with capacity  $K + 2T - (\sum_{e \in E(v)} w(e)) - 2w(v)$
    6.  $T$  is a valid answer if the maximum flow  $f < K|V|$
  - Minimum weight edge cover
    1. For each  $v \in V$  create a copy  $v'$ , and connect  $u' \rightarrow v'$  with weight  $w(u, v)$ .
    2. Connect  $v \rightarrow v'$  with weight  $2\mu(v)$ , where  $\mu(v)$  is the cost of the cheapest edge incident to  $v$ .
    3. Find the minimum weight perfect matching on  $G'$ .
  - Project selection problem
    1. If  $p_v > 0$ , create edge  $(s, v)$  with capacity  $p_v$ ; otherwise, create edge  $(v, t)$  with capacity  $-p_v$ .
    2. Create edge  $(u, v)$  with capacity  $w$  with  $w$  being the cost of choosing  $u$  without choosing  $v$ .
    3. The mincut is equivalent to the maximum profit of a subset of projects.

0/1 quadratic programming

$$\sum_x c_x x + \sum_y c_y y + \sum_{xy} c_{xy} xy + \sum_{xyx'y'} c_{xyx'y'} (x \dots)$$

can be minimized by the mincut of the following graph:

1. Create edge  $(x, t)$  with capacity  $c_x$  and create edge  $(s, y)$  with capacity  $c_y$ .
2. Create edge  $(x, y)$  with capacity  $c_{xy}$ .
3. Create edge  $(x, y)$  and edge  $(x', y')$  with capacity  $c_{xyx'y'}$ .

## 3 Data Structure

### 3.1 <ext/pbds>

```
#include <bits/extc++.h>
#include <ext/rope>
using namespace __gnu_pbds;
using namespace __gnu_cxx;
#include <ext/pb_ds/assoc_container.hpp>
typedef tree<int, null_type, std::less<int>, rb_tree_tag,
tree_order_statistics_node_update>
tree_set;
typedef cc_hash_table<int, int> umap;
typedef priority_queue<int> heap;

int main() {
    // rb tree
    tree_set s;
    s.insert(71); s.insert(22);
    assert(*s.find_by_order(0) == 22);
    assert(*s.find_by_order(1) == 71);
    assert(s.order_of_key(22) == 0); assert(
    (s.order_of_key(71) == 1);
    s.erase(22);
    assert(*s.find_by_order(0) == 71);
    assert(s.order_of_key(71) == 0);
    // mergable heap
    heap a, b; a.join(b);
    // persistent
    rope<char> r[2];
    r[1] = r[0];
    std::string st = "abc";
    r[1].insert(0, st.c_str());
    r[1].erase(1, 1);
    std::cout << r[1].substr(0, 2) << std::endl;
    return 0;
}
```

### 3.2 Li Chao Tree

```
constexpr i64 INF = 4e18;
struct Line {
    i64 a, b;
    Line() : a(0), b(INF) {}
    Line(i64 a, i64 b) : a(a), b(b) {}
    i64 operator()(i64 x) { return a * x + b; }
};
// [, ) !!!!!!!!!!!!!
struct Lichao {
    int n;
    vector<int> vals;
    vector<Line> lines;
    Lichao() {}
    void init(const vector<int> &v) {
        n = v.size();
        vals = v;
        sort(vals.begin(), vals.end());
        vals.erase(unique(vals.begin(), vals.end()), vals.end());
        lines.assign(4 * n, {});
    }
    int get(int x) { return lower_bound(
        vals.begin(), vals.end(), x) -
        vals.begin(); }
    void apply(Line p, int id, int l, int r) {
        Line &q = lines[id];
        if (p(vals[l]) < q(vals[l])) { swap(p, q); }
        if (l + 1 == r) { return; }
        int m = l + r >> 1;
        if (p(vals[m]) < q(vals[m])) {
            swap(p, q);
            apply(p, id << 1, l, m);
        } else {
            apply(p, id << 1 | 1, m, r);
        }
    }
    void add(int ql, int qr, Line p) {
        ql = get(ql), qr = get(qr);
        auto go = [&](auto go, int id, int l, int r) -> void {
            if (qr <= l || r <= ql) { return; }
            if (ql <= l && r <= qr) {
                apply(p, id, l, r);
                return;
            }
            int m = l + r >> 1;
            go(go, id << 1, l, m);
            go(go, id << 1 | 1, m, r);
        };
        go(go, 1, 0, n);
    }
    i64 query(int p) {
        p = get(p);
        auto go = [&](auto go, int id, int l, int r) -> i64 {
            if (l + 1 == r) { return lines[id](vals[p]); }
            int m = l + r >> 1;
            return min(lines[id](vals[p]), p < m ? go(go, id << 1, l, m) : go(
            go, id << 1 | 1, m, r));
        };
        return go(go, 1, 0, n);
    }
};
```

### 3.3 Treap

```
struct Treap {
    Treap *lc = nullptr, *rc = nullptr;
    int sz = 1;
    unsigned w = rng();
    i64 m = 0, b = 0, val = 0;
};
int size(Treap *t) {
    return t == nullptr ? 0 : t->sz;
}
void apply(Treap *t, i64 m, i64 b) {
    t->m += m;
    t->b += b;
    t->val += m * size(t->lc) + b;
}
```

```
void pull(Treap *t) {
    t->sz = size(t->lc) + size(t->rc) + 1;
}
void push(Treap *t) {
    if (t->lc != nullptr) {
        apply(t->lc, t->m, t->b);
    }
    if (t->rc != nullptr) {
        apply(t->rc, t->m, t->b + t->m *
            (size(t->lc) + 1));
    }
    t->m = t->b = 0;
}
pair<Treap*, Treap*> split(Treap *t, int s) {
    if (t == nullptr) { return {t, t}; }
    push(t);
    Treap *a, *b;
    if (s <= size(t->lc)) {
        b = t;
        tie(a, b->lc) = split(t->lc, s);
    } else {
        a = t;
        tie(a->rc, b) = split(t->rc, s -
            size(t->lc) - 1);
    }
    pull(t);
    return {a, b};
}
Treap* merge(Treap *t1, Treap *t2) {
    if (t1 == nullptr) { return t2; }
    if (t2 == nullptr) { return t1; }
    push(t1), push(t2);
    if (t1->w > t2->w) {
        t1->rc = merge(t1->rc, t2);
        pull(t1);
        return t1;
    } else {
        t2->lc = merge(t1, t2->lc);
        pull(t2);
        return t2;
    }
}
int rnk(Treap *t, i64 val) {
    int res = 0;
    while (t != nullptr) {
        push(t);
        if (val <= t->val) {
            res += size(t->lc) + 1;
            t = t->rc;
        } else {
            t = t->lc;
        }
    }
    return res;
}
Treap* join(Treap *t1, Treap *t2) {
    if (size(t1) > size(t2)) {
        swap(t1, t2);
    }
    Treap *t = nullptr;
    while (t1 != nullptr) {
        auto [u1, v1] = split(t1, 1);
        t1 = v1;
        int r = rnk(t2, u1->val);
        if (r > 0) {
            auto [u2, v2] = split(t2, r);
            t = merge(t, u2);
            t2 = v2;
        }
        t = merge(t, u1);
    }
    t = merge(t, t2);
    return t;
}
```



### 3.4 Link-Cut Tree

```

struct Splay {
    array<Splay*, 2> ch = {nullptr, nullptr};
    Splay* fa = nullptr;
    int sz = 1;
    bool rev = false;
    Splay() {}
    void applyRev(bool x) {
        if (x) {
            swap(ch[0], ch[1]);
            rev ^= 1;
        }
    }
    void push() {
        for (auto k : ch) {
            if (k) {
                k->applyRev(rev);
            }
        }
        rev = false;
    }
    void pull() {
        sz = 1;
        for (auto k : ch) {
            if (k) {
                sz += k->sz;
            }
        }
    }
    int relation() { return this == fa->ch[1]; }
    bool isRoot() { return !fa || fa->ch[0] != this && fa->ch[1] != this; }
    void rotate() {
        Splay *p = fa;
        bool x = !relation();
        p->ch[x] = ch[x];
        if (ch[x]) { ch[x]->fa = p; }
        fa = p->fa;
        if (!p->isRoot()) { p->fa->ch[p->relation()] = this; }
        ch[x] = p;
        p->fa = this;
        p->pull();
    }
    void splay() {
        vector<Splay*> s;
        for (Splay *p = this; !p->isRoot(); p = p->fa) { s.push_back(p->fa); }
        while (!s.empty()) {
            s.back()->push();
            s.pop_back();
        }
        push();
        while (!isRoot()) {
            if (!fa->isRoot()) {
                if (relation() == fa->relation()) {
                    fa->rotate();
                } else {
                    rotate();
                }
            }
            rotate();
        }
        pull();
    }
    void access() {
        for (Splay *p = this, *q = nullptr; p; q = p, p = p->fa) {
            p->splay();
            p->ch[1] = q;
            p->pull();
        }
        splay();
    }
    void makeRoot() {
        access();
        applyRev(true);
    }
    Splay* findRoot() {
        access();
        Splay *p = this;
        while (p->ch[0]) { p = p->ch[0]; }
        p->splay();
    }
};

```

```

return p;
}
friend void split(Splay *x, Splay *y) {
    x->makeRoot();
    y->access();
}
// link if not connected
friend void link(Splay *x, Splay *y) {
    x->makeRoot();
    if (y->findRoot() != x) {
        x->fa = y;
    }
}
// delete edge if doesn't exist
friend void cut(Splay *x, Splay *y) {
    split(x, y);
    if (x->fa == y && !x->ch[1]) {
        x->fa = y->ch[0] = nullptr;
        x->pull();
    }
}
bool connected(Splay *x, Splay *y) {
    return x->findRoot() == y->findRoot();
}
};

```

## 4 Graph

### 4.1 2-Edge-Connected Components

```

struct EBCC {
    int n, cnt = 0, T = 0;
    vector<vector<int>> adj, comps;
    vector<int> stk, dfn, low, id;
    EBCC(int n) : n(n), adj(n), dfn(n, -1), low(n), id(n, -1) {}
    void addEdge(int u, int v) { adj[u].push_back(v), adj[v].push_back(u); }
    void build() { for (int i = 0; i < n; i++) { if (dfn[i] == -1) { dfs(i, -1); } } }
    void dfs(int u, int p) {
        dfn[u] = low[u] = T++;
        stk.push_back(u);
        for (auto v : adj[u]) {
            if (v == p) { continue; }
            if (dfn[v] == -1) {
                dfs(v, u);
                low[u] = min(low[u], low[v]);
            } else if (id[v] == -1) {
                low[u] = min(low[u], dfn[v]);
            }
        }
        if (dfn[u] == low[u]) {
            int x;
            comps.emplace_back();
            do {
                x = stk.back();
                comps.back().push_back(x);
                id[x] = cnt;
                stk.pop_back();
            } while (x != u);
            cnt++;
        }
    }
};

```

### 4.2 2-Vertex-Connected Components

```

// is articulation point if appear in >= 2 comps
auto dfs = [&](auto dfs, int u, int p) -> void {
    dfn[u] = low[u] = T++;
    for (auto v : adj[u]) {
        if (v == p) { continue; }
        if (dfn[v] == -1) {
            stk.push_back(v);
            dfs(dfs, v, u);
            low[u] = min(low[u], low[v]);
        }
    }
};

```

```

if (low[v] >= dfn[u]) {
    comps.emplace_back();
    int x;
    do {
        x = stk.back();
        cnt[x]++;
        stk.pop_back();
    } while (x != v);
    comps.back().push_back(u);
    cnt[u]++;
}
else {
    low[u] = min(low[u], dfn[v]);
}
}
for (int i = 0; i < n; i++) {
    if (!adj[i].empty()) {
        dfs(dfs, i, -1);
    }
    else {
        comps.push_back({i});
    }
}

```

### 4.3 3-Edge-Connected Components

```

// DSU
struct ETCC {
    int n, cnt = 0;
    vector<vector<int>> adj, comps;
    vector<int> in, out, low, up, nx, id;
    ETCC(int n) : n(n), adj(n), in(n, -1), out(n), low(n), up(n), nx(n), id(n) {}
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
    void build() {
        int T = 0;
        DSU d(n);
        auto merge = [&](int u, int v) {
            d.join(u, v);
            up[u] += up[v];
        };
        auto dfs = [&](auto dfs, int u, int p) -> void {
            in[u] = low[u] = T++;
            for (auto v : adj[u]) {
                if (v == u) { continue; }
                if (v == p) {
                    p = -1;
                    continue;
                }
                if (in[v] == -1) {
                    dfs(dfs, v, u);
                    if (nx[v] == -1 && up[v] <= 1) {
                        up[u] += up[v];
                        low[u] = min(low[u], low[v]);
                        continue;
                    }
                    if (up[v] == 0) { v = nx[v]; }
                    if (low[u] > low[v]) { low[u] = low[v], swap(nx[u], v); }
                    while (v != -1) { merge(u, v); v = nx[v]; }
                }
                else if (in[v] < in[u]) {
                    low[u] = min(low[u], in[v]);
                    up[u]++;
                }
                else {
                    for (int &x = nx[u]; x != -1 && in[x] <= in[v] && in[v] < out[x]; x = nx[x]) {
                        merge(u, x);
                    }
                    up[u]--;
                }
            }
            out[u] = T;
        };
        for (int i = 0; i < n; i++) { if (in[i] == -1) { dfs(dfs, i, -1); } }
        for (int i = 0; i < n; i++) { if (d.find(i) == i) { id[i] = cnt++; } }
    }
};

```

```

    }
    comps.resize(cnt);
    for (int i = 0; i < n; i++) { comps[
        id[d.find(i)]].push_back(i); }
}
};

```

#### 4.4 Heavy-Light Decomposition

```

struct HLD {
    int n, cur = 0;
    vector<int> sz, top, dep, par, tin,
        tout, seq;
    vector<vector<int>> adj;
    HLD(int n) : n(n), sz(n, 1), top(n),
        dep(n), par(n), tin(n), tout(n),
        seq(n), adj(n) {}
    void addEdge(int u, int v) { adj[u].
        push_back(v), adj[v].push_back(u); }
    void build(int root = 0) {
        top[root] = root, dep[root] = 0, par[
            root] = -1;
        dfs1(root), dfs2(root);
    }
    void dfs1(int u) {
        if (auto it = find(adj[u].begin(),
            adj[u].end(), par[u]); it != adj
                [u].end()) {
            adj[u].erase(it);
        }
        for (auto &v : adj[u]) {
            par[v] = u;
            dep[v] = dep[u] + 1;
            dfs1(v);
            sz[u] += sz[v];
            if (sz[v] > sz[adj[u][0]]) { swap(v
                , adj[u][0]); }
        }
    }
    void dfs2(int u) {
        tin[u] = cur++;
        seq[tin[u]] = u;
        for (auto v : adj[u]) {
            top[v] = v == adj[u][0] ? top[u] :
                v;
            dfs2(v);
        }
        tout[u] = cur - 1;
    }
    int lca(int u, int v) {
        while (top[u] != top[v]) {
            if (dep[top[u]] > dep[top[v]]) {
                u = par[top[u]];
            } else {
                v = par[top[v]];
            }
        }
        return dep[u] < dep[v] ? u : v;
    }
    int dist(int u, int v) { return dep[u]
        + dep[v] - 2 * dep[lca(u, v)]; }
    int jump(int u, int k) {
        if (dep[u] < k) { return -1; }
        int d = dep[u] - k;
        while (dep[top[u]] > d) { u = par[top
            [u]]; }
        return seq[tin[u] - dep[u] + d];
    }
    // u is v's ancestor
    bool isAncestor(int u, int v) { return
        tin[u] <= tin[v] && tin[v] <= tout
            [u]; }
    // root's parent is itself
    int rootedParent(int r, int u) {
        if (r == u) { return u; }
        if (isAncestor(r, u)) { return par[u
            ]; }
        auto it = upper_bound(adj[u].begin(),
            adj[u].end(), r, [&](int x, int
                y) {
            return tin[x] < tin[y];
        }) - 1;
        return *it;
    }
}

```

```

// rooted at u, v's subtree size
int rootedSize(int r, int u) {
    if (r == u) { return n; }
    if (isAncestor(u, r)) { return sz[u]; }
    return n - sz[rootedParent(r, u)];
}
int rootedLca(int r, int a, int b) {
    return lca(a, b) ^ lca(a, r) ^ lca
        (b, r); }
};

```

#### 4.5 Centroid Decomposition

```

vector<int> sz(n), vis(n);
auto build = [&](auto build, int u, int p
    ) -> void {
    sz[u] = 1;
    for (auto v : g[u]) {
        if (v != p && !vis[v]) {
            build(build, v, u);
            sz[u] += sz[v];
        }
    }
};
auto find = [&](auto find, int u, int p,
    int tot) -> int {
    for (auto v : g[u]) {
        if (v != p && !vis[v] && 2 * sz[v] >
            tot) {
            return find(find, v, u, tot);
        }
    }
    return u;
};
auto dfs = [&](auto dfs, int cen) -> void
    {
        build(build, cen, -1);
        cen = find(find, cen, -1, sz[cen]);
        vis[cen] = 1;
        build(build, cen, -1);

        for (auto v : g[cen]) {
            if (!vis[v]) {
                dfs(dfs, v);
            }
        }
    };
dfs(dfs, 0);

```

#### 4.6 Strongly Connected Components

```

struct SCC {
    int n, cnt = 0, cur = 0;
    vector<int> id, dfn, low, stk;
    vector<vector<int>> adj, comps;
    void addEdge(int u, int v) { adj[u].
        push_back(v); }
    SCC(int n) : n(n), id(n, -1), dfn(n,
        -1), low(n, -1), adj(n) {}
    void build() {
        auto dfs = [&](auto dfs, int u) ->
            void {
            dfn[u] = low[u] = cur++;
            stk.push_back(u);
            for (auto v : adj[u]) {
                if (dfn[v] == -1) {
                    dfs(dfs, v);
                    low[u] = min(low[u], low[v]);
                } else if (id[v] == -1) {
                    low[u] = min(low[u], dfn[v]);
                }
            }
            if (dfn[u] == low[u]) {
                int v;
                comps.emplace_back();
                do {
                    v = stk.back();
                    comps.back().push_back(v);
                    id[v] = cnt;
                    stk.pop_back();
                } while (u != v);
                cnt++;
            }
        };
    }
}

```

```

};
for (int i = 0; i < n; i++) { if (dfn
    [i] == -1) { dfs(dfs, i); } }
for (int i = 0; i < n; i++) { id[i] =
    cnt - 1 - id[i]; }
reverse(comps.begin(), comps.end());
}
// the comps are in topological sorted
// order
};

```

#### 4.7 2-SAT

```

struct TwoSat {
    int n, N;
    vector<vector<int>> adj;
    vector<int> ans;
    TwoSat(int n) : n(n), N(n), adj(2 * n)
        {}
    // u == x
    void addClause(int u, bool x) { adj[2 *
        u + !x].push_back(2 * u + x); }
    // u == x || v == y
    void addClause(int u, bool x, int v,
        bool y) {
        adj[2 * u + !x].push_back(2 * v + y);
        adj[2 * v + !y].push_back(2 * u + x);
    }
    // u == x -> v == y
    void addImplied(int u, bool x, int v,
        bool y) { addClause(u, !x, v, y); }
    void addVar() {
        adj.emplace_back(), adj.emplace_back
            ();
        N++;
    }
    // at most one in var is true
    // adds prefix or as supplementary
    // variables
    void atMostOne(const vector<pair<int,
        bool>> &vars) {
        int sz = vars.size();
        for (int i = 0; i < sz; i++) {
            addVar();
            auto [u, x] = vars[i];
            addImplied(u, x, N - 1, true);
            if (i > 0) {
                addImplied(N - 2, true, N - 1, true
                    );
                addClause(u, !x, N - 2, false);
            }
        }
    }
    // does not return supplementary
    // variables from atMostOne()
    bool satisfiable() {
        // run tarjan scc on 2 * N
        for (int i = 0; i < 2 * N; i++) { if
            (dfn[i] == -1) { dfs(dfs, i); } }
        for (int i = 0; i < N; i++) { if (id
            [2 * i] == id[2 * i + 1]) {
            return false; } }
        ans.resize(n);
        for (int i = 0; i < n; i++) { ans[i]
            = id[2 * i] > id[2 * i + 1]; }
        return true;
    }
};

```

#### 4.8 count 3-cycles and 4-cycles

```

sort(ord.begin(), ord.end(), [&](auto i,
    auto j) { return pair(deg[i], i) >
        pair(deg[j], j); });
for (int i = 0; i < n; i++) { rnk[ord[i]]
    = i; }
if (rnk[u] < rnk[v]) { dag[u].push_back(v
    ); }
// c3
for (int x = 0; x < n; x++) {
    for (auto y : dag[x]) { vis[y] = 1; }
    for (auto y : dag[x]) { for (auto z :
        dag[y]) { ans += vis[z]; } }
    for (auto y : dag[x]) { vis[y] = 0; }
}

```

```

}
// c4
for (int x = 0; x < n; x++) {
    for (auto y : dag[x]) { for (auto z :
        adj[y]) { if (rnk[z] > rnk[x]) {
            ans += vis[z]++; }}}
    for (auto y : dag[x]) { for (auto z :
        adj[y]) { if (rnk[z] > rnk[x]) {
            vis[z]--; }}}
}

```

## 4.9 Minimum Mean Cycle

create a new vertex  $S$ , connect  $S$  to all vertices with arbitrary weight (0). Let  $f_i(u)$  be the shortest path from  $S$  to  $u$  with exactly  $i$  edges.

$$ans = \min_{f_{n+1}(i) \neq \infty} \max_{j=1}^n \frac{f_{n+1}(i) - f_j(i)}{n+1-j}$$

## 4.10 Directed Minimum Spanning Tree

```

// DSU with rollback
template <typename Cost>
struct DMST {
    int n;
    vector<int> s, t, lc, rc, h;
    vector<Cost> c, tag;
    DMST(int n) : n(n), h(n, -1) {}
    void addEdge(int u, int v, Cost w) {
        int id = s.size();
        s.push_back(u), t.push_back(v), c.
            push_back(w);
        lc.push_back(-1), rc.push_back(-1);
        tag.emplace_back();
        h[v] = merge(h[v], id);
    }
    pair<Cost, vector<int>> build(int root
        = 0) {
        DSU d(n);
        Cost res{};
        vector<int> vis(n, -1), path(n), q(n),
            in(n, -1);
        vis[root] = root;
        vector<pair<int, vector<int>>> cycles
            ;
        for (auto r = 0; r < n; ++r) {
            auto u = r, b = 0, w = -1;
            while (!~vis[u]) {
                if (!~h[u]) { return {-1, {}}; }
                push(h[u]);
                int e = h[u];
                res += c[e], tag[h[u]] -= c[e];
                h[u] = pop(h[u]);
                q[b] = e, path[b++] = u, vis[u] =
                    r;
                u = d.find(s[e]);
                if (vis[u] == r) {
                    int cycle = -1, e = b;
                    do {
                        w = path[--b];
                        cycle = merge(cycle, h[w]);
                    } while (d.join(u, w));
                    u = d.find(u);
                    h[u] = cycle, vis[u] = -1;
                    cycles.emplace_back(u, vector<
                        int>(q.begin() + b, q.
                            begin() + e));
                }
            }
            for (auto i = 0; i < b; ++i) { in[d
                .find(t[q[i]])] = q[i]; }
        }
        reverse(cycles.begin(), cycles.end())
    }
};
for (const auto &[u, comp] : cycles)
    {
        int count = int(comp.size()) - 1;
        d.back(count);
        int ine = in[u];
        for (auto e : comp) { in[d.find(t[e
            ])] = e; }
        in[d.find(t[ine])] = ine;
    }
vector<int> par;

```

```

par.reserve(n);
for (auto i : in) { par.push_back(i
    != -1 ? s[i] : -1); }
return {res, par};
}
void push(int u) {
    c[u] += tag[u];
    if (int l = lc[u]; l != -1) { tag[l]
        += tag[u]; }
    if (int r = rc[u]; r != -1) { tag[r]
        += tag[u]; }
    tag[u] = 0;
}
int merge(int u, int v) {
    if (u == -1 || v == -1) { return u !=
        -1 ? u : v; }
    push(u);
    push(v);
    if (c[u] > c[v]) { swap(u, v); }
    rc[u] = merge(v, rc[u]);
    swap(lc[u], rc[u]);
    return u;
}
int pop(int u) {
    push(u);
    return merge(lc[u], rc[u]);
}
};

```

## 4.11 Maximum Clique

```

pair<int, vector<int>> maxClique(int n,
    const vector<bitset<N>> adj) {
    int mx = 0;
    vector<int> ans, cur;
    auto rec = [&](auto rec, bitset<N> s)
        -> void {
        int sz = s.count();
        if (int(cur.size()) > mx) { mx = cur.
            size(), ans = cur; }
        if (int(cur.size()) + sz <= mx) {
            return; }
        int e1 = -1, e2 = -1;
        vector<int> d(n);
        for (int i = 0; i < n; i++) {
            if (s[i]) {
                d[i] = (adj[i] & s).count();
                if (e1 == -1 || d[i] > d[e1]) {
                    e1 = i; }
                if (e2 == -1 || d[i] < d[e2]) {
                    e2 = i; }
            }
        }
        if (d[e1] >= sz - 2) {
            cur.push_back(e1);
            auto s1 = adj[e1] & s;
            rec(rec, s1);
            cur.pop_back();
            return;
        }
        cur.push_back(e2);
        auto s2 = adj[e2] & s;
        rec(rec, s2);
        cur.pop_back();
        s.reset(e2);
        rec(rec, s);
    };
    bitset<N> all;
    for (int i = 0; i < n; i++) {
        all.set(i);
    }
    rec(rec, all);
    return pair(mx, ans);
}

```

## 4.12 Dominator Tree

```

// res : parent of each vertex in
// dominator tree, -1 is root, -2 if
// not in tree
struct DominatorTree {
    int n, cur = 0;
    vector<int> dfn, rev, fa, sd, dom,
        val, rp, res;
    vector<vector<int>> adj, rdom, r;
}

```

```

DominatorTree(int n) : n(n), dfn(n, -1)
    , res(n, -2), adj(n), rdom(n), r(n)
    {}
    rev = fa = sd = dom = val = rp =
        dfn;
}
void addEdge(int u, int v) {
    adj[u].push_back(v);
}
void dfs(int u) {
    dfn[u] = cur;
    rev[cur] = u;
    fa[cur] = sd[cur] = val[cur] = cur;
    cur++;
    for (int v : adj[u]) {
        if (dfn[v] == -1) {
            dfs(v);
            rp[dfn[v]] = dfn[u];
            r[dfn[v]].push_back(dfn[u]);
        }
    }
}
int find(int u, int c) {
    if (fa[u] == u) { return c != 0 ? -1
        : u; }
    int p = find(fa[u], 1);
    if (p == -1) { return c != 0 ? fa[u]
        : val[u]; }
    if (sd[val[u]] > sd[val[fa[u]]]) {
        val[u] = val[fa[u]]; }
    fa[u] = p;
    return c != 0 ? p : val[u];
}
void build(int s = 0) {
    dfs(s);
    for (int i = cur - 1; i >= 0; i--) {
        for (int u : r[i]) { sd[u] = min(
            sd[u], sd[find(u, 0)]); }
        if (i > 0) { rdom[sd[i]].
            push_back(i); }
        for (int u : rdom[i]) {
            int p = find(u, 0);
            if (sd[p] == i) {
                dom[u] = i;
            } else {
                dom[u] = p;
            }
        }
        if (i > 0) { fa[i] = rp[i]; }
    }
    res[s] = -1;
    for (int i = 1; i < cur; i++) { if (
        sd[i] != dom[i]) { dom[i] =
            dom[dom[i]]; } }
    for (int i = 1; i < cur; i++) { res[
        rev[i]] = rev[dom[i]]; }
}
};

```

## 4.13 Edge Coloring

```

// bipartite
e[i] = pair(u, v + a), deg[u]++, deg[v +
    a]++;
int col = *max_element(deg.begin(), deg.
    end());
vector<int> ans(m, -1);
vector has(a + b, vector<pair<int, int>>(
    col, {-1, -1}));
for (int i = 0; i < m; i++) {
    auto [u, v] = e[i];
    vector<int> c;
    for (auto x : {u, v}) {
        c.push_back(0);
        while (has[x][c.back()].first != -1)
            { c.back()++; }
    }
    if (c[0] != c[1]) {
        auto dfs = [&](auto dfs, int u, int x
            ) -> void {
            auto [v, i] = has[u][c[x]];
            if (v != -1) {
                if (has[v][c[x ^ 1]].first != -1)
                    {
                        dfs(dfs, v, x ^ 1);
                    }
                else {

```

```

        has[v][c[x]] = {-1, -1};
    }
    has[u][c[x ^ 1]] = {v, i}, has[v]
    ][c[x ^ 1]] = {u, i};
    ans[i] = c[x ^ 1];
}
};
dfs(dfs, v, 0);
}
has[u][c[0]] = {v, i};
has[v][c[0]] = {u, i};
ans[i] = c[0];
}
// general
auto vizing(int n, const vector<pair<int,
int>> &e) {
    vector<int> deg(n);
    for (auto [u, v] : e) {
        deg[u]++, deg[v]++;
    }
    int col = *max_element(deg.begin(), deg
    .end()) + 1;
    vector<int> free(n);
    vector ans(n, vector<int>(n, -1));
    vector at(n, vector<int>(col, -1));
    auto update = [&](int u) {
        free[u] = 0;
        while (at[u][free[u]] != -1) {
            free[u]++;
        }
    };
    auto color = [&](int u, int v, int c1)
    {
        int c2 = ans[u][v];
        ans[u][v] = ans[v][u] = c1;
        at[u][c1] = v, at[v][c1] = u;
        if (c2 != -1) {
            at[u][c2] = at[v][c2] = -1;
            free[u] = free[v] = c2;
        } else {
            update(u), update(v);
        }
        return c2;
    };
    auto flip = [&](int u, int c1, int c2)
    {
        int v = at[u][c1];
        swap(at[u][c1], at[u][c2]);
        if (v != -1) {
            ans[u][v] = ans[v][u] = c2;
        }
        if (at[u][c1] == -1) {
            free[u] = c1;
        }
        if (at[u][c2] == -1) {
            free[u] = c2;
        }
        return v;
    };
    for (int i = 0; i < int(e.size()); i++)
    {
        auto [u, v1] = e[i];
        int v2 = v1, c1 = free[u], c2 = c1, d
        ;
        vector<pair<int, int>> fan;
        vector<int> vis(n);
        while (ans[u][v1] == -1) {
            fan.emplace_back(v2, d = free[v2]);
            if (at[v2][c2] == -1) {
                for (int j = int(fan.size()) - 1;
                j >= 0; j--) {
                    c2 = color(u, fan[j].first, c2)
                    ;
                }
            } else if (at[u][d] == -1) {
                for (int j = int(fan.size()) - 1;
                j >= 0; j--) {
                    color(u, fan[j].first, fan[j].
                    second);
                }
            } else if (vis[d] == 1) {
                break;
            } else {
                vis[d] = 1, v2 = at[u][d];
            }
        }
        if (ans[u][v1] == -1) {

```

```

        while (v2 != -1) {
            v2 = flip(v2, c2, d);
            swap(c2, d);
        }
        if (at[u][c1] != -1) {
            int j = int(fan.size()) - 2;
            while (j >= 0 && fan[j].second !=
            c2) {
                j--;
            }
            while (j >= 0) {
                color(u, fan[j].first, fan[j].
                second);
                j--;
            }
        } else {
            i--;
        }
    }
    return pair(col, ans);
}

```

## 5 String

### 5.1 Prefix Function

```

template <typename T>
vector<int> prefixFunction(const T &s) {
    int n = int(s.size());
    vector<int> p(n);
    for (int i = 1; i < n; i++) {
        int j = p[i - 1];
        while (j > 0 && s[i] != s[j]) { j = p
        [j - 1]; }
        if (s[i] == s[j]) { j++; }
        p[i] = j;
    }
    return p;
}

```

### 5.2 Z Function

```

template <typename T>
vector<int> zFunction(const T &s) {
    int n = int(s.size());
    if (n == 0) return {};
    vector<int> z(n);
    for (int i = 1, j = 0; i < n; i++) {
        int &k = z[i];
        k = j + z[j] <= i ? 0 : min(j + z[j]
        - i, z[i - j]);
        while (i + k < n && s[k] == s[i + k])
            { k++; }
        if (j + z[j] < i + z[i]) { j = i; }
    }
    z[0] = n;
    return z;
}

```

### 5.3 Suffix Array

```

// need to discretize
struct SuffixArray {
    int n;
    vector<int> sa, as, ha;
    template <typename T>
    vector<int> sais(const T &s) {
        int n = s.size(), m = *max_element(s.
        begin(), s.end()) + 1;
        vector<int> pos(m + 1), f(n);
        for (auto ch : s) { pos[ch + 1]++; }
        for (int i = 0; i < m; i++) { pos[i +
        1] += pos[i]; }
        for (int i = n - 2; i >= 0; i--) { f[
        i] = s[i] != s[i + 1] ? s[i] < s
        [i + 1] : f[i + 1]; }
        vector<int> x(m), sa(n);
        auto induce = [&](const vector<int> &
        ls) {
            fill(sa.begin(), sa.end(), -1);
            auto l = [&](int i) { if (i >= 0 &&
            !f[i]) { sa[x[s[i]]++] = i; }
            };

```

```

        auto S = [&](int i) { if (i >= 0 &&
        f[i]) { sa[--x[s[i]]] = i; }
        };
        for (int i = 0; i < m; i++) { x[i]
        = pos[i + 1]; }
        for (int i = int(ls.size()) - 1; i
        >= 0; i--) { S(ls[i]); }
        for (int i = 0; i < m; i++) { x[i]
        = pos[i]; }
        L(n - 1);
        for (int i = 0; i < n; i++) { L(sa[
        i] - 1); }
        for (int i = 0; i < m; i++) { x[i]
        = pos[i + 1]; }
        for (int i = n - 1; i >= 0; i--) {
            S(sa[i] - 1); }
    };
    auto ok = [&](int i) { return i == n
    || !f[i - 1] && f[i]; };
    auto same = [&](int i, int j) {
        do { if (s[i++] != s[j++]) { return
        false; } } while (!ok(i) && !
        ok(j));
        return ok(i) && ok(j);
    };
    vector<int> val(n), lms;
    for (int i = 1; i < n; i++) { if (ok(
        i)) { lms.push_back(i); }
    }
    induce(lms);
    if (!lms.empty()) {
        int p = -1, w = 0;
        for (auto v : sa) {
            if (v != 0 && ok(v)) {
                if (p != -1 && same(p, v)) { w
                --; }
                val[p = v] = w++;
            }
        }
        auto b = lms;
        for (auto &v : b) { v = val[v]; }
        b = sais(b);
        for (auto &v : b) { v = lms[v]; }
        induce(b);
    }
    return sa;
}
template <typename T>
SuffixArray(const T &s) : n(s.size()),
sa(sais(s)), as(n), ha(n - 1) {
    for (int i = 0; i < n; i++) { as[sa[i]
    ] = i; }
    for (int i = 0, j = 0; i < n; ++i) {
        if (as[i] == 0) {
            j = 0;
        } else {
            for (j -= j > 0; i + j < n && sa[
            as[i] - 1] + j < n && s[i +
            j] == s[sa[as[i] - 1] + j];
            ) { ++j; }
            ha[as[i] - 1] = j;
        }
    }
}
}

```

### 5.4 Manacher's Algorithm

```

// returns radius of t, length of s : rad
(t) - 1, radius of s : rad(t) / 2
vector<int> manacher(string s) {
    string t = "#";
    for (auto c : s) { t += c, t += '#'; }
    int n = t.size();
    vector<int> r(n);
    for (int i = 0, j = 0; i < n; i++) {
        if (2 * j - i >= 0 && j + r[j] > i) {
            r[i] = min(r[2 * j - i], j + r[
            j] - i);
        }
        while (i - r[i] >= 0 && i + r[i] < n
        && t[i - r[i]] == t[i + r[i]]) {
            r[i]++;
        }
        if (i + r[i] > j + r[j]) { j = i; }
    }
    return r;
}

```



## 5.5 Aho-Corasick Automaton

```
constexpr int K = 26;
struct Node {
    array<int, K> nxt;
    int fail = -1;
    // other vars
    Node() { nxt.fill(-1); }
};
vector<Node> aho(1);
for (int i = 0; i < n; i++) {
    string s;
    cin >> s;
    int u = 0;
    for (auto ch : s) {
        int c = ch - 'a';
        if (aho[u].nxt[c] == -1) {
            aho[u].nxt[c] = aho.size();
            aho.emplace_back();
        }
        u = aho[u].nxt[c];
    }
}
vector<int> q;
for (auto &i : aho[0].nxt) {
    if (i == -1) {
        i = 0;
    } else {
        q.push_back(i);
        aho[i].fail = 0;
    }
}
for (int i = 0; i < int(q.size()); i++) {
    int u = q[i];
    if (u > 0) {
        // maintain
    }
    for (int c = 0; c < K; c++) {
        if (int v = aho[u].nxt[c]; v != -1) {
            aho[v].fail = aho[aho[u].fail].nxt[c];
            q.push_back(v);
        } else {
            aho[u].nxt[c] = aho[aho[u].fail].nxt[c];
        }
    }
}
}
```

## 5.6 Suffix Automaton

```
struct SAM {
    static constexpr int A = 26;
    struct Node {
        int len = 0, link = -1, cnt = 0;
        array<int, A> nxt;
        Node() { nxt.fill(-1); }
    };
    vector<Node> t;
    SAM() : t(1) {}
    int size() { return t.size(); }
    Node& operator[](int i) { return t[i]; }
    int newNode() {
        t.emplace_back();
        return t.size() - 1;
    }
    int extend(int p, int c) {
        int cur = newNode();
        t[cur].len = t[p].len + 1;
        t[cur].cnt = 1;
        while (p != -1 && t[p].nxt[c] == -1) {
            t[p].nxt[c] = cur;
            p = t[p].link;
        }
        if (p == -1) {
            t[cur].link = 0;
        } else {
            int q = t[p].nxt[c];
            if (t[p].len + 1 == t[q].len) {
                t[cur].link = q;
            } else {
                int clone = newNode();
                t[clone].len = t[p].len + 1;
                t[clone].link = t[q].link;
                t[clone].nxt = t[q].nxt;
                while (p != -1 && t[p].nxt[c] == q) {
                    t[p].nxt[c] = clone;
                    p = t[p].link;
                }
                t[q].link = t[cur].link = clone;
            }
        }
        return cur;
    }
};
```

```
t[clone].link = t[q].link;
t[clone].nxt = t[q].nxt;
while (p != -1 && t[p].nxt[c] == q) {
    t[p].nxt[c] = clone;
    p = t[p].link;
}
t[q].link = t[cur].link = clone;
}
return cur;
}
```

## 5.7 Lexicographically Smallest Rotation

```
template <typename T>
T minRotation(T s) {
    int n = s.size();
    int i = 0, j = 1;
    s.insert(s.end(), s.begin(), s.end());
    while (i < n && j < n) {
        int k = 0;
        while (k < n && s[i + k] == s[j + k]) {
            k++;
        }
        if (s[i + k] <= s[j + k]) {
            j += k + 1;
        } else {
            i += k + 1;
        }
        if (i == j) {
            j++;
        }
    }
    int ans = i < n ? i : j;
    return T(s.begin() + ans, s.begin() + ans + n);
}
```

## 5.8 EER Tree

```
// cnt : occurrences, (dfs fail tree)
// num : number of pal ending here
struct PAM {
    static constexpr int A = 26;
    struct Node {
        int len = 0, link = 0, cnt = 0, num = 0;
        array<int, A> nxt;
        Node() {}
    };
    vector<Node> t;
    int suf = 1;
    string s;
    PAM() : t(2) { t[0].len = -1; }
    int size() { return t.size(); }
    Node& operator[](int i) { return t[i]; }
    int newNode() {
        t.emplace_back();
        return t.size() - 1;
    }
    bool add(int c, char offset = 'a') {
        int pos = s.size();
        s += c + offset;
        int cur = suf, curlen = 0;
        while (true) {
            curlen = t[cur].len;
            if (pos - 1 - curlen >= 0 && s[pos] - 1 - curlen == s[pos]) {
                break;
            }
            cur = t[cur].link;
        }
        if (t[cur].nxt[c]) {
            suf = t[cur].nxt[c];
            t[suf].cnt++;
            return false;
        }
        suf = newNode();
        t[suf].len = t[cur].len + 2;
        t[suf].cnt = t[suf].num = 1;
        t[cur].nxt[c] = suf;
        if (t[suf].len == 1) {
            t[suf].link = t[q].link;
            t[clone].nxt = t[q].nxt;
            while (p != -1 && t[p].nxt[c] == q) {
                t[p].nxt[c] = clone;
                p = t[p].link;
            }
            t[q].link = t[cur].link = clone;
        }
        return cur;
    }
};
```

```
t[suf].link = 1;
return true;
}
while (true) {
    cur = t[cur].link;
    curlen = t[cur].len;
    if (pos - 1 - curlen >= 0 && s[pos] - 1 - curlen == s[pos]) {
        t[suf].link = t[cur].nxt[c];
        break;
    }
}
t[suf].num += t[t[suf].link].num;
return true;
}
```

## 6 Math

### 6.1 Extended GCD

```
array<i64, 3> extgcd(i64 a, i64 b) {
    if (b == 0) { return {a, 1, 0}; }
    auto [g, x, y] = extgcd(b, a % b);
    return {g, y, x - a / b * y};
}
```

### 6.2 Chinese Remainder Theorem

```
// returns (rem, mod), n = 0 return (0, 1), no solution return (0, 0)
pair<i64, i64> crt(vector<i64> r, vector<i64> m) {
    int n = r.size();
    for (int i = 0; i < n; i++) {
        r[i] %= m[i];
        if (r[i] < 0) { r[i] += m[i]; }
    }
    i64 r0 = 0, m0 = 1;
    for (int i = 0; i < n; i++) {
        i64 r1 = r[i], m1 = m[i];
        if (m0 < m1) { swap(r0, r1), swap(m0, m1); }
        if (m0 % m1 == 0) {
            if (r0 % m1 != r1) { return {0, 0}; }
            continue;
        }
        auto [g, a, b] = extgcd(m0, m1);
        i64 u1 = m1 / g;
        if ((r1 - r0) % g != 0) { return {0, 0}; }
        i64 x = (r1 - r0) / g * u1 * a % u1;
        r0 += x * m0;
        m0 *= u1;
        if (r0 < 0) { r0 += m0; }
    }
    return {r0, m0};
}
```

### 6.3 NTT and polynomials

```
template <int P>
struct Modint {
    int v;
    // need constexpr, constructor, +, -, *, /, qpow, inv()
};
template <int P>
constexpr Modint<P> findPrimitiveRoot() {
    Modint<P> i = 2;
    int k = __builtin_ctz(P - 1);
    while (true) {
        if (i.qpow((P - 1) / 2).v != 1) {
            break;
        }
        i = i + 1;
    }
    return i.qpow(P - 1 >> k);
}
template <int P>
constexpr Modint<P> primitiveRoot = findPrimitiveRoot<P>();
vector<int> rev;
template <int P>
```

```

vector<Modint<P>> roots{0, 1};
template <int P>
void dft(vector<Modint<P>> &a) {
    int n = a.size();
    if (n == 1) { return; }
    if (int(rev.size()) != n) {
        int k = __builtin_ctz(n) - 1;
        rev.resize(n);
        for (int i = 0; i < n; i++) { rev[i]
            = rev[i >> 1] >> 1 | (i & 1) <<
                k; }
    }
    for (int i = 0; i < n; i++) { if (rev[i]
        < i) { swap(a[i], a[rev[i]]); } }
    if (roots<P>.size() < n) {
        int k = __builtin_ctz(roots<P>.size()
            );
        roots<P>.resize(n);
        while ((1 << k) < n) {
            auto e = Modint<P>(primitiveRoot<P>
                >).qpow(P - 1 >> k + 1);
            for (int i = 1 << k - 1; i < 1 << k
                ; i++) {
                roots<P>[2 * i] = roots<P>[i];
                roots<P>[2 * i + 1] = roots<P>[i]
                    * e;
            }
            k++;
        }
    }
    // fft : just do roots[i] = exp(2 * PI
    // / n * i * complex<double>(0, 1))
    for (int k = 1; k < n; k *= 2) {
        for (int i = 0; i < n; i += 2 * k) {
            for (int j = 0; j < k; j++) {
                Modint<P> u = a[i + j];
                Modint<P> v = a[i + j + k] *
                    roots<P>[k + j];
                // fft : v = a[i + j + k] * roots
                // [n / (2 * k) * j]
                a[i + j] = u + v;
                a[i + j + k] = u - v;
            }
        }
    }
}
template <int P>
void idft(vector<Modint<P>> &a) {
    int n = a.size();
    reverse(a.begin() + 1, a.end());
    dft(a);
    Modint<P> x = (1 - P) / n;
    for (int i = 0; i < n; i++) { a[i] = a[
        i] * x; }
}
template <int P>
struct Poly : vector<Modint<P>> {
    using Mint = Modint<P>;
    Poly() {}
    explicit Poly(int n) : vector<Mint>(n)
    {}
    explicit Poly(const vector<Mint> &a) :
        vector<Mint>(a) {}
    explicit Poly(const initializer_list<
        Mint> &a) : vector<Mint>(a) {}
}
template <class F>
explicit Poly(int n, F f) : vector<Mint>
    >(n) { for (int i = 0; i < n; i++)
        { (*this)[i] = f(i); } }
template <class InputIt>
explicit constexpr Poly(InputIt first,
    InputIt last) : vector<Mint>(first
        , last) {}
Poly mulxk(int k) {
    auto b = *this;
    b.insert(b.begin(), k, 0);
    return b;
}
Poly modxk(int k) {
    k = min(k, int(this->size()));
    return Poly(this->begin(), this->
        begin() + k);
}
Poly divxk(int k) {
    if (this->size() <= k) { return Poly
        (); }
    return Poly(this->begin() + k, this->
        end());
}
friend Poly operator+(const Poly &a,
    const Poly &b) {
    Poly res(max(a.size(), b.size()));
    for (int i = 0; i < int(a.size()); i
        ++){ res[i] = res[i] + a[i]; }
    for (int i = 0; i < int(b.size()); i
        ++){ res[i] = res[i] + b[i]; }
    return res;
}
friend Poly operator-(const Poly &a,
    const Poly &b) {
    Poly res(max(a.size(), b.size()));
    for (int i = 0; i < int(a.size()); i
        ++){ res[i] = res[i] + a[i]; }
    for (int i = 0; i < int(b.size()); i
        ++){ res[i] = res[i] - b[i]; }
    return res;
}
friend Poly operator*(Poly a, Poly b) {
    if (a.empty() || b.empty()) { return
        Poly(); }
    int sz = 1, tot = a.size() + b.size()
        - 1;
    while (sz < tot) { sz *= 2; }
    a.resize(sz);
    b.resize(sz);
    dft(a);
    dft(b);
    for (int i = 0; i < sz; i++) { a[i] =
        a[i] * b[i]; }
    idft(a);
    a.resize(tot);
    return a;
}
friend Poly operator*(Poly a, Mint b) {
    for (int i = 0; i < int(a.size()); i
        ++){ a[i] = a[i] * b; }
    return a;
}
Poly derivative() {
    if (this->empty()) { return Poly(); }
    Poly res(this->size() - 1);
    for (int i = 0; i < this->size() - 1;
        ++i) { res[i] = (i + 1) * (*
        this)[i + 1]; }
    return res;
}
Poly integral() {
    Poly res(this->size() + 1);
    for (int i = 0; i < this->size(); ++i
        ) { res[i + 1] = (*this)[i] *
        Mint(i + 1).inv(); }
    return res;
}
Poly inv(int m) {
    // a[0] != 0
    Poly x((*this)[0].inv());
    int k = 1;
    while (k < m) {
        x = (x * (Poly({2}) - modxk(k) * x)
            ).modxk(k);
    }
    return x.modxk(m);
}
Poly log(int m) {
    return (derivative() * inv(m)).
        integral().modxk(m);
}
Poly exp(int m) {
    Poly x({1});
    int k = 1;
    while (k < m) {
        k *= 2;
        x = (x * (Poly({1}) - x.log(k) +
            modxk(k))).modxk(k);
    }
    return x.modxk(m);
}
Poly pow(i64 k, int m) {
    if (k == 0) { return Poly(m, [&](int
        i) { return i == 0; }); }
    int i = 0;
    while (i < this->size() && (*this)[i]
        .v == 0) { i++; }
    if (i == this->size() || __int128(i)
        * k >= m) { return Poly(m); }
    Mint v = (*this)[i];
    auto f = divxk(i) * v.inv();
    return (f.log(m - i * k) * k).exp(m -
        i * k).mulxk(i * k) * v.qpow(k)
        ;
}
Poly sqrt(int m) {
    // a[0] == 1, otherwise quadratic
    // residue?
    Poly x({1});
    int k = 1;
    while (k < m) {
        k *= 2;
        x = (x + (modxk(k) * x.inv(k)).
            modxk(k)) * ((P + 1) / 2);
    }
    return x.modxk(m);
}
Poly mult(Poly b) const {
    if (b.empty()) { return Poly(); }
    int n = b.size();
    reverse(b.begin(), b.end());
    return (*this * b).divxk(n - 1);
}
vector<Mint> evaluate(vector<Mint> x) {
    if (this->empty()) { return vector<
        Mint>(x.size()); }
    int n = max(x.size(), this->size());
    vector<Poly> q(4 * n);
    vector<Mint> ans(x.size());
    x.resize(n);
    auto build = [&](auto build, int id,
        int l, int r) -> void {
        if (r - l == 1) {
            q[id] = Poly({1, -x[l].v});
        } else {
            int m = (l + r) / 2;
            build(build, 2 * id, l, m);
            build(build, 2 * id + 1, m, r);
            q[id] = q[2 * id] * q[2 * id +
                1];
        }
    };
    build(build, 1, 0, n);
    auto work = [&](auto work, int id,
        int l, int r, const Poly &num)
        -> void {
        if (r - l == 1) {
            if (l < int(ans.size())) { ans[l]
                = num[0]; }
        } else {
            int m = (l + r) / 2;
            work(work, 2 * id, l, m, num.mult
                (q[2 * id + 1]).modxk(m - l)
                );
            work(work, 2 * id + 1, m, r, num.
                mult(q[2 * id]).modxk(r - m)
                );
        }
    };
    work(work, 1, 0, n, mult(q[1].inv(n))
        );
    return ans;
}
}
template <int P>
Poly<P> interpolate(vector<Modint<P>> x,
    vector<Modint<P>> y) {
    // f(xi) = yi
    int n = x.size();
    vector<Poly<P>> p(4 * n), q(4 * n);
    auto dfs1 = [&](auto dfs1, int id, int
        l, int r) -> void {
        if (l == r) {
            p[id] = Poly<P>({-x[l].v, 1});
            return;
        }
        int m = l + r >> 1;
        dfs1(dfs1, id << 1, l, m);
        dfs1(dfs1, id << 1 | 1, m + 1, r);
        p[id] = p[id << 1] * p[id << 1 | 1];
    };
}

```

```

dfs1(dfs1, 1, 0, n - 1);
Poly<P> f = Poly<P>(p[1].derivative().
    evaluate(x));
auto dfs2 = [&](auto dfs2, int id, int
    l, int r) -> void {
    if (l == r) {
        q[id] = Poly<P>({y[l] * f[l].inv()
        });
        return;
    }
    int m = l + r >> 1;
    dfs2(dfs2, id << 1, l, m);
    dfs2(dfs2, id << 1 | 1, m + 1, r);
    q[id] = q[id << 1] * p[id << 1 | 1] +
        q[id << 1 | 1] * p[id << 1];
};
dfs2(dfs2, 1, 0, n - 1);
return q[1];
}

```

## 6.4 Any Mod NTT

```

constexpr int P0 = 998244353, P1 =
    1004535809, P2 = 469762049;
constexpr i64 P01 = 1LL * P0 * P1;
constexpr int inv0 = Modint<P1>(P0).inv()
    .v;
constexpr int inv01 = Modint<P2>(P01).inv()
    .v;
for (int i = 0; i < int(c.size()); i++) {
    i64 x = 1LL * (c1[i] - c0[i] + P1) % P1
        * inv0 % P1 * P0 + c0[i];
    c[i] = ((c2[i] - x % P2 + P2) % P2 *
        inv01 % P2 * (P01 % P) % P + x) %
        P;
}

```

## 6.5 Newton's Method

$$Q_{k+1} = Q_k - \frac{F(Q_k)}{F'(Q_k)} \pmod{x^{2^{k+1}}}$$

## 6.6 Fast Walsh-Hadamard Transform

- XOR Convolution
  - $f(A) = (f(A_0) + f(A_1), f(A_0) - f(A_1))$
  - $f^{-1}(A) = (f^{-1}(\frac{A_0+A_1}{2}), f^{-1}(\frac{A_0-A_1}{2}))$
- OR Convolution
  - $f(A) = (f(A_0), f(A_0) + f(A_1))$
  - $f^{-1}(A) = (f^{-1}(A_0), f^{-1}(A_1) - f^{-1}(A_0))$
- AND Convolution
  - $f(A) = (f(A_0) + f(A_1), f(A_1))$
  - $f^{-1}(A) = (f^{-1}(A_0) - f^{-1}(A_1), f^{-1}(A_1))$

## 6.7 Simplex Algorithm

Description: maximize  $c^T x$  subject to  $Ax \leq b$  and  $x \geq 0$ . Returns  $-\infty$  if infeasible and  $\infty$  if unbounded.

```

const double eps = 1e-9;
const double inf = 1e+9;
int n, m;
vector<vector<double>> d;
vector<int> p, q;
void pivot(int r, int s) {
    double inv = 1.0 / d[r][s];
    for (int i = 0; i < m + 2; ++i) {
        for (int j = 0; j < n + 2; ++j) {
            if (i != r && j != s) d[i][j] -= d[r][j] * d[i][s] * inv;
        }
    }
    for (int i = 0; i < m + 2; ++i) if (i
        != r) d[i][s] *= -inv;
    for (int j = 0; j < n + 2; ++j) if (j
        != s) d[r][j] *= +inv;
    d[r][s] = inv;
    swap(p[r], q[s]);
}
bool phase(int z) {

```

```

int x = m + z;
while (true) {
    int s = -1;
    for (int i = 0; i <= n; ++i) {
        if (!z && q[i] == -1) continue;
        if (s == -1 || d[x][i] < d[x][s]) s = i;
    }
    if (d[x][s] > -eps) return true;
    int r = -1;
    for (int i = 0; i < m; ++i) {
        if (d[i][s] < eps) continue;
        if (r == -1 || d[i][s + 1] / d[i][s]
            < d[r][s + 1] / d[r][s]) r = i;
    }
    if (r == -1) return false;
    pivot(r, s);
}
vector<double> solve(const vector<vector<
    double>> &a, const vector<double> &b
    , const vector<double> &c) {
    m = b.size(), n = c.size();
    d = vector<vector<double>>(m + 2,
        vector<double>(n + 2));
    for (int i = 0; i < m; ++i) {
        for (int j = 0; j < n; ++j) d[i][j] =
            a[i][j];
    }
    p.resize(m), q.resize(n + 1);
    for (int i = 0; i < m; ++i) p[i] = n +
        i, d[i][n] = -1, d[i][n + 1] = b[i];
    for (int i = 0; i < n; ++i) q[i] = i, d
        [m][i] = -c[i];
    q[n] = -1, d[m + 1][n] = 1;
    int r = 0;
    for (int i = 1; i < m; ++i) if (d[i][n]
        + 1 < d[r][n + 1]) r = i;
    if (d[r][n + 1] < -eps) {
        pivot(r, n);
        if (!phase(1) || d[m + 1][n + 1] < -
            eps) return vector<double>(n, -
            inf);
        for (int i = 0; i < m; ++i) if (p[i]
            == -1) {
            int s = min_element(d[i].begin(), d
                [i].end() - 1) - d[i].begin();
            pivot(i, s);
        }
    }
    if (!phase(0)) return vector<double>(n,
        inf);
    vector<double> x(n);
    for (int i = 0; i < m; ++i) if (p[i] <
        n) x[p[i]] = d[i][n + 1];
    return x;
}

```

### 6.7.1 Construction

Standard form: maximize  $c^T x$  subject to  $Ax \leq b$  and  $x \geq 0$ .  
 Dual LP: minimize  $b^T y$  subject to  $A^T y \geq c$  and  $y \geq 0$ .  
 $\bar{x}$  and  $\bar{y}$  are optimal if and only if for all  $i \in [1, n]$ , either  $\bar{x}_i = 0$  or  $\sum_{j=1}^m A_{ji} \bar{y}_j = c_i$  holds and for all  $i \in [1, m]$  either  $\bar{y}_i = 0$  or  $\sum_{j=1}^n A_{ij} \bar{x}_j = b_j$  holds.

- In case of minimization, let  $c'_i = -c_i$
- $\sum_{1 \leq i \leq n} A_{ji} x_i \geq b_j \rightarrow \sum_{1 \leq i \leq n} -A_{ji} x_i \leq -b_j$
- $\sum_{1 \leq i \leq n} A_{ji} x_i = b_j$ 
  - $\sum_{1 \leq i \leq n} A_{ji} x_i \leq b_j$
  - $\sum_{1 \leq i \leq n} A_{ji} x_i \geq b_j$
- If  $x_i$  has no lower bound, replace  $x_i$  with  $x_i - x'_i$

## 6.8 Subset Convolution

Description:  $h(s) = \sum_{s' \subseteq s} f(s') g(s \setminus s')$

```

vector<int> SubsetConv(int n, const
    vector<int> &f, const vector<int> &g
    ) {

```

```

const int m = 1 << n;
vector<vector<int>> a(n + 1, vector<int>
    (m)), b(n + 1, vector<int>(m));
for (int i = 0; i < m; ++i) {
    a[__builtin_popcount(i)][i] = f[i];
    b[__builtin_popcount(i)][i] = g[i];
}
for (int i = 0; i <= n; ++i) {
    for (int j = 0; j < n; ++j) {
        for (int s = 0; s < m; ++s) {
            if (s >> j & 1) {
                a[i][s] += a[i][s ^ (1 << j)];
                b[i][s] += b[i][s ^ (1 << j)];
            }
        }
    }
}
vector<vector<int>> c(n + 1, vector<int>
    (m));
for (int s = 0; s < m; ++s) {
    for (int i = 0; i <= n; ++i) {
        for (int j = 0; j <= i; ++j) c[i][s]
            += a[j][s] * b[i - j][s];
    }
}
for (int i = 0; i <= n; ++i) {
    for (int j = 0; j < n; ++j) {
        for (int s = 0; s < m; ++s) {
            if (s >> j & 1) c[i][s] -= c[i][s
                ^ (1 << j)];
        }
    }
}
vector<int> res(m);
for (int i = 0; i < m; ++i) res[i] = c[
    __builtin_popcount(i)][i];
return res;
}

```

## 6.9 Berlekamp Massey Algorithm

```

// find \sum a_{i-j}c_j = 0 for d <= i
template <typename T>
vector<T> berlekampMassey(const vector<T>
    &a) {
    vector<T> c(1, 1), oldC(1);
    int oldI = -1;
    T oldD = 1;
    for (int i = 0; i < int(a.size()); i++)
        {
            T d = 0;
            for (int j = 0; j < int(c.size()); j
                ++){ d += c[j] * a[i - j]; }
            if (d == 0) { continue; }
            T mul = d / oldD;
            vector<T> nc = c;
            nc.resize(max(int(c.size()), i - oldI
                + int(oldC.size())));
            for (int j = 0; j < int(oldC.size());
                j++) { nc[j + i - oldI] -= oldC
                [j] * mul; }
            if (i - int(c.size()) > oldI - int(
                oldC.size())) {
                oldI = i;
                oldD = d;
                swap(oldC, c);
            }
            swap(c, nc);
        }
    return c;
}

```

## 6.10 Fast Linear Recurrence

```
// p : a[0] ~ a[d - 1]
// q : a[i] = \sum a[i - j]q[j]
template <typename T>
T linearRecurrence(vector<T> p, vector<T>
    q, i64 n) {
    int d = q.size() - 1;
    assert(int(p.size()) == d);
    p = p * q;
    p.resize(d);
    while (n > 0) {
        auto nq = q;
        for (int i = 1; i <= d; i += 2) {
            nq[i] *= -1;
        }
        auto np = p * nq;
        nq = q * nq;
        for (int i = 0; i < d; i++) {
            p[i] = np[i * 2 + n % 2];
        }
        for (int i = 0; i <= d; i++) {
            q[i] = nq[i * 2];
        }
        n /= 2;
    }
    return p[0] / q[0];
}
```

## 6.11 Prime check and factor-ize

```
i64 mul(i64 a, i64 b, i64 mod) {}
i64 qpow(i64 x, i64 p, i64 mod) {}
bool isPrime(i64 n) {
    if (n == 1) { return false; }
    int r = __builtin_ctzll(n - 1);
    i64 d = n - 1 >> r;
    auto checkComposite = [&](i64 p) {
        i64 x = qpow(p, d, n);
        if (x == 1 || x == n - 1) { return
            false; }
        for (int i = 1; i < r; i++) {
            x = mul(x, x, n);
            if (x == n - 1) { return false; }
        }
        return true;
    };
    for (auto p : {2, 3, 5, 7, 11, 13, 17,
        19, 23, 29, 31, 37}) {
        if (n == p) {
            return true;
        } else if (checkComposite(p)) {
            return false;
        }
    }
    return true;
}
vector<i64> pollardRho(i64 n) {
    vector<i64> res;
    auto work = [&](auto work, i64 n) {
        if (n <= 10000) {
            for (int i = 2; i * i <= n; i++) {
                while (n % i == 0) {
                    res.push_back(i);
                    n /= i;
                }
            }
            if (n > 1) { res.push_back(n); }
            return;
        } else if (isPrime(n)) {
            res.push_back(n);
            return;
        }
    };
    i64 x0 = 2;
    auto f = [&](i64 x) { return (mul(x,
        x, n) + 1) % n; };
    while (true) {
        i64 x = x0, y = x0, d = 1, power =
            1, lam = 0, v = 1;
        while (d == 1) {
            y = f(y);
            ++lam;
            v = mul(v, abs(x - y), n);
            if (lam % 127 == 0) {
                d = gcd(v, n);
                v = 1;
            }
        }
    }
}
```

```
}
    if (power == lam) {
        x = y;
        power *= 2;
        lam = 0;
        d = gcd(v, n);
        v = 1;
    }
}
    if (d != n) {
        work(work, d);
        work(work, n / d);
        return;
    }
    ++x0;
};
work(work, n);
sort(res.begin(), res.end());
return res;
}
```

## 6.12 Count Primes leq n

```
// __attribute__((target("avx2"),
    optimize("O3", "unroll-loops")))
i64 primeCount(const i64 n) {
    if (n <= 1) { return 0; }
    if (n == 2) { return 1; }
    const int v = sqrtl(n);
    int s = (v + 1) / 2;
    vector<int> smalls(s), roughs(s), skip(
        v + 1);
    vector<i64> larges(s);
    iota(smalls.begin(), smalls.end(), 0);
    for (int i = 0; i < s; i++) {
        roughs[i] = 2 * i + 1;
        larges[i] = (n / roughs[i] - 1) / 2;
    }
    const auto half = [](int n) -> int {
        return (n - 1) >> 1; };
    int pc = 0;
    for (int p = 3; p <= v; p += 2) {
        if (skip[p]) { continue; }
        int q = p * p;
        if (1LL * q * q > n) { break; }
        skip[p] = true;
        for (int i = q; i <= v; i += 2 * p)
            skip[i] = true;
        int ns = 0;
        for (int k = 0; k < s; k++) {
            int i = roughs[k];
            if (skip[i]) { continue; }
            i64 d = 1LL * i * p;
            larges[ns] = larges[k] - (d <= v ?
                larges[smalls[d / 2] - pc] :
                smalls[half(n / d)] + pc;
            roughs[ns++] = i;
        }
        s = ns;
        for (int i = half(v), j = v / p - 1;
            1; j >= p; j -= 2) {
            int c = smalls[j / 2] - pc;
            for (int e = j * p / 2; i >= e; i
                --) { smalls[i] -= c; }
        }
        pc++;
    }
    larges[0] += 1LL * (s + 2 * (pc - 1)) *
        (s - 1) / 2;
    for (int k = 1; k < s; k++) { larges[0]
        -= larges[k]; }
    for (int l = 1; l < s; l++) {
        i64 q = roughs[l];
        i64 M = n / q;
        int e = smalls[half(M / q)] - pc;
        if (e <= 1) { break; }
        i64 t = 0;
        for (int k = l + 1; k <= e; k++) { t
            += smalls[half(M / roughs[k])];
        }
        larges[0] += t - 1LL * (e - l) * (pc
            + l - 1);
    }
    return larges[0] + 1;
}
```

## 6.13 Discrete Logarithm

```
// return min x >= 0 s.t. a ^ x = b mod m
    , 0 ^ 0 = 1, -1 if no solution
// (I think) if you want x > 0 (m != 1),
    remove if (b == k) return add;
int discreteLog(int a, int b, int m) {
    if (m == 1) {
        return 0;
    }
    a %= m, b %= m;
    int k = 1, add = 0, g;
    while ((g = gcd(a, m)) > 1) {
        if (b == k) {
            return add;
        } else if (b % g) {
            return -1;
        }
        b /= g, m /= g, ++add;
        k = 1LL * k * a / g % m;
    }
    if (b == k) {
        return add;
    }
    int n = sqrt(m) + 1;
    int an = 1;
    for (int i = 0; i < n; ++i) {
        an = 1LL * an * a % m;
    }
    unordered_map<int, int> vals;
    for (int q = 0, cur = b; q < n; ++q) {
        vals[cur] = q;
        cur = 1LL * a * cur % m;
    }
    for (int p = 1, cur = k; p <= n; ++p) {
        cur = 1LL * cur * an % m;
        if (vals.count(cur)) {
            int ans = n * p - vals[cur] + add;
            return ans;
        }
    }
    return -1;
}
```

## 6.14 Quadratic Residue

```
// rng
int jacobi(int a, int m) {
    int s = 1;
    while (m > 1) {
        a %= m;
        if (a == 0) { return 0; }
        int r = __builtin_ctz(a);
        if (r % 2 == 1 && (m + 2 & 4) != 0) {
            s = -s;
        }
        a >>= r;
        if ((a & m & 2) != 0) { s = -s; }
        swap(a, m);
    }
    return s;
}
int quadraticResidue(int a, int p) {
    if (p == 2) { return a % 2; }
    int j = jacobi(a, p);
    if (j == 0 || j == -1) { return j; }
    int b, d;
    while (true) {
        b = rng() % p;
        d = (1LL * b * b + p - a) % p;
        if (jacobi(d, p) == -1) { break; }
    }
    int f0 = b, f1 = 1, g0 = 1, g1 = 0, tmp;
    for (int e = p + 1 >> 1; e > 0; e >>=
        1) {
        if (e % 2 == 1) {
            tmp = (1LL * g0 * f0 + 1LL * d * g1
                % p * f1 % p) % p;
            g1 = (1LL * g0 * f1 + 1LL * g1 * f0
                % p) % p;
            g0 = tmp;
        }
        tmp = (1LL * f0 * f0 + 1LL * d * f1 %
            p * f1 % p) % p;
        f1 = 2LL * f0 * f1 % p;
        f0 = tmp;
    }
    return g0;
}
```



## 6.15 Characteristic Polynomial

```
vector<vector<int>> Hessenberg(const
vector<vector<int>> &A) {
    int N = A.size();
    vector<vector<int>> H = A;
    for (int i = 0; i < N - 2; ++i) {
        if (!H[i + 1][i]) {
            for (int j = i + 2; j < N; ++j) {
                if (H[j][i]) {
                    for (int k = i; k < N; ++k)
                        swap(H[i + 1][k], H[j][k]);
                    for (int k = 0; k < N; ++k)
                        swap(H[k][i + 1], H[k][j]);
                    break;
                }
            }
        }
        if (!H[i + 1][i]) continue;
        int val = fpow(H[i + 1][i], kP - 2);
        for (int j = i + 2; j < N; ++j) {
            int coef = 1LL * val * H[j][i] % kP;
            for (int k = i; k < N; ++k) H[j][k]
                = (H[j][k] + 1LL * H[i + 1][k]
                    * (kP - coef)) % kP;
            for (int k = 0; k < N; ++k) H[k][i
                + 1] = (H[k][i + 1] + 1LL * H[
                    k][j] * coef) % kP;
        }
    }
    return H;
}
vector<int> CharacteristicPoly(const
vector<vector<int>> &A) {
    int N = A.size();
    auto H = Hessenberg(A);
    for (int i = 0; i < N; ++i) {
        for (int j = 0; j < N; ++j) H[i][j] =
            kP - H[i][j];
    }
    vector<vector<int>> P(N + 1, vector<int>
        >(N + 1));
    P[0][0] = 1;
    for (int i = 1; i <= N; ++i) {
        P[i][0] = 0;
        for (int j = 1; j <= i; ++j) P[i][j]
            = P[i - 1][j - 1];
        int val = 1;
        for (int j = i - 1; j >= 0; --j) {
            int coef = 1LL * val * H[j][i - 1]
                % kP;
            for (int k = 0; k <= j; ++k) P[i][k]
                = (P[i][k] + 1LL * P[j][k] *
                    coef) % kP;
            if (j) val = 1LL * val * (kP - H[j]
                [j - 1]) % kP;
        }
    }
    if (N & 1) {
        for (int i = 0; i <= N; ++i) P[N][i]
            = kP - P[N][i];
    }
    return P[N];
}
```

## 6.16 Linear Sieve Related

```
vector<int> minp(N + 1), primes, mobius(N
+ 1);
mobius[1] = 1;
for (int i = 2; i <= N; ++i) {
    if (!minp[i]) {
        primes.push_back(i);
        minp[i] = i;
        mobius[i] = -1;
    }
    for (int p : primes) {
        if (p > N / i) {
            break;
        }
        minp[p * i] = p;
        mobius[p * i] = -mobius[i];
        if (i % p == 0) {
            mobius[p * i] = 0;
            break;
        }
    }
}
```

```
mobius[p * i] = 0;
break;
}
}
```

## 6.17 De Bruijn Sequence

```
int res[kN], aux[kN], a[kN], sz;
void Rec(int t, int p, int n, int k) {
    if (t > n) {
        if (n % p == 0)
            for (int i = 1; i <= p; ++i) res[sz
                ++] = aux[i];
    } else {
        aux[t] = aux[t - p];
        Rec(t + 1, p, n, k);
        for (aux[t] = aux[t - p] + 1; aux[t]
            < k; ++aux[t]) Rec(t + 1, t, n,
                k);
    }
}
int DeBruijn(int k, int n) {
    // return cyclic string of length k^n
    // such that every string of length n
    // using k character appears as a
    // substring.
    if (k == 1) return res[0] = 0, 1;
    fill(aux, aux + k * n, 0);
    return sz = 0, Rec(1, 1, n, k), sz;
}
```

## 6.18 Floor Sum

```
// \sum_{i=0}^{n-1} floor((a * i + b) / c)
i64 floorSum(i64 a, i64 b, i64 c, i64 n)
{
    if (n < 0) { return 0; }
    if (n == 0) { return b / c; }
    if (a == 0) { return b / c * (n + 1); }
    i64 res = 0;
    if (a >= c) { res += a / c * n * (n +
        1) / 2, a %= c; }
    if (b >= c) { res += b / c * (n + 1), b
        %= c; }
    i64 m = (a * n + b) / c;
    return res + n * m - (m == 0 ? 0 :
        floorSum(c, c - b - 1, a, m - 1));
}
```

## 6.19 More Floor Sum

$$\bullet \quad m = \lfloor \frac{an+b}{c} \rfloor$$

$$g(a, b, c, n) = \sum_{i=0}^n i \lfloor \frac{ai+b}{c} \rfloor$$

$$= \begin{cases} \lfloor \frac{a}{c} \rfloor \cdot \frac{n(n+1)(2n+1)}{6} + \lfloor \frac{b}{c} \rfloor \cdot \frac{n(n+1)}{2} \\ + g(a \bmod c, b \bmod c, c, n), \\ 0, \\ \frac{1}{2} \cdot (n(n+1)m - f(c, c-b-1, a, m-1)) \\ - h(c, c-b-1, a, m-1), \end{cases}$$

$$h(a, b, c, n) = \sum_{i=0}^n \lfloor \frac{ai+b}{c} \rfloor^2$$

$$= \begin{cases} \lfloor \frac{a}{c} \rfloor^2 \cdot \frac{n(n+1)(2n+1)}{6} + \lfloor \frac{b}{c} \rfloor^2 \cdot (n+1) \\ + \lfloor \frac{a}{c} \rfloor \cdot \lfloor \frac{b}{c} \rfloor \cdot n(n+1) \\ + h(a \bmod c, b \bmod c, c, n) \\ + 2 \lfloor \frac{a}{c} \rfloor \cdot g(a \bmod c, b \bmod c, c, n) \\ + 2 \lfloor \frac{b}{c} \rfloor \cdot f(a \bmod c, b \bmod c, c, n), \\ 0, \\ nm(m+1) - 2g(c, c-b-1, a, m-1) \\ - 2f(c, c-b-1, a, m-1) - f(a, b, c, n), \end{cases}$$

## 6.20 Min Mod Linear

```
// \min_{i: [0, n)} (a * i + b) % m
// ok in 1e9
int minModLinear(int n, int m, int a, int
    b, int cnt = 1, int p = 1, int q =
    1) {
    if (a == 0) { return b; }
    if (cnt % 2 == 1) {
        if (b >= a) {
            return minModLinear(n, m, a, b,
                cnt + 1, p * a, q * a);
        }
    }
    return minModLinear(n, m, a, b, cnt + 1,
        p, q);
}
```

```
int t = (m - b + a - 1) / a;
int c = (t - 1) * p + q;
if (n <= c) { return b; }
n -= c;
b += a * t - m;
}
b = a - 1 - b;
} else {
    if (b < m - a) {
        int t = (m - b - 1) / a;
        int c = t * p;
        if (n <= c) { return (n - 1) / p *
            a + b; }
        n -= c;
        b += a * t;
    }
    b = m - 1 - b;
}
cnt++;
int d = m / a;
int c = minModLinear(n, a, m % a, b,
    cnt, (d - 1) * p + q, d * p + q);
return cnt % 2 == 1 ? m - 1 - c : a - 1
    - c;
}
```

## 6.21 Count of subsets with sum (mod P) leq T

```
int n, T;
cin >> n >> T;
vector<int> cnt(T + 1);
for (int i = 0; i < n; ++i) {
    int a;
    cin >> a;
    cnt[a]++;
}
vector<int> inv(T + 1);
for (int i = 1; i <= T; ++i) {
    inv[i] = i == 1 ? 1 : -P / i * inv[P %
        i];
}
FPS f(T + 1);
for (int i = 1; i <= T; ++i) {
    for (int j = 1; j * i <= T; ++j) {
        f[i * j] = f[i * j] + (j % 2 == 1 ? 1
            : -1) * cnt[i] * inv[j];
    }
}
f = f.exp(T + 1);
```

## 6.22 Theorem

- Kirchhoff's Theorem

Denote  $L$  be a  $n \times n$  matrix as the Laplacian matrix of graph  $G$ , where  $L_{ii} = d(i)$ ,  $L_{ij} = -c$  where  $c$  is the number of edge  $(i, j)$  in  $G$ .

$a \geq c \vee b \geq c$   
 $n < 0 \vee a = 0$   
 The number of undirected spanning trees in  $G$  is  $|\det(\tilde{L}_{11})|$ .

otherwise  
 The number of directed spanning tree rooted at  $r$  in  $G$  is  $|\det(\tilde{L}_{rr})|$ .

- Tutte's Matrix

Let  $D$  be a  $n \times n$  matrix, where  $d_{ij} = x_{ij}$  ( $x_{ij}$  is chosen uniformly at random) if  $i < j$  and  $(i, j) \in E$ , otherwise  $d_{ij} = -d_{ji}$ .  
 $\frac{\text{rank}(D)}{2}$  is the maximum matching on  $G$ .

- Cayley's Formula

$n < 0 \vee a = 0$   
 Given a degree sequence  $d_1, d_2, \dots, d_n$  for each labeled vertices, there are

$$\frac{(n-2)!}{(d_1-1)!(d_2-1)!\cdots(d_n-1)!}$$

spanning trees.

- Let  $T_{n,k}$  be the number of labeled forests on  $n$  vertices with  $k$  components, such that vertex  $1, 2, \dots, k$  belong to different components. Then  $T_{n,k} = kn^{n-k-1}$ .

- Erdős–Gallai Theorem

A sequence of non-negative integers  $d_1 \geq d_2 \geq \dots \geq d_n$  can be represented as the degree sequence of a finite simple graph on  $n$  vertices if and only if  $d_1 + d_2 + \dots + d_n$  is even and

$$\sum_{i=1}^k d_i \leq k(k-1) + \sum_{i=k+1}^n \min(d_i, k)$$

holds for all  $1 \leq k \leq n$ .

- Burnside's Lemma

Let  $X$  be a set and  $G$  be a group that acts on  $X$ . For  $g \in G$ , denote by  $X^g$  the elements fixed by  $g$ :

$$X^g = \{x \in X \mid gx \in X\}$$

Then

$$|X/G| = \frac{1}{|G|} \sum_{g \in G} |X^g|.$$

- Gale–Ryser theorem

A pair of sequences of nonnegative integers  $a_1 \geq \dots \geq a_n$  and  $b_1, \dots, b_n$  is bigraphic

if and only if  $\sum_{i=1}^n a_i = \sum_{i=1}^n b_i$  and  $\sum_{i=1}^k a_i \leq \sum_{i=1}^k b_i$

holds for every  $1 \leq k \leq n$ .

Sequences  $a$  and  $b$  called bigraphic if there is a labeled simple bipartite graph such that  $a$  and  $b$  is the degree sequence of this bipartite graph.

- Fulkerson–Chen–Anstee theorem

A sequence  $(a_1, b_1), \dots, (a_n, b_n)$  of non-negative integer pairs with  $a_1 \geq \dots \geq a_n$

is digraphic if and only if  $\sum_{i=1}^n a_i = \sum_{i=1}^n b_i$

and  $\sum_{i=1}^k a_i \leq \sum_{i=1}^k b_i$  holds for every  $1 \leq k \leq n$ .

Sequences  $a$  and  $b$  called digraphic if there is a labeled simple directed graph such that each vertex  $v_i$  has indegree  $a_i$  and outdegree  $b_i$ .

- Pick's theorem

For simple polygon, when points are all integer, we have  $A = \frac{\#\{\text{lattice points in the interior}\} + \#\{\text{lattice points on the boundary}\}}{2} - 1$

- Möbius inversion formula

$$\begin{aligned} -f(n) &= \sum_{d|n} g(d) \Leftrightarrow g(n) = \sum_{d|n} \mu(d) f\left(\frac{n}{d}\right) \\ -f(n) &= \sum_{n|d} g(d) \Leftrightarrow g(n) = \sum_{n|d} \mu\left(\frac{d}{n}\right) f(d) \end{aligned}$$

- Spherical cap

- A portion of a sphere cut off by a plane.
- $r$ : sphere radius,  $a$ : radius of the base of the cap,  $h$ : height of the cap,  $\theta$ :  $\arcsin(a/r)$ .
- Volume  $= \pi h^2(3r - h)/3 = \pi h(3a^2 + h^2)/6 = \pi r^3(2 + \cos \theta)(1 - \cos \theta)^2/3$ .
- Area  $= 2\pi rh = \pi(a^2 + h^2) = 2\pi r^2(1 - \cos \theta)$ .

- The number of divisors of  $n$  is at most around 100 for  $n < 5e4$ , 500 for  $n < 1e7$ , 2000 for  $n < 1e10$ , 200000 for  $n < 1e19$ .

- The number of ways of writing  $n$  as a sum of positive integers, disregarding the order of the summands. 1, 1, 2, 3, 5, 7, 11, 15, 22, 30 for  $n = 0 \sim 9$ , 627 for  $n = 20$ ,  $\sim 2e5$  for  $n = 50$ ,  $\sim 2e8$  for  $n = 100$ .

- Total number of partitions of  $n$  distinct elements:  $B(n) = 1, 1, 2, 5, 15, 52, 203, 877, 4140, 21147, 115975, 27644437, 190899322, \dots$

- Ordinary Generating Function  $A(x) = \sum_{i \geq 0} a_i x^i$

$$\begin{aligned} -A(rx) &\Rightarrow r^n a_n \\ -A(x) + B(x) &\Rightarrow a_n + b_n \\ -A(x)B(x) &\Rightarrow \sum_{i=0}^n a_i b_{n-i} \\ -A(x)^k &\Rightarrow \sum_{i_1+i_2+\dots+i_k=n} a_{i_1} a_{i_2} \dots a_{i_k} \\ -xA(x)' &\Rightarrow n a_n \\ -\frac{A(x)}{1-x} &\Rightarrow \sum_{i=0}^n a_i \end{aligned}$$

- Exponential Generating Function  $A(x) = \sum_{i \geq 0} \frac{a_i}{i!} x^i$

$$\begin{aligned} -A(x) + B(x) &\Rightarrow a_n + b_n \\ -A^{(k)}(x) &\Rightarrow a_n + b_n \\ -A(x)B(x) &\Rightarrow \sum_{i=0}^n \binom{n}{i} a_i b_{n-i} \\ -A(x)^k &\Rightarrow \sum_{i_1+i_2+\dots+i_k=n} \binom{n}{i_1, i_2, \dots, i_k} a_{i_1} a_{i_2} \dots a_{i_k} \\ -xA(x) &\Rightarrow n a_n \end{aligned}$$

- Special Generating Function

$$\begin{aligned} -(1+x)^n &= \sum_{i \geq 0} \binom{n}{i} x^i \\ -\frac{1}{(1-x)^n} &= \sum_{i \geq 0} \binom{n-1}{i} x^i \end{aligned}$$

- Bernoulli numbers

$$B_0 = 1, B_1^\pm = \pm \frac{1}{2}, B_2 = \frac{1}{6}, B_3 = 0$$

$$\sum_{j=0}^m \binom{m+1}{j} B_j = 0, \text{ EGF is } B(x) = \frac{x}{e^x - 1} = \sum_{n=0}^{\infty} B_n \frac{x^n}{n!}.$$

$$S_m(n) = \sum_{k=0}^m \binom{m+1}{k} B_k n^{m+1-k} = \frac{1}{m+1} \sum_{k=0}^m \binom{m+1}{k} B_k n^{m+1-k}$$

- Stirling numbers of the second kind Partitions of  $n$  distinct elements into exactly  $k$  groups.

$$S(n, k) = S(n-1, k-1) + kS(n-1, k), S(n, 1) = S(n, n) = 1$$

$$S(n, k) = \frac{1}{k!} \sum_{i=0}^k (-1)^{k-i} \binom{k}{i} i^n$$

$$x^n = \sum_{i=0}^n S(n, i) (x)_i$$

- Pentagonal number theorem

$$\prod_{n=1}^{\infty} (1 - x^n) = 1 + \sum_{k=1}^{\infty} (-1)^k \left( x^{k(3k+1)/2} + x^{k(3k-1)/2} \right)$$

- Eulerian numbers

Number of permutations  $\pi \in S_n$  in which exactly  $k$  elements are greater than the previous element.  $k$ :  $j$  s.t.  $\pi(j) > \pi(j+1)$ ,  $k+1$ :  $j$  s.t.  $\pi(j) \geq j$ ,  $k$ :  $j$  s.t.  $\pi(j) > j$ .

$$E(n, k) = (n-1)E(n-1, k-1) + (k+1)E(n-1, k)$$

$$E(n, 0) = E(n, n-1) = 1$$

$$E(n, k) = \sum_{j=0}^k (-1)^j \binom{n+1}{j} (k+1-j)^n$$

## 7 Dynamic Programming

### 7.1 Dynamic Convex Hull

```
struct Line {
    // kx + b
    mutable i64 k, b, p;
    bool operator<(const Line& o) const {
        return k < o.k;
    }
    bool operator<(i64 x) const { return p < x; }
};

struct DynamicConvexHullMax : multiset<Line, less<>> {
    // (for doubles, use INF = 1/.0, div(a, b) = a/b)
    static constexpr i64 INF = numeric_limits<i64>::max();
    i64 div(i64 a, i64 b) {
        // floor
        return a / b - ((a ^ b) < 0 && a % b);
    }
    bool isect(iterator x, iterator y) {
        if (y == end()) return x->p = INF, 0;
        if (x->k == y->k) x->p = x->b > y->b ? INF : -INF;
```

```
else x->p = div(y->b - x->b, x->k - y->k);
return x->p >= y->p;
}

void add(i64 k, i64 b) {
    auto z = insert({k, b, 0}), y = z++,
        x = y;
    while (isect(y, z)) z = erase(z);
    if (x != begin() && isect(--x, y))
        isect(x, y = erase(y));
    while ((y = x) != begin() && (--x)->p >= y->p)
        isect(x, erase(y));
}

i64 query(i64 x) {
    if (empty()) return -INF;
    auto l = *lower_bound(x);
    return l.k * x + l.b;
}
```

### 7.2 1D/1D Convex Optimization

```
struct segment {
    int i, l, r;
    segment(int a, int b, int c): i(a), l(b), r(c) {}
};

inline long long f(int l, int r) { return dp[l] + w(l+1, r); }

void solve() {
    dp[0] = 0;
    deque<segment> deq; deq.push_back(segment(0, 1, n));
    for (int i = 1; i <= n; ++i) {
        dp[i] = f(deq.front().i, i);
        while (deq.size() && deq.front().r < i+1) deq.pop_front();
        deq.front().l = i+1;
        segment seg = segment(i, i+1, n);
        while (deq.size() && f(i, deq.back().l) < f(deq.back().i, deq.back().l))
            deq.pop_back();
        if (deq.size()) {
            int d = 1048576, c = deq.back().l;
            while (d >= 1) if (c + d <= deq.back().r) {
                if (f(i, c+d) > f(deq.back().i, c+d)) c += d;
            }
            deq.back().r = c; seg.l = c+1;
        }
        if (seg.l <= n) deq.push_back(seg);
    }
}
```

### 7.3 Conditon

#### 7.3.1 Totally Monotone (Concave/Convex)

$$\begin{aligned} \forall i < i', j < j', B[i][j] \leq B[i'][j] &\Rightarrow B[i][j'] \leq B[i'][j'] \\ \forall i < i', j < j', B[i][j] \geq B[i'][j] &\Rightarrow B[i][j'] \geq B[i'][j'] \end{aligned}$$

#### 7.3.2 Monge Condition (Concave/Convex)

$$\begin{aligned} \forall i < i', j < j', B[i][j] + B[i'][j'] &\geq B[i][j'] + B[i'][j] \\ \forall i < i', j < j', B[i][j] + B[i'][j'] &\leq B[i][j'] + B[i'][j] \end{aligned}$$

#### 7.3.3 Optimal Split Point

If

$$B[i][j] + B[i+1][j+1] \geq B[i][j+1] + B[i+1][j]$$

then

$$H_{i,j-1} \leq H_{i,j} \leq H_{i+1,j}$$

## 8 Geometry

### 8.1 Basic

```
using Real = double; // modify these if
needed
constexpr Real eps = 1e-9;
int sign(T x) { return (x > 0) - (x < 0); }
int sign(Real x) { return (x > eps) - (x
< -eps); }
int cmp(T a, T b) { return sign(a - b); }
struct P {
    T x = 0, y = 0;
    P(T x = 0, T y = 0) : x(x), y(y) {}
    -, +, *, /=, !=, <, > (unary)
};
struct L {
    P<T> a, b;
    L(P<T> a = {}, P<T> b = {}) : a(a), b(b)
    {}
};
T dot(P<T> a, P<T> b) { return a.x * b.x
+ a.y * b.y; }
T square(P<T> a) { return dot(a, a); }
Real length(P<T> a) { return sqrt(square
(a)); }
Real dist(P<T> a, P<T> b) { return length
(a - b); }
T cross(P<T> a, P<T> b) { return a.x * b.
y - a.y * b.x; }
T cross(P<T> p, P<T> a, P<T> b) { return
cross(a - p, b - p); }
P<Real> normal(P<T> a) {
    Real len = length(a);
    return P<Real>(a.x / len, a.y / len);
}
bool up(P<T> a) { return sign(a.y) > 0 ||
sign(a.y) == 0 && sign(a.x) > 0; }
// 3 colinear? please remember to remove
(0, 0)
bool polar(P<T> a, P<T> b) {
    bool ua = up(a), ub = up(b);
    return ua != ub ? ua : sign(cross(a, b)
    ) == 1;
}
bool sameDirection(P<T> a, P<T> b) {
    return sign(cross(a, b)) == 0 &&
sign(dot(a, b)) == 1; }
// 1/0/1 if on a->b's left/ /right
int side(P<T> p, P<T> a, P<T> b) { return
sign(cross(p, a, b)); }
int side(P<T> p, L<T> l) { return side(p,
l.a, l.b); }
P<T> rotate90(P<T> p) { return {-p.y, p.x
}; }
P<Real> rotate(P<Real> p, Real ang) {
    return {p.x * cos(ang) - p.y * sin(
ang), p.x * sin(ang) + p.y * cos(ang)
}; }
Real angle(P<T> p) { return atan2(p.y, p.
x); }
P<T> direction(L<T> l) { return l.b - l.a
; }
bool sameDirection(L<T> l1, L<T> l2) {
    return sameDirection(direction(l1),
direction(l2)); }
P<Real> projection(P<Real> p, L<Real> l)
{
    auto d = direction(l);
    return l.a + d * (dot(p - l.a, d) /
square(d));
}
P<Real> reflection(P<Real> p, L<Real> l)
{ return projection(p, l) * 2 - p; }
Real pointToLineDist(P<Real> p, L<Real> l)
{ return dist(p, projection(p, l))
; }
// better use integers if you don't need
exact coordinate
// l <= r is not explicitly required
P<Real> lineIntersection(L<T> l1, L<T> l2)
{ return l1.a - direction(l1) * (
Real(cross(direction(l2), l1.a - l2.
a)) / cross(direction(l2), direction
(l1))); }
```

```
bool between(T m, T l, T r) { return cmp(
l, m) == 0 || cmp(m, r) == 0 || l <
m != r < m; }
bool pointOnSeg(P<T> p, L<T> l) { return
side(p, l) == 0 && between(p.x, l.a.
x, l.b.x) && between(p.y, l.a.y, l.b
.y); }
bool pointStrictlyOnSeg(P<T> p, L<T> l) {
    return side(p, l) == 0 && sign(dot(
p - l.a, direction(l))) * sign(dot(p
- l.b, direction(l))) < 0; }
bool overlap(T l1, T r1, T l2, T r2) {
    if (l1 > r1) { swap(l1, r1); }
    if (l2 > r2) { swap(l2, r2); }
    return cmp(r1, l2) != -1 && cmp(r2, l1)
    != -1;
}
bool segIntersect(L<T> l1, L<T> l2) {
    auto [p1, p2] = l1;
    auto [q1, q2] = l2;
    return overlap(p1.x, p2.x, q1.x, q2.x)
&& overlap(p1.y, p2.y, q1.y, q2.y)
&&
side(p1, l2) * side(p2, l2) <= 0 &&
side(q1, l1) * side(q2, l1) <= 0;
}
// parallel intersecting is false
bool segStrictlyIntersect(L<T> l1, L<T>
l2) {
    auto [p1, p2] = l1;
    auto [q1, q2] = l2;
    return side(p1, l2) * side(p2, l2) < 0
&&
side(q1, l1) * side(q2, l1) < 0;
}
// parallel or intersect at source doesn'
t count
bool rayIntersect(L<T> l1, L<T> l2) {
    int x = sign(cross(l1.b - l1.a, l2.b -
l2.a));
    return x == 0 ? false : side(l1.a, l2)
== x && side(l2.a, l1) == -x;
}
Real pointToSegDist(P<T> p, L<T> l) {
    auto d = direction(l);
    if (sign(dot(p - l.a, d)) >= 0 && sign(
dot(p - l.b, d)) <= 0) {
        return 1.0L * cross(p, l.a, l.b) /
dist(l.a, l.b);
    } else {
        return min(dist(p, l.a), dist(p, l.b)
);
    }
}
Real segDist(L<T> l1, L<T> l2) {
    if (segIntersect(l1, l2)) { return 0; }
    return min({pointToSegDist(l1.a, l2),
pointToSegDist(l1.b, l2),
pointToSegDist(l2.a, l1),
pointToSegDist(l2.b, l1)});
}
// 2 times area
T area(vector<P<T>> a) {
    T res = 0;
    int n = a.size();
    for (int i = 0; i < n; i++) { res +=
cross(a[i], a[(i + 1) % n]); }
    return res;
}
bool pointInPoly(P<T> p, vector<P<T>> a)
{
    int n = a.size(), res = 0;
    for (int i = 0; i < n; i++) {
        P<T> u = a[i], v = a[(i + 1) % n];
        if (pointOnSeg(p, {u, v})) { return
1; }
        if (cmp(u.y, v.y) <= 0) { swap(u, v);
        }
        if (cmp(p.y, u.y) > 0 || cmp(p.y, v.y)
<= 0) { continue; }
        res ^= cross(p, u, v) > 0;
    }
    return res;
}
```

### 8.2 Convex Hull and related

```
vector<P<T>> convexHull(vector<P<T>> a) {
    int n = a.size();
    if (n <= 1) { return a; }
    sort(a.begin(), a.end());
    a.resize(unique(a.begin(), a.end()), a.
end());
    vector<P<T>> b(2 * n);
    int j = 0;
    for (int i = 0; i < n; b[j++] = a[i++])
    {
        while (j >= 2 && side(b[j - 2], b[j -
1], a[i]) <= 0) { j--; }
    }
    for (int i = n - 2, k = j; i >= 0; b[j
++] = a[i--]) {
        while (j > k && side(b[j - 2], b[j -
1], a[i]) <= 0) { j--; }
    }
    b.resize(j - 1);
    return b;
}
// nonstrict : change <= 0 to < 0
// warning : if all point on same line
will return {1, 2, 3, 2}
```

### 8.3 Half Plane Intersection

```
vector<P<Real>> halfPlaneIntersection(
vector<L<Real>> a) {
    sort(a.begin(), a.end(), [&](auto l1,
auto l2) {
        if (sameDirection(l1, l2)) {
            return side(l1.a, l2) > 0;
        } else {
            return polar(direction(l1),
direction(l2));
        }
    });
    deque<L<Real>> dq;
    auto check = [&](L<Real> l, L<Real> l1,
L<Real> l2) { return side(
lineIntersection(l1, l2), l) > 0;
};
    for (int i = 0; i < int(a.size()); i++)
    {
        if (i > 0 && sameDirection(a[i], a[i
- 1])) { continue; }
        while (int(dq.size()) > 1 && !check(a
[i], dq.end()[-2], dq.back())) {
            dq.pop_back();
        }
        while (int(dq.size()) > 1 && !check(a
[i], dq[1], dq[0])) { dq.
pop_front(); }
        dq.push_back(a[i]);
    }
    while (int(dq.size()) > 2 && !check(dq
[0], dq.end()[-2], dq.back())) {
        dq.pop_back();
    }
    while (int(dq.size()) > 2 && !check(dq.
back(), dq[1], dq[0])) { dq.
pop_front(); }
    vector<P<Real>> res;
    dq.push_back(dq[0]);
    for (int i = 0; i + 1 < int(dq.size());
i++) { res.push_back(
lineIntersection(dq[i], dq[i + 1])
); }
    return res;
}
```

### 8.4 Triangle Centers

```
// radius: (a + b + c) * r / 2 = A or
pointToLineDist
P<Real> inCenter(P<Real> a, P<Real> b, P<
Real> c) {
    Real la = length(b - c), lb = length(c
- a), lc = length(a - b);
    return (a * la + b * lb + c * lc) / (la
+ lb + lc);
}
// used in min enclosing circle
P<Real> circumCenter(P<Real> a, P<Real> b
, P<Real> c) {
    P<Real> ba = b - a, ca = c - a;
    Real db = square(ba), dc = square(ca),
d = 2 * cross(ba, ca);
```

```

    return a - P<Real>(ba.y * dc - ca.y *
        db, ca.x * db - ba.x * dc) / d;
}
P<Real> orthoCenter(P<Real> a, P<Real> b,
    P<Real> c) {
    L<Real> u(c, P<Real>(c.x - a.y + b.y, c
        .y + a.x - b.x));
    L<Real> v(b, P<Real>(b.x - a.y + c.y, b
        .y + a.x - c.x));
    return lineIntersection(u, v);
}

```

## 8.5 Circle

```

const Real PI = acos(-1);
struct Circle {
    P<Real> o;
    Real r;
    Circle(P<Real> o = {}, Real r = 0) : o(o), r(r) {}
};
// actually counts number of tangent
// lines
int typeOfCircles(Circle c1, Circle c2) {
    auto [o1, r1] = c1;
    auto [o2, r2] = c2;
    Real d = dist(o1, o2);
    if (cmp(d, r1 + r2) == 1) { return 4; }
    if (cmp(d, r1 + r2) == 0) { return 3; }
    if (cmp(d, abs(r1 - r2)) == 1) { return
        2; }
    if (cmp(d, abs(r1 - r2)) == 0) { return
        1; }
    return 0;
}
// aligned l.a -> l.b;
vector<P<Real>> circleLineIntersection(
    Circle c, L<Real> l) {
    P<Real> p = projection(c.o, l);
    Real h = c.r * c.r - square(p - c.o);
    if (sign(h) < 0) { return {}; }
    P<Real> q = normal(direction(l)) *
        sqrt(c.r * c.r - square(p - c.o));
    return {p - q, p + q};
}
// circles shouldn't be identical
// duplicated if only one intersection,
// aligned c1 counterclockwise
vector<P<Real>> circleIntersection(Circle
    c1, Circle c2) {
    int type = typeOfCircles(c1, c2);
    if (type == 0 || type == 4) { return
        {}; }
    auto [o1, r1] = c1;
    auto [o2, r2] = c2;
    Real d = clamp(dist(o1, o2), abs(r1 -
        r2), r1 + r2);
    Real y = (r1 * r1 + d * d - r2 * r2) /
        (2 * d), x = sqrt(r1 * r1 - y * y);
    P<Real> dir = normal(o2 - o1), q1 = o1
        + dir * y, q2 = rotate90(dir) * x;
    return {q1 - q2, q1 + q2};
}
// counterclockwise, on circle -> no
// tangent
vector<P<Real>> pointCircleTangent(P<Real>
    p, Circle c) {
    Real x = square(p - c.o), d = x - c.r *
        c.r;
    if (sign(d) <= 0) { return {}; }
    P<Real> q1 = c.o + (p - c.o) * (c.r * c
        .r / x), q2 = rotate90(p - c.o) *
        (c.r * sqrt(d) / x);
    return {q1 - q2, q1 + q2};
}
// one-point tangent lines are not
// returned
vector<L<Real>> externalTangent(Circle c1
    , Circle c2) {
    auto [o1, r1] = c1;
    auto [o2, r2] = c2;
    vector<L<Real>> res;
    if (cmp(r1, r2) == 0) {
        P dr = rotate90(normal(o2 - o1)) * r1
            ;
        res.emplace_back(o1 + dr, o2 + dr);
        res.emplace_back(o1 - dr, o2 - dr);
    } else {
        P p = (o2 * r1 - o1 * r2) / (r1 - r2)
            ;
        auto ps = pointCircleTangent(p, c1),
            qs = pointCircleTangent(p, c2);
        for (int i = 0; i < int(min(ps.size(),
            qs.size())); i++) { res.
            emplace_back(ps[i], qs[i]); }
    }
    return res;
}
vector<L<Real>> internalTangent(Circle c1
    , Circle c2) {
    auto [o1, r1] = c1;
    auto [o2, r2] = c2;
    vector<L<Real>> res;
    P<Real> p = (o1 * r2 + o2 * r1) / (r1 +
        r2);
    auto ps = pointCircleTangent(p, c1), qs
        = pointCircleTangent(p, c2);
    for (int i = 0; i < int(min(ps.size(),
        qs.size())); i++) { res.
        emplace_back(ps[i], qs[i]); }
    return res;
}
// OAB and circle directed area
Real triangleCircleIntersectionArea(P<
    Real> p1, P<Real> p2, Real r) {
    auto angle = [&](P<Real> p1, P<Real> p2
        ) { return atan2(cross(p1, p2),
            dot(p1, p2)); };
    vector<P<Real>> v =
        circleLineIntersection(Circle(P<
            Real>(), r), L<Real>(p1, p2));
    if (v.empty()) { return r * r * angle(
        p1, p2) / 2; }
    bool b1 = cmp(square(p1), r * r) == 1,
        b2 = cmp(square(p2), r * r) == 1;
    if (b1 && b2) {
        if (sign(dot(p1 - v[0], p2 - v[0]))
            <= 0 && sign(dot(p1 - v[0], p2 -
                v[0])) <= 0) {
            return r * r * (angle(p1, v[0]) +
                angle(v[1], p2)) / 2 + cross(
                v[0], v[1]) / 2;
        } else {
            return r * r * angle(p1, p2) / 2;
        }
    } else if (b1) {
        return (r * r * angle(p1, v[0]) +
            cross(v[0], p2)) / 2;
    } else if (b2) {
        return (cross(p1, v[1]) + r * r *
            angle(v[1], p2)) / 2;
    } else {
        return cross(p1, p2) / 2;
    }
}
Real polyCircleIntersectionArea(const
    vector<P<Real>> &a, Circle c) {
    int n = a.size();
    Real ans = 0;
    for (int i = 0; i < n; i++) {
        ans += triangleCircleIntersectionArea
            (a[i], a[(i + 1) % n], c.r);
    }
    return ans;
}
Real circleIntersectionArea(Circle a,
    Circle b) {
    int t = typeOfCircles(a, b);
    if (t >= 3) {
        return 0;
    } else if (t <= 1) {
        Real r = min(a.r, b.r);
        return r * r * PI;
    }
    Real res = 0, d = dist(a.o, b.o);
    for (int i = 0; i < 2; ++i) {
        Real alpha = acos((b.r * b.r + d * d
            - a.r * a.r) / (2 * b.r * d));
        Real s = alpha * b.r * b.r;
        Real t = b.r * b.r * sin(alpha) * cos
            (alpha);
        res += s - t;
    }
    swap(a, b);
}
return res;
}

```

## 8.6 Delaunay Triangulation

```

const P<i64> pINF = P<i64>(1e18, 1e18);
using i128 = __int128_t;
struct Quad {
    P<i64> origin;
    Quad *rot = nullptr, *onext = nullptr;
    bool used = false;
    Quad* rev() const { return rot->rot; }
    Quad* lnext() const { return rot->rev()
        ->onext->rot; }
    Quad* oprev() const { return rot->onext
        ->rot; }
    P<i64> dest() const { return rev()->
        origin; }
};
Quad* makeEdge(P<i64> from, P<i64> to) {
    Quad *e1 = new Quad, *e2 = new Quad, *
        e3 = new Quad, *e4 = new Quad;
    e1->origin = from;
    e2->origin = to;
    e3->origin = e4->origin = pINF;
    e1->rot = e3;
    e2->rot = e4;
    e3->rot = e1;
    e4->rot = e2;
    e1->onext = e1;
    e2->onext = e2;
    e3->onext = e4;
    e4->onext = e3;
    return e1;
}
void splice(Quad *a, Quad *b) {
    swap(a->onext->rot->onext, b->onext->
        rot->onext);
    swap(a->onext, b->onext);
}
void delEdge(Quad *e) {
    splice(e, e->oprev());
    splice(e->rev(), e->rev()->oprev());
    delete e->rev()->rot;
    delete e->rev();
    delete e->rot;
    delete e;
}
Quad *connect(Quad *a, Quad *b) {
    Quad *e = makeEdge(a->dest(), b->origin
        );
    splice(e, a->lnext());
    splice(e->rev(), b);
    return e;
}
bool onLeft(P<i64> p, Quad *e) { return
    side(p, e->origin, e->dest()) > 0; }
bool onRight(P<i64> p, Quad *e) { return
    side(p, e->origin, e->dest()) < 0; }
template <class T>
T det3(T a1, T a2, T a3, T b1, T b2, T b3
    , T c1, T c2, T c3) {
    return a1 * (b2 * c3 - c2 * b3) - a2 *
        (b1 * c3 - c1 * b3) + a3 * (b1 *
        c2 - c1 * b2);
}
bool inCircle(P<i64> a, P<i64> b, P<i64>
    c, P<i64> d) {
    auto f = [&](P<i64> a, P<i64> b, P<i64>
        c) {
        return det3<i128>(a.x, a.y, square(a)
            , b.x, b.y, square(b), c.x, c.y,
            square(c));
    };
    i128 det = f(a, c, d) + f(a, b, c) - f(
        b, c, d) - f(a, b, d);
    return det > 0;
}
pair<Quad*, Quad*> build(int l, int r,
    vector<P<i64>> &p) {
    if (r - l == 2) {
        Quad *res = makeEdge(p[l], p[l + 1]);
        return pair(res, res->rev());
    } else if (r - l == 3) {
        Quad *a = makeEdge(p[l], p[l + 1]), *
            b = makeEdge(p[l + 1], p[l + 2])
            ;
    }
}

```



```

splice(a->rev(), b);
int sg = sign(cross(p[l], p[l + 1], p[l + 2]));
if (sg == 0) { return pair(a, b->rev()); }
Quad *c = connect(b, a);
if (sg == 1) {
    return pair(a, b->rev());
} else {
    return pair(c->rev(), c);
}
}
int m = l + r >> 1;
auto [ldo, ldi] = build(l, m, p);
auto [rdo, rdi] = build(m, r, p);
while (true) {
    if (onLeft(rdi->origin, ldi)) {
        ldi = ldi->lnext();
        continue;
    }
    if (onRight(ldi->origin, rdi)) {
        rdi = rdi->rev()->onext();
        continue;
    }
    break;
}
Quad *basel = connect(rdi->rev(), ldi);
auto valid = [&](Quad *e) { return onRight(e->dest(), basel); };
if (ldi->origin == ldo->origin) { ldo = basel->rev(); }
if (rdi->origin == rdo->origin) { rdo = basel; }
while (true) {
    Quad *lcand = basel->rev()->onext();
    if (valid(lcand)) {
        while (inCircle(basel->dest(), basel->origin, lcand->dest(), lcand->onext->dest())) {
            Quad *t = lcand->onext();
            delEdge(lcand);
            lcand = t;
        }
    }
    Quad *rcand = basel->oprev();
    if (valid(rcand)) {
        while (inCircle(basel->dest(), basel->origin, rcand->dest(), rcand->oprev->dest())) {
            Quad *t = rcand->oprev();
            delEdge(rcand);
            rcand = t;
        }
    }
    if (!valid(lcand) && !valid(rcand)) {
        break;
    }
    if (!valid(lcand) || valid(rcand) && inCircle(lcand->dest(), lcand->origin, rcand->origin, rcand->dest())) {
        basel = connect(rcand, basel->rev());
    }
    else {
        basel = connect(basel->rev(), lcand->rev());
    }
}
return pair(ldo, rdo);
}
vector<array<P<i64>, 3>> delaunay(vector<P<i64>> p) {
    sort(p.begin(), p.end());
    auto res = build(0, p.size(), p);
    Quad *e = res.first;
    vector<Quad*> edges = {e};
    while (sign(cross(e->onext->dest(), e->dest(), e->origin)) == -1) { e = e->onext; }
    auto add = [&]() {
        Quad *cur = e;
        do {
            cur->used = true;
            p.push_back(cur->origin);
            edges.push_back(cur->rev());
            cur = cur->lnext();
        } while (cur != e);
    };
};

```

```

add();
p.clear();
int i = 0;
while (i < int(edges.size())) { if (!e = edges[i++]->used) { add(); } }
vector<array<P<i64>, 3>> ans(p.size() / 3);
for (int i = 0; i < int(p.size()); i++) {
    ans[i / 3][i % 3] = p[i];
}
return ans;
}

```

## 8.7 ConvexHull Operations (yhchang3)

给定凸包，log n 内完成各种询问，具体操作有：

1. 判定一个点是否在凸包内
  2. 询问凸包外的点到凸包的两个切点
  3. 询问一个向量关于凸包的切点
  4. 询问一条直线和凸包的交点
- INF 为坐标范围，需要定义点类大于号改成实数只需修改 sign 函数，以及把 long long 改为 double 即可  
构造函数时传入凸包要求无重点，面积非空，以及 pair(x,y) 的最小点放在第一个

```

const int INF = 1e9;
struct Convex {
    int n;
    vector<Point> a, upper, lower;
    Convex(vector<Point> a_) : a(a_) {
        n = a_.size();
        int ptr = 0;
        for (int i = 1; i < n; i++) {
            if (a[ptr] < a[i]) ptr = i;
        }
        for (int i = 0; i <= ptr; i++) {
            lower.push_back(a[i]);
        }
        for (int i = ptr; i < n; i++) {
            upper.push_back(a[i]);
        }
        upper.push_back(a[0]);
    }
    int sign(long long x) { return x < 0 ? -1 : x > 0; }
    pair<long long, int> get_tangent(vector<Point> &convex, Point vec) {
        int l = 0, r = int(convex.size()) - 2;
        for (; l + 1 < r; ) {
            int mid = (l + r) / 2;
            if (sign((convex[mid + 1] - convex[mid]).det(vec)) > 0) r = mid;
            else l = mid;
        }
        return max(make_pair(vec.det(convex[r]), r), make_pair(vec.det(convex[l]), l));
    }
    void update_tangent(const Point &p, int id, int &i0, int &i1) {
        if ((a[i0] - p).det(a[id] - p) > 0) i0 = id;
        if ((a[i1] - p).det(a[id] - p) < 0) i1 = id;
    }
    void binary_search(int l, int r, Point p, int &i0, int &i1) {
        if (l == r) { return; }
        update_tangent(p, l % n, i0, i1);
        int sl = sign((a[l % n] - p).det(a[(l + 1) % n] - p));
        for (; l + 1 < r; ) {
            int mid = (l + r) / 2;
            int smid = sign((a[mid % n] - p).det(a[(mid + 1) % n] - p));
            if (smid == sl) l = mid;
            else r = mid;
        }
        update_tangent(p, r % n, i0, i1);
    }
    int binary_search(Point u, Point v, int l, int r) {
        int sl = sign((v - u).det(a[l % n] - u));
    };
};

```

```

for (; l + 1 < r; ) {
    int mid = (l + r) / 2;
    int smid = sign((v - u).det(a[mid % n] - u));
    if (smid == sl) l = mid;
    else r = mid;
}
return l % n;
}
// 判定点是否在凸包内，在边界返回 true
bool contain(Point p) {
    if (p.x < lower[0].x || p.x > lower.back().x) return false;
    int id = lower_bound(lower.begin(), lower.end(), Point(p.x, -INF)) - lower.begin();
    if (lower[id].x == p.x) {
        if (lower[id].y > p.y) return false;
    } else if ((lower[id - 1] - p).det(lower[id] - p) < 0) return false;
    id = lower_bound(upper.begin(), upper.end(), Point(p.x, INF), greater<Point>()) - upper.begin();
    if (upper[id].x == p.x) {
        if (upper[id].y < p.y) return false;
    } else if ((upper[id - 1] - p).det(upper[id] - p) < 0) return false;
    return true;
}
// 求点 p 关于凸包的两个切点，如果在凸包外则有序返回编号，共线的多个切点返回任意一个，否则返回 false
bool get_tangent(Point p, int &i0, int &i1) {
    if (contain(p)) return false;
    i0 = i1 = 0;
    int id = lower_bound(lower.begin(), lower.end(), p) - lower.begin();
    binary_search(0, id, p, i0, i1);
    binary_search(id, (int)lower.size(), p, i0, i1);
    id = lower_bound(upper.begin(), upper.end(), p, greater<Point>()) - upper.begin();
    binary_search((int)lower.size() - 1, (int)lower.size() - 1 + id, p, i0, i1);
    binary_search((int)lower.size() - 1 + id, (int)lower.size() - 1 + (int)upper.size(), p, i0, i1);
    return true;
}
// 求凸包上和向量 vec 叉积最大的点，返回编号，共线的多个切点返回任意一个
int get_tangent(Point vec) {
    pair<long long, int> ret = get_tangent(upper, vec);
    ret.second = (ret.second + int(lower.size()) - 1) % n;
    ret = max(ret, get_tangent(lower, vec));
    return ret.second;
}
// 求凸包和直线 u,v 的交点，如果无严格相交返回 false。如果有则是和(i, next(i)) 的交点，两个点无序，交点上不确定返回前后两条线段其中之一
bool get_intersection(Point p, Point v, int &i0, int &i1) {
    int p0 = get_tangent(u - v), p1 = get_tangent(v - u);
    if (sign((v - u).det(a[p0] - u)) * sign((v - u).det(a[p1] - u)) < 0) {
        if (p0 > p1) swap(p0, p1);
        i0 = binary_search(u, v, p0, p1);
        i1 = binary_search(u, v, p1, p0 + n);
        return true;
    } else { return false; }
}

```

## 9 Miscellaneous

### 9.1 Cactus 1

```
auto work = [&](const vector<int> cycle)
{
    // merge cycle info to u?
    int len = cycle.size(), u = cycle[0];
};
auto dfs = [&](auto dfs, int u, int p) {
    par[u] = p;
    vis[u] = 1;
    for (auto v : adj[u]) {
        if (v == p) { continue; }
        if (vis[v] == 0) {
            dfs(dfs, v, u);
            if (!cyc[v]) { // merge dp }
        } else if (vis[v] == 1) {
            for (int w = u; w != v; w = par[w])
                cyc[w] = 1;
        } else {
            vector<int> cycle = {u};
            for (int w = v; w != u; w = par[w])
                cycle.push_back(w);
            work(cycle);
        }
    }
    vis[u] = 2;
};
```

### 9.2 Cactus 2

```
// a component contains no articulation
// point, so P2 is a component
// but not a vertex biconnected component
// by definition
// resulting bct is rooted
struct BlockCutTree {
    int n, square = 0, cur = 0;
    vector<int> low, dfn, stk;
    vector<vector<int>> adj, bct;
    BlockCutTree(int n) : n(n), low(n), dfn(n),
        (n, -1), adj(n), bct(n) {}
    void build() { dfs(0); }
    void addEdge(int u, int v) { adj[u].
        push_back(v), adj[v].push_back(u); }
    void dfs(int u) {
        low[u] = dfn[u] = cur++;
        stk.push_back(u);
        for (auto v : adj[u]) {
            if (dfn[v] == -1) {
                dfs(v);
                low[u] = min(low[u], low[v]);
                if (low[v] == dfn[u]) {
                    bct.emplace_back();
                    int x;
                    do {
                        x = stk.back();
                        stk.pop_back();
                        bct.back().push_back(x);
                    } while (x != v);
                    bct[u].push_back(n + square);
                    square++;
                }
            } else {
                low[u] = min(low[u], dfn[v]);
            }
        }
    }
};
```

### 9.3 Dancing Links

```
#include <bits/stdc++.h>
using namespace std;
// tioj 1333
#define TRAV(i, link, start) for (int i =
    link[start]; i != start; i = link[i]
    ])
const int NN = 40000, RR = 200;
template<bool E> // E: Exact, NN: num of
    1s, RR: num of rows
```

```
struct DLX {
    int lt[NN], rg[NN], up[NN], dn[NN], rw[
        NN], cl[NN], bt[NN], s[NN], head,
        sz, ans;
    int rows, columns;
    bool vis[NN];
    bitset<RR> sol, cur; // not sure
    void remove(int c) {
        if (E) lt[rg[c]] = lt[c], rg[lt[c]] =
            rg[c];
        TRAV(i, dn, c) {
            if (E) {
                TRAV(j, rg, i)
                    up[dn[j]] = up[j], dn[up[j]] =
                        dn[j], --s[cl[j]];
            } else {
                lt[rg[i]] = lt[i], rg[lt[i]] = rg
                    [i];
            }
        }
    }
    void restore(int c) {
        TRAV(i, up, c) {
            if (E) {
                TRAV(j, lt, i)
                    ++s[cl[j]], up[dn[j]] = j, dn[
                        up[j]] = j;
            } else {
                lt[rg[i]] = rg[lt[i]] = i;
            }
        }
        if (E) lt[rg[c]] = c, rg[lt[c]] = c;
    }
    void init(int c) {
        rows = 0, columns = c;
        for (int i = 0; i < c; ++i) {
            up[i] = dn[i] = bt[i] = i;
            lt[i] = i == 0 ? c : i - 1;
            rg[i] = i == c - 1 ? c : i + 1;
            s[i] = 0;
        }
        rg[c] = 0, lt[c] = c - 1;
        up[c] = dn[c] = -1;
        head = c, sz = c + 1;
    }
    void insert(const vector<int> &col) {
        if (col.empty()) return;
        int f = sz;
        for (int i = 0; i < (int)col.size();
            ++i) {
            int c = col[i], v = sz++;
            dn[bt[c]] = v;
            up[v] = bt[c], bt[c] = v;
            rg[v] = (i + 1 == (int)col.size() ?
                f : v + 1);
            rw[v] = rows, cl[v] = c;
            ++s[c];
            if (i > 0) lt[v] = v - 1;
        }
        ++rows, lt[f] = sz - 1;
    }
    int h() {
        int ret = 0;
        fill_n(vis, sz, false);
        TRAV(x, rg, head) {
            if (vis[x]) continue;
            vis[x] = true, ++ret;
            TRAV(i, dn, x) TRAV(j, rg, i) vis[
                cl[j]] = true;
        }
        return ret;
    }
    void dfs(int dep) {
        if (dep + (E ? 0 : h()) >= ans)
            return;
        if (rg[head] == head) return sol =
            cur, ans = dep, void();
        if (dn[rg[head]] == rg[head]) return;
        int w = rg[head];
        TRAV(x, rg, head) if (s[x] < s[w]) w
            = x;
        if (E) remove(w);
        TRAV(i, dn, w) {
            if (!E) remove(i);
            TRAV(j, rg, i) remove(E ? cl[j] : j
                );
        }
    }
};
```

```
cur.set(rw[i]), dfs(dep + 1), cur.
    reset(rw[i]);
    TRAV(j, lt, i) restore(E ? cl[j] :
        j);
    if (!E) restore(i);
}
if (E) restore(w);
}
int solve() {
    for (int i = 0; i < columns; ++i)
        dn[bt[i]] = i, up[i] = bt[i];
    ans = 1e9, sol.reset(), dfs(0);
    return ans;
}
int main() {
    int n, m; cin >> n >> m;
    DLX<true> solver;
    solver.init(m);
    for (int i = 0; i < n; ++i) {
        vector<int> add;
        for (int j = 0; j < m; ++j) {
            int x; cin >> x;
            if (x == 1) {
                add.push_back(j);
            }
        }
        solver.insert(add);
    }
    cout << solver.solve() << '\n';
    return 0;
}
```

### 9.4 Offline Dynamic MST

```
int cnt[maxn], cost[maxn], st[maxn], ed[
    maxn];
pair<int, int> qr[maxn];
// qr[i].first = id of edge to be changed
// qr[i].second = weight after
// operation
// cnt[i] = number of operation on edge i
// call solve(0, q - 1, v, 0), where v
// contains edges i such that cnt[i] ==
// 0
void contract(int l, int r, vector<int> v
    , vector<int> &x, vector<int> &y) {
    sort(v.begin(), v.end(), [&](int i, int
        j) {
        if (cost[i] == cost[j]) return i <
            j;
        return cost[i] < cost[j];
    });
    djs.save();
    for (int i = l; i <= r; ++i) djs.merge(
        st[qr[i].first], ed[qr[i].first]);
    for (int i = 0; i < (int)v.size(); ++i)
        if (djs.find(st[v[i]]) != djs.find(ed
            [v[i]])) {
            x.push_back(v[i]);
            djs.merge(st[v[i]], ed[v[i]]);
        }
    djs.undo();
    djs.save();
    for (int i = 0; i < (int)x.size(); ++i)
        djs.merge(st[x[i]], ed[x[i]]);
    for (int i = 0; i < (int)v.size(); ++i)
        if (djs.find(st[v[i]]) != djs.find(ed
            [v[i]])) {
            y.push_back(v[i]);
            djs.merge(st[v[i]], ed[v[i]]);
        }
    djs.undo();
}
void solve(int l, int r, vector<int> v,
    long long c) {
    if (l == r) {
        cost[qr[l].first] = qr[l].second;
        if (st[qr[l].first] == ed[qr[l].first]
            ) {
            printf("%lld\n", c);
        }
    }
}
```

```

    return;
}
int minv = qr[l].second;
for (int i = 0; i < (int)v.size(); ++i) minv = min(minv, cost[v[i]]);
printf("%lld\n", c + minv);
return;
}
int m = (l + r) >> 1;
vector<int> lv = v, rv = v;
vector<int> x, y;
for (int i = m + 1; i <= r; ++i) {
    cnt[qr[i].first]--;
    if (cnt[qr[i].first] == 0) lv.push_back(qr[i].first);
}
contract(l, m, lv, x, y);
long long lc = c, rc = c;
djs.save();
for (int i = 0; i < (int)x.size(); ++i) {
    lc += cost[x[i]];
    djs.merge(st[x[i]], ed[x[i]]);
}
solve(l, m, y, lc);
djs.undo();
x.clear(), y.clear();
for (int i = m + 1; i <= r; ++i) cnt[qr[i].first]++;
for (int i = l; i <= m; ++i) {
    cnt[qr[i].first]--;
    if (cnt[qr[i].first] == 0) rv.push_back(qr[i].first);
}
contract(m + 1, r, rv, x, y);
djs.save();
for (int i = 0; i < (int)x.size(); ++i) {
    rc += cost[x[i]];
    djs.merge(st[x[i]], ed[x[i]]);
}
solve(m + 1, r, y, rc);
djs.undo();
for (int i = l; i <= m; ++i) cnt[qr[i].first]++;
}
}

```

## 9.5 Matroid Intersection

- $x \rightarrow y$  if  $S - \{x\} \cup \{y\} \in I_1$  with  $cost(\{y\})$ .
- $source \rightarrow y$  if  $S \cup \{y\} \in I_1$  with  $cost(\{y\})$ .
- $y \rightarrow x$  if  $S - \{x\} \cup \{y\} \in I_2$  with  $-cost(\{y\})$ .
- $y \rightarrow sink$  if  $S \cup \{y\} \in I_2$  with  $-cost(\{y\})$ .

Augmenting path is shortest path from source to sink.

## 9.6 Euler Tour

```

vector<int> euler, vis(V);
auto dfs = [&](auto dfs, int u) -> void {
    while (!adj[u].empty()) {
        while (!adj[u].empty() && del[adj[u].back()[1]]) {
            adj[u].pop_back();
        }
        if (!adj[u].empty()) {
            auto [v, i] = adj[u].back();
            del[i] = true;
            dfs(dfs, v);
        }
    }
    euler.push_back(u);
};
dfs(dfs, 0);
reverse(euler.begin(), euler.end());

```

## 9.7 SegTree Beats

```

struct SegmentTree {
    int n;
    struct node {
        i64 mx1, mx2, mxc;
        i64 mn1, mn2, mnc;
        i64 add;
        i64 sum;
        node(i64 v = 0) {
            mx1 = mn1 = sum = v;
        }
    };
    vector<node> t;
    void build(int id, int l, int r) {
        auto& c = t[id];
        if (l == r) {
            c.add = 0;
            c.sum = t[id].sum;
            return;
        }
        int m = (l + r) >> 1;
        build(id << 1, l, m);
        build(id << 1 | 1, m + 1, r);
        c.add = 0;
        c.sum = t[id << 1].sum + t[id << 1 | 1].sum;
        c.mx1 = max(t[id << 1].mx1, t[id << 1 | 1].mx1);
        c.mx2 = max(t[id << 1].mx2, t[id << 1 | 1].mx2);
        c.mn1 = min(t[id << 1].mn1, t[id << 1 | 1].mn1);
        c.mn2 = min(t[id << 1].mn2, t[id << 1 | 1].mn2);
        c.mxc = max(t[id << 1].mxc, t[id << 1 | 1].mxc);
        c.mnc = min(t[id << 1].mnc, t[id << 1 | 1].mnc);
    }
    void apply_add(int id, int l, int r, i64 v) {
        auto& c = t[id];
        if (v == 0) return;
        c.add += v;
        c.sum += v * (r - l + 1);
        c.mx1 += v;
        c.mx2 += v;
        c.mn1 += v;
        c.mn2 += v;
    }
    void apply_min(int id, int l, int r, i64 v) {
        auto& c = t[id];
        if (v <= c.mn1) return;
        c.sum -= c.mn1 * c.mnc;
        c.mn1 = v;
        c.sum += c.mn1 * c.mnc;
        if (l == r || v >= c.mx1) {
            c.mx1 = v;
        } else if (v > c.mx2) {
            c.mx2 = v;
        }
    }
    void apply_max(int id, int l, int r, i64 v) {
        auto& c = t[id];
        if (v >= c.mx1) return;
        c.sum -= c.mx1 * c.mxc;
        c.mx1 = v;
        c.sum += c.mx1 * c.mxc;
        if (l == r || v <= c.mn1) {
            c.mn1 = v;
        } else if (v < c.mn2) {
            c.mn2 = v;
        }
    }
    void pull(int id) {
        auto& c = t[id], &lc = t[id << 1], &rc = t[id << 1 | 1];
        c.sum = lc.sum + rc.sum;
        if (lc.mn1 == rc.mn1) {
            c.mn1 = lc.mn1;
            c.mn2 = min(lc.mn2, rc.mn2);
            c.mnc = lc.mnc + rc.mnc;
        } else if (lc.mn1 < rc.mn1) {
            c.mn1 = lc.mn1;
            c.mn2 = min(lc.mn2, rc.mn1);
            c.mnc = lc.mnc;
        } else {
            c.mn1 = rc.mn1;
            c.mn2 = min(lc.mn1, rc.mn2);
            c.mnc = rc.mnc;
        }
        if (lc.mx1 == rc.mx1) {
            c.mx1 = lc.mx1;
            c.mx2 = max(lc.mx2, rc.mx2);
            c.mxc = lc.mxc + rc.mxc;
        } else if (lc.mx1 > rc.mx1) {
            c.mx1 = lc.mx1;
            c.mx2 = max(lc.mx2, rc.mx1);
            c.mxc = lc.mxc;
        } else {
            c.mx1 = rc.mx1;
            c.mx2 = max(lc.mx1, rc.mx2);
            c.mxc = rc.mxc;
        }
    }
    void range_chmin(int id, int l, int r, int ql, int qr, i64 v) {
        if (r < ql || l > qr || v >= t[id].mx1) return;
        if (ql <= l && r <= qr && v > t[id].mx2) {
            apply_max(id, l, r, v);
            return;
        }
        push(id, l, r);
        int m = (l + r) >> 1;
        range_chmin(id << 1, l, m, ql, qr, v);
        range_chmin(id << 1 | 1, m + 1, r, ql, qr, v);
        pull(id);
    }
    void range_chmin(int ql, int qr, i64 v) {
        range_chmin(1, 0, n - 1, ql, qr, v);
    }
    void range_chmax(int id, int l, int r, int ql, int qr, i64 v) {
        if (r < ql || l > qr || v <= t[id].mn1) return;
        if (ql <= l && r <= qr && v < t[id].mn2) {
            apply_min(id, l, r, v);
            return;
        }
        push(id, l, r);
        int m = (l + r) >> 1;
        range_chmax(id << 1, l, m, ql, qr, v);
        range_chmax(id << 1 | 1, m + 1, r, ql, qr, v);
        pull(id);
    }
    void range_chmax(int ql, int qr, i64 v) {
        range_chmax(1, 0, n - 1, ql, qr, v);
    }
    void range_add(int id, int l, int r, int ql, int qr, i64 v) {
        if (r < ql || l > qr) return;
        if (ql <= l && r <= qr) {
            apply_add(id, l, r, v);
            return;
        }
        push(id, l, r);
        int m = (l + r) >> 1;
        range_add(id << 1, l, m, ql, qr, v);
        range_add(id << 1 | 1, m + 1, r, ql, qr, v);
        pull(id);
    }
    void range_add(int ql, int qr, i64 v) {
        range_add(1, 0, n - 1, ql, qr, v);
    }
    i64 range_sum(int id, int l, int r, int ql, int qr) {
        if (r < ql || l > qr) return 0;
        if (ql <= l && r <= qr) return t[id].sum;
        push(id, l, r);
        int m = (l + r) >> 1;
        return t[id << 1].sum + t[id << 1 | 1].sum;
    }
    i64 sum(int id, int l, int r) {
        return range_sum(id, l, r, l, r);
    }
    i64 sum() {
        return sum(1, 0, n - 1);
    }
}

```

```

    return range_sum(id << 1, l, m, ql,
        qr) + range_sum(id << 1 | 1, m +
            1, r, ql, qr);
}
i64 range_sum(int ql, int qr) {
    return range_sum(1, 0, n - 1, ql, qr)
        ;
}
};

```

## 9.8 unorganized

```

vector<pll> Minkowski(vector<pll> A,
    vector<pll> B) {
    hull(A), hull(B);
    vector<pll> C(1, A[0] + B[0]), s1, s2;
    for (int i = 0; i < SZ(A); ++i)
        s1.pb(A[i + 1] % SZ(A)) - A[i]);
    for (int i = 0; i < SZ(B); ++i)
        s2.pb(B[i + 1] % SZ(B)) - B[i]);
    for (int i = 0, j = 0; i < SZ(A) || j <
        SZ(B);)
        if (j >= SZ(B) || (i < SZ(A) && cross
            (s1[i], s2[j]) >= 0))
            C.pb(B[j % SZ(B)] + A[i++]);
        else
            C.pb(A[i % SZ(A)] + B[j++]);
    return hull(C), C;
}

bool PointInConvex(const vector<pll> &C,
    pll p, bool strict = true) {
    int a = 1, b = SZ(C) - 1, r = !strict;
    if (SZ(C) == 0) return false;
    if (SZ(C) < 3) return r && btw(C[0], C.
        back(), p);
    if (ori(C[0], C[a], C[b]) > 0) swap(a,
        b);
    if (ori(C[0], C[a], p) >= r || ori(C
        [0], C[b], p) <= -r)
        return false;
    while (abs(a - b) > 1) {
        int c = (a + b) / 2;
        (ori(C[0], C[c], p) > 0 ? b : a) = c;
    }
    return ori(C[a], C[b], p) < r;
}

const int N = 1021;
struct CircleCover {
    int C;
    Cir c[N];
    bool g[N][N], overlap[N][N];
    // Area[i] : area covered by at least i
    // circles
    double Area[N];
    void init(int _C) { C = _C; }
    struct Teve {
        pdd p; double ang; int add;
        Teve() {}
        Teve(_a, double _b, int _c): p(_a)
            , ang(_b), add(_c) {}
        bool operator<(const Teve &a) const
            { return ang < a.ang; }
    } eve[N * 2];
    // strict: x = 0, otherwise x = -1
    bool disjunct(Cir &a, Cir &b, int x)
    { return sign(abs(a.0 - b.0) - a.R - b.R
        ) > x; }
    bool contain(Cir &a, Cir &b, int x)
    { return sign(a.R - b.R - abs(a.0 - b.0)
        ) > x; }
    bool contain(int i, int j) {
        /* c[j] is non-strictly in c[i]. */
        return (sign(c[i].R - c[j].R) > 0 ||
            (sign(c[i].R - c[j].R) == 0 && i
                < j)) && contain(c[i], c[j],
                    -1);
    }
    void solve() {
        fill_n(Area, C + 2, 0);
        for (int i = 0; i < C; ++i)
            for (int j = 0; j < C; ++j)
                overlap[i][j] = contain(i, j);
        for (int i = 0; i < C; ++i)
            for (int j = 0; j < C; ++j)

```

```

                g[i][j] = !(overlap[i][j] ||
                    overlap[j][i] ||
                    disjunct(c[i], c[j], -1));
        for (int i = 0; i < C; ++i) {
            int E = 0, cnt = 1;
            for (int j = 0; j < C; ++j)
                if (j != i && overlap[j][i])
                    ++cnt;
            for (int j = 0; j < C; ++j)
                if (i != j && g[i][j]) {
                    pdd aa, bb;
                    CCinter(c[i], c[j], aa, bb);
                    double A = atan2(aa.Y - c[i].0.X,
                        Y, aa.X - c[i].0.X);
                    double B = atan2(bb.Y - c[i].0.X,
                        Y, bb.X - c[i].0.X);
                    eve[E++] = Teve(bb, B, 1), eve[
                        E++] = Teve(aa, A, -1);
                    if (B > A) ++cnt;
                }
            if (E == 0) Area[cnt] += pi * c[i].R
                * c[i].R;
            else {
                sort(eve, eve + E);
                eve[E] = eve[0];
                for (int j = 0; j < E; ++j) {
                    cnt += eve[j].add;
                    Area[cnt] += cross(eve[j].p,
                        eve[j + 1].p) * .5;
                    double theta = eve[j + 1].ang -
                        eve[j].ang;
                    if (theta < 0) theta += 2. * pi
                        ;
                    Area[cnt] += (theta - sin(theta)
                        ) * c[i].R * c[i].R * .5;
                }
            }
        }
    }
}

struct Point {
    double x, y, z;
    Point(double _x = 0, double _y = 0,
        double _z = 0): x(_x), y(_y), z(_z
        ) {}
    Point(pdd p) { x = p.X, y = p.Y, z =
        abs2(p); }
};

Point operator-(Point p1, Point p2)
{ return Point(p1.x - p2.x, p1.y - p2.y,
    p1.z - p2.z); }
Point operator+(Point p1, Point p2)
{ return Point(p1.x + p2.x, p1.y + p2.y,
    p1.z + p2.z); }
Point operator*(Point p1, double v)
{ return Point(p1.x * v, p1.y * v, p1.z *
    v); }
Point operator/(Point p1, double v)
{ return Point(p1.x / v, p1.y / v, p1.z /
    v); }
Point cross(Point p1, Point p2)
{ return Point(p1.y * p2.z - p1.z * p2.y,
    p1.z * p2.x - p1.x * p2.z, p1.x *
    p2.y - p1.y * p2.x); }
double dot(Point p1, Point p2)
{ return p1.x * p2.x + p1.y * p2.y + p1.z
    * p2.z; }
double abs(Point a)
{ return sqrt(dot(a, a)); }
Point cross3(Point a, Point b, Point c)
{ return cross(b - a, c - a); }
double area(Point a, Point b, Point c)
{ return abs(cross3(a, b, c)); }
double volume(Point a, Point b, Point c,
    Point d)
{ return dot(cross3(a, b, c), d - a); }
//Azimuthal angle (longitude) to x-axis
//in interval [-pi, pi]
double phi(Point p) { return atan2(p.y, p
    .x); }
//Zenith angle (latitude) to the z-axis
//in interval [0, pi]
double theta(Point p) { return atan2(sqrt
    (p.x * p.x + p.y * p.y), p.z); }
Point masscenter(Point a, Point b, Point
    c, Point d)

```

```

{ return (a + b + c + d) / 4; }
pdd proj(Point a, Point b, Point c, Point
    u) {
    // proj. u to the plane of a, b, and c
    Point e1 = b - a;
    Point e2 = c - a;
    e1 = e1 / abs(e1);
    e2 = e2 - e1 * dot(e2, e1);
    e2 = e2 / abs(e2);
    Point p = u - a;
    return pdd(dot(p, e1), dot(p, e2));
}
Point rotate_around(Point p, double angle
    , Point axis) {
    double s = sin(angle), c = cos(angle);
    Point u = axis / abs(axis);
    return u * dot(u, p) * (1 - c) + p * c
        + cross(u, p) * s;
}

struct convex_hull_3D {
    struct Face {
        int a, b, c;
        Face(int ta, int tb, int tc): a(ta), b(
            tb), c(tc) {}
    }; // return the faces with pt indexes
    vector<Face> res;
    vector<Point> P;
    convex_hull_3D(const vector<Point> &_P):
        res(), P(_P) {}
    // all points coplanar case will WA, O(n
        ^2)
    int n = SZ(P);
    if (n <= 2) return; // be careful about
    // edge case
    // ensure first 4 points are not
    // coplanar
    swap(P[1], *find_if(ALL(P), [&](auto p)
        { return sign(abs2(P[0] - p)) !=
            0; }));
    swap(P[2], *find_if(ALL(P), [&](auto p)
        { return sign(abs2(cross3(p, P
            [0], P[1]))) != 0; }));
    swap(P[3], *find_if(ALL(P), [&](auto p)
        { return sign(volume(P[0], P[1],
            P[2], p)) != 0; }));
    vector<vector<int>> flag(n, vector<int>
        >(n));
    res.emplace_back(0, 1, 2); res.
        emplace_back(2, 1, 0);
    for (int i = 3; i < n; ++i) {
        vector<Face> next;
        for (auto f : res) {
            int d = sign(volume(P[f.a], P[f.b],
                P[f.c], P[i]));
            if (d <= 0) next.pb(f);
            int ff = (d > 0) - (d < 0);
            flag[f.a][f.b] = flag[f.b][f.c] =
                flag[f.c][f.a] = ff;
        }
        for (auto f : res) {
            auto F = [&](int x, int y) {
                if (flag[x][y] > 0 && flag[y][x]
                    <= 0)
                    next.emplace_back(x, y, i);
            };
            F(f.a, f.b); F(f.b, f.c); F(f.c, f.
                a);
        }
        res = next;
    }
}

bool same(Face s, Face t) {
    if (sign(volume(P[s.a], P[s.b], P[s.c],
        P[t.a])) != 0) return 0;
    if (sign(volume(P[s.a], P[s.b], P[s.c],
        P[t.b])) != 0) return 0;
    if (sign(volume(P[s.a], P[s.b], P[s.c],
        P[t.c])) != 0) return 0;
    return 1;
}

int polygon_face_num() {
    int ans = 0;
    for (int i = 0; i < SZ(res); ++i)
        ans += none_of(res.begin(), res.begin
            () + i, [&](Face g) { return
                same(res[i], g); });
}

```



```

return ans;
}
double get_volume() {
double ans = 0;
for (auto f : res)
ans += volume(Point(0, 0, 0), P[f.a],
P[f.b], P[f.c]);
return fabs(ans / 6);
}
double get_dis(Point p, Face f) {
Point p1 = P[f.a], p2 = P[f.b], p3 = P[
f.c];
double a = (p2.y - p1.y) * (p3.z - p1.z
) - (p2.z - p1.z) * (p3.y - p1.y);
double b = (p2.z - p1.z) * (p3.x - p1.x
) - (p2.x - p1.x) * (p3.z - p1.z);
double c = (p2.x - p1.x) * (p3.y - p1.y
) - (p2.y - p1.y) * (p3.x - p1.x);
double d = 0 - (a * p1.x + b * p1.y + c
* p1.z);
return fabs(a * p.x + b * p.y + c * p.z
+ d) / sqrt(a * a + b * b + c * c
);
}
};
// n^2 delaunay: facets with negative z
normal of
// convexhull of (x, y, x^2 + y^2), use a
pseudo-point
// (0, 0, inf) to avoid degenerate case
vector<pdd> cut(vector<pdd> poly, pdd s,
pdd e) {
vector<pdd> res;
for (int i = 0; i < SZ(poly); ++i) {
pdd cur = poly[i], prv = i ? poly[i -
1] : poly.back();
bool side = ori(s, e, cur) < 0;
if (side != (ori(s, e, prv) < 0))
res.pb(intersect(s, e, cur, prv));
if (side)
res.pb(cur);
}
return res;
}
// p, q is convex
double TwoConvexHullMinDist(Point P[],
Point Q[], int n, int m) {
int YMinP = 0, YMaxQ = 0;
double tmp, ans = 999999999;
for (i = 0; i < n; ++i) if (P[i].y < P[
YMinP].y) YMinP = i;
for (i = 0; i < m; ++i) if (Q[i].y > Q[
YMaxQ].y) YMaxQ = i;
P[n] = P[0], Q[m] = Q[0];
for (int i = 0; i < n; ++i) {
while (tmp = Cross(Q[YMaxQ + 1] - P[
YMinP + 1], P[YMinP] - P[YMinP +
1]) > Cross(Q[YMaxQ] - P[YMinP
+ 1], P[YMinP] - P[YMinP + 1]))
YMaxQ = (YMaxQ + 1) % m;
if (tmp < 0) ans = min(ans,
PointToSegDist(P[YMinP], P[YMinP
+ 1], Q[YMaxQ]));
else ans = min(ans, TwoSegMinDist(P[
YMinP], P[YMinP + 1], Q[YMaxQ],
Q[YMaxQ + 1]));
YMinP = (YMinP + 1) % n;
}
return ans;
}
template <typename F, typename C> class
MCMF {
static constexpr F INF_F =
numeric_limits<F>::max();
static constexpr C INF_C =
numeric_limits<C>::max();
vector<tuple<int, int, F, C>> es;
vector<vector<int>> g;
vector<F> f;
vector<C> d;
vector<int> pre, inq;
void spfa(int s) {
fill(inq.begin(), inq.end(), 0);
fill(d.begin(), d.end(), INF_C);
fill(pre.begin(), pre.end(), -1);
queue<int> q;
d[s] = 0;
q.push(s);
while (!q.empty()) {
int u = q.front();
inq[u] = false;
q.pop();
for (int j : g[u]) {
int to = get<1>(es[j]);
C w = get<3>(es[j]);
if (f[j] == 0 || d[to] <= d[u] +
w)
continue;
d[to] = d[u] + w;
pre[to] = j;
if (!inq[to]) {
inq[to] = true;
q.push(to);
}
}
}
}
public:
MCMF(int n) : g(n), pre(n), inq(n) {}
void add_edge(int s, int t, F c, C w) {
g[s].push_back(es.size());
es.emplace_back(s, t, c, w);
g[t].push_back(es.size());
es.emplace_back(t, s, 0, -w);
}
pair<F, C> solve(int s, int t, C mx =
INF_C / INF_F) {
add_edge(t, s, INF_F, -mx);
f.resize(es.size()), d.resize(es.size
());
for (F I = INF_F ^ (INF_F / 2); I; I
>= 1) {
for (auto &fi : f)
fi *= 2;
for (size_t i = 0; i < f.size(); i
+= 2) {
auto [u, v, c, w] = es[i];
if ((c & I) == 0)
continue;
if (f[i]) {
f[i] += 1;
continue;
}
spfa(v);
if (d[u] == INF_C || d[u] + w >=
0) {
f[i] += 1;
continue;
}
f[i + 1] += 1;
while (u != v) {
int x = pre[u];
f[x] += 1;
f[x ^ 1] += 1;
u = get<0>(es[x]);
}
}
}
C w = 0;
for (size_t i = 1; i + 2 < f.size();
i += 2)
w -= f[i] * get<3>(es[i]);
return {f.back(), w};
}
};
auto [f, c] = mcmf.solve(s, t, 1e12);
cout << f << ' ' << c << '\n';
void MoAlgoOnTree() {
Dfs(0, -1);
vector<int> euler(tk);
for (int i = 0; i < n; ++i) {
euler[tin[i]] = i;
euler[tout[i]] = i;
}
vector<int> l(q), r(q), qr(q), sp(q,
-1);
for (int i = 0; i < q; ++i) {
if (tin[u[i]] > tin[v[i]]) swap(u[i],
v[i]);
int z = GetLCA(u[i], v[i]);
sp[i] = z[i];
if (z == u) l[i] = tin[u[i]], r[i] =
tin[v[i]];
else l[i] = tout[u[i]], r[i] = tin[v[
i]];
qr[i] = i;
}
sort(qr.begin(), qr.end(), [&](int i,
int j) {
if (l[i] / kB == l[j] / kB) return
r[i] < r[j];
return l[i] / kB < l[j] / kB;
});
vector<bool> used(n);
// Add(v): add/remove v to/from the
path based on used[v]
for (int i = 0, tl = 0, tr = -1; i < q;
++i) {
while (tl < l[qr[i]]) Add(euler[tl
++]);
while (tl > l[qr[i]]) Add(euler[--tl
]);
while (tr > r[qr[i]]) Add(euler[tr
--]);
while (tr < r[qr[i]]) Add(euler[++tr
]);
// add/remove LCA(u, v) if necessary
}
}
for (int l = 0, r = -1; auto [ql, qr, i]
: qs) {
if (ql / B == qr / B) {
for (int j = ql; j <= qr; j++) {
cntSmall[a[j]]++;
ans[i] = max(ans[i], 1LL * b[
a[j]] * cntSmall[a[j]]);
}
for (int j = ql; j <= qr; j++) {
cntSmall[a[j]]--;
}
continue;
}
if (int block = ql / B; block != lst)
{
int x = min((block + 1) * B, n);
while (r + 1 < x) { add(++r); }
while (r >= x) { del(r--); }
while (l < x) { del(l++); }
mx = 0;
lst = block;
}
while (r < qr) { add(++r); }
i64 tmpMx = mx;
int tmpL = l;
while (l > ql) { add(--l); }
ans[i] = mx;
mx = tmpMx;
while (l < tmpL) { del(l++); }
}
}
typedef pair<ll, int> T;
typedef struct heap* ph;
struct heap { // min heap
ph l = NULL, r = NULL;
int s = 0; T v; // s: path to leaf
heap(T _v):v(_v) {}
};
ph meld(ph p, ph q) {
if (!p || !q) return p ? q;
if (p->v > q->v) swap(p, q);
ph P = new heap(*p); P->r = meld(P->r, q
);
if (!P->l || P->l->s < P->r->s) swap(P
->l, P->r);
P->s = (P->r ? P->r->s : 0) + 1; return P;
}
ph ins(ph p, T v) { return meld(p, new
heap(v)); }
ph pop(ph p) { return meld(p->l, p->r); }
int N, M, src, des, K;
ph cand[MX];
vector<array<int, 3>> adj[MX], radj[MX];
pi pre[MX];

```

```

ll dist[MX];
struct state {
    int vert; ph p; ll cost;
    bool operator<(const state& s) const {
        return cost > s.cost;
    }
};
int main() {
    setIO(); re(N,M,src,des,K);
    F0R(i,M) {
        int u,v,w; re(u,v,w);
        adj[u].pb({v,w,i}); radj[v].pb({u,w,i}); // vert, weight, label
    }
    priority_queue<state> ans;
    {
        F0R(i,N) dist[i] = INF, pre[i] = {-1,-1};
        priority_queue<T,vector<T>,greater<T>> pq;
        auto ad = [&](int a, ll b, pi ind) {
            if (dist[a] <= b) return;
            pre[a] = ind; pq.push({dist[a] = b, a});
        };
        ad(des,0,{-1,-1});
        vi seq;
        while (sz(pq)) {
            auto a = pq.top(); pq.pop();
            if (a.f > dist[a.s]) continue;
            seq.pb(a.s); trav(t,radj[a.s]) ad(t[0],a.f+t[1],{t[2],a.s}); // edge index, vert
        }
        trav(t,seq) {
            trav(u,adj[t]) if (u[2] != pre[t].f && dist[u[0]] != INF) {
                ll cost = dist[u[0]]+u[1]-dist[t];
                cand[t] = ins(cand[t],{cost,u[0]});
            }
            if (pre[t].f != -1) cand[t] = meld(cand[t],cand[pre[t].s]);
            if (t == src) {
                ps(dist[t]); K --;
                if (cand[t]) ans.push(state{t, cand[t],dist[t]+cand[t]->v.f});
            }
        }
    }
    F0R(i,K) {
        if (!sz(ans)) {
            ps(-1);
            continue;
        }
        auto a = ans.top(); ans.pop();
        int vert = a.vert;
        ps(a.cost);
        if (a.p->l) {
            ans.push(state{vert,a.p->l,a.cost+a.p->l->v.f-a.p->v.f});
        }
        if (a.p->r) {
            ans.push(state{vert,a.p->r,a.cost+a.p->r->v.f-a.p->v.f});
        }
        int V = a.p->v.s;
        if (cand[V]) ans.push(state{V,cand[V],a.cost+cand[V]->v.f});
    }
}

Pt LinesInter(Line a, Line b) {
    double abc = (a.b - a.a) ^ (b.a - a.a);
    double abd = (a.b - a.a) ^ (b.b - a.a);
    if (sign(abc - abd) == 0) return b.b;
    // no inter
    return (b.b * abc - b.a * abd) / (abc - abd);
}

vector<Pt> SegsInter(Line a, Line b) {
    if (btw(a.a, a.b, b.a)) return {b.a};
    if (btw(a.a, a.b, b.b)) return {b.b};

```

```

    if (btw(b.a, b.b, a.a)) return {a.a};
    if (btw(b.a, b.b, a.b)) return {a.b};
    if (ori(a.a, a.b, b.a) * ori(a.a, a.b, b.b) == -1 && ori(b.a, b.b, a.a) * ori(b.a, b.b, a.b) == -1) {
        return {LinesInter(a, b)};
    }
    return {};
}

double polyUnion(vector<vector<Pt>> poly) {
    int n = poly.size();
    double ans = 0;
    auto solve = [&](Pt a, Pt b, int cid) {
        vector<pair<Pt, int>> event;
        for (int i = 0; i < n; ++i) {
            int st = 0, sz = poly[i].size();
            while (st < sz && ori(poly[i][st], a, b) != 1) st++;
            if (st == sz) continue;
            for (int j = 0; j < sz; ++j) {
                Pt c = poly[i][(j + st) % sz], d = poly[i][(j + st + 1) % sz];
                if (sign((a - b) ^ (c - d)) != 0) {
                    int ok1 = ori(c, a, b) == 1;
                    int ok2 = ori(d, a, b) == 1;
                    if (ok1 ^ ok2) event.emplace_back(LinesInter({a, b}, {c, d}), ok1 ? 1 : -1);
                } else if (ori(c, a, b) == 0 && sign((a - b) * (c - d)) > 0 && i <= cid) {
                    event.emplace_back(c, -1);
                    event.emplace_back(d, 1);
                }
            }
        }
        sort(all(event), [&](pair<Pt, int> i, pair<Pt, int> j) {
            return ((a - i.first) * (a - b)) < ((a - j.first) * (a - b));
        });
        int now = 0;
        Pt lst = a;
        for (auto [x, y] : event) {
            if (btw(a, b, lst) && btw(a, b, x) && now == 0) ans += lst ^ x;
            now += y, lst = x;
        }
    };
    for (int i = 0; i < n; ++i) for (int j = 0; j < poly[i].size(); ++j) {
        Pt a = poly[i][j], b = poly[i][(j + 1) % poly[i].size()];
        solve(a, b, i);
    }
    return ans / 2;
}

// Minimum Steiner Tree, 0(V 3^T + V^2 2^T)
struct SteinerTree { // 0-base
    static const int T = 10, N = 105, INF = 1e9;
    int n, dst[N][N], dp[1 << T][N], tdst[N];
    int vcost[N]; // the cost of vertexs
    void init(int _n) {
        n = _n;
        for (int i = 0; i < n; ++i) {

```

```

            for (int j = 0; j < n; ++j) dst[i][j] = INF;
            dst[i][i] = vcost[i] = 0;
        }
    }
    void add_edge(int ui, int vi, int wi) {
        dst[ui][vi] = min(dst[ui][vi], wi);
    }
    void shortest_path() {
        for (int k = 0; k < n; ++k)
            for (int i = 0; i < n; ++i)
                for (int j = 0; j < n; ++j)
                    dst[i][j] = min(dst[i][j], dst[i][k] + dst[k][j]);
    }
    int solve(const vector<int> &ter) {
        shortest_path();
        int t = SZ(ter);
        for (int i = 0; i < (1 << t); ++i)
            for (int j = 0; j < n; ++j) dp[i][j] = INF;
        for (int i = 0; i < n; ++i) dp[0][i] = vcost[i];
        for (int msk = 1; msk < (1 << t); ++msk) {
            if (!(msk & (msk - 1))) {
                int who = __lg(msk);
                for (int i = 0; i < n; ++i)
                    dp[msk][i] = vcost[ter[who]] + dst[ter[who]][i];
            }
            for (int i = 0; i < n; ++i)
                for (int submsk = (msk - 1) & msk; submsk; submsk = (submsk - 1) & msk)
                    dp[msk][i] = min(dp[msk][i], dp[submsk][i] + dp[msk ^ submsk][i] - vcost[i]);
            for (int i = 0; i < n; ++i) {
                tdst[i] = INF;
                for (int j = 0; j < n; ++j)
                    tdst[i] = min(tdst[i], dp[msk][j] + dst[j][i]);
            }
            for (int i = 0; i < n; ++i) dp[msk][i] = tdst[i];
        }
        int ans = INF;
        for (int i = 0; i < n; ++i)
            ans = min(ans, dp[(1 << t) - 1][i]);
        return ans;
    }
}

double rat(p11 a, p11 b) {
    return sign(b.X) ? (double)a.X / b.X : (double)a.Y / b.Y;
} // all poly. should be ccw
double polyUnion(vector<vector<p11>> & poly) {
    double res = 0;
    for (auto &p : poly)
        for (int a = 0; a < SZ(p); ++a) {
            p11 A = p[a], B = p[(a + 1) % SZ(p)];
        }
    vector<pair<double, int>> segs = {{0, 0}, {1, 0}};
    for (auto &q : poly) {
        if (&p == &q) continue;
        for (int b = 0; b < SZ(q); ++b) {
            p11 C = q[b], D = q[(b + 1) % SZ(q)];
            int sc = ori(A, B, C), sd = ori(A, B, D);
            if (sc != sd && min(sc, sd) < 0) {
                double sa = cross(D - C, A - C), sb = cross(D - C, B - C);
                segs.emplace_back(sa / (sa - sb), sign(sc - sd));
            }
        }
    }

```

```

    }
    if (!sc && !sd && &q < &p &&
        sign(dot(B - A, D - C)) >
        0) {
        segs.emplace_back(rat(C - A,
            B - A), 1);
        segs.emplace_back(rat(D - A,
            B - A), -1);
    }
}
sort(ALL(segs));
for (auto &s : segs) s.X = clamp(s.
    X, 0.0, 1.0);
double sum = 0;
int cnt = segs[0].second;
for (int j = 1; j < SZ(segs); ++j)
{
    if (!cnt) sum += segs[j].X - segs
        [j - 1].X;
    cnt += segs[j].Y;
}
res += cross(A, B) * sum;
}
return res / 2;
}

llf simp(llf l, llf r) {
llf m = (l + r) / 2;
return (f(l) + f(r) + 4.0 * f(m)) * (r -
    l) / 6.0;
}

llf F(llf L, llf R, llf v, llf eps) {
llf M = (L + R) / 2, vl = simp(L, M), vr
    = simp(M, R);
if (abs(vl + vr - v) <= 15 * eps)
return vl + vr + (vl + vr - v) / 15.0;
return F(L, M, vl, eps / 2.0) +
    F(M, R, vr, eps / 2.0);
} // call F(L, r, simp(L, r), 1e-6)

pair<int, int> get_tangent(const vector<P
    > &v, P p) {
const auto gao = [&, N = int(v.size())](
    int s) {
    const auto lt = [&](int x, int y) {
return ori(p, v[x % N], v[y % N]) == s;
    };
    int l = 0, r = N; bool up = lt(0, 1);
    while (r - l > 1) {
    int m = (l + r) / 2;
    if (lt(m, 0) ? up : !lt(m, m+1)) r = m;
    else l = m;
    }
    return (lt(l, r) ? r : l) % N;
}; // test @ codeforces.com/gym/101201/
    problem/E
return {gao(-1), gao(1)}; // (a,b):ori(p,
    v[a],v[b])<0
} // plz ensure that point strictly out
    of hull

1: Initialize m[] M and w[] W to free
2: while[] free man m who has a woman w
    to propose to do
3: w[] first woman on m' s list to whom m
    has not yet proposed
4: if[] some pair (m'
    , w) then
5: if w prefers m to m'
    then
6: m'[] free
7: (m, w)[] engaged
8: end if
9: else
10: (m, w)[] engaged
11: end if
12: end while

// virtual tree
vector<pair<int, int>> build(vector<int>
    vs, int r) {
vector<pair<int, int>> res;
sort(vs.begin(), vs.end(), [](int i,
    int j) {
return dfn[i] < dfn[j]; });
vector<int> s = {r};

```

```

for (int v : vs) if (v != r) {
    if (int o = lca(v, s.back()); o != s.
        back()) {
        while (s.size() >= 2) {
            if (dfn[s[s.size() - 2]] < dfn[o
                ]) break;
            res.emplace_back(s[s.size() - 2],
                s.back());
            s.pop_back();
        }
        if (s.back() != o) {
            res.emplace_back(o, s.back());
            s.back() = o;
        }
    }
    s.push_back(v);
}
for (size_t i = 1; i < s.size(); ++i)
    res.emplace_back(s[i - 1], s[i]);
return res; // (x, y): x->y
}

#define pb emplace_back
#define rep(i, l, r) for (int i=(l); i<=(
    r); ++i)
struct WeightGraph { // 1-based
    static const int inf = INT_MAX;
    struct edge { int u, v, w; }; int n, nx
        ;
    vector<int> lab; vector<vector<edge>> g
        ;
    vector<int> slack, match, st, pa, S,
        vis;
    vector<vector<int>> flo, flo_from;
    queue<int> q;
    WeightGraph(int n_) : n(n_), nx(n * 2),
        lab(nx + 1),
        g(nx + 1, vector<edge>(nx + 1)), slack
            (nx + 1),
        flo(nx + 1), flo_from(nx + 1, vector<
            n + 1, 0)) {
        match = st = pa = S = vis = slack;
        rep(u, 1, n) rep(v, 1, n) g[u][v] = {
            u, v, 0};
    }
    int ED(edge e) {
        return lab[e.u] + lab[e.v] - g[e.u][e
            .v].w * 2;
    }
    void update_slack(int u, int x, int &s)
        {
        if (!s || ED(g[u][x]) < ED(g[s][x]))
            s = u;
    }
    void set_slack(int x) {
        slack[x] = 0;
        for (int u = 1; u <= n; ++u)
            if (g[u][x].w > 0 && st[u] != x &&
                S[st[u]] == 0)
                update_slack(u, x, slack[x]);
    }
    void q_push(int x) {
        if (x <= n) q.push(x);
        else for (int y : flo[x]) q.push(y);
    }
    void set_st(int x, int b) {
        st[x] = b;
        if (x > n) for (int y : flo[x])
            set_st(y, b);
    }
    vector<int> split_flo(auto &f, int xr)
        {
        auto it = find(ALL(f), xr);
        if (auto pr = it - f.begin(); pr % 2
            == 1)
            reverse(1 + ALL(f), it = f.end() -
                pr;
        auto res = vector(f.begin(), it);
        return f.erase(f.begin(), it), res;
    }
    void set_match(int u, int v) {
        match[u] = g[u][v].v;
        if (u <= n) return;
        int xr = flo_from[u][g[u][v].u];
        auto &f = flo[u], z = split_flo(f, xr
            );
        rep(i, 0, int(z.size())-1) set_match(
            z[i], z[i ^ 1]);
    }

```

```

set_match(xr, v); f.insert(f.end(),
    all(z));
}
void augment(int u, int v) {
    for (;;) {
        int xnv = st[match[u]]; set_match(u
            , v);
        if (!xnv) return;
        set_match(xnv, st[pa[xnv]]);
        u = st[pa[xnv]], v = xnv;
    }
}
int lca(int u, int v) {
    static int t = 0; ++t;
    for (++t; u || v; swap(u, v)) if (u)
        {
            if (vis[u] == t) return u;
            vis[u] = t; u = st[match[u]];
            if (u) u = st[pa[u]];
        }
    return 0;
}
void add_blossom(int u, int o, int v) {
    int b = int(find(n + 1 + ALL(st), 0)
        - begin(st));
    lab[b] = 0, S[b] = 0; match[b] =
        match[o];
    vector<int> f = {o};
    for (int x = u, y; x != o; x = st[pa[
        y]])
        f.pb(x), f.pb(y = st[match[x]]),
        q_push(y);
    reverse(1 + ALL(f));
    for (int x = v, y; x != o; x = st[pa[
        y]])
        f.pb(x), f.pb(y = st[match[x]]),
        q_push(y);
    flo[b] = f; set_st(b, b);
    for (int x = 1; x <= nx; ++x)
        g[b][x].w = g[x][b].w = 0;
    for (int x = 1; x <= n; ++x) flo_from
        [b][x] = 0;
    for (int xs : flo[b]) {
        for (int x = 1; x <= nx; ++x)
            if (g[b][x].w == 0 || ED(g[xs][x
                ]) < ED(g[b][x]))
                g[b][x] = g[xs][x], g[x][b] = g
                    [xs][x];
        for (int x = 1; x <= n; ++x)
            if (flo_from[xs][x]) flo_from[b][
                x] = xs;
    }
    set_slack(b);
}
void expand_blossom(int b) {
    for (int x : flo[b]) set_st(x, x);
    int xr = flo_from[b][g[b][pa[b]].u],
        xs = -1;
    for (int x : split_flo(flo[b], xr)) {
        if (xs == -1) { xs = x; continue; }
        pa[xs] = g[x][xs].u; S[xs] = 1, S[x
            ] = 0;
        slack[xs] = 0; set_slack(x); q_push
            (x); xs = -1;
    }
    for (int x : flo[b])
        if (x == xr) S[x] = 1, pa[x] = pa[b
            ];
        else S[x] = -1, set_slack(x);
    st[b] = 0;
}
bool on_found_edge(const edge &e) {
    if (int u = st[e.u], v = st[e.v]; S[v
        ] == -1) {
        int nu = st[match[v]]; pa[v] = e.u;
        S[v] = 1;
        slack[v] = slack[nu] = 0; S[nu] =
            0; q_push(nu);
    } else if (S[v] == 0) {
        if (int o = lca(u, v)) add_blossom(
            u, o, v);
        else return augment(u, v), augment(
            v, u), true;
    }
    return false;
}

```

```

bool matching() {
    ranges::fill(S, -1); ranges::fill(
        slack, 0);
    q = queue<int>();
    for (int x = 1; x <= nx; ++x)
        if (st[x] == x && !match[x])
            pa[x] = 0, S[x] = 0, q.push(x);
    if (q.empty()) return false;
    for (;;) {
        while (q.size()) {
            int u = q.front(); q.pop();
            if (S[st[u]] == 1) continue;
            for (int v = 1; v <= n; ++v)
                if (g[u][v].w > 0 && st[u] !=
                    st[v]) {
                    if (ED(g[u][v]) != 0)
                        update_slack(u, st[v],
                            slack[st[v]]);
                    else if (on_found_edge(g[u][v]
                        )) return true;
                }
        }
        int d = inf;
        for (int b = n + 1; b <= nx; ++b)
            if (st[b] == b && S[b] == 1)
                d = min(d, lab[b] / 2);
        for (int x = 1; x <= nx; ++x)
            if (int s = slack[x]; st[x] == x
                && s && S[x] <= 0)
                d = min(d, ED(g[s][x]) / (S[x]
                    + 2));
        for (int u = 1; u <= n; ++u)
            if (S[st[u]] == 1) lab[u] += d;
            else if (S[st[u]] == 0) {
                if (lab[u] <= d) return false;
                lab[u] -= d;
            }
        rep(b, n + 1, nx) if (st[b] == b &&
            S[b] >= 0)
            lab[b] += d * (2 - 4 * S[b]);
        for (int x = 1; x <= nx; ++x)
            if (int s = slack[x]; st[x] == x
                &&
                s && st[s] != x && ED(g[s][x]
                    )) == 0)
                if (on_found_edge(g[s][x]))
                    return true;
        for (int b = n + 1; b <= nx; ++b)
            if (st[b] == b && S[b] == 1 &&
                lab[b] == 0)
                expand_blossom(b);
    }
    return false;
}

pair<lld, int> solve() {
    ranges::fill(match, 0);
    rep(u, 0, n) st[u] = u, flo[u].clear
        ();
    int w_max = 0;
    rep(u, 1, n) rep(v, 1, n) {
        flo_from[u][v] = (u == v ? u : 0);
        w_max = max(w_max, g[u][v].w);
    }
    for (int u = 1; u <= n; ++u) lab[u] =
        w_max;
    int n_matches = 0; lld tot_weight =
        0;
    while (matching()) ++n_matches;
    rep(u, 1, n) if (match[u] && match[u]
        < u)
        tot_weight += g[u][match[u]].w;
    return make_pair(tot_weight,
        n_matches);
}

void set_edge(int u, int v, int w) {
    g[u][v].w = g[v][u].w = w; }
};

// 2D range add, range sum in log^2
struct seg {
    int l, r;
    ll sum, lz;
    seg *ch[2]{};
    seg(int _l, int _r) : l(_l), r(_r), sum
        (0), lz(0) {}
    void push() {

```

```

        if (lz) ch[0]->add(l, r, lz), ch[1]->
            add(l, r, lz), lz = 0;
    }
    void pull() { sum = ch[0]->sum + ch
        [1]->sum; }
    void add(int _l, int _r, ll d) {
        if (_l <= l && r <= _r) {
            sum += d * (r - l), lz += d;
            return;
        }
        if (!ch[0]) ch[0] = new seg(l, l + r
            >> 1), ch[1] = new seg(l + r >>
            1, r);
        push();
        if (_l < l + r >> 1) ch[0]->add(_l,
            _r, d);
        if (l + r >> 1 < _r) ch[1]->add(_l,
            _r, d);
        pull();
    }
    ll qsum(int _l, int _r) {
        if (_l <= l && r <= _r) return sum;
        if (!ch[0]) return lz * (min(r, _r) -
            max(l, _l));
        push();
        ll res = 0;
        if (_l < l + r >> 1) res += ch[0]->
            qsum(_l, _r);
        if (l + r >> 1 < _r) res += ch[1]->
            qsum(_l, _r);
        return res;
    }
};

struct seg2 {
    int l, r;
    seg v, lz;
    seg2 *ch[2]{};
    seg2(int _l, int _r) : l(_l), r(_r), v
        (0, N), lz(0, N) {
        if (l < r - 1) ch[0] = new seg2(l, l
            + r >> 1), ch[1] = new seg2(l +
            r >> 1, r);
    }
    void add(int _l, int _r, int _l2, int
        _r2, ll d) {
        v.add(_l2, _r2, d * (min(r, _r) - max
            (l, _l)));
        if (_l <= l && r <= _r)
            return lz.add(_l2, _r2, d), void(0)
                ;
        if (_l < l + r >> 1)
            ch[0]->add(_l, _r, _l2, _r2, d);
        if (l + r >> 1 < _r)
            ch[1]->add(_l, _r, _l2, _r2, d);
    }
    ll qsum(int _l, int _r, int _l2, int
        _r2) {
        if (_l <= l && r <= _r) return v.qsum
            (_l2, _r2);
        ll d = min(r, _r) - max(l, _l);
        ll res = lz.qsum(_l2, _r2) * d;
        if (_l < l + r >> 1)
            res += ch[0]->qsum(_l, _r, _l2,
                _r2);
        if (l + r >> 1 < _r)
            res += ch[1]->qsum(_l, _r, _l2,
                _r2);
        return res;
    }
};

PPPPPPPartition number

ans[0] = tmp[0] = 1;
for (int i = 1; i * i <= n; i++) {
    for (int rep = 0; rep < 2; rep++)
        for (int j = i; j <= n - i * i; j++)
            modadd(tmp[j], tmp[j-i]);
    for (int j = i * i; j <= n; j++)
        modadd(ans[j], tmp[j - i * i]);
}

vector<string> Duval(const string& s){//b
    b abb a
    vector<string> fact;int n=s.size();
    for(int i=0;i<n;){
        int j=i+1,k=i;

```

```

        for(;j<n&&s[k]<=s[j];j++) if(s[k]<s
            [j]) k=i;else k++;
        for(;i<=k;i+=j-k) fact.emplace_back
            (s.substr(i,j-k));
    }
    return fact;
}

```