

Contents

1 Basic	1	6 Math	10
1.1 install vscode	1	6.1 質因數分解	10
1.2 default code	1	6.2 模除計算	10
1.3 compare fuction	1	6.3 中國餘數定理	11
1.4 pbds	1	6.4 矩陣與快速幂	11
1.5 浮點數誤差	1	6.5 樹論分塊	11
2 Graph	2	6.6 Mobius Theorem	12
2.1 DFS 跟 BFS	2	6.7 莫比烏斯反演	12
2.2 Prim	2	6.8 Catalan Theorem	12
2.3 BellmanFord	2	6.9 Burnside's Lemma	12
2.4 FloydWarshall	2	7 Search and Greedy	12
2.5 歐拉環與歐拉路	2	7.1 二分搜	12
2.6 SCC	2	7.2 三分搜	12
2.7 VBCC	3	8 Tree	12
2.8 EBCC	3	8.1 LCA	12
2.9 2-SAT	3	8.2 樹重心	13
2.10 Funtional Graph	4	8.3 樹壓平	13
3 Data Structure	4	8.4 Heavy Light Decomposition	13
3.1 BIT	4	8.5 Link Cut Tree	14
3.2 RangeBit	4	8.6 Virtual Tree	15
3.3 DSU	5	8.7 Dominator Tree	15
3.4 線段樹	5	9 DP	15
3.5 懶標線段樹	6	9.1 LCS	15
3.6 莫隊	7	9.2 LIS	15
3.7 Treap	7	9.3 Edit Distance	16
4 Flow	7	9.4 Bitmask	16
4.1 Dinic	7	9.5 Projects	16
4.2 Min Cut	7	9.6 Removal Game	16
4.3 Hangarian	8	9.7 Codeforces Example	16
4.4 MCMF	8	9.8 CHT	17
5 String	9	9.9 DNC	17
5.1 KMP	9	9.10 LiChaoSegmentTree	17
5.2 Z Function	9	10 Geometry	17
5.3 SA	9	10.1 Basic	17
5.4 Duval Algorithm	9	10.2 Convex Hull	19
5.5 Manacher	9	10.3 MinEuclideanDistance	19
5.6 Trie	10	10.4 LatticePoints	20
		10.5 MinRadiusCoverCircle	20

1 Basic

1.1 install vscode [d41d8c]

```
// 如何安裝 vscode
// 1. 下載 vscode & msys2
// 2. 在跳出的 terminal 中 / 或打開 ucrt64 , 打上
// "pacman -S --needed base-devel mingw-w64-x86_64-toolchain"
// 3. 環境變數加上 C:\msys64\ucrt64\bin
// 4. 重開 vscode, 載 C/C++, 運行, 編譯器選擇 g++
// 5. 打開 settings -> compiler -> add compilerPath
// -> 在 "" 裡打上 C:\msys64\ucrt64\bin\g++.exe
```

1.2 default code [e5bd34]

```
#include <bits/stdc++.h>
#pragma GCC optimize("03")
#pragma GCC target("popcnt")
#define all(x) (x).begin(), (x).end()
using namespace std;
using ll = long long;

void solve() {
}

int main() {
    ios_base::sync_with_stdio(false);
    cin.tie(nullptr);
    int t = 1;
    cin >> t;
    while (t--) {
        solve();
    }
}
```

1.3 compare fuction [4bc3e0]

```
struct cmp { // 在有 template 的資結使用
    bool operator()(const int &a, const int &b) const {
        return a < b;
    }
}

// sort, bound 不用 struct
// priority queue 小到大是 > , set 是 <
// set 不能 = , multiset 要 =
// 每個元素都要比到, 不然會不見
// pbds_multiset 不要用 lower_bound
// 如果要 find, 插入 inf 後使用 upper_bound
// 內建 multiset 可以跟 set 一樣正常使用
// 如果有自定義比較結構就比照以上
};
```

```
struct cmp { // 要在 template 的資結用外部變數
    vector<int> &v;
    cmp(vector<int>& vec) : v(vec) {}
    bool operator() (int a, int b) const {
        return v[a] > v[b];
    }
}

// main: cmp cmp1(vector);
// priority_queue<int, vector<int>, cmp> pq(cmp1);
};
```

1.4 pbds [e28ae8]

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

1.5 浮點數誤差 [a0d4e5]

```
struct EDouble {
    double x;
    constexpr static double Eps = 1e-9;
    constexpr EDouble() : x{} {}
    constexpr EDouble(double v) : x{v} {}
    constexpr double val() const {
        return x;
    }
    explicit constexpr operator double() const {
        return x;
    }
    constexpr EDouble operator-() const {
        return EDouble(-x);
    }
    constexpr EDouble &operator+=(const EDouble &rhs) & {
        x += rhs.x;
        return *this;
    }
    constexpr EDouble &operator-=(const EDouble &rhs) & {
        x -= rhs.x;
        return *this;
    }
    constexpr EDouble &operator*=(const EDouble &rhs) & {
        x *= rhs.x;
        return *this;
    }
    constexpr EDouble &operator/=(const EDouble &rhs) & {
        assert(fabs(rhs.x) > Eps);
        x /= rhs.x;
        return *this;
    }
    friend constexpr
        EDouble operator+(EDouble lhs, const EDouble &rhs) {
        lhs += rhs;
        return lhs;
    }
    friend constexpr
        EDouble operator-(EDouble lhs, const EDouble &rhs) {
        lhs -= rhs;
        return lhs;
    }
    friend constexpr
        EDouble operator*(EDouble lhs, const EDouble &rhs) {
        lhs *= rhs;
        return lhs;
    }
    friend constexpr
        EDouble operator/(EDouble lhs, const EDouble &rhs) {
        lhs /= rhs;
        return lhs;
    }
    friend constexpr bool
        operator<(const EDouble &lhs, const EDouble &rhs) {
        return lhs.x - rhs.x < -Eps;
    }
    friend constexpr bool
        operator>(const EDouble &lhs, const EDouble &rhs) {
        return lhs.x - rhs.x > Eps;
    }
    friend constexpr bool
        operator==(const EDouble &lhs, const EDouble &rhs) {
        return fabs(lhs.x - rhs.x) < Eps;
    }
    friend constexpr bool
        operator<=(const EDouble &lhs, const EDouble &rhs) {
        return lhs < rhs || lhs == rhs;
    }
    friend constexpr bool
        operator>=(const EDouble &lhs, const EDouble &rhs) {
        return lhs > rhs || lhs == rhs;
    }
    friend constexpr bool
        operator!=(const EDouble &lhs, const EDouble &rhs) {
        return !(lhs == rhs);
    }
    friend istream &operator>>(istream &is, EDouble &a) {
        double v; is >> v;
    }
```

```

    a = EDouble(v);
    return is;
}
friend ostream &operator<<(ostream &os, const EDouble &a) {
    return os << fixed << setprecision(7) << a.val
        () + (a.val() > 0 ? Eps : a.val() < 0 ? -Eps : 0);
} // Eps should < precision
};
namespace std {
    template<>
    class numeric_limits<EDouble> {
    public:
        static constexpr EDouble max() noexcept {
            return EDouble(numeric_limits<double>::max());
        }
        static constexpr EDouble min() noexcept {
            return EDouble(numeric_limits<double>::min());
        }
    };
}
using E = EDouble;

```

2 Graph

2.1 DFS 跟 BFS [cdd1d5]

```

int main() {
    int n;
    vector<vector<int>> adj(n + 1, vector<int>());
    // dfs_graph
    vector<bool> vis(n + 1, 0);
    auto dfs = [&](auto self, int u) -> void {
        if (vis[u]) return;
        vis[u] = true;
        for (auto v : adj[u]) {
            self(self, v);
        }
    };
    dfs(dfs, 1);
    // bfs
    vector<int> depth(n + 1, 1e9);
    queue<int> q;
    auto bfs = [&](auto self, int u) -> void {
        vis[u] = true;
        depth[u] = 0;
        q.push(u);
        while (!q.empty()) {
            int u = q.front(); q.pop();
            for (auto v : adj[u]) {
                if (vis[v]) continue;
                vis[v] = true;
                depth[v] = depth[u] + 1;
                q.push(v);
            }
        }
    };
    bfs(bfs, 1);
}

```

2.2 Prim [f00ec0]

```

auto prim =
    [&](int n, vector<vector<pair<int, int>>> &adj) -> bool {
        int node_sz = 0;
        priority_queue<pair<int, int>,
            vector<pair<int, int>>, greater<pair<int, int>>> pq;
        pq.push({0, 1}); // w, vertex
        vector<bool> vis(n);
        while (!pq.empty()) {
            auto [u, w] = pq.top(); pq.pop();
            if (vis[u]) continue;
            vis[u] = true;
            node_sz++;
            for (auto v : adj[u]) {
                if (!vis[v]) {
                    pq.push({v.second, v.first});
                }
            }
        }
        if (node_sz == n) return true;
        return false;
    };

```

2.3 BellmanFord [430ded]

```

// 用 Bellman Ford 找負環
int main() {
    int n, m; cin >> n >> m;
    vector<array<int, 3>> e;
    for (int i = 0; i < m; i++) {
        int u, v, w; cin >> u >> v >> w;
        u--, v--; e.push_back({u, v, w});
    }
    vector<ll> dis(n, inf), par(n);
    int t = -1; dis[0] = 0;
    for (int i = 1; i <= n; i++) {
        for (auto [u, v, w] : e) {
            if (dis[v] > dis[u] + w) {
                dis[v] = dis[u] + w;
                par[v] = u;
                if (i == n) t = v;
            }
        }
    }
    if (t != -1) {
        // 有負環
        cout << "YES\n";
    } else {
        // 無負環
        cout << "NO\n";
    }
}

```

```

    }
}
if (t == -1) { cout << "NO\n"; return; }
for (int i = 1; i < n; i++) t = par[t];
vector<int> ans {t};
int i = t;
do {
    i = par[i];
    ans.push_back(i);
} while (i != t);
reverse(ans.begin(), ans.end());
cout << "YES\n";
for (auto x : ans) cout << x + 1 << " ";
}

```

2.4 FloydWarshall [206b76]

```

const int inf = 1e18;
int main() {
    int n, m, q; cin >> n >> m >> q;
    vector<vector<int>> graph(n + 1, vector<int>(n + 1, inf));
    vector<vector<int>> dis(n + 1, vector<int>(n + 1));
    for (int i = 0; i < m; i++) {
        int u, v, w; cin >> u >> v >> w;
        cin >> u >> v >> w;
        graph[u][v] = min(graph[u][v], w);
        graph[v][u] = min(graph[v][u], w);
    }
    for (int i = 0; i <= n; i++) {
        for (int j = 0; j <= n; j++) {
            dis[i][j] = graph[i][j];
        }
    }
    for (int i = 0; i <= n; i++) // 自己到自己是 0
        dis[i][i] = 0;

    for (int k = 1; k <= n; k++) {
        for (int i = 1; i <= n; i++) {
            for (int j = 1; j <= n; j++) {
                dis[i][j] = min(dis[i][j], dis[i][k] + dis[k][j]);
            }
        }
    }
    for (int i = 0; i < q; i++) {
        int u, v; cin >> u >> v;
        cout << (dis[u][v] >= inf ? -1 : dis[u][v]) << "\n";
    }
}

```

2.5 歐拉環與歐拉路 [0911ed]

```

// 無向圖、尤拉環：檢查每個點的出度為偶數
// 有向圖、尤拉路：可以看成 1 走到 n，所以檢查所有點的出度等於入度
int n, m;
const int maxn = 1e5 + 5;
vector<set<int>> adj;
vector<int> in;
void dfs(int now, vector<int> &road) {
    while (!adj[now].empty()) {
        int nxt = *adj[now].begin();
        adj[now].erase(nxt);
        dfs(nxt, road);
    }
    road.push_back(now);
}
void solve() {
    cin >> n >> m;
    in.assign(n + 1, 0);
    adj.assign(n + 1, set<int>());
    for (int i = 1; i <= m; i++) {
        int u, v; cin >> u >> v;
        adj[u].insert(v);
        in[v]++;
    }
    in[1]++;
    in[n]--;
    for (int i = 1; i <= n; i++) {
        if (adj[i].size() != in[i]) {
            cout << "IMPOSSIBLE";
            return;
        }
    }
    vector<int> road;
    dfs(1, road);
    if (road.size() != m + 1) {
        cout << "IMPOSSIBLE";
        return;
    }
    reverse(road.begin(), road.end());
    for (auto i : road) cout << i << " ";
}

```

2.6 SCC [5d3e16]

```

struct SCC {
    int n, cur, cnt;
    vector<vector<int>> adj;
    vector<int> stk, dfn, low, bel;
};

```

```

SCC(int n_ = 0) {
    init(n_);
}
void init(int n_) {
    n = n_;
    adj.assign(n, {});
    dfn.assign(n, -1);
    low.resize(n);
    bel.assign(n, -1);
    stk.clear();
    cur = cnt = 0;
}
void addEdge(int u, int v) {
    adj[u].push_back(v);
}
void dfs(int x) {
    dfn[x] = low[x] = cur++;
    stk.push_back(x);
    for (auto y : adj[x]) {
        if (dfn[y] == -1) {
            dfs(y);
            low[x] = min(low[x], low[y]);
        } else if (bel[y] == -1) {
            low[x] = min(low[x], dfn[y]);
        }
    }
    if (dfn[x] == low[x]) {
        int y;
        do {
            y = stk.back();
            bel[y] = cnt;
            stk.pop_back();
        } while (y != x);
        cnt++;
    }
}
vector<int> work() {
    for (int i = 0; i < n; i++) {
        if (dfn[i] == -1) dfs(i);
    }
    return bel;
}
struct Graph {
    int n;
    vector<pair<int, int>> edges;
    vector<int> siz;
    vector<int> cnte;
};
Graph compress() {
    Graph g;
    g.n = cnt;
    g.siz.resize(cnt);
    g.cnte.resize(cnt);
    for (int i = 0; i < n; i++) {
        g.siz[bel[i]]++;
        for (auto j : adj[i]) {
            if (bel[i] != bel[j]) {
                g.edges.emplace_back(bel[i], bel[j]);
            } else {
                g.cnte[bel[i]]++;
            }
        }
    }
    return g;
}
};

```

2.7 VBCC [170604]

```

struct VBCC {
    int n, cur;
    vector<vector<int>> adj;
    vector<int> dfn, low, parent;
    vector<bool> is_cut;
    VBCC(int n_ = 0) {
        init(n_);
    }
    void init(int n_) {
        n = n_;
        adj.assign(n, {});
        dfn.assign(n, -1);
        low.resize(n);
        parent.assign(n, -1);
        is_cut.assign(n, false);
        cur = 0;
    }
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
    void dfs(int x) {
        int children = 0;
        dfn[x] = low[x] = cur++;
        for (int v : adj[x]) {
            if (dfn[v] == -1) {
                children++;
                parent[v] = x;
                dfs(v);
                low[x] = min(low[x], low[v]);
            }
            if (parent[x] != -1 && low[v] >= dfn[x]) {
                is_cut[x] = true;
            }
        }
    }
}

```

```

        }
        else if (v != parent[x]) {
            low[x] = min(low[x], dfn[v]);
        }
    }
    if (parent[x] == -1 && children > 1) {
        is_cut[x] = true;
    }
}
void work() {
    for (int i = 0; i < n; i++) {
        if (dfn[i] == -1) {
            dfs(i);
        }
    }
}
};

```

2.8 EBCC [49d862]

```

struct EBCC { // CF/contest/1986/pF
    int n, cur, cnt;
    vector<vector<int>> adj;
    vector<int> stk, dfn, low, bel;
    vector<pair<int, int>> bridges; // 關鍵邊
    EBCC(int n_) {
        init(n_);
    }
    void init(int n_) {
        n = n_;
        adj.assign(n, {});
        dfn.assign(n, -1);
        low.resize(n);
        bel.assign(n, -1);
        stk.clear();
        bridges.clear();
        cur = cnt = 0;
    }
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
    void dfs(int x, int p) {
        dfn[x] = low[x] = cur++;
        stk.push_back(x);
        for (auto y : adj[x]) {
            if (y == p) continue;
            if (dfn[y] == -1) {
                dfs(y, x);
                low[x] = min(low[x], low[y]);
                if (low[y] > dfn[x]) {
                    bridges.emplace_back(x, y);
                }
            } else if (bel[y] == -1) {
                low[x] = min(low[x], dfn[y]);
            }
        }
        if (dfn[x] == low[x]) {
            int y;
            do {
                y = stk.back();
                bel[y] = cnt;
                stk.pop_back();
            } while (y != x);
            cnt++;
        }
    }
    vector<int> work() { // not connected
        for (int i = 0; i < n; i++) {
            if (dfn[i] == -1) {
                dfs(i, -1);
            }
        }
        return bel;
    }
}
struct Graph {
    int n;
    vector<pair<int, int>> edges;
    vector<int> siz; // BCC 內節點數
    vector<int> cnte; // BCC 內邊數
};
Graph compress() {
    Graph g;
    g.n = cnt;
    g.siz.resize(cnt);
    g.cnte.resize(cnt);
    for (int i = 0; i < n; i++) {
        g.siz[bel[i]]++;
        for (auto j : adj[i]) {
            if (bel[i] < bel[j]) {
                g.edges.emplace_back(bel[i], bel[j]);
            } else if (i < j) {
                g.cnte[bel[i]]++;
            }
        }
    }
    return g;
}
};

```

2.9 2-SAT [eeddc1]

```
// CSES Giant Pizza
struct TwoSat {
    int n;
    vector<vector<int>>> e;
    vector<bool> ans;
    TwoSat(int n) : n(n), e(2 * n), ans(n) {}
    void addClause(int u, bool f, int v, bool g) {
        e[2 * u + !f].push_back(2 * v + g);
        e[2 * v + !g].push_back(2 * u + f);
    }
    bool satisfiable() {
        vector<int>
            > id(2 * n, -1), dfn(2 * n, -1), low(2 * n, -1);
        vector<int> stk;
        int now = 0, cnt = 0;
        function<void(int)> tarjan = [&](int u) {
            stk.push_back(u);
            dfn[u] = low[u] = now++;
            for (auto v : e[u]) {
                if (dfn[v] == -1) {
                    tarjan(v);
                    low[u] = min(low[u], low[v]);
                } else if (id[v] == -1) { // in stk
                    low[u] = min(low[u], dfn[v]);
                }
            }
            if (dfn[u] == low[u]) {
                int v;
                do {
                    v = stk.back();
                    stk.pop_back();
                    id[v] = cnt;
                } while (v != u);
                ++cnt;
            }
        };
        for (int i = 0; i < 2 * n; ++i) if (dfn[i] == -1) tarjan(i);
        for (int i = 0; i < n; ++i) {
            if (id[2 * i] == id[2 * i + 1]) return false;
            ans[i] = id[2 * i] > id[2 * i + 1];
        }
        return true;
    }
    vector<bool> answer() { return ans; }
};

int main() {
    int m, n; cin >> m >> n;
    TwoSat ts(n);
    for (int i = 0; i < m; ++i) {
        int u, v; char x, y;
        cin >> x >> u >> y >> v;
        ts.addClause(u - 1, x == '+', v - 1, y == '+');
    }
    if (ts.satisfiable()) {
        for (int i = 0; i < n; ++i) {
            cout << (ts.answer()[i] ? '+' : '-') << " ";
        }
    } else cout << "IMPOSSIBLE\n";
}
```

2.10 Funlional Graph [85c464]

```
constexpr int N = 2e5 + 5;
int cht[N][31]; // 倍增表, 放外面不然 TLE
struct FunlionalGraph {
    int n, cnt;
    vector<int> g, bel, id, len, in, top;
    FunlionalGraph() : n(0) {}
    FunlionalGraph(vector<int> g_) { init(g_); }
    void init(vector<int> g_) {
        n = g_.size(); cnt = 0;
        g = g_; bel.assign(n, -1);
        id.resize(n); len.clear();
        in.assign(n, 0); top.assign(n, -1);
        build();
    }
    void build() {
        for (int i = 0; i < n; i++) {
            cht[i][0] = g[i];
            in[g[i]]++;
        }
        for (int i = 1; i <= 30; i++)
            for (int u = 0; u < n; u++)
                cht[u][i] = cht[cht[u][i - 1]][i - 1];
        for (int i = 0; i < n; i++)
            if (in[i] == 0) label(i);
        for (int i = 0; i < n; i++)
            if (top[i] == -1) label(i);
    }
    void label(int u) {
        vector<int> p; int cur = u;
        while (top[cur] == -1) {
            top[cur] = u;
            p.push_back(cur);
            cur = g[cur];
        }
        auto s = std::find(p.begin(), p.end(), cur);
        vector<int> cyc(s, p.end());
        p.erase(s, p.end()); p.push_back(cur);
        for (int i = 0; i < (int)cyc.size(); i++) {

```

```
            bel[cyc[i]] = cnt;
            id[cyc[i]] = i;
        }
        cnt++; len.push_back(cyc.size());
        for (int i = p.size() - 1; i > 0; i--)
            id[p[i - 1]] = id[p[i]] - 1;
    }
    int jump(int u, int k) {
        for (int b = 0; k > 0; b++) {
            if (k & 1) u = cht[u][b];
            k >>= 1;
        }
        return u;
    }
};
```

3 Data Structure

3.1 BIT [d41d8c]

```
template <typename T>
struct Fenwick { // 全部以 0 based 使用
    int n;
    vector<T> a;
    Fenwick(int n_ = 0) {
        init(n_);
    }
    void init(int n_) {
        n = n_;
        a.assign(n, T{});
    }
    void add(int x, const T &v) {
        for (int i = x + 1; i <= n; i += i & -i) {
            a[i - 1] = a[i - 1] + v;
        }
    }
    T sum(int x) { // 左閉右開查詢
        T ans{};
        for (int i = x; i > 0; i -= i & -i) {
            ans = ans + a[i - 1];
        }
        return ans;
    }
    T rangeSum(int l, int r) { // 左閉右開查詢
        return sum(r) - sum(l);
    }
    int select(const T &k) { // 找到最小的 x, 使得 sum(x) > k
        int x = 0;
        T cur{};
        for (int i = 1 << __lg(n); i; i /= 2) {
            if (x + i <= n && cur + a[x + i - 1] <= k) {
                x += i;
                cur = cur + a[x - 1];
            }
        }
        return x;
    }
};

template <class T>
struct TwoDFenwick { // 全部以 0 based 使用
    int nx, ny; // row, col 個數
    vector<vector<T>>> a;
    TwoDFenwick(int nx_ = 0, int ny_ = 0) {
        init(nx_, ny_);
    }
    void init(int nx_, int ny_) {
        nx = nx_; ny = ny_;
        a.assign(nx, vector<T>(ny, T{}));
    }
    void add(int x, int y, const T &v) {
        for (int i = x + 1; i <= nx; i += i & -i) {
            for (int j = y + 1; j <= ny; j += j & -j) {
                a[i - 1][j - 1] = a[i - 1][j - 1] + v;
            }
        }
    }
    T sum(int x, int y) { // 左閉右開查詢
        T ans{};
        for (int i = x; i > 0; i -= i & -i) {
            for (int j = y; j > 0; j -= j & -j) {
                ans = ans + a[i - 1][j - 1];
            }
        }
        return ans;
    }
    T rangeSum
        (int lx, int ly, int rx, int ry) { // 左閉右開查詢
        return sum(
            rx, ry) - sum(lx, ry) - sum(rx, ly) + sum(lx, ly);
    }
};
```

3.2 RangeBit [d41d8c]

```
template <typename T>
struct rangeFenwick { // 全部以 0 based 使用
    int n;
    vector<T> d, di;
    rangeFenwick(int n_ = 0) {
        init(n_);
    }

```

```

}
void init(int n_) {
    n = n_;
    d.assign(n, T{});
    di.assign(n, T{});
}
void add(int x, const T &v) {
    T vi = v * (x + 1);
    for (int i = x + 1; i <= n; i += i & -i) {
        d[i - 1] = d[i - 1] + v;
        di[i - 1] = di[i - 1] + vi;
    }
}
void rangeAdd(int l, int r, const T &v) {
    add(l, v); add(r, -v);
}
T sum(int x) { // 左閉右開查詢
    T ans{};
    for (int i = x; i > 0; i -= i & -i) {
        ans = ans + T(x + 1) * d[i - 1];
        ans = ans - di[i - 1];
    }
    return ans;
}
T rangeSum(int l, int r) { // 左閉右開查詢
    return sum(r) - sum(l);
}
int select(const T &k) { // 找到最小的 x, 使得 sum(x) > k
    int x = 0;
    T cur{};
    for (int i = 1 << __lg(n); i; i /= 2) {
        if (x + i <= n) {
            T val = T(
                x + i + 1) * d[x + i - 1] - di[x + i - 1];
            if (cur + val <= k) {
                x += i;
                cur = cur + val;
            }
        }
    }
    return x;
}
};
template <class T>
struct rangeTwoDFenwick { // 全部以 0 based 使用
    int nx, ny; // row, col 個數
    vector<vector<T>> d, di, dj, dij;
    rangeTwoDFenwick(int nx_ = 0, int ny_ = 0) {
        init(nx_, ny_);
    }
    void init(int nx_, int ny_) {
        nx = nx_; ny = ny_;
        d.assign(nx, vector<T>(ny, T{}));
        di.assign(nx, vector<T>(ny, T{}));
        dj.assign(nx, vector<T>(ny, T{}));
        dij.assign(nx, vector<T>(ny, T{}));
    }
    void add(int x, int y, const T &v) {
        T vi = v * (x + 1);
        T vj = v * (y + 1);
        T vij = v * (x + 1) * (y + 1);
        for (int i = x + 1; i <= nx; i += i & -i) {
            for (int j = y + 1; j <= ny; j += j & -j) {
                d[i - 1][j - 1] = d[i - 1][j - 1] + v;
                di[i - 1][j - 1] = di[i - 1][j - 1] + vi;
                dj[i - 1][j - 1] = dj[i - 1][j - 1] + vj;
                dij[i - 1][j - 1] = dij[i - 1][j - 1] + vij;
            }
        }
    }
    void rangeAdd(int lx, int ly, int rx, int ry, const T &v) {
        add(rx, ry, v);
        add(lx, ry, -v);
        add(rx, ly, -v);
        add(lx, ly, v);
    }
    T sum(int x, int y) { // 左閉右開查詢
        T ans{};
        for (int i = x; i > 0; i -= i & -i) {
            for (int j = y; j > 0; j -= j & -j) {
                ans = ans
                    + T(x * y + x + y + 1) * d[i - 1][j - 1];
                ans = ans - T(y + 1) * di[i - 1][j - 1];
                ans = ans - T(x + 1) * dj[i - 1][j - 1];
                ans = ans + dij[i - 1][j - 1];
            }
        }
        return ans;
    }
    T rangeSum
        (int lx, int ly, int rx, int ry) { // 左閉右開查詢
        return sum(
            rx, ry) - sum(lx, ry) - sum(rx, ly) + sum(lx, ly);
    }
};

```

3.3 DSU [d41d8c]

```

struct DSU {
    int n;
    vector<int> boss, siz;

```

```

DSU() {}
DSU(int n_) {
    init(n_);
}
void init(int n_) {
    n = n_;
    boss.resize(n);
    iota(boss.begin(), boss.end(), 0);
    siz.assign(n, 1);
}
int find_boss(int x) {
    if (boss[x] == x) return x;
    return boss[x] = find_boss(boss[x]);
}
bool same(int x, int y) {
    return find_boss(x) == find_boss(y);
}
bool merge(int x, int y) {
    x = find_boss(x);
    y = find_boss(y);
    if (x == y) {
        return false;
    }
    if (siz[x] < siz[y]) swap(x, y);
    siz[x] += siz[y];
    boss[y] = x;
    n--;
    return true;
}
int size(int x) {
    return siz[find_boss(x)];
}
};

struct DSU {
    int n;
    vector<int> boss, siz, stk;
    DSU() {}
    DSU(int n_) {
        init(n_);
    }
    void init(int n_) {
        n = n_;
        boss.resize(n);
        iota(boss.begin(), boss.end(), 0);
        siz.assign(n, 1);
        stk.clear();
    }
    int find(int x) {
        return x == boss[x] ? x : find(boss[x]);
    }
    bool same(int x, int y) {
        return find(x) == find(y);
    }
    bool merge(int x, int y) {
        x = find(x);
        y = find(y);
        if (x == y) {
            return false;
        }
        if (siz[x] < siz[y]) swap(x, y);
        siz[x] += siz[y];
        boss[y] = x;
        n--;
        stk.push_back(y);
        return true;
    }
    void undo(int x) {
        while (stk.size() > x) {
            int y = stk.back();
            stk.pop_back();
            n++;
            siz[boss[y]] -= siz[y];
            boss[y] = y;
        }
    }
    int size(int x) {
        return siz[find(x)];
    }
}
};

```

3.4 線段樹 [d41d8c]

```

template <class Info>
struct Seg { // 左閉右開寫法
    int n; vector<Info> info;
    Seg() : n(0) {}
    Seg(int n_, Info v_ = Info()) {
        init(n_, v_);
    }
    template <class T>
    Seg(vector<T> init_) {
        init(init_);
    }
    void init(int n_, Info v_ = Info()) {
        init(vector(n_, v_));
    }
    template <class T>
    void init(vector<T> init_) {
        n = init_.size();
        info.assign(4 << __lg(n), Info());
    }

```

```

function <void(
    int, int, int)> build = [&](int p, int l, int r) {
    if (r - l == 1) {
        info[p] = init_[l];
        return;
    }
    int m = (l + r) / 2;
    build(p * 2, l, m);
    build(p * 2 + 1, m, r);
    pull(p);
};
build(1, 0, n);
}
void pull
(int p) { info[p] = info[p * 2] + info[p * 2 + 1]; }
void modify(int p, int l, int r, int x, const Info &v) {
    if (r - l == 1) {
        info[p] = v;
        return;
    }
    int m = (l + r) / 2;
    if (x < m) {
        modify(2 * p, l, m, x, v);
    } else {
        modify(2 * p + 1, m, r, x, v);
    }
    pull(p);
}
void modify(int p, const Info &i) {
    modify(1, 0, n, p, i);
}
Info query(int p, int l, int r, int ql, int qr) {
    if (qr <= l || ql >= r) return Info();
    if (ql <= l && r <= qr) return info[p];
    int m = (l + r) / 2;
    return query(p * 2, l, m, ql, qr) + query(p * 2 + 1, m, r, ql, qr);
}
Info query
(int ql, int qr) { return query(1, 0, n, ql, qr); }
template<class F> // 尋找區間內，第一個符合條件的
int findFirst
(int p, int l, int r, int x, int y, F &&pred) {
    if (l >= y || r <= x)
        return -1;
    if (l >= x && r <= y && !pred(info[p]))
        return -1;
    if (r - l == 1)
        return l;
    int m = (l + r) / 2;
    int res = findFirst(2 * p, l, m, x, y, pred);
    if (res == -1)
        res = findFirst(2 * p + 1, m, r, x, y, pred);
    return res;
}
template<class F> // 若要找 last，先右子樹遞迴即可
int findFirst(int l, int r, F &&pred) {
    return findFirst(1, 0, n, l, r, pred);
}
};
// ---define structure and info plus---
struct Info {
    int n = 1;
    int sum = 0;
};
Info operator+(const Info &a, const Info &b) {
    return { a.n + b.n, a.sum + b.sum };
}

```

3.5 懶標線段樹 [d41d8c]

```

template <class Info, class Tag>
struct LazySeg { // 左閉右開寫法
    int n;
    vector<Info> info;
    vector<Tag> tag;
    LazySeg() : n(0) {}
    LazySeg(int n_, Info v_ = Info()) {
        init(n_, v_);
    }
    template <class T>
    LazySeg(vector<T> init_) {
        init(init_);
    }
    void init(int n_, Info v_ = Info()) {
        init(vector(n_, v_));
    }
    template <class T>
    void init(vector<T> init_) {
        n = init_.size();
        info.assign(4 << __lg(n), Info());
        tag.assign(4 << __lg(n), Tag());
        function <void(
            int, int, int)> build = [&](int p, int l, int r) {
            if (r - l == 1) {
                info[p] = init_[l];
                return;
            }
            int m = (l + r) / 2;
            build(p * 2, l, m);
            build(p * 2 + 1, m, r);

```

```

            pull(p);
        };
        build(1, 0, n);
    }
    void pull
        (int p) { info[p] = info[p * 2] + info[p * 2 + 1]; }
    void apply(int p, int l, int r, const Tag &v) {
        info[p].apply(l, r, v);
        tag[p].apply(v);
    }
    void push(int p, int l, int r) {
        int m = (l + r) / 2;
        if (r - l >= 1) {
            apply(p * 2, l, m, tag[p]);
            apply(p * 2 + 1, m, r, tag[p]);
        }
        tag[p] = Tag();
    }
    void modify(int p, int l, int r, int x, const Info &v) {
        if (r - l == 1) {
            info[p] = v;
            return;
        }
        int m = (l + r) / 2;
        push(p, l, r);
        if (x < m) {
            modify(2 * p, l, m, x, v);
        } else {
            modify(2 * p + 1, m, r, x, v);
        }
        pull(p);
    }
    void modify(int p, const Info &i) {
        modify(1, 0, n, p, i);
    }
    Info query(int p, int l, int r, int ql, int qr) {
        if (qr <= l || ql >= r) return Info();
        if (ql <= l && r <= qr) return info[p];
        int m = (l + r) / 2;
        push(p, l, r);
        return query(p * 2, l, m, ql, qr) + query(p * 2 + 1, m, r, ql, qr);
    }
    Info query
        (int ql, int qr) { return query(1, 0, n, ql, qr); }
    void range_apply
        (int p, int l, int r, int ql, int qr, const Tag &v) {
        if (qr <= l || ql >= r) return;
        if (ql <= l && r <= qr) {
            apply(p, l, r, v);
            return;
        }
        int m = (l + r) / 2;
        push(p, l, r);
        range_apply(p * 2, l, m, ql, qr, v);
        range_apply(p * 2 + 1, m, r, ql, qr, v);
        pull(p);
    }
    void range_apply(int l, int r, const Tag &v) {
        range_apply(1, 0, n, l, r, v);
    }
    template<class F> // 尋找區間內，第一個符合條件的
    int findFirst
        (int p, int l, int r, int x, int y, F &&pred) {
        if (l >= y || r <= x) {
            return -1;
        }
        if (l >= x && r <= y && !pred(info[p])) {
            return -1;
        }
        if (r - l == 1) {
            return l;
        }
        int m = (l + r) / 2;
        push(p);
        int res = findFirst(2 * p, l, m, x, y, pred);
        if (res == -1) {
            res = findFirst(2 * p + 1, m, r, x, y, pred);
        }
        return res;
    }
    template<class F> // 若要找 last，先右子樹遞迴即可
    int findFirst(int l, int r, F &&pred) {
        return findFirst(1, 0, n, l, r, pred);
    }
};
// ---define structure and info plus---
struct Tag { // 有些 Tag 不用 push 例如 sweepLine
    int set_val; int add;
    void apply(const Tag &v) {
        if (v.set_val) {
            set_val = v.set_val;
            add = v.add;
        }
        else {
            add += v.add;
        }
    }
};
struct Info {
    int sum;

```



```

void apply(int l, int r, const Tag &v) {
    if (v.set_val) {
        sum = (r - l) * v.set_val;
    }
    sum += (r - l) * v.add;
}
// Info& operator=(const Info &rhs) {
//     // 部分 assignment 使用
//     return *this;
// }
};
Info operator+(const Info &a, const Info &b) {
    return { a.sum + b.sum };
}

```

3.6 莫隊 [d41d8c]

```

struct query {
    int l, r, id;
} typedef query;
void MO(int n, vector<query> &queries) {
    int block = sqrt(n);
    function<bool(query, query)> cmp = [&](query a, query b) {
        int block_a = a.l / block;
        int block_b = b.l / block;
        if (block_a != block_b) return block_a < block_b;
        return a.r < b.r;
    };
    sort(queries.begin(), queries.end(), cmp);
}
void compress(vector<int> &nums) {
    vector<int> sorted = nums;
    sort(sorted.begin(), sorted.end());
    sorted.erase(
        unique(sorted.begin(), sorted.end(), sorted.end());
    );
    for (int i = 0; i < nums.size(); i++) {
        nums[i] = lower_bound(sorted.begin(), sorted.end(), nums[i]) - sorted.begin() + 1;
    }
}

```

3.7 Treap [d41d8c]

```

struct Treap {
    Treap *lc, *rc;
    int pri, siz; bool rev_valid;
    int val; int min;
    Treap(int val_) {
        min = val = val_;
        pri = rand();
        lc = rc = nullptr;
        siz = 1; rev_valid = 0;
    }
    void pull() { // update siz or other information
        siz = 1;
        min = val;
        for (auto c : {lc, rc}) {
            if (!c) continue;
            siz += c->siz;
            min = std::min(min, c->min);
        }
    }
    void push() {
        if (rev_valid) {
            swap(lc, rc);
            if (lc) lc->rev_valid ^= 1;
            if (rc) rc->rev_valid ^= 1;
        }
        rev_valid = false;
    }
    int find(int k) { // 找到 min 是 k 的位置 (1-based)
        push();
        int ls = (lc ? lc->siz : 0) + 1;
        if (val == k) return ls;
        if (lc && lc->min == k) return lc->find(k);
        else return rc->find(k) + ls;
    }
};
int size(Treap *t) {
    return t ? t->siz : 0;
}
Treap *merge(Treap *a, Treap *b) {
    if (!a || !b) return a ? a : b;
    a->push(); b->push();
    if (a->pri > b->pri) {
        a->rc = merge(a->rc, b);
        a->pull();
        return a;
    }
    else {
        b->lc = merge(a, b->lc);
        b->pull();
        return b;
    }
}
pair<Treap*, Treap*> split(Treap *t, int k) {
    // 分割前 k 個在 first, 剩下的在 second
    if (t == nullptr) return {nullptr, nullptr};
    t->push();
    if (size(t->lc) < k) {
        auto [a, b] = split(t->rc, k - size(t->lc) - 1);
    }
}

```

```

t->rc = a;
t->pull();
return {t, b};
}
else {
    auto [a, b] = split(t->lc, k);
    t->lc = b;
    t->pull();
    return {a, t};
}
}
void Print(Treap *t) {
    if (!t) return;
    t->push();
    Print(t->lc);
    cout << t->val;
    Print(t->rc);
}

```

4 Flow

4.1 Dinic [287fe8]

```

template<class T>
struct Dinic {
    struct Edge {
        int to;
        T flow, cap; // 流量跟容量
    };
    int n, m, s, t;
    T INF_FLOW = numeric_limits<T>::max() / 2;
    vector<vector<int>> adj; // 此點對應的 edges 編號
    vector<Edge> edges; // 幫每個 edge 編號
    vector<int> dis, ptr;
    Dinic(int n_) { init(n_); }
    void init(int n_ = 0) {
        n = n_; m = 0;
        dis.resize(n); ptr.resize(n);
        adj.assign(n, vector<int>{});
        edges.clear();
    }
    void add_edge(int u, int v, T cap) {
        // 偶數 id 是正向邊
        edges.push_back({ v, 0, cap });
        edges.push_back({ u, 0, 0 });
        adj[u].push_back(m++);
        adj[v].push_back(m++);
    }
    bool bfs() {
        fill(dis.begin(), dis.end(), -1);
        dis[s] = 0; queue<int> q;
        q.push(s);
        while (!q.empty() && dis[t] == -1) {
            int u = q.front(); q.pop();
            for (int id : adj[u]) {
                Edge &e = edges[id];
                if (e.flow == e.cap) continue;
                if (dis[e.to] == -1) {
                    dis[e.to] = dis[u] + 1;
                    q.push(e.to);
                }
            }
        }
        return dis[t] != -1;
    }
    T dfs(int u, T flow) {
        if (flow == 0) return 0;
        if (u == t) return flow;
        for (int &cur = ptr[u]; cur < (int)adj[u].size(); cur++) {
            Edge &e = edges[adj[u][cur]];
            if (dis[u] + 1 != dis[e.to]) continue;
            if (e.cap == e.flow) continue;
            T mn = dfs(e.to, min(flow, e.cap - e.flow));
            if (mn > 0) {
                e.flow += mn;
                edges[adj[u][cur] ^ 1].flow -= mn;
                return mn;
            }
        }
        return 0; // 到不了終點就會 return 0
    }
    T work(int s_, int t_) {
        s = s_; t = t_; T flow = 0;
        while (bfs()) {
            fill(ptr.begin(), ptr.end(), 0);
            while (true) {
                T res = dfs(s, INF_FLOW);
                if (res == 0) break;
                flow += res;
            }
        }
        return flow;
    }
    void reset() {
        for (int i = 0; i < m; i++) edges[i].flow = 0;
    }
};

```

4.2 Min Cut [44ae6c]

```
// CSES Police Chase
int main() {
    int n, m; cin >> n >> m;
    Dinic<int> g(n);
    for (int i = 0; i < m; i++) {
        int u, v, cap = 1;
        cin >> u >> v;
        u--; v--;
        g.add_edge(u, v, cap);
        g.add_edge(v, u, cap);
    }
    int res = g.work(0, n - 1);
    cout << res << "\n";
    if (res == 0) return;

    vector<int> vis(n);
    auto find = [&](auto self, int u) -> void {
        if (!vis[u]) {
            vis[u] = 1;
            for (int id : g.adj[u]) {
                auto e = g.edges[id];
                if (e.cap - e.flow > 0) {
                    self(self, e.to);
                }
            }
        }
    };
    find(find, 0);
    for (int i = 0; i < n; i++) {
        if (!vis[i]) continue;
        for (int id : g.adj[i]) {
            if (id & 1) continue;
            auto e = g.edges[id];
            if (!vis[e.to]) {
                cout << i + 1 << " " << e.to + 1 << "\n";
            }
        }
    }
}
```

4.3 Hangarian [350fc3]

```
struct Hangarian { // 0-based
    int n, m; // 最短路徑覆蓋，二分匹配
    vector<vector<int>> adj;
    vector<int> used, vis;
    vector<pair<int, int>> match;
    Hangarian(int n_ = 0, int m_ = 0) {
        init(n_, m_);
    }
    void init(int n_ = 0, int m_ = 0) {
        n = n_; m = m_;
        adj.assign(n + m, vector<int>());
        used.assign(n + m, -1);
        vis.assign(n + m, 0);
    }
    void addEdge(int u, int v) {
        adj[u].push_back(n + v);
        adj[n + v].push_back(u);
    }
    vector<pair<int, int>> work() {
        match.clear();
        used.assign(n + m, -1);
        vis.assign(n + m, 0);
        auto dfs = [&](auto self, int u) -> bool {
            for (int v : adj[u]) {
                if (vis[v] == 0) {
                    vis[v] = 1;
                    if (used[v] == -1 || self(self, used[v])) {
                        used[v] = u;
                        return true;
                    }
                }
            }
            return false;
        };
        for (int i = 0; i < n; i++) {
            fill(vis.begin(), vis.end(), 0);
            dfs(dfs, i);
        }
        for (int i = n; i < n + m; i++) {
            if (used[i] != -1) {
                match.emplace_back(used[i], i - n);
            }
        }
        return match;
    }
};
```

4.4 MCMF [f667f8]

```
template<class Tf, class Tc>
struct MCMF {
    // 可以只用 spfa 或 dijkstra，把跟 pot 有關的拿掉就好
    int n, m, s, t;
    Tf INF_FLOW = numeric_limits<Tf>::max() / 2;
    Tc INF_COST = numeric_limits<Tc>::max() / 2;
    struct Edge {
        int to;
        Tf flow, cap; // 流量跟容量
        Tc cost;
    };
    vector<Edge> edges;
    vector<Tc> dis, pot; // johnson algorithm, using spfa
    vector<int> rt; // 路徑恢復，對應 id
    vector<bool> inq;
    MCMF(int n_ = 0) { init(n_); }
    void init(int n_ = 0) {
        n = n_;
        m = 0;
        edges.clear();
        adj.assign(n, vector<int>());
    }
    void add_edge(int u, int v, Tf cap, Tc cost) {
        edges.push_back({v, 0, cap, cost});
        edges.push_back({u, 0, 0, -cost});
        adj[u].push_back(m++);
        adj[v].push_back(m++);
    }
    bool spfa() {
        dis.assign(n, INF_COST);
        rt.assign(n, -1);
        inq.assign(n, false);
        queue<int> q;
        q.push(s);
        dis[s] = 0;
        inq[s] = true;
        while (!q.empty()) {
            int u = q.front(); q.pop();
            inq[u] = false;
            for (int id : adj[u]) {
                auto [v, flow, cap, cost] = edges[id];
                Tc ndis = dis[u] + cost + pot[u] - pot[v];
                if (flow < cap && dis[v] > ndis) {
                    dis[v] = ndis;
                    rt[v] = id;
                    if (!inq[v]) {
                        q.push(v);
                        inq[v] = true;
                    }
                }
            }
        }
        return dis[t] != INF_COST;
    }
    bool dijkstra() {
        dis.assign(n, INF_COST);
        rt.assign(n, -1);
        priority_queue<pair<Tc, int>, vector<pair<Tc, int>, greater<pair<Tc, int>>> pq;
        dis[s] = 0;
        pq.emplace(dis[s], s);
        while (!pq.empty()) {
            auto [d, u] = pq.top(); pq.pop();
            if (dis[u] < d) continue;
            for (int id : adj[u]) {
                auto [v, flow, cap, cost] = edges[id];
                Tc ndis = dis[u] + cost + pot[u] - pot[v];
                if (flow < cap && dis[v] > ndis) {
                    dis[v] = ndis;
                    rt[v] = id;
                    pq.emplace(ndis, v);
                }
            }
        }
        return dis[t] != INF_COST;
    }
    // 限定 flow, 最小化 cost
    pair<Tf, Tc> work_flow(int s_, int t_, Tf need) {
        s = s_, t = t_;
        pot.assign(n, 0);
        Tf flow{}; Tc cost{};
        bool fr = true;
        while ((fr ? spfa() : dijkstra())) {
            for (int i = 0; i < n; i++) {
                dis[i] += pot[i] - pot[s];
            }
            Tf f = INF_FLOW;
            for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
                f = min(f, edges[rt[i]].cap - edges[rt[i]].flow);
            }
            f = min<Tf>(f, need);
            for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
                edges[rt[i]].flow += f;
                edges[rt[i] ^ 1].flow -= f;
            }
            flow += f;
            need -= f;
            cost += f * dis[t];
            fr = false;
            if (need == 0) break;
        }
        return make_pair(flow, cost);
    }
    // 限定 cost, 最大化 flow
    pair<Tf, Tc> work_budget(int s_, int t_, Tc budget) {
        s = s_, t = t_;
        pot.assign(n, 0);
        Tf flow{}; Tc cost{};
        bool fr = true;
        while ((fr ? spfa() : dijkstra())) {
            for (int i = 0; i < n; i++) {
                dis[i] += pot[i] - pot[s];
            }
            Tf f = INF_FLOW;
            for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
                f = min(f, edges[rt[i]].cap - edges[rt[i]].flow);
            }
            f = min<Tf>(f, budget / dis[t]);
            for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
                edges[rt[i]].flow += f;
            }
            flow += f;
            cost += f * dis[t];
            fr = false;
            if (cost == budget) break;
        }
        return make_pair(flow, cost);
    }
};
```

```
};
vector<vector<int>> adj;
vector<Edge> edges; // 幫每個 edge 編號
vector<Tc> dis, pot; // johnson algorithm, using spfa
vector<int> rt; // 路徑恢復，對應 id
vector<bool> inq;
MCMF(int n_ = 0) { init(n_); }
void init(int n_ = 0) {
    n = n_;
    m = 0;
    edges.clear();
    adj.assign(n, vector<int>());
}
void add_edge(int u, int v, Tf cap, Tc cost) {
    edges.push_back({v, 0, cap, cost});
    edges.push_back({u, 0, 0, -cost});
    adj[u].push_back(m++);
    adj[v].push_back(m++);
}
bool spfa() {
    dis.assign(n, INF_COST);
    rt.assign(n, -1);
    inq.assign(n, false);
    queue<int> q;
    q.push(s);
    dis[s] = 0;
    inq[s] = true;
    while (!q.empty()) {
        int u = q.front(); q.pop();
        inq[u] = false;
        for (int id : adj[u]) {
            auto [v, flow, cap, cost] = edges[id];
            Tc ndis = dis[u] + cost + pot[u] - pot[v];
            if (flow < cap && dis[v] > ndis) {
                dis[v] = ndis;
                rt[v] = id;
                if (!inq[v]) {
                    q.push(v);
                    inq[v] = true;
                }
            }
        }
    }
    return dis[t] != INF_COST;
}
bool dijkstra() {
    dis.assign(n, INF_COST);
    rt.assign(n, -1);
    priority_queue<pair<Tc, int>, vector<pair<Tc, int>, greater<pair<Tc, int>>> pq;
    dis[s] = 0;
    pq.emplace(dis[s], s);
    while (!pq.empty()) {
        auto [d, u] = pq.top(); pq.pop();
        if (dis[u] < d) continue;
        for (int id : adj[u]) {
            auto [v, flow, cap, cost] = edges[id];
            Tc ndis = dis[u] + cost + pot[u] - pot[v];
            if (flow < cap && dis[v] > ndis) {
                dis[v] = ndis;
                rt[v] = id;
                pq.emplace(ndis, v);
            }
        }
    }
    return dis[t] != INF_COST;
}
// 限定 flow, 最小化 cost
pair<Tf, Tc> work_flow(int s_, int t_, Tf need) {
    s = s_, t = t_;
    pot.assign(n, 0);
    Tf flow{}; Tc cost{};
    bool fr = true;
    while ((fr ? spfa() : dijkstra())) {
        for (int i = 0; i < n; i++) {
            dis[i] += pot[i] - pot[s];
        }
        Tf f = INF_FLOW;
        for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
            f = min(f, edges[rt[i]].cap - edges[rt[i]].flow);
        }
        f = min<Tf>(f, need);
        for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
            edges[rt[i]].flow += f;
            edges[rt[i] ^ 1].flow -= f;
        }
        flow += f;
        need -= f;
        cost += f * dis[t];
        fr = false;
        if (need == 0) break;
    }
    return make_pair(flow, cost);
}
// 限定 cost, 最大化 flow
pair<Tf, Tc> work_budget(int s_, int t_, Tc budget) {
    s = s_, t = t_;
    pot.assign(n, 0);
    Tf flow{}; Tc cost{};
    bool fr = true;
    while ((fr ? spfa() : dijkstra())) {
        for (int i = 0; i < n; i++) {
            dis[i] += pot[i] - pot[s];
        }
        Tf f = INF_FLOW;
        for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
            f = min(f, edges[rt[i]].cap - edges[rt[i]].flow);
        }
        f = min<Tf>(f, budget / dis[t]);
        for (int i = t; i != s; i = edges[rt[i] ^ 1].to) {
            edges[rt[i]].flow += f;
        }
        flow += f;
        cost += f * dis[t];
        fr = false;
        if (cost == budget) break;
    }
    return make_pair(flow, cost);
}
};
```



```

        edges[rt[i] ^ 1].flow -= f;
    }
    flow += f; budget -= f * dis[t];
    cost += f * dis[t]; fr = false;
    swap(dis, pot);
    if (budget == 0 || f == 0) break;
}
return make_pair(flow, cost);
}
void reset() {
    for (int i = 0; i < m; i++) edges[i].flow = 0;
}
};

```

5 String

5.1 KMP [cddfd9]

```

struct KMP {
    string sub;
    vector<int> failure;
    KMP(string sub_) {
        sub = sub_;
        failure.resize(sub.size(), -1);
        buildFailFunction();
    }
    void buildFailFunction() {
        for (int i = 1; i < (int)sub.size(); i++) {
            int now = failure[i - 1];
            while (now != -1
                && sub[now + 1] != sub[i]) now = failure[now];
            if (sub[now + 1] == sub[i]) failure[i] = now + 1;
        }
    }
    vector<int> match(string &s) {
        vector<int> match;
        for (int i = 0, now = -1; i < (int)s.size(); i++) {
            // now is the compare succeeded length -1
            while (s[i] !=
                sub[now + 1] && now != -1) now = failure[now];
            // failure stores if comparison fail, move to where
            if (s[i] == sub[now + 1]) now++;
            if (now + 1 == (int)sub.size()) {
                match.push_back(i - now);
                now = failure[now];
            }
        }
        return match;
    }
};

```

5.2 Z Function [8dd6ac]

```

// z[i] 表示 s 和 s[i, n - 1] (以 s[i] 開頭的后綴)
// 的最長公共前綴 (LCP) 的長度
vector<int> Z(string s) {
    int n = s.size();
    vector<int> z(n);
    z[0] = n;
    for (int i = 1, j = 1; i < n; i++) {
        z[i] = max(0, min(j + z[j] - i, z[i - j]));
        while (i + z[i] < n && s[z[i]] == s[i + z[i]]) {
            z[i]++;
        }
        if (i + z[i] > j + z[j]) {
            j = i;
        }
    }
    return z; // 最後一格不算
}

```

5.3 SA [32e429]

```

struct SuffixArray {
    int n; vector<int> sa, rk, lc;
    // n: 字串長度
    // sa: 後綴數組, sa[i] 表示第 i 小的後綴的起始位置
    // rk: 排名數組, rk[i] 表示從位置 i 開始的後綴的排名
    // lc: LCP
    // 數組, lc[i] 表示 sa[i] 和 sa[i+1] 的最長公共前綴長度
    SuffixArray(const string &s) {
        n = s.length();
        sa.resize(n);
        lc.resize(n - 1);
        rk.resize(n);
        iota(sa.begin(), sa.end(), 0);
        sort(sa.begin(), sa.end(), [&](int a, int b) { return s[a] < s[b]; });
        rk[sa[0]] = 0;
        for (int i = 1; i < n; i++)
            rk[sa[i]] = rk[sa[i - 1]] + (s[sa[i]] != s[sa[i - 1]]);
        int k = 1;
        vector<int> tmp, cnt(n);
        tmp.reserve(n);
        while (rk[sa[n - 1]] < n - 1) {
            tmp.clear();
            for (int i = 0; i < k; i++)
                tmp.push_back(n - k + i);
            for (auto i : sa)

```

```

                if (i >= k)
                    tmp.push_back(i - k);
            fill(cnt.begin(), cnt.end(), 0);
            for (int i = 0; i < n; i++)
                ++cnt[rk[i]];
            for (int i = 1; i < n; i++)
                cnt[i] += cnt[i - 1];
            for (int i = n - 1; i >= 0; --i)
                sa[--cnt[rk[i]]] = tmp[i];
            swap(rk, tmp);
            rk[sa[0]] = 0;
            for (int i = 1; i < n; i++)
                rk[sa[i]] = rk[sa[i - 1]] + (tmp[sa[i - 1]] < tmp[sa[i]] || sa[i - 1] + k ==
                    n || tmp[sa[i - 1] + k] < tmp[sa[i] + k]);
            k *= 2;
        }
        for (int i = 0, j = 0; i < n; i++) {
            if (rk[i] == 0) {
                j = 0;
            } else {
                for (j
                    - = j > 0; i + j < n && sa[rk[i] - 1] + j
                    < n && s[i + j] == s[sa[rk[i] - 1] + j]; )
                    ++j;
                lc[rk[i] - 1] = j;
            }
        }
    }
};

```

5.4 Duval Algorithm [f9dcca]

```

// duval_algorithm
// 將字串分解成若干個非嚴格遞減的非嚴格遞增字串
vector<string> duval(string s) {
    int i = 0, n = s.size();
    vector<string> res;
    while (i < n) {
        int k = i, j = i + 1;
        while (s[k] <= s[j] && j < n) {
            if (s[k] < s[j]) k = i;
            else k++;
            j++;
        }
        while (i <= k) {
            res.push_back(s.substr(i, j - k));
            i += j - k;
        }
    }
    return res;
}
// 最小旋轉字串
string min_round(string s) {
    s += s;
    int i = 0, n = s.size();
    int start = i;
    while (i < n / 2) {
        start = i;
        int k = i, j = i + 1;
        while (s[k] <= s[j] && j < n) {
            if (s[k] < s[j]) k = i;
            else k++;
            j++;
        }
        while (i <= k) {
            i += j - k;
        }
    }
    return s.substr(start, n / 2);
}

```

5.5 Manacher [9c9ca6]

```

// 找到對於每個位置的迴文半徑
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++) { // i 是中心, j 是最長回文字串中心
        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] += 1;
        }
        if (i + r[i] > j + r[j]) {
            j = i;
        }
    }
    return r;
}
// # a # b # a #
// 1 2 1 4 1 2 1
// # a # b # b # a #
// 1 2 1 2 5 2 1 2 1

```

```
// 值 -1 代表原回文字串長度
// (id - val + 1) / 2 可得原字串回文開頭
}
```

5.6 Trie [3b3aa0]

```
struct Trie {
    struct trie_node {
        bool is_word;
        vector<trie_node*> children;
        trie_node() {
            is_word = false;
            children.resize(26, NULL);
        }
    };
    trie_node *root = new trie_node();
    void insert(string &s) {
        trie_node *cur = root;
        for (int i = 0; i < s.size(); i++) {
            int idx = s[i] - 'a';
            if (cur->children[idx] == NULL) {
                cur->children[idx] = new trie_node();
            }
            cur = cur->children[idx];
        }
        cur->is_word = true;
    }
    bool is_in_trie(string &s) {
        trie_node *cur = root;
        for (int i = 0; i < s.size(); i++) {
            if (cur->children[s[i] - 'a'] == nullptr) return false;
            cur = cur->children[s[i] - 'a'];
        }
        return true;
    }
    int search_i_start(string &s, int i, vector<int> &dp) {
        trie_node *cur = root;
        int sz = s.size(), ans = 0;
        for (int j = i; j < sz; j++) {
            if (cur->children[s[j] - 'a'] == nullptr) return ans;
            cur = cur->children[s[j] - 'a'];
            if (cur->is_word)
                (ans += dp[j + 1]) %= mod;
        }
        return ans;
    }
};

int main() {
    // 找到 sub 集合裡，可以重複用，組成 s 的組數
    Trie trie;
    string s; cin >> s;
    int sz = s.size();
    // dp 代表 i 開頭到最後的配對總數
    // 找到有結尾為 stop 的 dp[i] += dp[j + 1]
    int n; cin >> n;
    vector<int> dp(sz + 1, 0);
    for (int i = 0; i < n; i++) {
        string sub; cin >> sub;
        trie.insert(sub);
    }
    dp[sz] = 1;
    for (int i = sz - 1; i >= 0; i--) {
        dp[i] = trie.search_i_start(s, i, dp);
    }
    cout << dp[0] << endl;
}
```

6 Math

6.1 質因數分解 [ee1622]

```
// a^(m-1) = 1 (mod m)
// a^(m-2) = 1/a (mod m)
// EXP2: cout << fast_exp(x, fast_exp(y, p, MOD - 1), MOD)
// Filter + DP; DP save min factor, recur factor decomposition
// FacNums = (x+1)(y+1)(z+1)...
// FacSum = (a^0+a^1...+a^x)(b^0+...+b^y)
// FacMul = N(x+1)(y+1)(z+1)/2

vector<int> is_prime;
// 1 代表是質數，非 1 不是
void init(int n) {
    is_prime.assign(n + 1, 1);
    for (int i = 2; i <= (int)sqrt(n) + 1; i++) {
        if (is_prime[i] == 1) {
            for (int j = i + i; j <= n; j += i) {
                is_prime[j] = 0;
            }
        }
    }
}

int main() {
    init(1000000);
    ll ans = 1;
    ll q; cin >> q;
    map<ll, ll> mp;
    while (is_prime[q] != 1) {
        mp[is_prime[q]]++;
    }
}
```

```
q /= is_prime[q];
}
if (q != 1) mp[q]++;
for (auto [a, b] : mp) {
    ans *= b + 1;
}
cout << ans << "\n";
}
```

6.2 模除計算 [9b1014]

```
using i64 = long long;
template<class T>
constexpr T power(T a, i64 b) {
    T res = 1;
    for (; b; b /= 2, a *= a) {
        if (b % 2) {
            res *= a;
        }
    }
    return res;
}

constexpr i64 mul(i64 a, i64 b, i64 p) {
    i64 res = a * b - i64(1.L * a * b / p) * p;
    res %= p;
    if (res < 0) {
        res += p;
    }
    return res;
}

template<i64 P>
struct MLong {
    i64 x;
    constexpr MLong() : x{} {}
    constexpr MLong(i64 x) : x{norm(x % getMod())} {}

    static i64 Mod;
    constexpr static i64 getMod() {
        if (P > 0) {
            return P;
        } else {
            return Mod;
        }
    }
    constexpr static void setMod(i64 Mod_) {
        Mod = Mod_;
    }
    constexpr i64 norm(i64 x) const {
        if (x < 0) {
            x += getMod();
        }
        if (x >= getMod()) {
            x -= getMod();
        }
        return x;
    }
    constexpr i64 val() const {
        return x;
    }
    explicit constexpr operator i64() const {
        return x;
    }
    constexpr MLong operator-(const MLong res) const {
        MLong res;
        res.x = norm(getMod() - x);
        return res;
    }
    constexpr MLong inv() const {
        assert(x != 0);
        return power(*this, getMod() - 2);
    }
    constexpr MLong &operator*=(MLong rhs) & {
        x = mul(x, rhs.x, getMod());
        return *this;
    }
    constexpr MLong &operator+=(MLong rhs) & {
        x = norm(x + rhs.x);
        return *this;
    }
    constexpr MLong &operator-=(MLong rhs) & {
        x = norm(x - rhs.x);
        return *this;
    }
    constexpr MLong &operator/=(MLong rhs) & {
        return *this *= rhs.inv();
    }
    friend constexpr MLong operator*(MLong lhs, MLong rhs) {
        MLong res = lhs;
        res *= rhs;
        return res;
    }
    friend constexpr MLong operator+(MLong lhs, MLong rhs) {
        MLong res = lhs;
        res += rhs;
        return res;
    }
    friend constexpr MLong operator-(MLong lhs, MLong rhs) {
        MLong res = lhs;
        res -= rhs;
        return res;
    }
}
```

```

friend constexpr MLong operator/(MLong lhs, MLong rhs) {
    MLong res = lhs;
    res /= rhs;
    return res;
}
friend
constexpr istream &operator>>(istream &is, MLong &a) {
    i64 v;
    is >> v;
    a = MLong(v);
    return is;
}
friend constexpr
ostream &operator<<(ostream &os, const MLong &a) {
    return os << a.val();
}
friend constexpr bool operator==(MLong lhs, MLong rhs) {
    return lhs.val() == rhs.val();
}
friend constexpr bool operator!=(MLong lhs, MLong rhs) {
    return lhs.val() != rhs.val();
}
};

template<>
i64 MLong<0LL>::Mod = i64(1E18) + 9;

constexpr i64 P = 998244353;
using Z = MLong<P>;
// using Z = MLong<0LL>; // change Mod

struct Comb {
    i64 n;
    vector<Z> _fac;
    vector<Z> _invfac;
    vector<Z> _inv;
    Comb() : n{0}, _fac{1}, _invfac{1}, _inv{0} {}
    Comb(i64 n) : Comb() { init(n); }

    void init(i64 m) {
        m = min(m, Z::getMod() - 1);
        if (m <= n) return;
        _fac.resize(m + 1);
        _invfac.resize(m + 1);
        _inv.resize(m + 1);

        for (int i = n + 1; i <= m; i++) {
            _fac[i] = _fac[i - 1] * i;
        }
        _invfac[m] = _fac[m].inv();
        for (int i = m; i > n; i--) {
            _invfac[i - 1] = _invfac[i] * i;
            _inv[i] = _invfac[i] * _fac[i - 1];
        }
        n = m;
    }
    Z fac(i64 m) {
        if (m > n) init(2 * m);
        return _fac[m];
    }
    Z invfac(i64 m) {
        if (m > n) init(2 * m);
        return _invfac[m];
    }
    Z inv(i64 m) {
        if (m > n) init(2 * m);
        return _inv[m];
    }
    Z binom(i64 n, i64 m) {
        if (n < m || m < 0) return 0;
        return fac(n) * invfac(m) * invfac(n - m);
    }
    Z Lucas(Z m, Z n) {
        return n == 0 ? Z(1) : Lucas(m.val() / Z::getMod(),
            n.val() / Z::getMod()) * binom(m.val(), n.val());
    }
} comb; // 注意宣告，若要換模數需重新宣告

```

6.3 中國餘數定理 [d41d8c]

```

ll exgcd(ll a, ll b, ll &x, ll &y) {
    if (!b) {
        x = 1, y = 0;
        return a;
    }

    ll g = exgcd(b, a % b, y, x);
    y -= a / b * x;
    return g;
}

ll inv(ll x, ll m) {
    ll a, b;
    exgcd(x, m, a, b);
    a %= m;
    if (a < 0) a += m;
    return a;
}

// remain, mod
ll CRT(vector<pair<ll, ll>> &a) {
    ll prod = 1;
    for (auto x : a) {
        prod *= x.second;
    }
}

```

```

}
ll res = 0;
for (auto x : a) {
    auto t = prod / x.second;
    res += x.first * t % prod * inv(t, x.second) % prod;
    if (res >= prod) res -= prod;
}
return res;
}

```

6.4 矩陣與快速幂 [08b5fe]

```

template<class T>
struct Mat {
    int m, n;
    constexpr static ll mod = 1e9 + 7;
    vector<vector<T>> matrix;
    Mat(int n_ = 0) { init(n_, n_); }
    Mat(int m_, int n_) { init(m_, n_); }
    Mat(vector<vector<T>> matrix_) { init(matrix_); }
    void init(int m_, int n_) {
        m = m_; n = n_;
        matrix.assign(m, vector<T>(n));
    }
    void init(vector<vector<T>> &matrix_) {
        m = matrix_.size();
        n = matrix_[0].size();
        matrix = matrix_;
    }
    vector<vector<T>> unit(int n) { // 單位矩陣
        vector<vector<T>> res(n, vector<T>(n));
        for (int i = 0; i < n; i++) {
            res[i][i] = 1;
        }
        return res;
    }
    constexpr Mat &operator*=(const Mat &rhs) & {
        assert(matrix[0].size() == rhs.matrix.size());
        int m = matrix.size(), k = matrix[0].size(), n = rhs.matrix[0].size();
        Mat ans(m, n);
        for (int i = 0; i < m; i++) {
            for (int j = 0; j < n; j++) {
                for (int l = 0; l < k; l++) {
                    (ans.matrix[i][j] += (matrix[i][l] *
                        rhs.matrix[l][j] % mod)) %= mod;
                }
            }
        }
        matrix = ans.matrix;
        return *this;
    }
    constexpr Mat &operator^=(ll p) & {
        assert(m == n); assert(p >= 0);
        Mat ans(p == 0 ? unit(m) : matrix);
        while (p > 0) {
            if (p & 1) ans *= *this;
            *this *= *this;
            p >>= 1;
        }
        matrix = ans.matrix;
        return *this;
    }
    friend Mat operator*(Mat lhs, const Mat &rhs) {
        lhs *= rhs;
        return lhs;
    }
    friend Mat operator^(Mat lhs, const ll p) {
        lhs ^= p;
        return lhs;
    }
};

// fn = fn-3 + fn-2 + fn-1
// 初始矩陣 轉移式
// f4 f3 f2 1 1 0 f5 f4 f3
// f3 f2 f1 1 0 1 => f4 f3 f2
// f2 f1 f0 1 0 0 f3 f2 f1

```

6.5 樹論分塊 [06204a]

```

// CSES_Sum_of_Divisors
const int mod = 1e9 + 7;
const int inv_2 = 500000004;
// n / 1 * 1 + n / 2 * 2 + n / 3 * 3 + ... + n / n * n
signed main() {
    ll ans = 0;
    ll n; cin >> n;
    for (ll l = 1, r; l <= n; l = r + 1) {
        r = n / (n / l);
        ll val = n / l; // n / l 到 n / r 一樣的值
        ll sum = (((l + r) % mod) *
            ((r - l + 1) % mod)) % mod * inv_2; // l 加到 r
        val %= mod; sum %= mod;
        ans += val * sum;
        ans %= mod;
    }
    cout << ans << "\n";
}

```

6.6 Mobius Theorem

- 數論分塊可以快速計算一些含有除法向下取整的和式，就是像 $\sum_{i=1}^n f(i)g(\lfloor \frac{n}{i} \rfloor)$ 的和式。當可以在 $O(1)$ 內計算 $f(r) - f(l)$ 或已經預處理出 f 的前綴和時，數論分塊就可以在 $O(\sqrt{n})$ 的時間內計算上述和式的值。
- 迪利克雷捲積 $h(x) = \sum_{d|x} f(d)g(\frac{x}{d})$
- 積性函數
 - 莫比烏斯函數
 - 定義

$$\mu(d) = \begin{cases} 1 & \text{for } n=1 \\ 0 & \text{for } n \neq 1 \end{cases}$$

- μ 是常數函數 1 的反元素

$\Rightarrow \mu * 1 = \epsilon, \epsilon(n)$ 只在 $n=1$ 時為 1，其餘情況皆為 0。

- ϕ 歐拉函數: x 以下與 x 互質的數量

$$\begin{aligned} \phi * 1 &= \sum_{d|n} \phi\left(\frac{n}{d}\right) \text{ 質因數分解} \\ &= \sum_{i=0}^c \phi(p^i) \\ &= 1 + p^0(p-1) + p^1(p-1) + \dots + p^{c-1}(p-1) \\ &= p^c \\ &= id \end{aligned}$$

- 莫比烏斯反演公式

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

- 例子

$$\begin{aligned} \sum_{i=a}^b \sum_{j=c}^d [gcd(i, j) = k] \\ \Rightarrow \sum_{i=1}^{\lfloor \frac{x}{k} \rfloor} \sum_{j=1}^{\lfloor \frac{y}{k} \rfloor} [gcd(i, j) = k] \\ = \sum_{i=1}^{\lfloor \frac{x}{k} \rfloor} \sum_{j=1}^{\lfloor \frac{y}{k} \rfloor} \epsilon(gcd(i, j)) \\ = \sum_{i=1}^{\lfloor \frac{x}{k} \rfloor} \sum_{j=1}^{\lfloor \frac{y}{k} \rfloor} \sum_{d|gcd(i, j)} \mu(d) \\ = \sum_{d=1}^{\infty} \mu(d) \sum_{i=1}^{\lfloor \frac{x}{kd} \rfloor} \sum_{j=1}^{\lfloor \frac{y}{kd} \rfloor} [d \text{ 可整除 } i \text{ 時為 } 1] \\ = \sum_{d=1}^{\min(\lfloor \frac{x}{k} \rfloor, \lfloor \frac{y}{k} \rfloor)} \mu(d) \lfloor \frac{x}{kd} \rfloor \lfloor \frac{y}{kd} \rfloor \end{aligned}$$

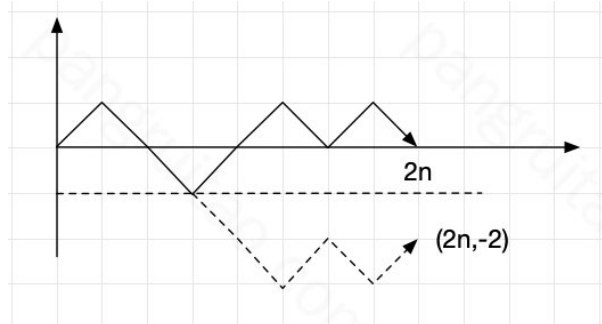
6.7 莫比烏斯反演 [d41d8c]

```
const int maxn = 2e5;
ll mobius_pref[maxn];
void init() {
    mobius_pref[1] = 1;
    vector<ll> wei;
    (maxn); // wei = 0 代表是質數, -1 代表可被平方數整除
    for (ll i = 2; i < maxn; i++) {
        if (wei[i] == -1) {
            mobius_pref[i] = mobius_pref[i - 1];
            continue; // 包含平方
        }
        if (wei[i] == 0) {
            wei[i] = 1;
            for (ll j = 2; i * j < maxn; j++) {
                if (j % i == 0) wei[i * j] = -1;
                else if (wei[i * j] != -1) wei[i * j]++;
            }
        }
        mobius_pref[i] = mobius_pref[i - 1] + (wei[i] % 2 == 0 ? 1 : -1);
    }
}

void solve() {
    ll a, b, c, d, k; cin >> a >> b >> c >> d >> k;
    auto cal = [&](ll x, ll y) -> int {
        int res = 0;
        for (int l = 1, r; l <= min(x, y); l = r + 1) {
            r = min(x / (x / l), y / (y / l));
            res += (mobius_pref[r] - mobius_pref[l - 1]) * (x / l) * (y / l); // 代推出來的式子
        }
        return res;
    };
}
```

```
};
cout << cal
(b / k, d / k) - cal((a - 1) / k, d / k) - cal(b / k,
(c - 1) / k) + cal((a - 1) / k, (c - 1) / k) << "n";
}
```

6.8 Catalan Theorem



- n 個往上 n 個往下，先枚舉所有情況 $\frac{(2n)!}{n!n!} = C_n^{2n}$
 - 扣掉非法的，有多少種可能讓最後的點落在 $(2n, -2)$
- 假設往上有 x 個，往下有 y 個，會有：

$$\begin{cases} x + y = 2n \\ y - x = 2 \end{cases} \Rightarrow \begin{cases} x = n - 1 \\ y = n + 1 \end{cases}$$

所以只要扣掉 C_{n-1}^{2n-1} 即可

6.9 Burnside's Lemma

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

- G : 各種翻轉操作所構成的置換群
- X/G : 本質不同的方案的集合
- X^g : 對於某一種操作 g ，所有方案中，經過 g 這種翻轉後保持不變的方案
- 集合取絕對值代表集合數

7 Search and Greedy

7.1 二分搜 [d41d8c]

```
int main() {
    int l = 1, r = 10;
    // 1 to tar, find tar
    while (l <= r) {
        int m = (l + r) / 2;
        if (check(m)) l = m + 1;
        else r = m - 1;
    }
    cout << r;
    // tar to end
    while (l <= r) {
        int m = (l + r) / 2;
        if (check(m)) r = m - 1;
        else l = m + 1;
    }
    cout << l;
}
```

7.2 三分搜 [d41d8c]

```
// 找極值問題，遞增遞減
void solve() {
    int l = 0, r = 10, ans = 0; // ans 紀錄答案
    while (l <= r) {
        int d = (r - l) / 3; // 差
        int ml = l + d, mr = r - d; // mr 要用減的
        auto cal = [&](int m) -> int {
            int x = 0;
            return x; // 計算答案
        };
        int ans1 = cal(ml), ans2 = cal(mr);
        if (ans1 < ans2) {
            l = ml + 1;
        }
        else r = mr - 1;
    }
}
```

8 Tree

8.1 LCA [9f95b1]

```
vector<vector<int>> par(maxn, vector<int>(18));
vector<int> depth(maxn + 1);
vector<int> dfn(maxn);
void build_lca(int n, vector<vector<pair<int, int>>> &tree) {
    auto dfs = [&](auto self, int u, int pre) -> void {
        for (auto [v, w] : tree[u]) {
            if (v == pre) continue;
            par[v][0] = u; // 2^0
            depth[v] = depth[u] + 1;
            self(self, v, u);
        }
    };
}
```

```

};
dfs(dfs, 1, 0);
for (int i = 1; i <= 18; i++) {
    for (int j = 1; j <= n; j++) {
        par[j][i] = par[par[j][i-1]][i-1];
    }
}
int lca(int a, int b) {
    if (depth[a] < depth[b]) swap(a, b);
    int pull = depth[a] - depth[b];
    for (int i = 0; i < 18; i++) {
        if (pull & (1 << i)) {
            a = par[a][i];
        }
    }
    if (a == b) return a;
    for (int i = 17; i >= 0; i--) {
        if (par[a][i] != par[b][i]) {
            a = par[a][i], b = par[b][i];
        }
    }
    return par[a][0];
}
}

```

8.2 樹重心 [30b436]

```

struct centroid_decomposition {
    int n;
    vector<vector<int>> adj;
    vector<bool> vis;
    vector<int> siz;
    centroid_decomposition() {}
    centroid_decomposition(int n_) { init(n_); }
    void init(int n_) {
        n = n_;
        adj.assign(n, {});
        vis.assign(n, false);
        siz.assign(n, 1);
    }
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
    void get_siz(int dep, int x, int p = -1) {
        siz[x] = 1;
        for (int y : adj[x]) {
            if (y == p || vis[y]) continue;
            get_siz(dep + 1, y, x);
            siz[x] += siz[y];
        }
    }
    int get_cen(int x, int sz, int p = -1) {
        for (int y : adj[x]) {
            if (y == p || vis[y]) continue;
            if (siz[y] * 2 > sz) {
                return get_cen(y, sz, x);
            }
        }
        return x;
    }
    void work(int x = 0) {
        get_siz(0, x);
        int cen = get_cen(x, siz[x]);
        vis[cen] = true;
        // do something
        for (int y : adj[cen]) {
            if (vis[y]) continue;
            work(y);
        }
    }
};

```

8.3 樹壓平 [51199c]

```

// 父節
點加值 = 所有子節點區間加值，求單點，使用 bit，做前綴差分
// CSES 1138_Path Queries
int main() {
    int n, q; cin >> n >> q;
    vector<int> node_value(n + 1), euler_ordered_value(n);
    for (int i = 1; i <= n; i++) {
        cin >> node_value[i];
    }
    vector<vector<int>> tree(n + 1);
    for (int i = 1; i < n; i++) {
        int u, v; cin >> u >> v;
        tree[u].push_back(v);
        tree[v].push_back(u);
    }
    vector<pair<int, int>> tree_mapping(n + 1);
    int cnt = 0;
    auto dfs = [&](auto self, int u, int par) -> void {
        euler_ordered_value[++cnt] = node_value[u];
        tree_mapping[u].first = cnt;
        for (auto v : tree[u]) {
            if (v == par) continue;
            self(self, v, u);
        }
        tree_mapping[u].second = cnt;
    };
    dfs(dfs, 1, 0);
}

```

```

BIT bit(n);
for (int i = 1; i <= n; i++) {
    bit.modify(tree_mapping[i].first, node_value[i]);
    if (tree_mapping[i].first < n) { // root 就不用扣了
        bit.modify(
            (tree_mapping[i].second + 1, -node_value[i]);
        );
    }
}
for (int i = 0; i < q; i++) {
    int op; cin >> op;
    if (op == 1) {
        int s, x; cin >> s >> x;
        int add = x
            - euler_ordered_value[tree_mapping[s].first];
        euler_ordered_value[tree_mapping[s].first] = x;
        bit.modify(tree_mapping[s].first, add);
        if (tree_mapping[s].first < n) { // root 就不用扣了
            bit.modify(tree_mapping[s].second + 1, -add);
        }
    }
    else {
        int node; cin >> node;
        cout <<
            bit.query(tree_mapping[node].first) << "\n";
    }
}
}

```

8.4 Heavy Light Decomposition [ad25b6]

```

struct HLD {
    int n, cur;
    vector<int> siz, top, dep, parent, in, out, seq;
    vector<vector<int>> adj;
    HLD(int n_) { init(n_); }
    void init(int n_) {
        n = n_; cur = 0;
        siz.resize(n); top.resize(n); dep.resize(n);
        parent.resize(n); in.resize(n); out.resize(n);
        seq.resize(n); adj.assign(n, {});
    }
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
    void work(int root = 0) {
        top[root] = root;
        dep[root] = 0;
        parent[root] = -1;
        dfs1(root); dfs2(root);
    }
    void dfs1(int u) {
        if (parent[u] != -1)
            adj[u].erase(find(
                adj[u].begin(), adj[u].end(), parent[u]));
        siz[u] = 1;
        for (auto &v : adj[u]) {
            parent[v] = u, dep[v] = dep[u] + 1;
            dfs1(v);
            siz[u] += siz[v];
            if (siz[v] > siz[adj[u][0]]) {
                swap(v, adj[u][0]);
            } // 讓 adj[u][0] 是重子節點
        }
    }
    void dfs2(int u) {
        in[u] = cur++;
        seq[in[u]] = u; // dfn 對應的編號
        for (auto v : adj[u]) {
            top[v] = v == adj[u][0] ? top[u] : v;
            dfs2(v);
        }
        out[u] = cur;
    }
    int lca(int u, int v) {
        while (top[u] != top[v]) {
            if (dep[top[u]] > dep[top[v]]) {
                u = parent[top[u]];
            } else {
                v = parent[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 = parent[top[u]];
        return seq[in[u] - dep[u] + d];
    }
    bool isAncestor(int u, int v) {
        // 判斷 u 是否是 v 的祖先
        return in[u] <= in[v] && in[v] < out[u];
    }
    int rootedParent(int u, int v) {
        // 根據新根節點 u 計算 v 的父節點
        swap(u, v);
    }
}

```

```

    if (u == v) return u;
    if (!isAncestor(u, v)) return parent[u];
    auto it = upper_bound(adj[u].begin(), adj[u].end(), v, [&](int x, int y) {
        return in[x] < in[y];
    }) - 1;
    return *it;
}
int rootedSize(int u, int v) {
    // 根據新根節點 u 計算子樹 v 的大小
    if (u == v) return n;
    if (!isAncestor(v, u)) return siz[v];
    return n - siz[rootedParent(u, v)];
}
int rootedLca(int a, int b, int c) {
    // 根據新的根節點計算三個節點 a、b 和 c 的最近公共祖先
    return lca(a, b) ^ lca(b, c) ^ lca(c, a);
}
};

```

8.5 Link Cut Tree [c26f51]

```

#include <bits/stdc++.h>
using namespace std;
using i64 = long long;
constexpr i64 Mod = 51061;

struct Tag {
    i64 add = 0;
    i64 mul = 1;
    void apply(const Tag &v) {
        mul = mul * v.mul % Mod;
        add = (add * v.mul % Mod + v.add) % Mod;
    }
};

struct Info {
    i64 val = 1;
    i64 sum = 1;
    void apply(int size, const Tag &v) {
        val = (val * v.mul % Mod + v.add) % Mod;
        sum = (sum * v.mul % Mod + v.add * size % Mod) % Mod;
    }
};

struct Node {
    Node *ch[2], *p;
    int rev = 0;
    int size = 1;
    void make_rev() {
        swap(ch[0], ch[1]);
        rev ^= 1;
    }
    Node() : ch {nullptr, nullptr}, p(nullptr) {}

    Info info = Info();
    Tag tag = Tag();

    void apply(const Tag &v) {
        info.apply(size, v);
        tag.apply(v);
    }

    void push_tag() {
        if (rev) {
            if (ch[0]) ch[0]->make_rev();
            if (ch[1]) ch[1]->make_rev();
            rev = 0;
        }
        if (ch[0]) {
            ch[0]->apply(tag);
        }
        if (ch[1]) {
            ch[1]->apply(tag);
        }
        tag = Tag();
    }

    void pull_info() {
        size = (ch[0] ?
            ch[0]->size : 0) + (ch[1] ? ch[1]->size : 0) + 1;
        info.sum = ((ch[0] ? ch[0]->info.sum : 0)
            + (ch[1] ? ch[1]->info.sum : 0) + info.val) % Mod;
    }
};

bool isroot(Node *t) {
    return t->p
        == nullptr || (t->p->ch[0] != t && t->p->ch[1] != t);
}

int pos(Node *t) { // 回傳 1 代表是右子節點
    return t->p->ch[1] == t;
}

void rotate(Node *t) {
    Node *q = t->p;
    int x = !pos(t);
    q->ch[!x] = t->ch[x];
    if (t->ch[x]) {
        t->ch[x]->p = q;
    }
    t->p = q->p;
    if (!isroot(q)) {
        q->p->ch[pos(q)] = t;
    }
}

```

```

t->ch[x] = q;
q->p = t;
q->pull_info();
}

void splay(Node *t) { // 單點修改前必須呼叫
    // 把 t 旋轉到目前 splay 的根
    while (!isroot(t)) {
        Node *p = t->p;
        p->push_tag();
        t->push_tag();
        rotate(t);
    }
    t->push_tag();
    t->pull_info();
}

void access(Node *t) {
    // 把從根到 t 的所有點都放在一條實鏈裡，使根
    // 到 t 成為一條實路徑，並且在同一棵 splay 裡
    for (Node *i = t, *q = nullptr; i; q = i, i = i->p) {
        splay(i);
        i->ch[1] = q;
    }
    splay(t);
}

void makeRoot(Node *t) { // 使 t 點成為其所在樹的根
    access(t);
    swap(t->ch[0], t->ch[1]);
    t->rev ^= 1;
}

Node* findRoot(Node *t) { // 找到 t 的 root
    access(t);
    splay(t);
    t->push_tag();
    while (t->ch[0]) {
        t = t->ch[0];
        t->push_tag();
    }
    splay(t);
    return t;
}

void link(Node *t, Node *p) {
    makeRoot(t);
    if (findRoot(p) != t) {
        makeRoot(p);
        t->p = p;
        p->pull_info();
    }
}

bool cut(Node *x, Node *y) { // 不存在邊，回傳 false
    makeRoot(x);
    access(y);
    if (y->ch[0] != x || x->ch[1]) return false;
    y->ch[0]->p = nullptr;
    y->ch[0] = nullptr;
    y->pull_info();
    return true;
}

void split(Node *x, Node *y) { // 以 y 做根，區間修改用，apply 在 y 上
    makeRoot(x);
    access(y);
    splay(y);
}

bool isconnected(Node *x, Node *y) { // 查詢有沒有連通
    makeRoot(x);
    access(y);
    return findRoot(x) == findRoot(y);
}

int main() {
    int n; cin >> n;
    vector<Node*> nodes(n);
    int q; cin >> q;
    for (int i = 0; i < n; i++) {
        nodes[i] = new Node();
        nodes[i]->info.val = nodes[i]->info.sum = 1LL;
    }
    for (int i = 0; i < n - 1; i++) {
        int u, v; cin >> u >> v;
        u--; v--;
        link(nodes[u], nodes[v]);
    }
    for (int i = 0; i < q; i++) {
        char op; cin >> op;
        if (op == '+') {
            int u, v; cin >> u >> v;
            u--; v--;
            split(nodes[u], nodes[v]);
            Tag tag;
            cin >> tag.add;
            tag.add % Mod;
            nodes[v]->apply(tag);
        }
        else if (op == '-') {
            int u1, v1; cin >> u1 >> v1;
            int u2, v2; cin >> u2 >> v2;
            u1--; v1--; u2--; v2--;
            cut(nodes[u1], nodes[v1]);
            link(nodes[u2], nodes[v2]);
        }
    }
}

```



```

else if (op == '*') {
    int u, v; cin >> u >> v;
    u--; v--;
    split(nodes[u], nodes[v]);
    Tag tag;
    cin >> tag.mul;
    tag.mul % Mod;
    nodes[v]->apply(tag);
}
else {
    int u, v; cin >> u >> v;
    u--; v--;
    split(nodes[u], nodes[v]);
    cout << nodes[v]->info.sum << "\n";
}
}
return 0;
}

```

8.6 Virtual Tree [622e69]

// 當存在關鍵點且除了關鍵點的根關鍵點的 LCA 都沒用處
 // 可以建立虛樹達成快速樹 DP
 // 例如這題是有權樹，跟 vertex 1 隔開的最小成本

```

int top = -1; vector<int> stk(maxn);
void insert(int u, vector<vector<int>> &vt) {
    if (top == -1) return stk[++top] = u, void();
    int l = lca(stk[top], u);
    if (l == stk[top]) return stk[++top] = u, void();
    while (dfn[l] < dfn[stk[top - 1]])
        vt[stk[top - 1]].push_back(stk[top]), top--;
    if (stk[top - 1] != l) {
        vt[l].push_back(stk[top]);
        stk[top] = l;
    } else vt[l].push_back(stk[top--]);
    stk[++top] = u;
}
void reset(int u, vector<vector<int>> &vt) {
    for (int i : vt[u]) reset(i, vt);
    vt[u].clear();
}
void solve(int n, int q) {
    vector g(n + 1, vector<pair<int, int>>());
    vector vt(n + 1, vector<int>()); // dfs 完清除，否則會退化
    vector<ll> dp(n + 1, iskey(n + 1));
    for (int i = 0; i < n - 1; i++) {
        int u, v, w; cin >> u >> v >> w;
        g[u].push_back({v, w});
        g[v].push_back({u, w});
    }
    build_lca(n, g);
    build(n, g);
    for (int i = 0; i < q; i++) {
        int m; top = -1; cin >> m;
        vector<int> key(m);
        for (int j = 0; j < m; j++) {
            cin >> key[j];
            iskey[key[j]] = 1;
        }
        key.push_back(1); // 看題目，需要才放
        sort(all(key), [&](int a, int b) {
            return dfn[a] < dfn[b];
        });
        for (int x : key) insert(x, vt);
        while (top > 0) vt[stk[top - 1]].push_back(stk[top]), --top;
        // DP
        auto dfs = [&](auto self, int u) -> void {
            for (auto v : vt[u]) {
                self(self, v);
                if (iskey[v]) {
                    dp[u] += min_dis[v];
                    // 砍掉 1 到 v 之間最短的路
                } else {
                    dp[u] += min(dp[v], min_dis[v]);
                }
                iskey[v] = dp[v] = 0;
            }
            vt[u].clear();
        };
        dfs(dfs, key[0]); // key[0] 一定是 root
        cout << dp[key[0]] << "\n";
        iskey[key[0]] = dp[key[0]] = 0;
    }
}

```

8.7 Dominator Tree [baa540]

```

struct Dominator_tree {
    int n, id;
    vector<vector<int>> adj, radj, bucket;
    vector<int> sdom, dom, vis, rev, pa, rt, mn, res;
    Dominator_tree(int n = 0) { init(n); }
    void init(int n) {
        n = _n, id = 0;
        adj.assign(n, vector<int>());
        radj.assign(n, vector<int>());
        bucket.assign(n, vector<int>());
        sdom.resize(n); dom.assign(n, -1);
    }
}

```

```

vis.assign(n, -1); rev.resize(n);
pa.resize(n); rt.resize(n);
mn.resize(n); res.resize(n);
}
void add_edge(int u, int v) { adj[u].push_back(v); }
int query(int v, int x) {
    if (rt[v] == v) return x ? -1 : v;
    int p = query(rt[v], 1);
    if (p == -1) return x ? rt[v] : mn[v];
    if (sdom[mn[v]] > sdom[mn[rt[v]]]) mn[v] = mn[rt[v]];
    rt[v] = p;
    return x ? p : mn[v];
}
void dfs(int v) {
    vis[v] = id, rev[id] = v;
    rt[id] = mn[id] = sdom[id] = id, id++;
    for (int u : adj[v]) {
        if (vis[u] == -1) dfs(u), pa[vis[u]] = vis[v];
        radj[vis[u]].push_back(vis[v]);
    }
}
void build(int s) {
    dfs(s);
    for (int i = id - 1; i >= 0; i--) {
        for (int u : radj[i])
            sdom[i] = min(sdom[i], sdom[query(u, 0)]);
        if (i) bucket[sdom[i]].push_back(i);
        for (int u : bucket[i]) {
            int p = query(u, 0);
            dom[u] = sdom[p] == i ? i : p;
        }
        if (i) rt[i] = pa[i];
    }
    res.assign(n, -1);
    for (int i = 1; i < id; i++)
        if (dom[i] != sdom[i]) dom[i] = dom[dom[i]];
    for (int i = 1; i < id; i++) res[rev[i]] = rev[dom[i]];
    res[s] = s;
    for (int i = 0; i < n; i++) dom[i] = res[i];
}
}

```

9 DP

9.1 LCS [5781cf]

```

int main() {
    int m, n; cin >> m >> n;
    string s1, s2; cin >> s1 >> s2;
    int L = 0;
    vector<vector<int>> dp(m + 1, vector<int>(n + 1, 0));
    for (int i = 1; i <= m; i++) {
        for (int j = 1; j <= n; j++) {
            if (s1[i - 1] == s2[j - 1])
                dp[i][j] = dp[i - 1][j - 1] + 1;
            else
                dp[i][j] = max(dp[i - 1][j], dp[i][j - 1]);
        }
    }
    int length = dp[m][n]; cout << length << "\n";
    string s(length, 'c'); // backtracking
    while (m >= 1 && n >= 1) {
        if (s1[m - 1] == s2[n - 1]) {
            s[length - 1] = s1[m - 1];
            m--, n--, length--;
        } else {
            if (dp[m - 1][n] > dp[m][n - 1]) m--;
            else n--;
        }
    }
    cout << s << "\n";
}

```

9.2 LIS [66d09f]

```

int main() {
    int n; cin >> n;
    vector<int> v(n);
    for (int i = 0; i < n; i++) cin >> v[i];
    int dp[n]; vector<int> stk;
    stk.push_back(v[0]);
    dp[0] = 1; int L = 1;
    for (int i = 1; i < n; i++) {
        if (v[i] > stk.back()) {
            stk.push_back(v[i]);
            dp[i] = ++L;
        } else {
            auto it
                = lower_bound(stk.begin(), stk.end(), v[i]);
            *it = v[i]; dp[i] = it - stk.begin() + 1;
        }
    }
    vector<int> ans; cout << L << "\n";
    for (int i = n - 1; i >= 0; i--) {
        if (dp[i] == L) {
            ans.push_back(v[i]), L--;
        }
    }
    reverse(ans.begin(), ans.end());
    for (auto i : ans) cout << i << " ";
}

```

9.3 Edit Distance [308023]

```
int main() {
    string s1, s2; cin >> s1 >> s2;
    int n1 = s1.size(), n2 = s2.size();
    // dp[i][j] 為 s1 的前 i 個字元，跟 s2 的前 j 個字元
    vector<int> dp(n2 + 1);
    iota(dp.begin(), dp.end(), 0);
    for (int i = 1; i <= n1; i++) {
        vector<int> cur(n2 + 1); cur[0] = i;
        for (int j = 1; j <= n2; j++) {
            if (s1[i - 1] == s2[j - 1]) {
                cur[j] = dp[j - 1];
            } else {
                // s1 新增等價於 s2 砍掉
                // dp[i][j] = min(s2 新增, 修改, s1 新增);
                cur[j] = min({cur[j - 1], dp[j - 1], dp[j]}) + 1;
            }
        }
        swap(dp, cur);
    }
    cout << dp[n2] << "\n";
}
```

9.4 Bitmask [a626f9]

```
void hamiltonianPath() {
    int n, m; cin >> n >> m;
    vector adj(n, vector<int>());
    for (int i = 0; i < m; i++) {
        int u, v; cin >> u >> v;
        adj[-v].push_back(--u);
    }
    // 以...為終點，走過...
    vector dp(n, vector<int>(findBit(n)));
    dp[0][1] = 1;
    for (int mask = 1; mask < findBit(n); mask++) {
        if ((mask & 1) == 0) continue;
        for (int i = 0; i < n; i++) {
            if ((mask & findBit(i)) == 0) continue;
            if (i == n - 1 && mask != findBit(n) - 1) continue;
            int pre_mask = mask ^ findBit(i);
            for (int j : adj[i]) {
                if ((pre_mask & findBit(j)) == 0) continue;
                dp[i][mask] = (dp[i][mask] + dp[j][pre_mask]) % Mod;
            }
        }
    }
    cout << dp[n - 1][findBit(n) - 1] << "\n";
}

void elevatorRides() {
    int n, x; cin >> n >> x; vector<int> a(n);
    for (int i = 0; i < n; i++) cin >> a[i];
    vector<array<int, 2>> dp(findBit(n));
    dp[0][0] = 1; // 次數、已使用人數
    for (int mask = 1; mask < findBit(n); mask++) {
        dp[mask][0] = dp[mask][1] = 2e9;
        for (int i = 0; i < n; i++) {
            if ((mask & findBit(i)) == 0) continue;
            int pre_mask = mask ^ findBit(i);
            if (dp[pre_mask][1] + a[i] <= x) {
                if (dp[pre_mask][0] < dp[mask][0]) {
                    dp[mask][0] = dp[pre_mask][0];
                    dp[mask][1] = dp[pre_mask][1] + a[i];
                }
            } else if (dp[pre_mask][0] + 1 < dp[mask][0] || dp[pre_mask][0] + 1 == dp[mask][0] && a[i] < dp[mask][1]) {
                dp[mask][0] = dp[pre_mask][0] + 1;
                dp[mask][1] = a[i];
            }
        }
    }
    cout << dp[findBit(n) - 1][0] << "\n";
}
```

9.5 Projects [0942aa]

```
int main() { // 排程有權重問題，輸出價值最多且時間最少
    struct E {
        int from, to, w, id;
        bool operator<(const E &rhs) {
            return to == rhs.to ? w > rhs.w : to < rhs.to;
        }
    };
    int n; cin >> n; vector<E> a(n + 1);
    for (int i = 1; i <= n; i++) {
        int u, v, w; cin >> u >> v >> w;
        a[i] = {u, v, w, i};
    }
    vector<array<ll, 2>> dp(n + 1); // w, time
    vector<array<int, 2>> rec(n + 1); // 有沒選，上個是誰
    sort(a.begin(), a.end());
    for (int i = 1; i <= n; i++) {
        auto it = --lower_bound(all(a), E({0, a[i].from})),
            [(E x, E y){ return x.to < y.to; }];
        int id = it - a.begin(); dp[i] = dp[i - 1];
        ll nw = dp[id][0] + a[i].w;
        ll nt = dp[id][1] + a[i].to - a[i].from;
        if (dp[i][0] < nw || dp[i][0] == nw && dp[i][1] > nt) {
            dp[i] = {nw, nt}; rec[i] = {1, id};
        }
    }
    vector<int> ans;
    for (int i = n; i != 0; i--) {
        if (rec[i][0]) {
            ans.push_back(a[i].id);
            i = rec[i][1];
        } else i--;
    }
}
```

```
ll nt = dp[id][1] + a[i].to - a[i].from;
if (dp[i][0] < nw || dp[i][0] == nw && dp[i][1] > nt) {
    dp[i] = {nw, nt}; rec[i] = {1, id};
}
}
vector<int> ans;
for (int i = n; i != 0; i--) {
    if (rec[i][0]) {
        ans.push_back(a[i].id);
        i = rec[i][1];
    } else i--;
}
}
```

9.6 Removal Game [7bb56b]

```
// 兩個人比賽，每個人輪流取一個數字且只能是頭尾
// 問兩人都選得好，第一出手的人可取得的最大分數
int main() {
    int n; cin >> n;
    vector<ll> a(n);
    for (int i = 0; i < n; i++) cin >> a[i];
    vector dp(n, vector<ll>(n)); // i 到 j 區間的最大 diff
    for (int i = n - 1; i >= 0; i--) {
        dp[i][i] = a[i];
        for (int j = i + 1; j < n; j++) {
            dp[i][j] = max(a[i] - dp[i + 1][j], a[j] - dp[i][j - 1]);
        }
    }
    // x + y = sum; // x - y = dp[0][n - 1]
    cout << (accumulate
        (a.begin(), a.end(), 0LL) + dp[0][n - 1]) / 2 << "\n";
}
```

9.7 Codeforces Example [7d37ea]

```
// CF 1932 pF
// 給你很多區間，你可以選一些點，重疊到的線段得到 1 分
// 請問在線段不重複的情況下，最多獲得幾分
int main() {
    int n, m;
    cin >> n >> m;
    // 記錄每點有幾個線段
    // 再一個紀錄，包含這個點的左界
    vector<int> l_side(n + 1, inf), cnt(n + 5, 0);
    for (int i = 0; i < m; i++) {
        int l, r; cin >> l >> r;
        l_side[r] = min(l_side[r], l);
        cnt[l]++;
        cnt[r + 1]--;
    }
    for (int i = 2; i <= n; i++) {
        cnt[i] += cnt[i - 1];
    }
    for (int i = n; i >= 2; i--) {
        l_side[i - 1] = min(l_side[i - 1], l_side[i]);
    }
    vector<int> dp(n + 1);
    dp[0] = 0;
    for (int i = 1; i <= n; i++) {
        dp[i] = cnt[i];
        if (l_side[i] != inf) {
            dp[i] += dp[l_side[i] - 1];
        }
        dp[i] = max(dp[i], dp[i - 1]);
    }
    cout << dp[n] << "\n";
}

// CF 1935 pC
// 給你每個事件的 a, b，挑事件會把 a 全部加起來
// 再加上 max(bi) - min(bi)
int main() {
    int n, k, ans = 0; cin >> n >> k;
    vector<pii> v(n + 1);
    for (int i = 1; i <= n; i++) {
        int a, b; cin >> a >> b;
        v[i] = {a, b};
        if (a <= k) ans = 1;
    }
    sort(v.begin() + 1, v.end(), [(pii &a, pii &b) {
        return a.second < b.second;
    }]);
    // 用 bi 來排，考慮第 i 個時可以先扣
    vector<vector<int>> dp(n + 1, vector<int>(n + 1, inf));
    // 考慮 v[i] 時，選 j 個的 sum(ai) - min(bi)
    for (int i = 1; i <= n; i++) { // 滾動 dp
        for (int j = n; j >= 2; j--) {
            dp[i][j] = min
                (dp[i - 1][j], dp[i - 1][j - 1] + v[i].first);
            // min(不選, 選)
            if (dp[i]
                - 1][j - 1] + v[i].first + v[i].second <= k) {
                // 假如可以選，更新 ans 時再加回去 bi
                ans = max(ans, j);
            }
        }
        dp[i][1] = min(dp[i - 1][1], v[i].first - v[i].second);
    }
    cout << ans << endl;
}
```

9.8 CHT [5f5c25]

```
struct Line {
    ll m, b;
    Line(ll m = 0, ll b = 0) : m(m), b(b) {}
    ll eval(ll x) {
        return m * x + b;
    }
};

struct CHT { // 用在查詢單調斜率也單調
    int n, lptr, rptr; vector<Line> hull;
    CHT(int n_ = 0, Line init_ = Line()) {
        init(n_, init_);
    }
    void init(int n_ = 0, Line init_ = Line()) {
        n = n_; hull.resize(n); reset(init_);
    }
    void reset(Line init_ = Line()) {
        lptr = rptr = 0; hull[0] = init_;
    }
    bool pop_front(Line &l1, Line &l2, ll x) {
        // 斜率遞減、查詢遞增，因此只要左直線的 y >= 右直線的 y
        // 代表查詢的當下，右線段的高度已經低於左線段了
        return l1.eval(x) >= l2.eval(x);
    }
    bool pop_back(Line &l1, Line &l2, Line &l3) {
        // 本題斜率遞減、上凸包
        // 因此只要 l2 跟
        // l3 的 x 交點 <= l1 跟 l3 的 x 交點，l2 就用不到了
        return (l3.b - l2.b)
            * (l1.m - l3.m) <= (l3.b - l1.b) * (l2.m - l3.m);
    }
    void insert(Line L) {
        while (rptr - lptr
            > 0 && pop_back(hull[rptr - 1], hull[rptr], L))
            rptr--;
        hull[++rptr] = L;
    }
    ll query(ll x) {
        while (rptr - lptr
            > 0 && pop_front(hull[lptr], hull[lptr + 1], x))
            lptr++;
        return hull[lptr].eval(x);
    }
};
```

9.9 DNC [61c639]

```
constexpr int N = 3e3 + 5;
constexpr ll inf = 4e18;
// dp[k][j] = min(dp[k - 1][i] + cost[i][j])
// cost: (i, j)
ll dp[N][N]; // 1-based
ll get_cost(int l, int r) {}
void DNC(int k, int l, int r, int optl, int optr) {
    if (l > r) return;
    int m = (l + r) >> 1, opt = -1;
    dp[k][m] = inf;
    for (int i = max(k, optl); i <= min(m, optr); i++) {
        // 注意 i 的範圍、get_cost 與 dp 的邊界
        ll cur = dp[k - 1][i] + get_cost(i, m);
        if (cur < dp[k][m]) {
            dp[k][m] = cur, opt = i;
        }
    }
    DNC(k, l, m - 1, optl, opt);
    DNC(k, m + 1, r, opt, optr);
}

int main() {
    // first build cost...
    for (int i = 1; i <= n; i++) {
        // init dp[i][i]
    }
    for (int i = 2; i <= k; i++) {
        DNC(i, 1, n, 1, n);
    }
    cout << dp[k][n] << "\n";
}
```

9.10 LiChaoSegmentTree [a6e320]

```
constexpr ll Inf = 4e18;
// dp[i] = min(f[j] * s[i] + dp[j])
// y = m * x + b
struct Line {
    ll m, b;
    Line(ll m = 0, ll b = Inf) : m(m), b(b) {}
    ll eval(ll x) const { return m * x + b; }
};

struct LiChaoSeg { // 取 max 再變換就好
    int n;
    vector<Line> info;
    LiChaoSeg(int n_ = 0) { init(n_); }
    void init(int n_ = 0) {
        n = n_;
        info.assign(4 << __lg(n), Line());
    }
    void update(Line line, int node, int l, int r) {
        int m = (l + r) / 2;
        bool left = line.eval(l) < info[node].eval(l);
```

```
        bool mid = line.eval(m) < info[node].eval(m);
        if (mid) swap(info[node], line); // 如果新線段比較好
        if (r - l == 1) return;
        else if (left != mid) update(line, 2 * node, l, m);
        // 代表左半有交點
        else update(line, 2 * node + 1, m, r);
        // 代表如果有交點一定在右半
    }
    void add_line(Line line) { update(line, 1, 0, n); }
    ll query(int x, int node, int l, int r) {
        if (r - l == 1) return info[node].eval(x);
        int m = (l + r) / 2;
        if (x < m) return
            min(info[node].eval(x), query(x, 2 * node, l, m));
        else return min(
            info[node].eval(x), query(x, 2 * node + 1, m, r));
    }
    ll query(int x) { return query(x, 1, 0, n); }
```

10 Geometry

10.1 Basic [d41d8c]

```
template<class T>
struct Point {
    T x;
    T y;
    Point(const T &x_ = 0, const T &y_ = 0) : x(x_), y(y_) {}

    template<class U>
    operator Point<U>() {
        return Point<U>(U(x), U(y));
    }
    Point &operator+=(const Point &p) & {
        x += p.x;
        y += p.y;
        return *this;
    }
    Point &operator-=(const Point &p) & {
        x -= p.x;
        y -= p.y;
        return *this;
    }
    Point &operator*=(const T &v) & {
        x *= v;
        y *= v;
        return *this;
    }
    Point &operator/=(const T &v) & {
        x /= v;
        y /= v;
        return *this;
    }
    Point operator-() const {
        return Point(-x, -y);
    }
    friend Point operator+(Point a, const Point &b) {
        return a += b;
    }
    friend Point operator-(Point a, const Point &b) {
        return a -= b;
    }
    friend Point operator*(Point a, const T &b) {
        return a *= b;
    }
    friend Point operator/(Point a, const T &b) {
        return a /= b;
    }
    friend Point operator*(const T &a, Point b) {
        return b *= a;
    }
    friend bool operator==(const Point &a, const Point &b) {
        return a.x == b.x && a.y == b.y;
    }
    friend istream &operator>>(istream &is, Point &p) {
        return is >> p.x >> p.y;
    }
    friend ostream &operator<<(ostream &os, const Point &p) {
        return os << "(" << p.x << ", " << p.y << ")";
    }
};
```

```
template<class T>
struct Line {
    Point<T> a;
    Point<T> b;
    Line(const Point<T> &a_ = Point<T>(),
        const Point<T> &b_ = Point<T>()) : a(a_), b(b_) {}
};

template<class T>
T dot(const Point<T> &a, const Point<T> &b) {
    return a.x * b.x + a.y * b.y;
}

template<class T>
T cross(const Point<T> &a, const Point<T> &b) {
    return a.x * b.y - a.y * b.x;
}
```

```

template<class T>
T square(const Point<T> &p) {
    return dot(p, p);
}

template<class T>
double length(const Point<T> &p) {
    return sqrt(square(p));
}

template<class T>
double length(const Line<T> &l) {
    return length(l.a - l.b);
}

template<class T>
Point<T> normalize(const Point<T> &p) {
    return p / length(p);
}

template<class T>
bool parallel(const Line<T> &l1, const Line<T> &l2) {
    return cross(l1.b - l1.a, l2.b - l2.a) == 0;
}

template<class T>
double distance(const Point<T> &a, const Point<T> &b) {
    return length(a - b);
}

template<class T>
double distancePL(const Point<T> &p, const Line<T> &l) {
    return abs(cross(l.a - l.b, l.a - p)) / length(l);
}

template<class T>
double distancePS(const Point<T> &p, const Line<T> &l) {
    if (dot(p - l.a, l.b - l.a) < 0) {
        return distance(p, l.a);
    }
    if (dot(p - l.b, l.a - l.b) < 0) {
        return distance(p, l.b);
    }
    return distancePL(p, l);
}

template<class T>
Point<T> rotate(const Point<T> &a) {
    return Point(-a.y, a.x);
}

template<class T>
int sgn(const Point<T> &a) {
    return a.y > 0 || (a.y == 0 && a.x > 0) ? 1 : -1;
}

template<class T>
bool pointOnLineLeft(const Point<T> &p, const Line<T> &l) {
    return cross(l.b - l.a, p - l.a) > 0;
}

template<class T>
Point<T>
> lineIntersection(const Line<T> &l1, const Line<T> &l2) {
    return l1.a + (l1.b - l1.a) * (cross(l2.b - l2.a, l1.a - l2.a) / cross(l2.b - l2.a, l1.a - l1.b));
}

template<class T>
bool pointOnSegment(const Point<T> &p, const Line<T> &l) {
    return cross(p - l.a, l.b - l.a) == 0 &&
        min(l.a.x, l.b.x) <= p.x && p.x <= max(l.a.x, l.b.x)
        && min(l.a.y, l.b.y) <= p.y && p.y <= max(l.a.y, l.b.y);
}

template<class T>
bool pointInPolygon(const Point<T> &a, const vector<Point<T>> &p) {
    int n = p.size();
    for (int i = 0; i < n; i++) {
        if (pointOnSegment(a, Line(p[i], p[(i + 1) % n]))) {
            return true;
        }
    }

    int t = 0;
    for (int i = 0; i < n; i++) {
        auto u = p[i];
        auto v = p[(i + 1) % n];
        if (u.x < a.x
            && v.x >= a.x && pointOnLineLeft(a, Line(v, u))) {
            t ^= 1;
        }
        if (u.x >= a.x
            && v.x < a.x && pointOnLineLeft(a, Line(u, v))) {
            t ^= 1;
        }
    }

    return t == 1;
}

```

```

// 0 : not intersect
// 1 : strictly intersect
// 2 : overlap
// 3 : intersect at endpoint
template<class T>
tuple<int, Point<T>, Point<T>> segmentIntersection(
    const Line<T> &l1, const Line<T> &l2) {
    if (max(l1.a.x, l1.b.x) < min(l2.a.x, l2.b.x)) {
        return {0, Point<T>(), Point<T>()};
    }
    if (min(l1.a.x, l1.b.x) > max(l2.a.x, l2.b.x)) {
        return {0, Point<T>(), Point<T>()};
    }
    if (max(l1.a.y, l1.b.y) < min(l2.a.y, l2.b.y)) {
        return {0, Point<T>(), Point<T>()};
    }
    if (min(l1.a.y, l1.b.y) > max(l2.a.y, l2.b.y)) {
        return {0, Point<T>(), Point<T>()};
    }
    if (cross(l1.b - l1.a, l2.b - l2.a) == 0) {
        if (cross(l1.b - l1.a, l2.a - l1.a) != 0) {
            return {0, Point<T>(), Point<T>()};
        } else {
            auto maxx1 = max(l1.a.x, l1.b.x);
            auto minx1 = min(l1.a.x, l1.b.x);
            auto maxy1 = max(l1.a.y, l1.b.y);
            auto miny1 = min(l1.a.y, l1.b.y);
            auto maxx2 = max(l2.a.x, l2.b.x);
            auto minx2 = min(l2.a.x, l2.b.x);
            auto maxy2 = max(l2.a.y, l2.b.y);
            auto miny2 = min(l2.a.y, l2.b.y);
            Point<T> p1(max(minx1, minx2), max(miny1, miny2));
            Point<T> p2(min(maxx1, maxx2), min(maxy1, maxy2));
            if (!pointOnSegment(p1, l1)) {
                swap(p1.y, p2.y);
            }
            if (p1 == p2) {
                return {3, p1, p2};
            } else {
                return {2, p1, p2};
            }
        }
    }
    auto cp1 = cross(l2.a - l1.a, l2.b - l1.a);
    auto cp2 = cross(l2.a - l1.b, l2.b - l1.b);
    auto cp3 = cross(l1.a - l2.a, l1.b - l2.a);
    auto cp4 = cross(l1.a - l2.b, l1.b - l2.b);

    if ((cp1 > 0 && cp2 > 0) || (cp1 < 0 && cp2 < 0) ||
        (cp3 > 0 && cp4 > 0) || (cp3 < 0 && cp4 < 0)) {
        return {0, Point<T>(), Point<T>()};
    }

    Point p = lineIntersection(l1, l2);
    if (cp1 != 0 && cp2 != 0 && cp3 != 0 && cp4 != 0) {
        return {1, p, p};
    } else {
        return {3, p, p};
    }
}

template<class T>
double distanceSS(const Line<T> &l1, const Line<T> &l2) {
    if (get<0>(segmentIntersection(l1, l2)) != 0) {
        return 0.0;
    }
    return min({distancePS(l1.a, l2), distancePS(l1.b, l2), distancePS(l2.a, l1), distancePS(l2.b, l1)});
}

template<class T>
bool segmentInPolygon(const Line<T> &l, const vector<Point<T>> &p) {
    int n = p.size();
    if (!pointInPolygon(l.a, p)) {
        return false;
    }
    if (!pointInPolygon(l.b, p)) {
        return false;
    }
    for (int i = 0; i < n; i++) {
        auto u = p[i];
        auto v = p[(i + 1) % n];
        auto w = p[(i + 2) % n];
        auto [t, p1, p2] = segmentIntersection(l, Line(u, v));

        if (t == 1) {
            return false;
        }
        if (t == 0) {
            continue;
        }
        if (t == 2) {
            if (pointOnSegment(v, l) && v != l.a && v != l.b) {
                if (cross(v - u, w - v) > 0) {
                    return false;
                }
            }
        }
    }
    else {
        if (p1 != u && p1 != v) {
            if (pointOnLineLeft(l.a, Line(v, u)))

```

```

        || pointOnLineLeft(l.b, Line(v, u))) {
            return false;
        }
    } else if (p1 == v) {
        if (l.a == v) {
            if (pointOnLineLeft(u, l)) {
                if (pointOnLineLeft(w, l)
                    && pointOnLineLeft
                        (w, Line(u, v))) {
                    return false;
                }
            } else {
                if (pointOnLineLeft(w, l)
                    || pointOnLineLeft
                        (w, Line(u, v))) {
                    return false;
                }
            }
        } else if (l.b == v) {
            if (pointOnLineLeft(u, Line(l.b, l.a))) {
                if (pointOnLineLeft(w, Line(l.b, l.a))
                    && pointOnLineLeft
                        (w, Line(u, v))) {
                    return false;
                }
            } else {
                if (pointOnLineLeft(w, Line(l.b, l.a))
                    || pointOnLineLeft
                        (w, Line(u, v))) {
                    return false;
                }
            }
        } else {
            if (pointOnLineLeft(u, l)) {
                if (pointOnLineLeft(w, Line(l.b, l.a))
                    || pointOnLineLeft
                        (w, Line(u, v))) {
                    return false;
                }
            } else {
                if (pointOnLineLeft(w, l)
                    || pointOnLineLeft
                        (w, Line(u, v))) {
                    return false;
                }
            }
        }
    }
}
return true;
}

template<class T>
vector<Point<T>> hp(vector<Line<T>> lines) {
    sort(lines.begin(), lines.end(), [&](auto l1, auto l2) {
        auto d1 = l1.b - l1.a;
        auto d2 = l2.b - l2.a;

        if (sgn(d1) != sgn(d2)) {
            return sgn(d1) == 1;
        }

        return cross(d1, d2) > 0;
    });

    deque<Line<T>> ls;
    deque<Point<T>> ps;
    for (auto l : lines) {
        if (ls.empty()) {
            ls.push_back(l);
            continue;
        }

        while (!ps.empty() && !pointOnLineLeft(ps.back(), l)) {
            ps.pop_back();
            ls.pop_back();
        }

        while (!ps.empty() && !pointOnLineLeft(ps[0], l)) {
            ps.pop_front();
            ls.pop_front();
        }

        if (cross(l.b - l.a, ls.back().b - ls.back().a) == 0) {
            if (dot
                (l.b - l.a, ls.back().b - ls.back().a) > 0) {
                if (!pointOnLineLeft(ls.back().a, l)) {
                    assert(ls.size() == 1);
                    ls[0] = l;
                }
                continue;
            }
            return {};
        }

        ps.push_back(lineIntersection(ls.back(), l));
        ls.push_back(l);
    }

    while (!ps.empty() && !pointOnLineLeft(ps.back(), ls[0])) {

```

```

        ps.pop_back();
        ls.pop_back();
    }
    if (ls.size() <= 2) {
        return {};
    }
    ps.push_back(lineIntersection(ls[0], ls.back()));

    return vector(ps.begin(), ps.end());
}

```

```
using P = Point<ll>;
```

10.2 Convex Hull [b5758d]

```

int main() {
    int n; cin >> n;
    vector<P> P(n), U, L;
    for (int i = 0; i < n; i++) {
        cin >> P[i];
    }
    sort(P.begin(), P
        .end(), [](const Point<i64> &a, const Point<i64> &b) {
            return a.x == b.x ? a.y < b.y : a.x < b.x;
        });
    for (int i = 0; i < n; i++) {
        while (L.size() >= 2 && cross(L.back() -
            L[L.size() - 2], P[i] - L[L.size() - 2]) <= 0LL) {
            L.pop_back();
        }
        while (U.size() >= 2 && cross(U.back() -
            U[U.size() - 2], P[i] - U[U.size() - 2]) >= 0LL) {
            U.pop_back();
        }
        if (L.empty() || !(L.back() == P[i])) L.push_back(P[i]);
        if (U.empty() || !(U.back() == P[i])) U.push_back(P[i]);
    }
    if (L.size() <= 2 && U.size() <= 2) {
        // No Hull
    }
    cout << L.size() + U.size() - 2 << "\n";
    for (int i = 0; i < L.size() - 1; i++) {
        cout << L[i].x << " " << L[i].y << "\n";
    }
    for (int i = U.size() - 1; i > 0; i--) {
        cout << U[i].x << " " << U[i].y << "\n";
    }
}

```

10.3 MinEuclideanDistance [469a8f]

```

template<class T>
T distanceSquare(const Point<T> &a, const Point<T> &b) {
    return square(a - b);
}

void solve() {
    int n; cin >> n;
    constexpr i64 inf = 8e18;
    vector<Point<i64>> a(n);
    for (int i = 0; i < n; i++) {
        i64 x, y;
        cin >> x >> y;
        a[i] = Point<i64>(x, y);
    }

    struct sortY {
        bool operator()
            (const Point<i64> &a, const Point<i64> &b) const {
            return a.y < b.y;
        }
    };
    struct sortXY {
        bool operator()
            (const Point<i64> &a, const Point<i64> &b) const {
            if (a.x == b.x) return a.y < b.y;
            else return a.x < b.x;
        }
    };

    sort(a.begin(), a.end(), sortXY());
    vector<Point<i64>> t(n);
    auto divide = [&](auto &&self, int l, int r) -> i64 {
        if (l == r) return inf;
        int m = (l + r) / 2;
        i64 ans = min(self(self, l, m), self(self, m + 1, r));
        i64 midval = a[m].x;
        i64 p = 0;
        for (int i = l; i <= r; i++) {
            if ((midval - a[i].x) * (midval - a[i].x) <= ans) {
                t[p++] = a[i];
            }
        }
        sort(t.begin(), t.begin() + p, sortY());
        for (int i = 0; i < p; i++) {
            for (int j = i + 1; j < p; j++) {
                ans = min(ans, distanceSquare(t[i], t[j]));
                if ((t[i].y -
                    t[j].y) * (t[i].y - t[j].y) > ans) break;
            }
        }
        return ans;
    };
}

```

```
    cout << devide(devide, 0, n - 1) << "\n";
}
```

10.4 LatticePoints [7750d6]

```
int main() {
    // Polygon 內整數點數
    int n; cin >> n;
    vector<Point<i64>> polygon(n);
    for (int i = 0; i < n; i++) cin >> polygon[i];
    i64 area = 0;
    for (int i = 0; i < n; i++) {
        area += cross(polygon[i], polygon[(i + 1) % n]);
    }
    area = abs(area);
    auto countBoundaryPoints
        = [](const vector<Point<i64>>& polygon) -> i64 {
        i64 res = 0;
        int n = polygon.size();
        for (int i = 0; i < n; i++) {
            i64 dx = polygon[(i + 1) % n].x - polygon[i].x;
            i64 dy = polygon[(i + 1) % n].y - polygon[i].y;
            res += std::gcd(abs(dx), abs(dy));
        }
        return res;
    };
    i64 res = countBoundaryPoints(polygon);
    i64 ans = (area - res + 2) / 2;
    cout << ans << " " << res << "\n";
}
```

10.5 MinRadiusCoverCircle [a9fa76]

```
constexpr double Eps = 1e-7;
void solve(int n, vector<P> a, double maxR) {
    auto cal = [&](P center) {
        double mx = 0;
        for (auto& p : a)
            mx = max(mx, distance(center, p));
        return mx;
    };
    auto searchY = [&](double x) {
        double l = -maxR, r = maxR;
        while (r - l > Eps) {
            double d = (r - l) / 3;
            double ml = l + d, mr = r - d;
            double ansl = cal({x, ml}), ansr = cal({x, mr});
            if (ansl > ansr) l = ml;
            else r = mr;
        }
        return (l + r) / 2;
    };
    double l = -maxR, r = maxR;
    while (r - l > Eps) {
        double d = (r - l) / 3;
        double ml = l + d, mr = r - d;
        double yl = searchY(ml), yr = searchY(mr);
        double ansl = cal({ml, yl}), ansr = cal({mr, yr});
        if (ansl > ansr) l = ml;
        else r = mr;
    }
    double ansX = (l + r) / 2, ansY = searchY(ansX);
}
```