Содержание

1 Strategy.txt

```
- Проверить руками сэмплы
- Подумать как дебагать после написания
- Выписать сложные формулы и все +-1

- Проверить имена файлов
- Прогнать сэмплы
- Переполнения int, переполнения long long
- Выход за границу массива: _GLIBCXX_DEBUG
- Переполнения по модулю: в
 ↪ псевдо-онлайн-генераторе, в функциях-обертках
- Проверить мультитест на разных тестах
- Прогнать минимальный по каждому параметру тест
- Прогнать псевдо-максимальный тест(немного чисел,
 ↪ но очень большие или очень маленькие)
- Представить что не зайдет и заранее написать
 ↪ assert'ы, прогнать слегка модифицированные тесты
- cout.precision: в том числе в интерактивных
 ↪ задачах
- Удалить debug-output, отсечения для тестов,
 ↪ вернуть оригинальный maxn, удалить
 ↪ _GLIBCXX_DEBUG

- Вердикт может врать
- Если много тестов(>3), дописать в конец каждого
 ↪ теста ответ, чтобы не забыть
- (WA) Потестить не только ответ, но и содержимое
 ↪ значимых массивов, переменных
- (WA) Изменить тест так, чтобы ответ не менялся:
 ↪ поменять координаты местами, сжать/растянуть
 ↪ координаты, поменять ROOT дерева
- (WA) Подвигать размер блока в корневой или
 ↪ битсете
- (WA) Поставить assert'ы, возможно написать чекер
 ↪ с assert'ом
- (WA) Проверить, что программа не печатает
 ↪ что-либо неожиданное, что должно попадать под
 ↪ PE: inf - 2, не лекс. мин. решение, одинаковые
 ↪ числа вместо разных, неправильное количество
 ↪ чисел, пустой ответ, перечитать output format
- (TL) cin -> scanf -> getchar
- (TL) Упихать в кэш большие массивы, поменять
 ↪ местами for'ы или измерения массива
- (RE) Проверить формулы на деление на 0, выход за
 ↪ область определения(sqrt(-eps), acos(1 + eps))
- (WA) Проверить, что ответ влезает в int
```

2 flows/dinic.cpp

```cpp
namespace Dinic {
const int maxn = 10010;

struct Edge {
    int to, c, f;
} es[maxn*2];
int ne = 0;

int n;
vector<int> e[maxn];
int q[maxn], d[maxn], pos[maxn];
int S, T;

void addEdge(int u, int v, int c) {
    assert(c <= 1000000000);
    es[ne] = {v, c, 0};
    e[u].push_back(ne++);
    es[ne] = {u, 0, 0};
    e[v].push_back(ne++);
}

bool bfs() {
    forn(i, n) d[i] = maxn;
    d[S] = 0, q[0] = S;
    int lq = 0, rq = 1;
    while (lq != rq) {
        int v = q[lq++];
        for (int id: e[v]) if (es[id].f < es[id].c) {
            int to = es[id].to;
            if (d[to] == maxn)
                d[to] = d[v] + 1, q[rq++] = to;
        }
    }
    return d[T] != maxn;
}

int dfs(int v, int curf) {
    if (v == T || curf == 0) return curf;
    for (int &i = pos[v]; i < (int)e[v].size(); ++i) {
        int id = e[v][i];
        int to = es[id].to;
        if (es[id].f < es[id].c && d[v] + 1 == d[to]) {
            if (int ret = dfs(to, min(curf, es[id].c-es[id].f)))
            {
                es[id].f += ret;
                es[id^1].f -= ret;
                return ret;
            }
        }
    }
    return 0;
}

i64 dinic(int S, int T) {
    Dinic::S = S, Dinic::T = T;
    i64 res = 0;
    while (bfs()) {
        forn(i, n) pos[i] = 0;
        while (int f = dfs(S, 1e9)) {
            assert(f <= 1000000000);
            res += f;
        }
    }
    return res;
}

} // namespace Dinic

void test() {
    Dinic::n = 4;
    Dinic::addEdge(0, 1, 1);
    Dinic::addEdge(0, 2, 2);
    Dinic::addEdge(2, 1, 1);
    Dinic::addEdge(1, 3, 2);
    Dinic::addEdge(2, 3, 1);
    cout << Dinic::dinic(0, 3) << endl; // 3

}

/*
LR-поток находит не максимальный поток.
Добавим новый сток S' и исток T'. Заменим ребро (u, v, l, r)
LR-сети на ребра (u, T', l), (S', v, l), (u, v, r - l).
Добавим ребро (T, S, k). Ставим значение k=inf, пускаем поток.
Проверяем, что все ребра из S' насыщены (иначе ответ не
существует). Бинпоиском находим наименьшее k, что величина
потока не изменится. Это k - величина МИНИМАЛЬНОГО потока,
удовлетворяющего ограничениям. */
```

3 flows/globalcut.cpp

```cpp
#include <bits/stdc++.h>
using namespace std;
#define forn(i,n) for (int i = 0; i < int(n); ++i)
const int inf = 1e9 + 1e5;
#define all(x) (x).begin(), (x).end()

const int maxn = 505;
namespace StoerWagner {
int g[maxn][maxn];
int dist[maxn];
bool used[maxn];
int n;

void addEdge(int u, int v, int c) {
    g[u][v] += c;
    g[v][u] += c;
}

int run() {
    vector<int> vertices;
    forn (i, n)
        vertices.push_back(i);
    int mincut = inf;
    while (vertices.size() > 1) {
        int u = vertices[0];
        for (auto v: vertices) {
            used[v] = false;
            dist[v] = g[u][v];
        }
        used[u] = true;
        forn (ii, vertices.size() - 2) {
            for (auto v: vertices)
                if (!used[v])
                    if (used[u] || dist[v] > dist[u])
                        u = v;
            used[u] = true;
            for (auto v: vertices)
                if (!used[v])
                    dist[v] += g[u][v];
        }
        int t = -1;
        for (auto v: vertices)
            if (!used[v])
                t = v;
        assert(t != -1);
        mincut = min(mincut, dist[t]);
        vertices.erase(find(all(vertices), t));
        for (auto v: vertices)
            addEdge(u, v, g[v][t]);
    }
    return mincut;
}
} // namespace StoerWagner

int main() {
    StoerWagner::n = 4;
    StoerWagner::addEdge(0, 1, 5);
    StoerWagner::addEdge(2, 3, 5);
    StoerWagner::addEdge(1, 2, 4);
    cerr << StoerWagner::run() << '\n'; // 4
}
```

4 flows/hungary.cpp

```cpp
// left half is the smaller one
namespace Hungary {
const int maxn = 505;
int a[maxn][maxn];
int p[2][maxn];
int match[maxn];
bool used[maxn];
int from[maxn];
int mind[maxn];
int n, m;

int hungary(int v) {
    used[v] = true;
    int u = match[v];
    int best = -1;
    forn (i, m + 1) {
        if (used[i])
            continue;
        int nw = a[u][i] - p[0][u] - p[1][i];
        if (nw <= mind[i]) {
            mind[i] = nw;
            from[i] = v;
        }
        if (best == -1 || mind[best] > mind[i])
            best = i;
    }
    v = best;
    int delta = mind[best];
    forn (i, m + 1) {
        if (used[i]) {
            p[1][i] -= delta;
            p[0][match[i]] += delta;
        } else
            mind[i] -= delta;
    }
    if (match[v] == -1)
        return v;
    return hungary(v);
}

void check() {
    int edges = 0, res = 0;
    forn (i, m)
        if (match[i] != -1) {
            ++edges;
            assert(p[0][match[i]] + p[1][i] == a[match[i]][i]);
            res += a[match[i]][i];
        } else
            assert(p[1][i] == 0);
    assert(res == -p[1][m]);
    forn (i, n) forn (j, m)
        assert(p[0][i] + p[1][j] <= a[i][j]);
}

int run() {
    forn (i, n)
        p[0][i] = 0;
    forn (i, m + 1) {
        p[1][i] = 0;
        match[i] = -1;
    }
    forn (i, n) {
        match[m] = i;
        fill(used, used + m + 1, false);
        fill(mind, mind + m + 1, inf);
        fill(from, from + m + 1, -1);
        int v = hungary(m);
        while (v != m) {
            int w = from[v];
            match[v] = match[w];
            v = w;
        }
    }
    check();
    return -p[1][m];
}
} // namespace Hungary
```

5 flows/mincost.cpp

```cpp
namespace MinCost {
const ll infc = 1e12;

struct Edge {
    int to;
    ll c, f, cost;

    Edge(int to, ll c, ll cost): to(to), c(c), f(0), cost(cost)
    {  }
};

int N, S, T;
int totalFlow;
ll totalCost;
const int maxn = 505;
vector<Edge> edge;
vector<int> g[maxn];

void addEdge(int u, int v, ll c, ll cost) {
    g[u].push_back(edge.size());
    edge.emplace_back(v, c, cost);
    g[v].push_back(edge.size());
    edge.emplace_back(u, 0, -cost);
}

ll dist[maxn];
int fromEdge[maxn];

bool inQueue[maxn];
bool fordBellman() {
    forn (i, N)
        dist[i] = infc;
    dist[S] = 0;
    inQueue[S] = true;
    vector<int> q;
    q.push_back(S);
    for (int ii = 0; ii < int(q.size()); ++ii) {
        int u = q[ii];
        inQueue[u] = false;
        for (int e: g[u]) {
            if (edge[e].f == edge[e].c)
                continue;
            int v = edge[e].to;
            ll nw = edge[e].cost + dist[u];
            if (nw >= dist[v])
                continue;
            dist[v] = nw;
            fromEdge[v] = e;
            if (!inQueue[v]) {
                inQueue[v] = true;
                q.push_back(v);
            }
        }
    }
    return dist[T] != infc;
}

ll pot[maxn];
bool dikstra() {
    typedef pair<ll, int> Pair;
    priority_queue<Pair, vector<Pair>, greater<Pair>> q;
    forn (i, N)
        dist[i] = infc;
    dist[S] = 0;
    q.emplace(dist[S], S);
    while (!q.empty()) {
        int u = q.top().second;
        ll cdist = q.top().first;
        q.pop();
        if (cdist != dist[u])
            continue;
        for (int e: g[u]) {
            int v = edge[e].to;
            if (edge[e].c == edge[e].f)
                continue;
            ll w = edge[e].cost + pot[u] - pot[v];
            assert(w >= 0);
            ll ndist = w + dist[u];
            if (ndist >= dist[v])
                continue;
            dist[v] = ndist;
            fromEdge[v] = e;
            q.emplace(dist[v], v);
        }
    }
    if (dist[T] == infc)
        return false;
    forn (i, N) {
        if (dist[i] == infc)
            continue;
        pot[i] += dist[i];
```

```
    }
    return true;
}

bool push() {
    //2 variants
    //if (!fordBellman())
    if (!dikstra())
        return false;
    ++totalFlow;
    int u = T;
    while (u != S) {
        int e = fromEdge[u];
        totalCost += edge[e].cost;
        edge[e].f++;
        edge[e ^ 1].f--;
        u = edge[e ^ 1].to;
    }
    return true;
}

//min-cost-circulation
ll d[maxn][maxn];
int dfrom[maxn][maxn];
int level[maxn];
void circulation() {
    while (true) {
        int q = 0;
        fill(d[0], d[0] + N, 0);
        forn (iter, N) {
            fill(d[iter + 1], d[iter + 1] + N, infc);
            forn (u, N)
                for (int e: g[u]) {
                    if (edge[e].c == edge[e].f)
                        continue;
                    int v = edge[e].to;
                    ll ndist = d[iter][u] + edge[e].cost;
                    if (ndist >= d[iter + 1][v])
                        continue;
                    d[iter + 1][v] = ndist;
                    dfrom[iter + 1][v] = e;
                }
            q ^= 1;
        }
        int w = -1;
        ld mindmax = 1e18;
        forn (u, N) {
            ld dmax = -1e18;
            forn (iter, N)
                dmax = max(dmax,
                    (d[N][u] - d[iter][u]) / ld(N - iter));
            if (mindmax > dmax)
                mindmax = dmax, w = u;
        }
        if (mindmax >= 0)
            break;
        fill(level, level + N, -1);
        int k = N;
        while (level[w] == -1) {
            level[w] = k;
            w = edge[dfrom[k--][w] ^ 1].to;
        }
        int k2 = level[w];
        ll delta = infc;
        while (k2 > k) {
            int e = dfrom[k2--][w];
            delta = min(delta, edge[e].c - edge[e].f);
            w = edge[e ^ 1].to;
        }
        k2 = level[w];
        while (k2 > k) {
            int e = dfrom[k2--][w];
            totalCost += edge[e].cost * delta;
            edge[e].f += delta;
            edge[e ^ 1].f -= delta;
            w = edge[e ^ 1].to;
        }
    }
}
} // namespace MinCost

int main() {
    MinCost::N = 3, MinCost::S = 1, MinCost::T = 2;
    MinCost::addEdge(1, 0, 3, 5);
    MinCost::addEdge(0, 2, 4, 6);
    while (MinCost::push());
    cout << MinCost::totalFlow << ' '
        << MinCost::totalCost << '\n'; //3 33
}
```

6 geometry/chan.cpp

```
#include <bits/stdc++.h>
using namespace std;
#define forn(i,n) for (int i = 0; i < int(n); ++i)
typedef long double ld;

const int maxn = 100100;
const ld eps = 1e-9;

mt19937 rr(111);
ld rndEps() {
    return (ld(rr()) / rr.max() - 0.5) / 1e5;
}

bool gt(ld a, ld b) { return a - b > eps; }
bool lt(ld a, ld b) { return b - a > eps; }
bool eq(ld a, ld b) { return fabsl(a - b) < eps; }

struct pt {
    ld x, y, z;
    ld ox, oy, oz;
    int pr, nx;
    bool inHull;

    static pt *NIL;

    pt() {}

    pt(ld x, ld y, ld z): x(x), y(y), z(z) {}

    pt operator-(const pt &p) const {
        return pt(x - p.x, y - p.y, z - p.z);
    }

    ld operator*(const pt &p) const {
        return x * p.x + y * p.y + z * p.z;
    }

    pt operator%(const pt &p) const {
        return pt(y * p.z - z * p.y,
                  z * p.x - x * p.z,
                  x * p.y - y * p.x);
    }

    bool operator==(const pt &a) {
        return eq(x, a.x) && eq(y, a.y) && eq(z, a.z);
    }

    void transform(bool rev) {
        if (rev) {
            x = ox, y = oy, z = oz;
        } else {
            ox = x, oy = y, oz = z;
            x += rndEps(), y += rndEps(), z += rndEps();
        }
    }
};

ostream &operator<<(ostream &out, pt &p) {
    return out << p.x << ' ' << p.y << ' ' << p.z;
}

istream &operator>>(istream &in, pt &p) {
    return in >> p.x >> p.y >> p.z;
}

typedef tuple<int, int, int> Facet;

namespace Chan {
int n;
pt p[maxn];

ld turn(int p1, int p2, int p3) {
    assert(p1 != -1 && p2 != -1 && p3 != -1);
    return (p[p2].x - p[p1].x) * (p[p3].y - p[p1].y) -
        (p[p3].x - p[p1].x) * (p[p2].y - p[p1].y);
}

//replace y with z
ld turnz(int p1, int p2, int p3) {
    assert(p1 != -1 && p2 != -1 && p3 != -1);
    return (p[p2].x - p[p1].x) * (p[p3].z - p[p1].z) -
        (p[p3].x - p[p1].x) * (p[p2].z - p[p1].z);
}

ld gett(int p1, int p2, int p3) {
    return turnz(p1, p2, p3) / turn(p1, p2, p3);
}

void act(int i) {
    if (p[i].inHull) {
        p[p[i].nx].pr = p[i].pr;
```

```
        p[p[i].pr].nx = p[i].nx;
    } else {
        p[p[i].nx].pr = p[p[i].pr].nx = i;
    }
    p[i].inHull ^= 1;
}

vector<int> buildHull(int l, int r, bool upper) {
    if (l + 1 >= r) {
        p[l].pr = p[l].nx = -1;
        p[l].inHull = true;
        return {};
    }
    int mid = (l + r) / 2;
    auto L = buildHull(l, mid, upper);
    auto R = buildHull(mid, r, upper);
    reverse(L.begin(), L.end());
    reverse(R.begin(), R.end());
    int u = mid - 1, v = mid;
    while (true) {
        if (p[u].pr != -1 &&
                ((turn(p[u].pr, u, v) < 0) ^ upper))
            u = p[u].pr;
        else if (p[v].nx != -1 &&
                ((turn(u, v, p[v].nx) < 0) ^ upper))
            v = p[v].nx;
        else
            break;
    }

    ld T = -1e100;
    ld t[6];
    vector<int> A;
    while (true) {
        forn (i, 6)
            t[i] = 1e100;
        if (!L.empty()) {
            int id = L.back();
            t[0] = gett(p[id].pr, id, p[id].nx);
        }
        if (!R.empty()) {
            int id = R.back();
            t[1] = gett(p[id].pr, id, p[id].nx);
        }
        if (p[u].pr != -1)
            t[2] = gett(p[u].pr, u, v);
        if (p[u].nx != -1)
            t[3] = gett(u, p[u].nx, v);
        if (p[v].pr != -1)
            t[4] = gett(u, p[v].pr, v);
        if (p[v].nx != -1)
            t[5] = gett(u, v, p[v].nx);
        ld nt = 1e100;
        int type = -1;
        forn (i, 6)
            if ((t[i] - T >= 1e-15) && t[i] < nt)
                nt = t[i], type = i;
        if (type == -1)
            break;

        if (type == 0) {
            act(L.back());
            if (L.back() < u)
                A.push_back(L.back());
            L.pop_back();
        } else if (type == 1) {
            act(R.back());
            if (R.back() > v)
                A.push_back(R.back());
            R.pop_back();
        } else if (type == 2) {
            A.push_back(u);
            u = p[u].pr;
        } else if (type == 3) {
            u = p[u].nx;
            A.push_back(u);
        } else if (type == 4) {
            v = p[v].pr;
            A.push_back(v);
        } else if (type == 5) {
            A.push_back(v);
            v = p[v].nx;
        } else
            assert(false);
        T = nt;
    }
    assert(L.empty() && R.empty());

    p[u].nx = v, p[v].pr = u;
    for (int i = u + 1; i < v; ++i)
        p[i].inHull = false;
    for (int i = int(A.size()) - 1; i >= 0; --i) {
        int id = A[i];
        if (id <= u || id >= v) {
            if (u == id)
                u = p[u].pr;
            if (v == id)
                v = p[v].nx;
            act(id);
        } else {
            p[id].pr = u, p[id].nx = v;
            act(id);
            if (id >= mid)
                v = id;
            else
                u = id;
        }
    }

    return A;
}

//facets are oriented ccw if look from the outside
vector<Facet> getFacets() {
    forn (i, n)
        p[i].transform(false);
    //WARNING: original order of points is changed
    sort(p, p + n, [](const pt &a, const pt &b) {
                return a.x < b.x;
            });

    vector<Facet> facets;
    forn (q, 2) {
        auto movie = buildHull(0, n, q);
        for (auto x: movie) {
            if (!p[x].inHull)
                facets.emplace_back(p[x].pr, x, p[x].nx);
            else
                facets.emplace_back(p[x].pr, p[x].nx, x);
            act(x);
        }
    }
    forn (i, n)
        p[i].transform(true);
    return facets;
}
} //namespace Chan

int main() {
    int n;
    cin >> n;
    Chan::n = n;
    forn (i, n)
        cin >> Chan::p[i];
    auto facets = Chan::getFacets();
    set<int> nodes;
    for (auto f: facets) {
        nodes.insert(get<0>(f));
        nodes.insert(get<1>(f));
        nodes.insert(get<2>(f));
    }
    assert(nodes.size() * 2 == facets.size() + 4);
    ld V = 0, S = 0;
    for (auto f: facets) {
        pt v1 = Chan::p[get<1>(f)] - Chan::p[get<0>(f)];
        pt v2 = Chan::p[get<2>(f)] - Chan::p[get<0>(f)];
        pt v3 = Chan::p[get<0>(f)];
        pt vv = v1 % v2;
        forn (i, n) {
            pt v4 = Chan::p[i] - Chan::p[get<0>(f)];
            assert(v4 * vv < 0.1);
        }
        S += sqrtl(vv.x * vv.x + vv.y * vv.y + vv.z * vv.z) / 2;
        V += vv * v3 / 6;
    }
    cout.precision(10);
    cout << fixed;
    cout << S << ' ' << V << '\n';
}
```

7 geometry/convex_hull.cpp

```cpp
#include <bits/stdc++.h>
using namespace std;
#define forn(i, n) for (int i = 0; i < int(n); ++i)
#define sz(x) ((int) (x).size())

#include "primitives.cpp"

bool cmpAngle(const pt &a, const pt &b) {
    bool ar = a.right(), br = b.right();
    if (ar ^ br)
        return ar;
    return gt(a % b, 0);
}

struct Hull {
    vector<pt> top, bot;

    void append(pt p) {
        while (bot.size() > 1 && ge((p - bot.back())
                % (bot.back() - *next(bot.rbegin())), 0))
            bot.pop_back();
        bot.push_back(p);
        while (top.size() > 1 && ge(0, (p - top.back())
                % (top.back() - *next(top.rbegin()))))
            top.pop_back();
        top.push_back(p);
    }

    void build(vector<pt> h) {
        sort(h.begin(), h.end());
        h.erase(unique(h.begin(), h.end()), h.end());
        top.clear(), bot.clear();
        for (pt p: h)
            append(p);
    }

    pt kth(int k) {
        if (k < sz(bot))
            return bot[k];
        else
            return top[sz(top) - (k - sz(bot)) - 2];
    }

    pt mostDistant(pt dir) {
        if (bot.empty()) {
            //empty hull
            return pt{1e18, 1e18};
        }
        if (bot.size() == 1)
            return bot.back();
        dir = dir.rot();
        int n = sz(top) + sz(bot) - 2;
        int L = -1, R = n;
        while (L + 1 < R) {
            int C = (L + R) / 2;
            pt v = kth((C + 1) % n) - kth(C);
            if (cmpAngle(dir, v)) //finds upper bound
                R = C;
            else
                L = C;
        }
        return kth(R % n);
    }
};
```

8 geometry/halfplanes.cpp

```cpp
#include <bits/stdc++.h>
using namespace std;
#define forn(i, n) for (int i = 0; i < int(n); ++i)
#define forab(i, a, b) for (int i = int(a); i < int(b); ++i)
#include "primitives.cpp"

ld det3x3(line &l1, line &l2, line &l3) {
    return l1.a * (l2.b * l3.c - l2.c * l3.b) +
           l1.b * (l2.c * l3.a - l2.a * l3.c) +
           l1.c * (l2.a * l3.b - l2.b * l3.a);
}

vector<pt> halfplanesIntersecion(vector<line> lines) {
    sort(lines.begin(), lines.end(),
        [](const line &a, const line &b) {
                bool ar = a.right(), br = b.right();
                if (ar ^ br)
                    return ar;
                ld prod = (pt{a.a, a.b} % pt{b.a, b.b});
                if (!eq(prod, 0))
                    return prod > 0;
                return a.c < b.c;
            });
    vector<line> lines2;
    pt pr;
    forn (i, lines.size()) {
        pt cur{lines[i].a, lines[i].b};
        if (i == 0 || cur != pr)
            lines2.push_back(lines[i]);
        pr = cur;
    }
    lines = lines2;
    int n = lines.size();
    forn (i, n)
        lines[i].id = i;
    vector<line> hull;
    forn (i, 2 * n) {
        line l = lines[i % n];
        while ((int) hull.size() >= 2) {
            ld D = det3x3(*next(hull.rbegin()), hull.back(), l);
            if (ge(D, 0))
                break;
            hull.pop_back();
        }
        hull.push_back(l);
    }
    vector<int> firstTime(n, -1);
    vector<line> v;
    forn (i, hull.size()) {
        int cid = hull[i].id;
        if (firstTime[cid] == -1) {
            firstTime[cid] = i;
            continue;
        }
        forab(j, firstTime[cid], i)
            v.push_back(hull[j]);
        break;
    }
    n = v.size();
    if (v.empty()) {
        //empty intersection
        return {};
    }
    v.push_back(v[0]);
    vector<pt> res;
    pt center{0, 0};
    forn (i, n) {
        res.push_back(linesIntersection(v[i], v[i + 1]));
        center = center + res.back();
    }
    center = center / n;
    for (auto l: lines)
        if (gt(0, l.signedDist(center))) {
            //empty intersection
            return {};
        }
    return res;
}
```

9 geometry/polygon.cpp

```cpp
bool pointInsidePolygon(pt a, pt *p, int n) {
    double sumAng = 0;
    forn (i, n) {
        pt A = p[i], B = p[(i + 1) % n];
        if (pointInsideSegment(a, A, B))
            return true;
        sumAng += atan2((A - a) % (B - a), (A - a) * (B - a));
    }
    return fabs(sumAng) > 1;
}

//p must be oriented counterclockwise
bool segmentInsidePolygon(pt a, pt b, pt *p, int n) {
    if (!pointInsidePolygon((a + b) / 2, p, n))
        return false;
    if (a == b)
        return true;
    forn (i, n) {
        pt c = p[i];
        if (eq((a - c) % (b - c), 0) &&
                gt(0, (a - c) * (b - c))) {
            //point on segment
            pt pr = p[(i + n - 1) % n];
            pt nx = p[(i + 1) % n];
            if (gt((c - pr) % (nx - c), 0))
                return false;
            ld s1 = (pr - a) % (b - a);
            ld s2 = (nx - a) % (b - a);
            if ((gt(s1, 0) || gt(s2, 0)) &&
                    (gt(0, s1) || gt(0, s2)))
                return false;
        }
        //interval intersection
        pt d = p[(i + 1) % n];
        ld s1 = (a - c) % (d - c);
        ld s2 = (b - c) % (d - c);
        if (ge(s1, 0) && ge(s2, 0))
            continue;
        if (ge(0, s1) && ge(0, s2))
            continue;

        s1 = (c - a) % (b - a);
        s2 = (d - a) % (b - a);
        if (ge(s1, 0) && ge(s2, 0))
            continue;
        if (ge(0, s1) && ge(0, s2))
            continue;

        return false;
    }
    return true;
}
```

10 geometry/primitives.cpp

```cpp
//WARNING! do not forget to normalize vector (a,b)
struct line {
    ld a, b, c;
    int id;

    line(pt p1, pt p2) {
        gassert(p1 != p2);
        pt n = (p2 - p1).rot();
        n /= n.abs();
        a = n.x, b = n.y;
        c = -(n * p1);
    }

    bool right() const {
        return gt(a, 0) || (eq(a, 0) && gt(b, 0));
    }

    line(ld _a, ld _b, ld _c): a(_a), b(_b), c(_c) {
        ld d = pt{a, b}.abs();
        gassert(!eq(d, 0));
        a /= d, b /= d, c /= d;
    }

    ld signedDist(pt p) {
        return p * pt{a, b} + c;
    }
};

ld pointSegmentDist(pt p, pt a, pt b) {
    ld res = min((p - a).abs(), (p - b).abs());
    if (a != b && ge((p - a) * (b - a), 0) &&
            ge((p - b) * (a - b), 0))
        res = min(res,
            fabsl((p - a) % (b - a)) / (b - a).abs());
    return res;
}

pt linesIntersection(line l1, line l2) {
    ld D = l1.a * l2.b - l1.b * l2.a;
    if (eq(D, 0)) {
        if (eq(l1.c, l2.c)) {
            //equal lines
        } else {
            //no intersection
        }
    }
    ld dx = -l1.c * l2.b + l1.b * l2.c;
    ld dy = -l1.a * l2.c + l1.c * l2.a;
    pt res{dx / D, dy / D};
    //gassert(eq(l1.signedDist(res), 0));
    //gassert(eq(l2.signedDist(res), 0));
    return res;
}

bool pointInsideSegment(pt p, pt a, pt b) {
    if (!eq((p - a) % (p - b), 0))
        return false;
    return ge(0, (a - p) * (b - p));
}

bool checkSegmentIntersection(pt a, pt b, pt c, pt d) {
    if (eq((a - b) % (c - d), 0)) {
        if (pointInsideSegment(a, c, d) ||
            pointInsideSegment(b, c, d) ||
            pointInsideSegment(c, a, b) ||
            pointInsideSegment(d, a, b)) {
            //intersection of parallel segments
            return true;
        }
        return false;
    }

    ld s1, s2;

    s1 = (c - a) % (b - a);
    s2 = (d - a) % (b - a);
    if (gt(s1, 0) && gt(s2, 0))
        return false;
    if (gt(0, s1) && gt(0, s2))
        return false;

    swap(a, c), swap(b, d);

    s1 = (c - a) % (b - a);
    s2 = (d - a) % (b - a);
    if (gt(s1, 0) && gt(s2, 0))
        return false;
    if (gt(0, s1) && gt(0, s2))
        return false;

    return true;
```

```
}

// WARNING! run checkSegmentIntersecion before and process
// parallel case manually
pt segmentsIntersection(pt a, pt b, pt c, pt d) {
    ld S = (b - a) % (d - c);
    ld s1 = (c - a) % (d - a);
    return a + (b - a) / S * s1;
}

vector<pt> circlesIntersction(pt a, ld r1, pt b, ld r2) {
    ld d2 = (a - b).abs2();
    ld d = (a - b).abs();

    if (a == b && eq(r1, r2)) {
        //equal circles
    }
    if (gt(d2, sqr(r1 + r2)) || gt(sqr(r1 - r2), d2)) {
        //empty intersection
        return {};
    }
    int num = 2;
    if (eq(sqr(r1 + r2), d2) || eq(sqr(r1 - r2), d2))
        num = 1;
    ld cosa = (sqr(r1) + d2 - sqr(r2)) / ld(2 * r1 * d);
    ld oh = cosa * r1;
    pt h = a + ((b - a) / d * oh);
    if (num == 1)
        return {h};
    ld hp = sqrtl(max(0.L, 1 - cosa * cosa)) * r1;

    pt w = ((b - a) / d * hp).rot();
    return {h + w, h - w};
}

//a is circle center, p is point
vector<pt> circleTangents(pt a, ld r, pt p) {
    ld d2 = (a - p).abs2();
    ld d = (a - p).abs();

    if (gt(sqr(r), d2)) {
        //no tangents
        return {};
    }
    if (eq(sqr(r), d2)) {
        //point lies on circle - one tangent
        return {p};
    }

    pt B = p - a;
    pt H = B * sqr(r) / d2;
    ld h = sqrtl(d2 - sqr(r)) * ld(r) / d;
    pt w = (B / d * h).rot();
    H = H + a;
    return {H + w, H - w};
}

vector<pt> lineCircleIntersection(line l, pt a, ld r) {
    ld d = l.signedDist(a);
    if (gt(fabsl(d), r))
        return {};
    pt h = a - pt{l.a, l.b} * d;
    if (eq(fabsl(d), r))
        return {h};
    pt w(pt{l.a, l.b}.rot() * sqrtl(max<ld>(0, sqr(r)-sqr(d))));
    return {h + w, h - w};
}

//modified magic from e-maxx
vector<line> commonTangents(pt a, ld r1, pt b, ld r2) {
    if (a == b && eq(r1, r2)) {
        //equal circles
        return {};
    }
    vector<line> res;
    pt c = b - a;
    ld z = c.abs2();
    for (int i = -1; i <= 1; i += 2)
        for (int j = -1; j <= 1; j += 2) {
            ld r = r2 * j - r1 * i;
            ld d = z - sqr(r);
            if (gt(0, d))
                continue;
            d = sqrtl(max<ld>(0, d));
            pt magic = pt{r, d} / z;
            line l(magic * c, magic % c, r1 * i);
            l.c -= pt{l.a, l.b} * a;
            res.push_back(l);
        }
    return res;
}
```

11 geometry/svg.cpp

```
struct SVG {
    FILE *out;
    ld sc = 50;

    void open() {
        out = fopen("image.svg", "w");
        fprintf(out, "<svg xmlns='http://www.w3.org/2000/svg'
    viewBox='-1000 -1000 2000 2000'>\n");
    }

    void line(pt a, pt b) {
        a = a * sc, b = b * sc;
        fprintf(out, "<line x1='%Lf' y1='%Lf' x2='%Lf' y2='%Lf'
    stroke='black'/>\n", a.x, -a.y, b.x, -b.y);
    }

    void circle(pt a, ld r = -1, string col = "red") {
        r = (r == -1 ? 10 : sc * r);
        a = a * sc;
        fprintf(out, "<circle cx='%Lf' cy='%Lf' r='%Lf'
    fill='%s'/>\n", a.x, -a.y, r, col.c_str());
    }

    void text(pt a, string s) {
        a = a * sc;
        fprintf(out, "<text x='%Lf' y='%Lf'
    font-size='10px'>%s</text>\n", a.x, -a.y, s.c_str());
    }

    void close() {
        fprintf(out, "</svg>\n");
        fclose(out);
        out = 0;
    }

    ~SVG() {
        if (out)
            close();
    }
} svg;
```

12 graphs/2sat.cpp

```cpp
const int maxn = 200100; //2 x number of variables

namespace TwoSAT {
    int n; //number of variables
    bool used[maxn];
    vector<int> g[maxn];
    vector<int> gr[maxn];
    int comp[maxn];
    int res[maxn];

    void addEdge(int u, int v) { //u or v
        g[u].push_back(v ^ 1);
        g[v].push_back(u ^ 1);
        gr[u ^ 1].push_back(v);
        gr[v ^ 1].push_back(u);
    }

    vector<int> ord;
    void dfs1(int u) {
        used[u] = true;
        for (int v: g[u]) {
            if (used[v])
                continue;
            dfs1(v);
        }
        ord.push_back(u);
    }

    int COL = 0;
    void dfs2(int u) {
        used[u] = true;
        comp[u] = COL;
        for (int v: gr[u]) {
            if (used[v])
                continue;
            dfs2(v);
        }
    }

    void mark(int u) {
        res[u / 2] = u % 2;
        used[u] = true;
        for (int v: g[u]) {
            if (used[v])
                continue;
            mark(v);
        }
    }

    bool run() {
        fill(res, res + 2 * n, -1);
        fill(used, used + 2 * n, false);
        forn (i, 2 * n)
            if (!used[i])
                dfs1(i);
        reverse(ord.begin(), ord.end());
        assert((int) ord.size() == (2 * n));
        fill(used, used + 2 * n, false);
        for (int u: ord) if (!used[u]) {
            dfs2(u);
            ++COL;
        }
        forn (i, n)
            if (comp[i * 2] == comp[i * 2 + 1])
                return false;

        reverse(ord.begin(), ord.end());
        fill(used, used + 2 * n, false);
        for (int u: ord) {
            if (res[u / 2] != -1) {
                continue;
            }
            mark(u);
        }
        return true;
    }
};

int main() {
    TwoSAT::n = 2;
    TwoSAT::addEdge(0, 2); //x or y
    TwoSAT::addEdge(0, 3); //x or !y
    TwoSAT::addEdge(3, 3); //!y or !y
    assert(TwoSAT::run());
    cout << TwoSAT::res[0] << ' ' << TwoSAT::res[1] << '\n';
    //1 0
}
```

13 graphs/directed_mst.cpp

```cpp
// WARNING: this code wasn't submitted anywhere

namespace TwoChinese {

struct Edge {
    int to, w, id;
    bool operator<(const Edge& other) const {
        return to < other.to || (to == other.to && w < other.w);
    }
};
typedef vector<vector<Edge>> Graph;

const int maxn = 2050;

// global, for supplementary algorithms
int b[maxn];
int tin[maxn], tup[maxn];
int dtime; // counter for tin, tout
vector<int> st;
int nc; // number of strongly connected components
int q[maxn];

int answer;

void tarjan(int v, const Graph& e, vector<int>& comp) {
    b[v] = 1;
    st.push_back(v);
    tin[v] = tup[v] = dtime++;

    for (Edge t: e[v]) if (t.w == 0) {
        int to = t.to;
        if (b[to] == 0) {
            tarjan(to, e, comp);
            tup[v] = min(tup[v], tup[to]);
        } else if (b[to] == 1) {
            tup[v] = min(tup[v], tin[to]);
        }
    }

    if (tin[v] == tup[v]) {
        while (true) {
            int t = st.back();
            st.pop_back();
            comp[t] = nc;
            b[t] = 2;
            if (t == v) break;
        }
        ++nc;
    }
}

vector<Edge> bfs(
    const Graph& e,const vi& init, const vi& comp)
{
    int n = e.size();
    forn(i, n) b[i] = 0;
    int lq = 0, rq = 0;
    for (int v: init) b[v] = 1, q[rq++] = v;

    vector<Edge> result;

    while (lq != rq) {
        int v = q[lq++];
        for (Edge t: e[v]) if (t.w == 0) {
            int to = t.to;
            if (b[to]) continue;
            if (!comp.empty() && comp[v] != comp[to]) continue;
            b[to] = 1;
            q[rq++] = to;
            result.push_back(t);
        }
    }

    return result;
}

// warning: check that each vertex is reachable from root
vector<Edge> run(Graph e, int root) {
    int n = e.size();

    // find minimum incoming weight for each vertex
    vector<int> minw(n, inf);
    forn(v, n) for (Edge t: e[v]) {
        minw[t.to] = min(minw[t.to], t.w);
    }
    forn(v, n) for (Edge &t: e[v]) if (t.to != root) {
        t.w -= minw[t.to];
    }
    forn(i, n) if (i != root) answer += minw[i];

    // check if each vertex is reachable from root by zero edges
```

```
92      vector<Edge> firstResult = bfs(e, {root}, {});
93      if ((int)firstResult.size() + 1 == n) {
94          return firstResult;
95      }
96
97      // find stongly connected comp-s and build compressed graph
98      vector<int> comp(n);
99      forn(i, n) b[i] = 0;
100     nc = 0;
101     dtime = 0;
102     forn(i, n) if (!b[i]) tarjan(i, e, comp);
103
104     // multiple edges may be removed here if needed
105     Graph ne(nc);
106     forn(v, n) for (Edge t: e[v]) {
107         if (comp[v] != comp[t.to]) {
108             ne[comp[v]].push_back({comp[t.to], t.w, t.id});
109         }
110     }
111
112     // run recursively on compressed graph
113     vector<Edge> subres = run(ne, comp[root]);
114
115     // find incoming edge id for each component, init queue
116     // if there is an edge (u, v) between different components
117     // than v is added to queue
118     vector<int> incomingId(nc);
119     for (Edge e: subres) {
120         incomingId[e.to] = e.id;
121     }
122
123     vector<Edge> result;
124     vector<int> init;
125     init.push_back(root);
126     forn(v, n) for (Edge t: e[v]) {
127         if (incomingId[comp[t.to]] == t.id) {
128             result.push_back(t);
129             init.push_back(t.to);
130         }
131     }
132
133     // run bfs to add edges inside components and return answer
134     vector<Edge> innerEdges = bfs(e, init, comp);
135     result.insert(result.end(), all(innerEdges));
136
137     assert((int)result.size() + 1 == n);
138     return result;
139 }
140
141 } // namespace TwoChinese
142
143 void test () {
144     auto res = TwoChinese::run({
145         {{1,5,0},{2,5,1}},
146         {{3,1,2}},
147         {{1,2,3},{4,1,4}},
148         {{1,1,5},{4,2,6}},
149         {{2,1,7}}},
150         0);
151     cout << TwoChinese::answer << endl;
152     for (auto e: res) cout << e.id << " ";
153     cout << endl;
154     // 9     0 6 2 7
155 }
```

14 graphs/edmonds_matching.cpp

```
1  int n;
2  vi e[maxn];
3  int mt[maxn], p[maxn], base[maxn], b[maxn], blos[maxn];
4  int q[maxn];
5  int blca[maxn]; // used for lca
6
7  int lca(int u, int v) {
8      forn(i, n) blca[i] = 0;
9      while (true) {
10         u = base[u];
11         blca[u] = 1;
12         if (mt[u] == -1) break;
13         u = p[mt[u]];
14     }
15     while (!blca[base[v]]) {
16         v = p[mt[base[v]]];
17     }
18     return base[v];
19 }
20
21 void mark_path(int v, int b, int ch) {
22     while (base[v] != b) {
23         blos[base[v]] = blos[base[mt[v]]] = 1;
24         p[v] = ch;
25         ch = mt[v];
26         v = p[mt[v]];
27     }
28 }
29
30 int find_path(int root) {
31     forn(i, n) {
32         base[i] = i;
33         p[i] = -1;
34         b[i] = 0;
35     }
36
37     b[root] = 1;
38     q[0] = root;
39     int lq = 0, rq = 1;
40     while (lq != rq) {
41         int v = q[lq++];
42         for (int to: e[v]) {
43             if (base[v] == base[to] || mt[v] == to) continue;
44             if (to==root || (mt[to] != -1 && p[mt[to]] != -1)) {
45                 int curbase = lca(v, to);
46                 forn(i, n) blos[i] = 0;
47                 mark_path(v, curbase, to);
48                 mark_path(to, curbase, v);
49                 forn(i, n) if (blos[base[i]]) {
50                     base[i] = curbase;
51                     if (!b[i]) b[i] = 1, q[rq++] = i;
52                 }
53             } else if (p[to] == -1) {
54                 p[to] = v;
55                 if (mt[to] == -1) {
56                     return to;
57                 }
58                 to = mt[to];
59                 b[to] = 1;
60                 q[rq++] = to;
61
62             }
63         }
64     }
65     return -1;
66 }
67
68 int matching() {
69     forn(i, n) mt[i] = -1;
70     int res = 0;
71     forn(i, n) if (mt[i] == -1) {
72         int v = find_path(i);
73         if (v != -1) {
74             ++res;
75             while (v != -1) {
76                 int pv = p[v], ppv = mt[p[v]];
77                 mt[v] = pv, mt[pv] = v;
78                 v = ppv;
79             }
80         }
81     }
82     return res;
83 }
```

15 graphs/euler_cycle.cpp

```cpp
struct Edge {
    int to, id;
};

bool usedEdge[maxm];
vector<Edge> g[maxn];
int ptr[maxn];

vector<int> cycle;
void eulerCycle(int u) {
    while (ptr[u] < sz(g[u]) && usedEdge[g[u][ptr[u]].id])
        ++ptr[u];
    if (ptr[u] == sz(g[u]))
        return;
    const Edge &e = g[u][ptr[u]];
    usedEdge[e.id] = true;
    eulerCycle(e.to);
    cycle.push_back(e.id);
    eulerCycle(u);
}

int edges = 0;
void addEdge(int u, int v) {
    g[u].push_back(Edge{v, edges});
    g[v].push_back(Edge{u, edges++});
}
```

16 math/factor.cpp

```cpp
//WARNING: only mod <= 1e18
ll mul(ll a, ll b, ll mod) {
    ll res = a * b - (ll(ld(a) * ld(b) / ld(mod)) * mod);
    while (res < 0)
        res += mod;
    while (res >= mod)
        res -= mod;
    return res;
}

bool millerRabinTest(ll n, ll a) {
    if (gcd(n, a) > 1)
        return false;
    ll x = n - 1;
    int l = 0;
    while (x % 2 == 0) {
        x /= 2;
        ++l;
    }
    ll c = binpow(a, x, n);
    for (int i = 0; i < l; ++i) {
        ll nx = mul(c, c, n);
        if (nx == 1) {
            if (c != 1 && c != n - 1)
                return false;
            else
                return true;
        }
        c = nx;
    }
    return c == 1;
}

bool isPrime(ll n) {
    if (n == 1)
        return false;
    if (n % 2 == 0)
        return n == 2;
    for (ll a = 2; a < min<ll>(8, n); ++a)
        if (!millerRabinTest(n, a))
            return false;
    return true;
}

//WARNING: p is not sorted
void factorize(ll x, vector<ll> &p) {
    if (x == 1)
        return;
    if (isPrime(x)) {
        p.push_back(x);
        return;
    }
    for (ll d: {2, 3, 5})
        if (x % d == 0) {
            p.push_back(d);
            factorize(x / d, p);
            return;
        }
    while (true) {
        ll x1 = rr() % (x - 1) + 1;
        ll x2 = (mul(x1, x1, x) + 1) % x;
        int i1 = 1, i2 = 2;
        while (true) {
            ll c = (x1 + x - x2) % x;
            if (c == 0)
                break;
            ll g = gcd(c, x);
            if (g > 1) {
                factorize(g, p);
                factorize(x / g, p);
                return;
            }
            if (i1 * 2 == i2) {
                i1 *= 2;
                x1 = x2;
            }
            ++i2;
            x2 = (mul(x2, x2, x) + 1) % x;
        }
    }
}

bool isPrimeSlow(int x) {
    for (int i = 2; i * i <= x; ++i)
        if (x % i == 0)
            return false;
    return x != 1;
}

void test() {
    forn (i, 100000) {
```

```
92          if (i == 0)
93              continue;
94          assert(isPrime(i) == isPrimeSlow(i));
95          vector<ll> p;
96          factorize(i, p);
97          ll prod = 1;
98          for (ll x: p) {
99              assert(x > 1);
100             assert(isPrimeSlow(x));
101             prod *= x;
102         }
103         assert(prod == i);
104     }
105 }
```

17 math/fft.cpp

```
1 const int maxlg = 20;
2
3 vector<base> ang[maxlg + 5];
4
5 void init_fft() {
6     int n = 1 << maxlg;
7     ld e = acosl(-1) * 2 / n;
8     ang[maxlg].resize(n);
9     forn(i, n) {
10        ang[maxlg][i] = { cos(e * i), sin(e * i) };
11    }
12
13    for (int k = maxlg - 1; k >= 0; --k) {
14        ang[k].resize(1 << k);
15        forn(i, 1<<k) {
16            ang[k][i] = ang[k+1][i*2];
17        }
18    }
19 }
20
21 void fft_rec(base *a, int lg, bool rev) {
22     if (lg == 0) {
23         return;
24     }
25     int len = 1 << (lg - 1);
26     fft_rec(a, lg-1, rev);
27     fft_rec(a+len, lg-1, rev);
28
29     forn(i, len) {
30         base w = ang[lg][i];
31         if (rev) {
32             w.im *= -1;
33         }
34         base u = a[i];
35         base v = a[i+len] * w;
36         a[i] = u + v;
37         a[i+len] = u - v;
38     }
39 }
40
41 //n must be power of 2
42 void fft(base *a, int n, bool rev) {
43     int lg = 0;
44     while ((1<<lg) != n) {
45         ++lg;
46     }
47     int j = 0, bit;
48     for (int i = 1; i < n; ++i) {
49         for (bit = n >> 1; bit & j; bit >>= 1)
50             j ^= bit;
51         j ^= bit;
52         if (i < j) swap(a[i], a[j]);
53     }
54     fft_rec(a, lg, rev);
55     if (rev) forn(i, n) {
56         a[i] = a[i] * (1.0 / n);
57     }
58 }
59
60 const int maxn = 1050000;
61
62 int n;
63 base a[maxn];
64 base b[maxn];
65
66 void test() {
67     int n = 8;
68     init_fft();
69     base a[8] = {1,3,5,2,4,6,7,1};
70     base b[16];
71     fft(b, 16, 0);
72     fft(a, n, 0);
73     forn(i, n) cout << a[i].re << " "; cout << endl;
74     forn(i, n) cout << a[i].im << " "; cout << endl;
75     // 29 -5.82843 -7 -0.171573 5 -0.171573 -7 -5.82843
76     // 0 -3.41421 6 0.585786 0 -0.585786 -6 3.41421
77 }
```

18 math/fft_inv.cpp

```cpp
vector <int> mul(vector <int> a, vector <int> b,
        bool carry = true) {
    int n = sz(a);
    if (carry) {
        a.resize(n * 2);
        b.resize(n * 2);
    }
    fft(a.data(), a.size(), false);
    fft(b.data(), b.size(), false);
    for (int i = 0; i < sz(a); ++i)
        a[i] = mul(a[i], b[i]);
    fft(a.data(), a.size(), true);
    a.resize(n);
    return a;
}

vector <int> inv(vector <int> v) {
    int n = 1;
    while (n < sz(v))
        n <<= 1;
    v.resize(n, 0);
    vector <int> res(1, binpow(v[0], mod - 2));
    for (int k = 1; k < n; k <<= 1) {
        vector <int> A(k * 2, 0);
        copy(v.begin(), v.begin() + k, A.begin());
        vector <int> C = res;
        C.resize(k * 2, 0);
        A = mul(A, C, false);
        for (int i = 0; i < 2 * k; ++i)
            A[i] = sub(0, A[i]);
        A[0] = sum(A[0], 1);
        for (int i = 0; i < k; ++i)
            assert(A[i] == 0);
        copy(A.begin() + k, A.end(), A.begin());
        A.resize(k);
        vector <int> B(k);
        copy(v.begin() + k, v.begin() + 2 * k, B.begin());
        C.resize(k);
        B = mul(B, C);
        for (int i = 0; i < k; ++i)
            A[i] = sub(A[i], B[i]);
        A = mul(A, C);
        res.resize(k * 2);
        copy(A.begin(), A.end(), res.begin() + k);
    }
    return res;
}
```

19 math/golden_search.cpp

```cpp
ld f(ld x) {
    return 5 * x * x + 100 * x + 1; //-10 is minimum
}

ld goldenSearch(ld l, ld r) {
    ld phi = (1 + sqrtl(5)) / 2;
    ld resphi = 2 - phi;
    ld x1 = l + resphi * (r - l);
    ld x2 = r - resphi * (r - l);
    ld f1 = f(x1);
    ld f2 = f(x2);
    forn (iter, 60) {
        if (f1 < f2) {
            r = x2;
            x2 = x1;
            f2 = f1;
            x1 = l + resphi * (r - l);
            f1 = f(x1);
        } else {
            l = x1;
            x1 = x2;
            f1 = f2;
            x2 = r - resphi * (r - l);
            f2 = f(x2);
        }
    }
    return (x1 + x2) / 2;
}

int main() {
    std::cout << goldenSearch(-100, 100) << '\n';
}
```

20 math/numbers.tex

- Simpson and Gauss numerical integration:

  $\int_a^b f(x)\mathrm{dx} = (b-a)/6 \cdot (f(a) + 4(f(a+b)/2) + f(b))$

  $\int_{-1}^{1}$, $x_{1,3} = \pm\sqrt{0.6}$, $x_2 = 0$; $a_{1,3} = 5/9$, $a_2 = 8/9$

- Large primes: $10^{18} + 3, +31, +3111$, $10^9 + 21, +33$

- FFT modules:

1 107 296 257	$2^{25} \cdot 3 \cdot 11 + 1$	10
1 161 822 209	$2^{22} \cdot 277 + 1$	3
1 261 007 895 663 738 881	$2^{55} \cdot 5 \cdot 7 + 1$	6 (check)

- Fibonacci numbers:

  1, 2 : 1
  45 : 1 134 903 170
  46 : 1 836 311 903 (*max int*)
  47 : 2 971 215 073 (*max unsigned*)
  91 : 4 660 046 610 375 530 309
  92 : 7 540 113 804 746 346 429 (*max i64*)
  93 : 12 200 160 415 121 876 738 (*max unsigned i64*)

- Powers of two

  $2^{31} = 2\,147\,483\,648 = 2.1 \cdot 10^9$
  $2^{32} = 4\,294\,967\,296 = 4.2 \cdot 10^9$
  $2^{63} = 9\,223\,372\,036\,854\,775\,808 = 9.2 \cdot 10^{18}$
  $2^{64} = 18\,446\,744\,073\,709\,551\,616 = 1.8 \cdot 10^{19}$

- Highly composite numbers
  - ≤ 1000: $d(840) = 32$, $\le 10^4$: $d(9\,240) = 64$
  - $\le 10^5$: $d(83\,160) = 128$, $\le 10^6$: $d(720\,720) = 240$
  - $\le 10^7$: $d(8\,648\,640) = 448$, $\le 10^8$: $d(91\,891\,800) = 768$
  - $\le 10^9$: $d(931\,170\,240) = 1344$
  - $\le 10^{11}$: $d(97\,772\,875\,200) = 4032$
  - $\le 10^{12}$: $d(963\,761\,198\,400) = 6720$
  - $\le 10^{15}$: $d(866\,421\,317\,361\,600) = 26880$
  - $\le 10^{18}$: $d(897\,612\,484\,786\,617\,600) = 103680$

- Misc
  - Расстояние между точками по сфере: $L = R \cdot \arccos(\cos\theta_1 \cdot \cos\theta_2 + \sin\theta_1 \cdot \sin\theta_2 \cdot \cos(\varphi_1 - \varphi_2))$, где θ — широты (от $-\frac{\pi}{2}$ до $\frac{\pi}{2}$), φ — долготы (от $-\pi$ до π).
  - Объём шарового сегмента: $V = \pi h^2(R - \frac{1}{3}h)$, где h — высота от вершины сектора до секущей плоскости
  - Площадь поверхности шарового сегмента: $S = 2\pi Rh$, где h — высота.

- Bell numbers: 0:1, 1:1, 2:2, 3:5, 4:15, 5:52, 6:203, 7:877, 8:4140, 9:21147, 10:115975, 11:678570, 12:4213597, 13:27644437, 14:190899322, 15:1382958545, 16:10480142147, 17:82864869804, 18:682076806159, 19:5832742205057, 20:51724158235372, 21:474869816156751, 22:4506715738447323, 23:44152005855084346

- Catalan numbers: 0:1, 1:1, 2:2, 3:5, 4:14, 5:42, 6:132, 7:429, 8:1430, 9:4862, 10:16796, 11:58786, 12:208012, 13:742900, 14:2674440, 15:9694845, 16:35357670, 17:129644790, 18:477638700, 19:1767263190, 20:6564120420, 21:24466267020, 22:91482563640, 23:343059613650, 24:1289904147324, 25:4861946401452

21 math/stuff.cpp

```cpp
const int M = 1e6;

int phi[M];

void calcPhi() {
    for (int i = 1; i < M; ++i)
        phi[i] = i;
    for (int j = 1; j < M; ++j)
        for (int i = 2 * j; i < M; i += j)
            phi[i] -= phi[j];
}
int inv[M];

void calcInv() {
    inv[1] = 1;
    for (int i = 2; i < M; ++i) {
        inv[i] = mul(sub(0, mod / i), inv[mod % i]);
        assert(mul(i, inv[i]) == 1);
    }
}

int gcd(int a, int b, int &x, int &y) {
    if (a == 0) {
        x = 0, y = 1;
        return b;
    }
    int x1, y1;
    int g = gcd(b % a, a, x1, y1);
    x = y1 - x1 * (b / a);
    y = x1;
    assert(a * x + b * y == g);
    return g;
}

int crt(int mod1, int mod2, int rem1, int rem2) {
    int r = (rem2 - (rem1 % mod2) + mod2) % mod2;
    int x, y;
    int g = gcd(mod1, mod2, x, y);
    assert(r % g == 0);

    x %= mod2;
    if (x < 0)
        x += mod2;

    int ans = (x * (r / g)) % mod2;
    ans = ans * mod1 + rem1;

    assert(ans % mod1 == rem1);
    assert(ans % mod2 == rem2);
    return ans;
}

int main() {
    calcPhi();
    assert(phi[30] == 1 * 2 * 4);
    calcInv();
    int x, y;
    gcd(3, 5, x, y);
    gcd(15, 10, x, y);
    crt(15, 13, 2, 5);
    crt(17, 3, 15, 2);
    return 0;
}
```

22 strings/automaton.cpp

```cpp
int t[maxn][26], lnk[maxn], len[maxn];
int sz;
int last;

void init() {
    sz = 3;
    last = 1;
    forn(i, 26) t[2][i] = 1;
    len[2] = -1;
    lnk[1] = 2;
}

void addchar(int c) {
    int nlast = sz++;
    len[nlast] = len[last] + 1;
    int p = last;
    for (; !t[p][c]; p = lnk[p]) {
        t[p][c] = nlast;
    }
    int q = t[p][c];
    if (len[p] + 1 == len[q]) {
        lnk[nlast] = q;
    } else {
        int clone = sz++;
        len[clone] = len[p] + 1;
        lnk[clone] = lnk[q];
        lnk[q] = lnk[nlast] = clone;
        forn(i, 26) t[clone][i] = t[q][i];
        for (; t[p][c] == q; p = lnk[p]) {
            t[p][c] = clone;
        }
    }
    last = nlast;
}

bool check(const string& s) {
    int v = 1;
    for (int c: s) {
        c -= 'a';
        if (!t[v][c]) return false;
        v = t[v][c];
    }
    return true;
}

int main() {
    string s;
    cin >> s;
    init();
    for (int i: s) {
        addchar(i-'a');
    }
    forn(i, s.length()) {
        assert(check(s.substr(i)));
    }
    cout << sz << endl;
    return 0;
}
```

23 strings/duval_manacher.cpp

```cpp
/*
   Строка простая, если строго меньше всех суффиксов <=>
   наименьший циклический сдвиг - первый.
   Декомпозиция Линдона - разбиение s на w1, w2, ... wk -
   простые строки такие, что w1 >= w2 >= ... wk.
*/
int duval(string s) {
    s += s; //remove this to find Lyndon decomposition of s
    int n = s.size();
    int i = 0;
    int ans = 0;
    //while (i < n) { //for Lyndon decomposition
    while (i < n / 2) {
        ans = i;
        int j = i + 1, k = i;
        while (j < n && s[k] <= s[j]) {
            if (s[k] < s[j])
                k = i;
            else
                ++k;
            ++j;
        }
        while (i <= k) {
            //s.substr(i, j - k) -
            //next prime string of Lyndon decomposition
            i += j - k;
        }
    }
    return ans;
}

//actual odd length is (odd[i] * 2 - 1)
//actual even length is (even[i] * 2)
void manacher(const string &s, vi &odd, vi &even) {
    int n = s.size();
    odd.resize(n);
    int c = -1, r = -1;
    forn (i, n) {
        int k = (r <= i ? 0 : min(odd[2 * c - i], r - i));
        while (i + k < n && i - k >= 0 && s[i + k] == s[i - k])
            ++k;
        odd[i] = k;
        if (i + k > r)
            r = i + k, c = i;
    }
    c = -1, r = -1;
    even.resize(n - 1);
    forn (i, n - 1) {
        int k = (r <= i ? 0 : min(even[2 * c - i], r - i));
        while (i + k + 1 < n && i - k >= 0 &&
                s[i + k + 1] == s[i - k])
            ++k;
        even[i] = k;
        if (i + k > r)
            c = i, r = i + k;
    }
}

void test() {
    vector<int> odd, even;
    string s = "aaaabbaaaaa";
    manacher(s, odd, even);
    for (int x: even)
        cerr << x << ' ';
    cerr << '\n';
    for (int x: odd)
        cerr << x << ' ';
    cerr << '\n';
    // 1 2 1 0 5 0 1 2 2 1
    // 1 2 2 1 1 1 1 2 3 2 1
}

int main() {
    cout << duval("ababcabab") << '\n'; // 5
    test();
}
```

24 strings/eertree.cpp

```cpp
#include <bits/stdc++.h>
using namespace std;
const int maxn = 5000100;
const int inf = 1e9 + 1e5;

char buf[maxn];
char *s = buf + 1;
int to[maxn][2];
int suff[maxn];
int len[maxn];
int sz;
int last;

const int odd = 1;
const int even = 2;
const int blank = 3;

inline void go(int &u, int pos) {
    while (u != blank && s[pos - len[u] - 1] != s[pos])
        u = suff[u];
}

void add_char(int pos) {
    go(last, pos);
    int u = suff[last];
    go(u, pos);
    int c = s[pos] - 'a';
    if (!to[last][c]) {
        to[last][c] = sz++;
        len[sz - 1] = len[last] + 2;
        assert(to[u][c]);
        suff[sz - 1] = to[u][c];
    }
    last = to[last][c];
}

void init() {
    sz = 4;
    to[blank][0] = to[blank][1] = even;
    len[blank] = suff[blank] = inf;
    len[even] = 0, suff[even] = odd;
    len[odd] = -1, suff[odd] = blank;
    last = 2;
}

void build() {
    init();
    scanf("%s", s);
    for (int i = 0; s[i]; ++i)
        add_char(i);
}
```

25 strings/suffix_array.cpp

```cpp
string s;
int n;
int sa[maxn], new_sa[maxn], cls[maxn], new_cls[maxn],
        cnt[maxn], lcp[maxn];
int n_cls;

void build() {
    n_cls = 256;
    forn(i, n) {
        sa[i] = i;
        cls[i] = s[i];
    }
    for (int d = 0; d < n; d = d ? d*2 : 1) {

        forn(i, n) new_sa[i] = (sa[i] - d + n) % n;
        forn(i, n_cls) cnt[i] = 0;
        forn(i, n) ++cnt[cls[i]];
        forn(i, n_cls) cnt[i+1] += cnt[i];
        for (int i = n-1; i >= 0; --i)
            sa[--cnt[cls[new_sa[i]]]] = new_sa[i];

        n_cls = 0;
        forn(i, n) {
            if (i && (cls[sa[i]] != cls[sa[i-1]] ||
                    cls[(sa[i]+d)%n] != cls[(sa[i-1]+d)%n])) {
                ++n_cls;
            }
            new_cls[sa[i]] = n_cls;
        }
        ++n_cls;
        forn(i, n) cls[i] = new_cls[i];
    }

    // cls is also a inv perm of sa if a string is not cyclic
    // (i.e. a position of i-th lexicographical suffix)
    int val = 0;
    forn(i, n) {
        if (val) --val;
        if (cls[i] == n-1) continue;
        int j = sa[cls[i] + 1];
        while (i+val != n && j+val != n && s[i+val] == s[j+val])
            ++val;
        lcp[cls[i]] = val;
    }
}

int main() {
    cin >> s;
    s += '$';
    n = s.length();
    build();
    forn(i, n) {
        cout << s.substr(sa[i]) << endl;
        cout << lcp[i] << endl;
    }
}
```

26 strings/ukkonen.cpp

```cpp
#include <bits/stdc++.h>
using namespace std;
#define sz(x) ((int) (x).size())
#define forn(i,n) for (int i = 0; i < int(n); ++i)
const int inf = int(1e9) + int(1e5);

string s;
const int alpha = 26;

namespace SuffixTree {
    struct Node {
        Node *to[alpha];
        Node *lnk, *par;
        int l, r;

        Node(int l, int r): l(l), r(r) {
            memset(to, 0, sizeof(to));
            lnk = par = 0;
        }
    };

    Node *root, *blank, *cur;
    int pos;

    void init() {
        root = new Node(0, 0);
        blank = new Node(0, 0);
        forn (i, alpha)
            blank->to[i] = root;
        root->lnk = root->par = blank->lnk = blank->par = blank;
        cur = root;
        pos = 0;
    }

    int at(int id) {
        return s[id];
    }

    void goDown(int l, int r) {
        if (l >= r)
            return;
        if (pos == cur->r) {
            int c = at(l);
            assert(cur->to[c]);
            cur = cur->to[c];
            pos = min(cur->r, cur->l + 1);
            ++l;
        } else {
            int delta = min(r - l, cur->r - pos);
            l += delta;
            pos += delta;
        }
        goDown(l, r);
    }

    void goUp() {
        if (pos == cur->r && cur->lnk) {
            cur = cur->lnk;
            pos = cur->r;
            return;
        }
        int l = cur->l, r = pos;
        cur = cur->par->lnk;
        pos = cur->r;
        goDown(l, r);
    }

    void setParent(Node *a, Node *b) {
        assert(a);
        a->par = b;
        if (b)
            b->to[at(a->l)] = a;
    }

    void addLeaf(int id) {
        Node *x = new Node(id, inf);
        setParent(x, cur);
    }

    void splitNode() {
        assert(pos != cur->r);
        Node *mid = new Node(cur->l, pos);
        setParent(mid, cur->par);
        cur->l = pos;
        setParent(cur, mid);
        cur = mid;
    }

    bool canGo(int c) {
        if (pos == cur->r)
            return cur->to[c];
        return at(pos) == c;
    }

    void fixLink(Node *&bad, Node *newBad) {
        if (bad)
            bad->lnk = cur;
        bad = newBad;
    }

    void addCharOnPos(int id) {
        Node *bad = 0;
        while (!canGo(at(id))) {
            if (cur->r != pos) {
                splitNode();
                fixLink(bad, cur);
                bad = cur;
            } else {
                fixLink(bad, 0);
            }
            addLeaf(id);
            goUp();
        }
        fixLink(bad, 0);
        goDown(id, id + 1);
    }

    int cnt(Node *u, int ml) {
        if (!u)
            return 0;
        int res = min(ml, u->r) - u->l;
        forn (i, alpha)
            res += cnt(u->to[i], ml);
        return res;
    }

    void build(int l) {
        init();
        forn (i, l)
            addCharOnPos(i);
    }
};

int main() {
    cin >> s;
    SuffixTree::build(s.size());
}
```

27 structures/convex_hull_trick.cpp

```cpp
/*
    WARNING!!!
    - finds maximum of A*x+B
    - double check max coords for int/long long overflow
    - set min x query in put function
    - add lines with non-descending A coefficient
*/
struct FastHull {
    int a[maxn];
    ll b[maxn];
    ll p[maxn];
    int c;

    FastHull(): c(0) {}

    ll get(int x) {
        if (c == 0)
            return -infl;
        int pos = upper_bound(p, p + c, x) - p - 1;
        assert(pos >= 0);
        return (ll) a[pos] * x + b[pos];
    }

    ll divideCeil(ll p, ll q) {
        assert(q > 0);
        if (p >= 0)
            return (p + q - 1) / q;
        return -((-p) / q);
    }

    void put(int A, ll B) {
        while (c > 0) {
            if (a[c - 1] == A && b[c - 1] >= B)
                return;
            ll pt = p[c - 1];
            if (a[c - 1] * pt + b[c - 1] < A * pt + B) {
                --c;
                continue;
            }
            ll q = A - a[c - 1];
            ll np = divideCeil(b[c - 1] - B, q);
            p[c] = np;
            a[c] = A;
            b[c] = B;
            ++c;
            return;
        }
        if (c == 0) {
            a[c] = A, b[c] = B;
            p[c] = -1e9; //min x query
            ++c;
            return;
        }
    }

};

struct SlowHull {
    vector<pair<int, ll>> v;

    void put(int a, ll b) {
        v.emplace_back(a, b);
    }

    ll get(ll x) {
        ll best = -infl;
        for (auto p: v)
            best = max(best, p.first * x + p.second);
        return best;
    }
};

int main() {
    FastHull hull1;
    SlowHull hull2;
    vector<int> as;
    forn (ii, 10000)
        as.push_back(rand() % int(1e8));
    sort(as.begin(), as.end());
    forn (ii, 10000) {
        int b = rand() % int(1e8);
        hull1.put(as[ii], b);
        hull2.put(as[ii], b);
        int x = rand() % int(2e8 + 1) - int(1e8);
        assert(hull1.get(x) == hull2.get(x));
    }
}
```

28 structures/heavy_light.cpp

```cpp
const int maxn = 100500;
const int maxd = 17;

vector<int> g[maxn];

struct Tree {
    vector<int> t;
    int base;

    Tree(): base(0) {
    }

    Tree(int n) {
        base = 1;
        while (base < n)
            base *= 2;
        t = vector<int>(base * 2, 0);
    }

    void put(int v, int delta) {
        assert(v < base);
        v += base;
        t[v] += delta;
        while (v > 1) {
            v /= 2;
            t[v] = max(t[v * 2], t[v * 2 + 1]);
        }
    }

    //Careful here: cr = 2 * maxn
    int get(int l, int r, int v=1, int cl=0, int cr = 2*maxn) {
        cr = min(cr, base);
        if (l <= cl && cr <= r)
            return t[v];
        if (r <= cl || cr <= l)
            return 0;
        int cc = (cl + cr) / 2;
        return max(get(l, r, v * 2, cl, cc),
            get(l, r, v * 2 + 1, cc, cr));
    }
};

namespace HLD {
    int h[maxn];
    int timer;
    int in[maxn], out[maxn], cnt[maxn];
    int p[maxd][maxn];
    int vroot[maxn];
    int vpos[maxn];
    int ROOT;
    Tree tree[maxn];

    void dfs1(int u, int prev) {
        p[0][u] = prev;
        in[u] = timer++;
        cnt[u] = 1;
        for (int v: g[u]) {
            if (v == prev)
                continue;
            h[v] = h[u] + 1;
            dfs1(v, u);
            cnt[u] += cnt[v];
        }
        out[u] = timer;
    }

    int dfs2(int u, int prev) {
        int to = -1;
        for (int v: g[u]) {
            if (v == prev)
                continue;
            if (to == -1 || cnt[v] > cnt[to])
                to = v;
        }
        int len = 1;
        for (int v: g[u]) {
            if (v == prev)
                continue;
            if (to == v) {
                vpos[v] = vpos[u] + 1;
                vroot[v] = vroot[u];
                len += dfs2(v, u);
            }
            else {
                vroot[v] = v;
                vpos[v] = 0;
                dfs2(v, u);
            }
        }
        if (vroot[u] == u)
            tree[u] = Tree(len);
```

```
92          return len;
93      }
94
95      void init(int n) {
96          timer = 0;
97          h[ROOT] = 0;
98          dfs1(ROOT, ROOT);
99          forn (d, maxd - 1)
100             forn (i, n)
101                 p[d + 1][i] = p[d][p[d][i]];
102         vroot[ROOT] = ROOT;
103         vpos[ROOT] = 0;
104         dfs2(ROOT, ROOT);
105         //WARNING: init all trees
106     }
107
108     bool isPrev(int u, int v) {
109         return in[u] <= in[v] && out[v] <= out[u];
110     }
111
112     int lca(int u, int v) {
113         for (int d = maxd - 1; d >= 0; --d)
114             if (!isPrev(p[d][u], v))
115                 u = p[d][u];
116         if (!isPrev(u, v))
117             u = p[0][u];
118         return u;
119     }
120
121     //for each v: h[v] >= toh
122     int getv(int u, int toh) {
123         int res = 0;
124         while (h[u] >= toh) {
125             int rt = vroot[u];
126             int l = max(0, toh - h[rt]), r = vpos[u] + 1;
127             res = max(res, tree[rt].get(l, r));
128             if (rt == ROOT)
129                 break;
130             u = p[0][rt];
131         }
132         return res;
133     }
134
135     int get(int u, int v) {
136         int w = lca(u, v);
137         return max(getv(u, h[w]), getv(v, h[w] + 1));
138     }
139
140     void put(int u, int val) {
141         int rt = vroot[u];
142         int pos = vpos[u];
143         tree[rt].put(pos, val);
144     }
145 };
```

29 structures/linkcut.cpp

```
1  namespace LinkCut {
2
3  typedef struct _node {
4      _node *l, *r, *p, *pp;
5      int size; bool rev;
6      _node();
7
8      explicit _node(nullptr_t) {
9          l = r = p = pp = this;
10         size = rev = 0;
11     }
12
13     void push() {
14         if (rev) {
15             l->rev ^= 1; r->rev ^= 1;
16             rev = 0; swap(l,r);
17         }
18     }
19
20     void update();
21 }* node;
22
23 node None = new _node(nullptr);
24 node v2n[maxn];
25
26 _node::_node(){
27     l = r = p = pp = None;
28     size = 1; rev = false;
29 }
30
31 void _node::update() {
32     size = (this != None) + l->size + r->size;
33     l->p = r->p = this;
34 }
35
36 void rotate(node v) {
37     assert(v != None && v->p != None);
38     assert(!v->rev);
39     assert(!v->p->rev);
40     node u = v->p;
41     if (v == u->l)
42         u->l = v->r, v->r = u;
43     else
44         u->r = v->l, v->l = u;
45     swap(u->p,v->p);
46     swap(v->pp,u->pp);
47     if (v->p != None) {
48         assert(v->p->l == u || v->p->r == u);
49         if (v->p->r == u)
50             v->p->r = v;
51         else
52             v->p->l = v;
53     }
54     u->update();
55     v->update();
56 }
57
58 void bigRotate(node v) {
59     assert(v->p != None);
60     v->p->p->push();
61     v->p->push();
62     v->push();
63     if (v->p->p != None) {
64         if ((v->p->l == v) ^ (v->p->p->r == v->p))
65             rotate(v->p);
66         else
67             rotate(v);
68     }
69     rotate(v);
70 }
71
72 inline void splay(node v) {
73     while (v->p != None)
74         bigRotate(v);
75 }
76
77 inline void splitAfter(node v) {
78     v->push();
79     splay(v);
80     v->r->p = None;
81     v->r->pp = v;
82     v->r = None;
83     v->update();
84 }
85
86 void expose(int x) {
87     node v = v2n[x];
88     splitAfter(v);
89     while (v->pp != None) {
90         assert(v->p == None);
91         splitAfter(v->pp);
```

```
92          assert(v->pp->r == None);
93          assert(v->pp->p == None);
94          assert(!v->pp->rev);
95          v->pp->r = v;
96          v->pp->update();
97          v = v->pp;
98          v->r->pp = None;
99      }
100     assert(v->p == None);
101     splay(v2n[x]);
102 }
103
104 inline void makeRoot(int x) {
105     expose(x);
106     assert(v2n[x]->p == None);
107     assert(v2n[x]->pp == None);
108     assert(v2n[x]->r == None);
109     v2n[x]->rev ^= 1;
110 }
111
112 inline void link(int x, int y) {
113     makeRoot(x);
114     v2n[x]->pp = v2n[y];
115 }
116
117 inline void cut(int x, int y) {
118     expose(x);
119     splay(v2n[y]);
120     if (v2n[y]->pp != v2n[x]) {
121         swap(x,y);
122         expose(x);
123         splay(v2n[y]);
124         assert(v2n[y]->pp == v2n[x]);
125     }
126     v2n[y]->pp = None;
127 }
128
129 inline int get(int x, int y) {
130     if (x == y)
131         return 0;
132     makeRoot(x);
133     expose(y);
134     expose(x);
135     splay(v2n[y]);
136     if (v2n[y]->pp != v2n[x])
137         return -1;
138     return v2n[y]->size;
139 }
140
141 }
```

30 structures/ordered_set.cpp

```
1 #include <ext/pb_ds/assoc_container.hpp>
2 #include <ext/pb_ds/tree_policy.hpp>
3
4 typedef __gnu_pbds::tree<int, __gnu_pbds::null_type,
5         std::less<int>,
6         t__gnu_pbds::rb_tree_tag,
7         __gnu_pbds::tree_order_statistics_node_update> oset;
8
9 #include <iostream>
10
11 int main() {
12     oset X;
13     X.insert(1);
14     X.insert(2);
15     X.insert(4);
16     X.insert(8);
17     X.insert(16);
18
19     std::cout << *X.find_by_order(1) << std::endl; // 2
20     std::cout << *X.find_by_order(2) << std::endl; // 4
21     std::cout << *X.find_by_order(4) << std::endl; // 16
22     std::cout << std::boolalpha <<
23         (end(X)==X.find_by_order(6)) << std::endl; // true
24
25     std::cout << X.order_of_key(-5) << std::endl;  // 0
26     std::cout << X.order_of_key(1) << std::endl;   // 0
27     std::cout << X.order_of_key(3) << std::endl;   // 2
28     std::cout << X.order_of_key(4) << std::endl;   // 2
29     std::cout << X.order_of_key(400) << std::endl; // 5
30 }
```

31 structures/treap.cpp

```cpp
struct node {
    int x, y;
    node *l, *r;
    node(int x) : x(x), y(rand()), l(r=NULL) {}
};

void split(node *t, node *&l, node *&r, int x) {
    if (!t) return (void)(l=r=NULL);
    if (x <= t->x) {
        split(t->l, l, t->l, x), r = t;
    } else {
        split(t->r, t->r, r, x), l = t;
    }
}

node *merge(node *l, node *r) {
    if (!l) return r;
    if (!r) return l;
    if (l->y > r->y) {
        l->r = merge(l->r, r);
        return l;
    } else {
        r->l = merge(l, r->l);
        return r;
    }
}

node *insert(node *t, node *n) {
    node *l, *r;
    split(t, l, r, n->x);
    return merge(l, merge(n, r));
}

node *insert(node *t, int x) {
    return insert(t, new node(x));
}

node *fast_insert(node *t, node *n) {
    if (!t) return n;
    node *root = t;
    while (true) {
        if (n->x < t->x) {
            if (!t->l || t->l->y < n->y) {
                split(t->l, n->l, n->r, n->x), t->l = n;
                break;
            } else {
                t = t->l;
            }
        } else {
            if (!t->r || t->r->y < n->y) {
                split(t->r, n->l, n->r, n->x), t->r = n;
                break;
            } else {
                t = t->r;
            }
        }
    }
    return root;
}

node *fast_insert(node *t, int x) {
    return fast_insert(t, new node(x));
}

int main() {
    node *t = NULL;
    forn(i, 1000000) {
        int x = rand();
        t = fast_insert(t, x);
    }
}
```

32 Сеточка

33 Сеточка