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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

```

1 namespace Dinic {
2 const int maxn = 100100;
3 struct Edge {
4     int to;
5     ll c, f;
6     Edge(int to, ll c): to(to), c(c), f(0) {}
7 };
8
9 vector<Edge> es;
10 vector<int> g[maxn];
11 int q[maxn], d[maxn], pos[maxn];
12 int N, S, T;
13
14 void addEdge(int u, int v, ll c) {
15     g[u].push_back(sz(es));
16     es.emplace_back(v, c);
17     g[v].push_back(sz(es));
18     es.emplace_back(u, 0);
19 }
20
21 bool bfs() {
22     fill(d, d + N, maxn);
23     d[S] = 0, q[0] = S;
24     int rq = 1;
25     for (ll lq, rq) {
26         int u = q[lq];
27         for (int id: g[u]) {
28             if (es[id].c == es[id].f)
29                 continue;
30             int v = es[id].to;
31             if (d[v] == maxn) {
32                 d[v] = d[u] + 1;
33                 q[rq++] = v;
34             }
35         }
36     }
37     return d[T] != maxn;
38 }
39
40 ll dfs(int u, ll curf) {
41     if (u == T)
42         return curf;
43     ll ret = 0;
44     for (int &i = pos[u]; i < sz(g[u]); ++i) {
45         int id = g[u][i];
46         int v = es[id].to;
47         ll delta = min(curf, es[id].c - es[id].f);
48         if (delta == 0 || d[v] != d[u] + 1)
49             continue;
50         delta = dfs(v, delta);
51         curf -= delta;
52         ret += delta;
53         es[id].f += delta;
54         es[id ^ 1].f -= delta;
55         if (curf == 0)
56             return ret;
57     }
58     return ret;
59 }
60
61 ll dinic(int S, int T) {
62     Dinic::S = S, Dinic::T = T;
63     ll res = 0;
64     while (bfs()) {
65         fill(pos, pos + N, 0);
66         while (ll cur = dfs(S, infl))
67             res += cur;
68     }
69     return res;
70 }
71
72 // namespace Dinic
73
74 void test() {
75     Dinic::N = 4;
76     Dinic::addEdge(0, 1, 1);
77     Dinic::addEdge(0, 2, 2);
78     Dinic::addEdge(2, 1, 1);
79     Dinic::addEdge(1, 3, 2);
80     Dinic::addEdge(2, 3, 1);
81     cout << Dinic::dinic(0, 3) << endl; // 3
82 }
83
84 LR-поток находит не максимальный поток.
85 Добавим новый сток S' и исток T'. Заменим ребро (u, v, l, r)
86 LR-сети на ребра (u, T', l), (S', v, l), (u, v, r - l).
87 Добавим ребро (T, S, k). Ставим значение k=inf, пускаем поток.
88 Проверяем, что все ребра из S' насыщены (иначе ответ не
89 существует). Бинариским находим наименьшее k, что величина
90 потока не изменится. Это k - величина МИНИМАЛЬНОГО потока,
91 удовлетворяющего ограничениям. */

```

3 flows/globalcut.cpp

```

1#include <bits/stdc++.h>
2using namespace std;
3#define forn(i,n) for (int i = 0; i < int(n); ++i)
4const int inf = 1e9 + 1e5;
5#define all(x) (x).begin(), (x).end()
6
7const int maxn = 505;
8namespace StoerWagner {
9int g[maxn][maxn];
10int dist[maxn];
11bool used[maxn];
12int n;
13
14void addEdge(int u, int v, int c) {
15    g[u][v] += c;
16    g[v][u] += c;
17}
18
19int run() {
20    vector<int> vertices;
21    forn (i, n)
22        vertices.push_back(i);
23    int mincut = inf;
24    while (vertices.size() > 1) {
25        int u = vertices[0];
26        for (auto v: vertices) {
27            used[v] = false;
28            dist[v] = g[u][v];
29        }
30        used[u] = true;
31        forn (ii, vertices.size() - 2) {
32            for (auto v: vertices)
33                if (!used[v])
34                    if (used[u] || dist[v] > dist[u])
35                        u = v;
36            used[u] = true;
37            for (auto v: vertices)
38                if (!used[v])
39                    dist[v] += g[u][v];
40        }
41        int t = -1;
42        for (auto v: vertices)
43            if (!used[v])
44                t = v;
45        assert(t != -1);
46        mincut = min(mincut, dist[t]);
47        vertices.erase(find(all(vertices), t));
48        for (auto v: vertices)
49            addEdge(u, v, g[v][t]);
50    }
51    return mincut;
52}
53} // namespace StoerWagner
54
55int main() {
56    StoerWagner::n = 4;
57    StoerWagner::addEdge(0, 1, 5);
58    StoerWagner::addEdge(2, 3, 5);
59    StoerWagner::addEdge(1, 2, 4);
60    cerr << StoerWagner::run() << '\n'; // 4
61}

```

4 flows/hungary.cpp

```

1// left half is the smaller one
2namespace Hungary {
3const int maxn = 505;
4int a[maxn][maxn];
5int p[2][maxn];
6int match[maxn];
7bool used[maxn];
8int from[maxn];
9int mind[maxn];
10int n, m;
11
12int hungary(int v) {
13    used[v] = true;
14    int u = match[v];
15    int best = -1;
16    forn (i, m + 1) {
17        if (used[i])
18            continue;
19        int nw = a[u][i] - p[0][u] - p[1][i];
20        if (nw <= mind[i]) {
21            mind[i] = nw;
22            from[i] = v;
23        }
24        if (best == -1 || mind[best] > mind[i])
25            best = i;
26    }
27    v = best;
28    int delta = mind[best];
29    forn (i, m + 1) {
30        if (used[i]) {
31            p[1][i] -= delta;
32            p[0][match[i]] += delta;
33        } else
34            mind[i] -= delta;
35    }
36    if (match[v] == -1)
37        return v;
38    return hungary(v);
39}
40
41void check() {
42    int edges = 0, res = 0;
43    forn (i, m)
44        if (match[i] != -1) {
45            ++edges;
46            assert(p[0][match[i]] + p[1][i] == a[match[i]][i]);
47            res += a[match[i]][i];
48        } else
49            assert(p[1][i] == 0);
50    assert(res == -p[1][m]);
51    forn (i, n) forn (j, m)
52        assert(p[0][i] + p[1][j] <= a[i][j]);
53}
54
55int run() {
56    forn (i, n)
57        p[0][i] = 0;
58    forn (i, m + 1) {
59        p[1][i] = 0;
60        match[i] = -1;
61    }
62    forn (i, n) {
63        match[m] = i;
64        fill(used, used + m + 1, false);
65        fill(mind, mind + m + 1, inf);
66        fill(from, from + m + 1, -1);
67        int v = hungary(m);
68        while (v != m) {
69            int w = from[v];
70            match[v] = match[w];
71            v = w;
72        }
73    }
74    check();
75    return -p[1][m];
76}
77} // namespace Hungary

```

5 flows/mincost.cpp

```

1 namespace MinCost {
2 const ll infc = 1e12;
3
4 struct Edge {
5     int to;
6     ll c, f, cost;
7
8     Edge(int to, ll c, ll cost): to(to), c(c), f(0), cost(cost) {
9         {}
10};
11
12 int N, S, T;
13 int totalFlow;
14 ll totalCost;
15 const int maxn = 505;
16 vector<Edge> edge;
17 vector<int> g[maxn];
18
19 void addEdge(int u, int v, ll c, ll cost) {
20     g[u].push_back(edge.size());
21     edge.emplace_back(v, c, cost);
22     g[v].push_back(edge.size());
23     edge.emplace_back(u, 0, -cost);
24}
25
26 ll dist[maxn];
27 int fromEdge[maxn];
28
29 bool inQueue[maxn];
30 bool fordBellman() {
31     for (i, N)
32         dist[i] = infc;
33     dist[S] = 0;
34     inQueue[S] = true;
35     vector<int> q;
36     q.push_back(S);
37     for (int ii = 0; ii < int(q.size()); ++ii) {
38         int u = q[ii];
39         inQueue[u] = false;
40         for (int e: g[u]) {
41             if (edge[e].f == edge[e].c)
42                 continue;
43             int v = edge[e].to;
44             ll nw = edge[e].cost + dist[u];
45             if (nw >= dist[v])
46                 continue;
47             dist[v] = nw;
48             fromEdge[v] = e;
49             if (!inQueue[v]) {
50                 inQueue[v] = true;
51                 q.push_back(v);
52             }
53         }
54     }
55     return dist[T] != infc;
56}
57
58 ll pot[maxn];
59 bool dikstra() {
60     typedef pair<ll, int> Pair;
61     priority_queue<Pair, vector<Pair>, greater<Pair>> q;
62     for (i, N)
63         dist[i] = infc;
64     dist[S] = 0;
65     q.emplace(dist[S], S);
66     while (!q.empty()) {
67         int u = q.top().second;
68         ll cdist = q.top().first;
69         q.pop();
70         if (cdist != dist[u])
71             continue;
72         for (int e: g[u]) {
73             int v = edge[e].to;
74             if (edge[e].c == edge[e].f)
75                 continue;
76             ll w = edge[e].cost + pot[u] - pot[v];
77             assert(w >= 0);
78             ll ndist = w + dist[u];
79             if (ndist >= dist[v])
80                 continue;
81             dist[v] = ndist;
82             fromEdge[v] = e;
83             q.emplace(dist[v], v);
84         }
85     }
86     if (dist[T] == infc)
87         return false;
88     for (i, N) {
89         if (dist[i] == infc)
90             continue;
91         pot[i] += dist[i];
92     }
93     return true;
94}
95
96 bool push() {
97     //2 variants
98     //if (!fordBellman())
99     if (!dikstra())
100         return false;
101     ++totalFlow;
102     int u = T;
103     while (u != S) {
104         int e = fromEdge[u];
105         totalCost += edge[e].cost;
106         edge[e].f++;
107         edge[e ^ 1].f--;
108         u = edge[e ^ 1].to;
109     }
110     return true;
111}
112
113 //min-cost-circulation
114 ll d[maxn][maxn];
115 int dfrom[maxn][maxn];
116 int level[maxn];
117 void circulation() {
118     while (true) {
119         int q = 0;
120         fill(d[0], d[0] + N, 0);
121         for (iter, N) {
122             fill(d[iter + 1], d[iter + 1] + N, infc);
123             for (u, N)
124                 for (int e: g[u]) {
125                     if (edge[e].c == edge[e].f)
126                         continue;
127                     int v = edge[e].to;
128                     ll ndist = d[iter][u] + edge[e].cost;
129                     if (ndist >= d[iter + 1][v])
130                         continue;
131                     d[iter + 1][v] = ndist;
132                     dfrom[iter + 1][v] = e;
133                 }
134             q ^= 1;
135         }
136         int w = -1;
137         ld mindmax = 1e18;
138         for (u, N) {
139             ld dmax = -1e18;
140             for (iter, N)
141                 dmax = max(dmax,
142                     (d[N][u] - d[iter][u]) / ld(N - iter));
143             if (mindmax > dmax)
144                 mindmax = dmax, w = u;
145         }
146         if (mindmax >= 0)
147             break;
148         fill(level, level + N, -1);
149         int k = N;
150         while (level[w] == -1) {
151             level[w] = k;
152             w = edge[dfrom[k--][w] ^ 1].to;
153         }
154         int k2 = level[w];
155         ll delta = infc;
156         while (k2 > k) {
157             int e = dfrom[k2--][w];
158             delta = min(delta, edge[e].c - edge[e].f);
159             w = edge[e ^ 1].to;
160         }
161         k2 = level[w];
162         while (k2 > k) {
163             int e = dfrom[k2--][w];
164             totalCost += edge[e].cost * delta;
165             edge[e].f += delta;
166             edge[e ^ 1].f -= delta;
167             w = edge[e ^ 1].to;
168         }
169     }
170}
171} // namespace MinCost
172
173 int main() {
174     MinCost::N = 3, MinCost::S = 1, MinCost::T = 2;
175     MinCost::addEdge(1, 0, 3, 5);
176     MinCost::addEdge(0, 2, 4, 6);
177     while (MinCost::push());
178     cout << MinCost::totalFlow << ' '
179         << MinCost::totalCost << '\n'; //3 33
180}

```

6 flows/push_relabel.cpp

```

1 namespace PushRelabel {
2 const int maxn = 200500;
3
4 struct Edge {
5     int to, c, f;
6 };
7 vector<Edge> edge;
8
9 int n;
10 vector<int> g[maxn];
11 int e[maxn];
12 int h[maxn];
13 int onH[maxn];
14 int S, T;
15 int ptr[maxn];
16 int relabelTimer;
17
18 void addEdge(int u, int v, int c) {
19     g[u].push_back(sz(edge));
20     edge.push_back({v, c, 0});
21     g[v].push_back(sz(edge));
22     edge.push_back({u, 0, 0});
23 }
24
25 void push(int id, int delta) {
26     int u = edge[id ^ 1].to;
27     int v = edge[id].to;
28     edge[id].f += delta;
29     edge[id ^ 1].f -= delta;
30     e[u] -= delta;
31     e[v] += delta;
32 }
33
34 void gap(int ch) {
35     forn (u, n) {
36         if (h[u] > ch)
37             h[u] = max(h[u], n);
38     }
39 }
40
41 int o[maxn];
42 void globalRelabeling() {
43     int oc = 0;
44     forn (i, n) {
45         h[i] = n;
46         onH[i] = 0;
47     }
48     onH[0] = 1;
49     h[T] = 0;
50     o[oc++] = T;
51     forn (ii, oc) {
52         int u = o[ii];
53         for (int id: g[u]) {
54             if (edge[id ^ 1].c == edge[id ^ 1].f)
55                 continue;
56             int v = edge[id].to;
57             if (h[v] != n)
58                 continue;
59             h[v] = h[u] + 1;
60             onH[h[v]]++;
61             o[oc++] = v;
62         }
63     }
64 }
65
66 void relabel(int u) {
67     int oldh = h[u];
68     int newh = inf;
69     for (int id: g[u]) {
70         if (edge[id].c == edge[id].f)
71             continue;
72         newh = min(newh, h[edge[id].to] + 1);
73     }
74     h[u] = newh;
75     onH[oldh]--;
76     onH[newh]++;
77     if (onH[oldh] == 0)
78         gap(oldh);
79     if (++relabelTimer == n)
80         globalRelabeling(), relabelTimer = 0;
81 }
82
83 void discharge(int u) {
84     while (e[u] > 0) {
85         int &i = ptr[u];
86         if (i == sz(g[u])) {
87             i = 0;
88             relabel(u);
89             if (h[u] >= n)
90                 break;
91             continue;
92         } else {
93             int id = g[u][i++];
94             int v = edge[id].to;
95             if (h[v] + 1 != h[u])
96                 continue;
97             int delta = min(e[u], ll(edge[id].c - edge[id].f));
98             push(id, delta);
99         }
100     }
101 }
102
103 int flow(int _S, int _T) {
104     S = _S, T = _T;
105     forn (i, n)
106         ptr[i] = 0, e[i] = 0;
107     for (int id: g[S]) {
108         int delta = edge[id].c;
109         push(id, delta);
110     }
111     globalRelabeling();
112     bool ok = false;
113     while (!ok) {
114         ok = true;
115         forn (u, n) {
116             if (h[u] < n && u != T && e[u] > 0)
117                 discharge(u), ok = false;
118         }
119     }
120     return e[T];
121 }
122
123 } //PushRelabel

```

7 geometry/basic3d.cpp

```

1 struct Plane {
2     pt v;
3     ld c;
4
5     Plane(pt a, pt b, pt c) {
6         v = ((b - a) % (c - a)).norm();
7         this->c = a * v;
8     }
9
10    ld dist(pt p) {
11        return p * v - c;
12    }
13};
14
15pt projection(pt p, pt a, pt b) {
16    pt v = b - a;
17    if (ze(v.abs2())) {
18        //stub: bad line
19        return a;
20    }
21    return a + v * (((p - a) * v) / (v * v));
22}
23
24pair<pt, pt> planesIntersection(Plane a, Plane b) {
25    pt dir = a.v % b.v;
26    if (ze(dir.abs2())) {
27        //stub: parallel planes
28        return {pt{1e18, 1e18, 1e18}, pt{1e18, 1e18, 1e18}};
29    }
30    ld s = a.v * b.v;
31    pt v3 = b.v - a.v * s;
32    pt h = a.v * a.c + v3 * ((b.c - a.c * s) / (v3 * v3));
33    return {h, h + dir};
34}
35
36pair<pt, pt> commonPerpendicular(pt a, pt b, pt c, pt d) {
37    pt v = (b - a) % (d - c);
38    ld S = v.abs();
39    if (ze(S)) {
40        //stub: parallel lines
41        return {pt{1e18, 1e18, 1e18}, pt{1e18, 1e18, 1e18}};
42    }
43    v = v.norm();
44    pt sh = v * (v * c - v * a);
45    pt a2 = a + sh;
46    ld s1 = ((c - a2) % (d - a2)) * v;
47    pt p = a + (b - a) * (s1 / S);
48    return {p, p + sh};
49}
50
51/*
52Absolute error test
53testProjection: 1e1 -> -16.3
54testProjection: 1e3 -> -14.1
55testProjection: 1e4 -> -13.1
56testProjection: 1e5 -> -12.3
57testProjection: 1e6 -> -11.2
58testPlanesIntersection: 1e1 -> -11.5
59testPlanesIntersection: 1e3 -> -8.6
60testPlanesIntersection: 1e4 -> -8.3
61testPlanesIntersection: 1e5 -> -7.4
62testPlanesIntersection: 1e6 -> -6.5
63testCommonPerpendicular: 1e1 -> -13.5
64testCommonPerpendicular: 1e3 -> -11.4
65testCommonPerpendicular: 1e4 -> -10.5
66testCommonPerpendicular: 1e5 -> -8.7
67testCommonPerpendicular: 1e6 -> -8.6
68*/

```

8 geometry/chan.cpp

```

1mt19937 rr(111);
2ld rndEps() {
3    return (ld(rr()) / rr.max() - 0.5) * 1e-7;
4}
5
6typedef tuple<int, int, int> Face;
7const ld infc = 1e100;
8
9int n;
10pt p[maxn];
11
12namespace Chan {
13pt _p[maxn];
14
15ld turny(int p1, int p2, int p3) {
16    return (p[p2].x - p[p1].x) * (p[p3].y - p[p1].y) -
17           (p[p3].x - p[p1].x) * (p[p2].y - p[p1].y);
18}
19
20//replace y with z
21ld turnz(int p1, int p2, int p3) {
22    return (p[p2].x - p[p1].x) * (p[p3].z - p[p1].z) -
23           (p[p3].x - p[p1].x) * (p[p2].z - p[p1].z);
24}
25
26ld gett(int p1, int p2, int p3) {
27    if (p1 == -1 || p2 == -1 || p3 == -1)
28        return infc;
29    ld ty = turny(p1, p2, p3);
30    if (ty >= 0)
31        return infc;
32    else
33        return turnz(p1, p2, p3) / ty;
34}
35
36void act(int i) {
37    if (p[i].onHull) {
38        p[p[i].nx].pr = p[i].pr;
39        p[p[i].pr].nx = p[i].nx;
40    } else {
41        p[p[i].nx].pr = p[p[i].pr].nx = i;
42    }
43    p[i].onHull ^= 1;
44}
45
46ld updt(vector<int> &V) {
47    if (V.empty())
48        return infc;
49    int id = V.back();
50    if (p[id].onHull)
51        return gett(p[id].pr, p[id].nx, id);
52    else
53        return gett(p[id].pr, id, p[id].nx);
54}
55
56//builds lower hull
57vector<int> buildHull(int l, int r) {
58    if (l + 1 >= r) {
59        p[l].pr = p[l].nx = -1;
60        p[l].onHull = true;
61        return {};
62    }
63    int mid = (l + r) / 2;
64    auto L = buildHull(l, mid);
65    auto R = buildHull(mid, r);
66    reverse(all(L));
67    reverse(all(R));
68    int u = mid - 1, v = mid;
69    while (true) {
70        if (p[u].pr != -1 &&
71            (turny(p[u].pr, u, v) <= 0))
72            u = p[u].pr;
73        else if (p[v].nx != -1 &&
74            (turny(u, v, p[v].nx) <= 0))
75            v = p[v].nx;
76        else
77            break;
78    }
79
80    ld t[6];
81    t[0] = updt(L);
82    t[1] = updt(R);
83    vector<int> A;
84    while (true) {
85        t[2] = gett(p[u].pr, v, u);
86        t[3] = gett(u, p[u].nx, v);
87        t[4] = gett(u, p[v].pr, v);
88        t[5] = gett(u, p[v].nx, v);
89        ld nt = infc;
90        int type = -1;
91        for (i, 6)

```

9 geometry/convex_hull_trick.cpp

```

92         if (t[i] < nt)
93             nt = t[i], type = i;
94     if (nt >= infc)
95         break;
96
97     if (type == 0) {
98         act(L.back());
99         if (L.back() < u)
100             A.push_back(L.back());
101         L.pop_back();
102         t[0] = updt(L);
103     } else if (type == 1) {
104         act(R.back());
105         if (R.back() > v)
106             A.push_back(R.back());
107         R.pop_back();
108         t[1] = updt(R);
109     } else if (type == 2) {
110         A.push_back(u);
111         u = p[u].pr;
112     } else if (type == 3) {
113         A.push_back(u = p[u].nx);
114     } else if (type == 4) {
115         A.push_back(v = p[v].pr);
116     } else if (type == 5) {
117         A.push_back(v);
118         v = p[v].nx;
119     }
120 }
121 assert(L.empty() && R.empty());
122
123 p[u].nx = v, p[v].pr = u;
124 for (int i = u + 1; i < v; ++i)
125     p[i].onHull = false;
126 for (int i = sz(A) - 1; i >= 0; --i) {
127     int id = A[i];
128     if (id <= u || id >= v) {
129         if (u == id)
130             u = p[u].pr;
131         if (v == id)
132             v = p[v].nx;
133         act(id);
134     } else {
135         p[id].pr = u, p[id].nx = v;
136         act(id);
137         if (id >= mid)
138             v = id;
139         else
140             u = id;
141     }
142 }
143 return A;
144 }
145
146 //faces are oriented ccw if look from the outside
147 vector<Face> getFaces() {
148     for (i, n) {
149         _p[i] = p[i];
150         p[i].x += rndEps();
151         p[i].y += rndEps();
152         p[i].z += rndEps();
153         p[i].id = i;
154     }
155     sort(p, p + n, [](const pt &a, const pt &b) {
156         return a.x < b.x;
157     });
158     vector<Face> faces;
159     for (q, 2) {
160         auto movie = buildHull(0, n);
161         for (int x: movie) {
162             int id = p[x].id;
163             int pid = p[p[x].pr].id;
164             int nid = p[p[x].nx].id;
165             if (!p[x].onHull)
166                 faces.emplace_back(pid, id, nid);
167             else
168                 faces.emplace_back(pid, nid, id);
169             act(x);
170         }
171         for (i, n) {
172             p[i].y *= -1;
173             p[i].z *= -1;
174         }
175     }
176     for (i, n)
177         p[i] = _p[i];
178     return faces;
179 }
180
181 //namespace Chan

```

```

1 struct Hull {
2     vector<pt> top, bot;
3
4     //check: add points in strictly increasing order
5     void append(pt p) {
6         while (sz(bot) > 1 && (p - bot.back()) %
7             (p - *next(bot.rbegin())) >= -eps)
8             bot.pop_back();
9         bot.push_back(p);
10        while (sz(top) > 1 && (p - top.back()) %
11            (p - *next(top.rbegin())) <= eps)
12            top.pop_back();
13        top.push_back(p);
14    }
15
16    pt mostDistant(pt dir) {
17        dir = dir.rot();
18        auto &v = dir.x < 0 ? top : bot;
19        int l = -1, r = sz(v) - 1;
20        while (l + 1 < r) {
21            int c = (l + r) / 2;
22            if (dir % (v[c + 1] - v[c]) > 0)
23                r = c;
24            else
25                l = c;
26        }
27        return v[r];
28    }
29 };

```

10 geometry/halfplanes.cpp

```

1ld det3x3(line a, line b, line c) {
2    return a.c * (b.v % c.v)
3        + b.c * (c.v % a.v)
4        + c.c * (a.v % b.v);
5}
6
7//check: bounding box is included
8vector<pt> halfplanesIntersection(vector<line> l) {
9    sort(all(l), cmpLine); //the strongest constraint is first
10   l.erase(unique(all(l), eqLine), l.end());
11   int n = sz(l);
12   vi st;
13   forn (iter, 2)
14       forn (i, n) {
15           while (sz(st) > 1) {
16               int j = st.back(), k = *next(st.rbegin());
17               if (l[k].v % l[i].v <= eps ||
18                   det3x3(l[k], l[j], l[i]) <= eps)
19                   break;
20               st.pop_back();
21           }
22           st.push_back(i);
23       }
24
25   vi pos(n, -1);
26   bool ok = false;
27   forn (i, sz(st)) {
28       int id = st[i];
29       if (pos[id] != -1) {
30           st = vi(st.begin() + pos[id], st.begin() + i);
31           ok = true;
32           break;
33       } else
34           pos[id] = i;
35   }
36   if (!ok)
37       return {};
38
39   vector<pt> res;
40   pt M{0, 0};
41   int k = sz(st);
42   forn (i, k) {
43       line l1 = l[st[i]], l2 = l[st[(i + 1) % k]];
44       res.push_back(linesIntersection(l1, l2));
45       M = M + res.back();
46   }
47   M = M * (1. / k);
48   for (int id: st)
49       if (l[id].signedDist(M) < -eps)
50           return {};
51   return res;
52}

```

11 geometry/nd_convex_hull.cpp

```

1const int DIM = 4;
2typedef array<ll, DIM> pt;
3pt operator-(const pt &a, const pt &b) {
4    pt res;
5    forn (i, DIM)
6        res[i] = a[i] - b[i];
7    return res;
8}
9typedef array<pt, DIM-1> Edge;
10typedef array<pt, DIM> Face;
11vector<Face> faces;
12
13ll det(pt *a) {
14    int p[DIM];
15    iota(p, p + DIM, 0);
16    ll res = 0;
17    do {
18        ll x = 1;
19        forn (i, DIM) {
20            forn (j, i)
21                if (p[j] > p[i])
22                    x *= -1;
23            x *= a[i][p[i]];
24        }
25        res += x;
26    } while (next_permutation(p, p + DIM));
27    return res;
28}
29
30ll V(Face f, pt pivot) {
31    pt p[DIM];
32    forn (i, DIM)
33        p[i] = f[i] - pivot;
34    return det(p);
35}
36
37void init(vector<pt> p) {
38    forn (i, DIM+1) {
39        Face a;
40        int q = 0;
41        forn (j, DIM+1)
42            if (j != i)
43                a[q++] = p[j];
44        ll v = V(a, p[i]);
45        assert(v != 0);
46        if (v < 0)
47            swap(a[0], a[1]);
48        faces.push_back(a);
49    }
50}
51
52void add(pt p) {
53    vector<Face> newf, bad;
54    for (auto f: faces) {
55        if (V(f, p) < 0)
56            bad.push_back(f);
57        else
58            newf.push_back(f);
59    }
60    if (bad.empty()) {
61        return;
62    }
63    faces = newf;
64    vector<pair<Edge, pt>> edges;
65    for (auto f: bad) {
66        sort(all(f));
67        forn (i, DIM) {
68            Edge e;
69            int q = 0;
70            forn (j, DIM)
71                if (i != j)
72                    e[q++] = f[j];
73            edges.emplace_back(e, f[i]);
74        }
75    }
76    sort(all(edges));
77    forn (i, sz(edges)) {
78        if (i + 1 < sz(edges) &&
79            edges[i + 1].first == edges[i].first) {
80            ++i;
81            continue;
82        }
83        Face f;
84        forn (j, DIM-1)
85            f[j] = edges[i].first[j];
86        f[DIM-1] = p;
87        if (V(f, edges[i].second) < 0)
88            swap(f[0], f[1]);
89        faces.push_back(f);
90    }
91}

```


12 geometry/planar_faces.cpp

```

1 int m, n; // segs, points
2 pair<pt, pt> segs[maxn];
3 pt p[maxn], from, to;
4 map<pt, int> shr;
5 vi e[maxn]; // points adjacent to point
6 int getPoint(pt x) {
7     if (shr.count(x)) return shr[x];
8     p[n] = x;
9     return shr[x] = n++;
10}
11// segIntersection: {bool, point}, true iff exactly one point
12 void genIntersections() {
13     forn(i, m) {
14         getPoint(segs[i].fi);
15         getPoint(segs[i].se);
16         forn(j, i) {
17             auto t = segmentsIntersection(
18                 segs[i].fi, segs[i].se, segs[j].fi, segs[j].se);
19             if (t.fi) getPoint(t.se);
20         }
21     }
22}
23
24 void genGraph() {
25     forn(i, m) {
26         vi pts;
27         forn(j, n) if (pointInsideSegment(
28             p[j], segs[i].fi, segs[i].se)) {
29             pts.push_back(j);
30         }
31         sort(all(pts), [](int i, int j) {
32             return p[i] < p[j]; });
33         forn(j, pts.size() - 1) {
34             int u = pts[j], v = pts[j+1];
35             e[u].push_back(v);
36             e[v].push_back(u);
37         }
38     }
39     forn(i, n) {
40         sort(all(e[i]), [i](int x, int y) {
41             pt a = p[x] - p[i];
42             pt b = p[y] - p[i];
43             if (a.right() != b.right()) return a.right();
44             return a % b > 0;
45         });
46     }
47}
48
49 vector<pt> faces[maxn];
50 bool inner[maxn];
51 int nf;
52 map<pii, int> faceForEdge;
53 vi ef[maxn]; // graph on faces
54
55 void genFaces() {
56     forn(i, n) for (int to: e[i]) {
57         if (faceForEdge.count({i, to})) continue;
58         int f = nf++;
59         int v = i, u = to;
60         do {
61             faces[f].push_back(p[v]);
62             faceForEdge[{v, u}] = f;
63             auto it = lower_bound(all(e[u]), v,
64                 [u](int x, int y) {
65                     pt a = p[x] - p[u];
66                     pt b = p[y] - p[u];
67                     if (a.right() != b.right()) return a.right();
68                     return a % b > 0;
69                 });
70             assert(*it == v);
71             if (it == e[u].begin()) it = e[u].end();
72             v = u;
73             u = *--it;
74         } while (v != i || u != to);
75     }
76     forn(i, nf) {
77         ld s = 0;
78         forn(j, faces[i].size()) {
79             s += faces[i][j] % faces[i][(j+1)%faces[i].size()];
80         }
81         inner[i] = gt(s, 0);
82     }
83     forn(v, n) for (int to: e[v]) {
84         int f1 = faceForEdge[{v, to}];
85         int f2 = faceForEdge[{to, v}];
86         if (f1 != f2) {
87             ef[f1].push_back(f2);
88             ef[f2].push_back(f1);
89         }
90     }
91}

```

13 geometry/polygon.cpp

```

1 bool pointInsidePolygon(pt a, pt *p, int n) {
2     double sumAng = 0;
3     forn(i, n) {
4         pt A = p[i], B = p[(i + 1) % n];
5         if (pointInsideSegment(a, A, B))
6             return true;
7         sumAng += atan2((A - a) % (B - a), (A - a) * (B - a));
8     }
9     return fabs(sumAng) > 1;
10}
11
12//check: p is oriented ccw
13 bool segmentInsidePolygon(pt a, pt b, pt *p, int n) {
14     if (!pointInsidePolygon((a + b) * .5, p, n))
15         return false;
16     if (ze((a - b).abs()))
17         return true;
18     forn(i, n) {
19         pt c = p[i];
20         if (ze((a - c) % (b - c)) &&
21             (a - c) * (b - c) < -eps) {
22             //point inside interval
23             pt pr = p[(i + n - 1) % n];
24             pt nx = p[(i + 1) % n];
25             if ((c - pr) % (nx - c) > eps)
26                 return false;
27             ld s1 = (pr - a) % (b - a);
28             ld s2 = (nx - a) % (b - a);
29             if ((s1 > eps || s2 > eps) &&
30                 (s1 < -eps || s2 < -eps))
31                 return false;
32         }
33         //interval intersection
34         pt d = p[(i + 1) % n];
35         ld s1 = (a - c) % (d - c);
36         ld s2 = (b - c) % (d - c);
37         if (s1 >= -eps && s2 >= -eps)
38             continue;
39         if (s1 <= eps && s2 <= eps)
40             continue;
41
42         s1 = (c - a) % (b - a);
43         s2 = (d - a) % (b - a);
44         if (s1 >= -eps && s2 >= -eps)
45             continue;
46         if (s1 <= eps && s2 <= eps)
47             continue;
48
49         return false;
50     }
51     return true;
52}

```

14 geometry/polygon_tangents.cpp

```

1 struct Cmp {
2     pt M, v0;
3
4     bool operator()(const pt &a, const pt &b) {
5         pt va{v0 * (a - M), v0 % (a - M)};
6         pt vb{v0 * (b - M), v0 % (b - M)};
7         return cmpAngle(va, vb);
8     }
9 };
10
11 struct Hull {
12     vector<pt> h;
13     int n;
14
15     void build() {
16         sort(all(h));
17         h.erase(unique(all(h)), h.end());
18         vector<pt> top, bot;
19         for (auto p: h) {
20             while (sz(bot) > 1 && (p - bot.back()) %
21                 (p - *next(bot.rbegin())) >= -eps)
22                 bot.pop_back();
23             bot.push_back(p);
24             while (sz(top) > 1 && (p - top.back()) %
25                 (p - *next(top.rbegin())) <= eps)
26                 top.pop_back();
27             top.push_back(p);
28         }
29         if (sz(top))
30             top.pop_back();
31         reverse(all(top));
32         if (sz(top))
33             top.pop_back();
34         h = bot;
35         h.insert(h.end(), all(top));
36         n = sz(h);
37     }
38
39     bool visSide(pt a, int i) {
40         return (h[(i + 1) % n] - a) % (h[i % n] - a) > eps;
41     }
42
43     bool vis(pt a, int i) {
44         return visSide(a, i) || visSide(a, i + n - 1);
45     }
46
47     bool isTangent(pt a, int i) {
48         return visSide(a, i) != visSide(a, i + n - 1);
49     }
50
51     int binSearch(int l, int r, pt a) {
52         //tricky binsearch; l < r not necessarily
53         while (abs(l - r) > 1) {
54             int c = (l + r) / 2;
55             if (vis(a, c))
56                 l = c;
57             else
58                 r = c;
59         }
60         assert(isTangent(a, l));
61         return l % n;
62     }
63
64     //check: n >= 3
65     pair<int, int> tangents(pt a) {
66         assert(n >= 3);
67         pt M = (h[0] + h[1] + h[2]) * (1. / 3);
68         if (a == M)
69             return {-1, -1};
70         Cmp cmp{M, h[0] - M};
71         //assert(is_sorted(all(h), cmp));
72         int pos = upper_bound(all(h), a, cmp) - h.begin();
73         pt L = h[(pos + n - 1) % n], R = h[pos % n];
74         if ((R - L) % (a - L) >= -eps)
75             return {-1, -1}; //point inside hull
76         int pos2 = upper_bound(all(h), M*2-a, cmp) - h.begin();
77         assert(pos % n != pos2 % n);
78         if (pos > pos2)
79             pos2 += n;
80         return {binSearch(pos, pos2, a),
81             binSearch(pos + n - 1, pos2 - 1, a)};
82     }
83 };

```

15 geometry/primitives.cpp

```

1 struct line {
2     pt v;
3     ld c; // v * p = c
4
5     //check: p1 != p2
6     line(pt p1, pt p2) {
7         v = (p2 - p1).rot();
8         v = v * (1. / v.abs());
9         c = v * p1;
10    }
11
12    // Convert from ax + by + c = 0
13
14    //check: a^2+b^2 > 0
15    line(ld a, ld b, ld _c): v(pt{a, b}), c(-_c) {
16        ld d = v.abs();
17        v = v * (1. / d);
18        c /= d;
19    }
20
21    //check: v.abs() == 1
22    ld signedDist(pt p) {
23        return v * p - c;
24    }
25 };
26
27 //check: a != b
28 pt lineProjection(pt p, pt a, pt b) {
29     pt v = (b - a).rot();
30     ld s = (p - a) % (b - a);
31     return p + v * (s / v.abs2());
32 }
33
34 ld pointSegmentDist(pt p, pt a, pt b) {
35     if ((p - a) * (b - a) <= 0 || ze((b - a).abs()))
36         return (p - a).abs();
37     if ((p - b) * (a - b) <= 0)
38         return (p - b).abs();
39     return fabs1((p - a) % (p - b)) / (b - a).abs();
40 }
41
42 pt linesIntersection(line l1, line l2) {
43     ld d = l1.v.x * l2.v.y - l1.v.y * l2.v.x;
44     if (ze(d)) {
45         if (eq(l1.c, l2.c)) {
46             //stub: equal lines
47         } else {
48             //stub: empty intersection
49         }
50         return pt{1e18, 1e18};
51     }
52     ld dx = l1.c * l2.v.y - l1.v.y * l2.c;
53     ld dy = l1.v.x * l2.c - l1.c * l2.v.x;
54     return pt{dx / d, dy / d};
55 }
56
57 pt linesIntersection(pt a, pt b, pt c, pt d) {
58     ld s = (b - a) % (d - c);
59     if (ze(s)) {
60         //stub: parallel or equal lines
61         return pt{1e18, 1e18};
62     }
63     ld s1 = (c - a) % (d - a);
64     return a + (b - a) * (s1 / s);
65 }
66
67 bool pointInsideSegment(pt p, pt a, pt b) {
68     if (!ze((p - a) % (p - b)))
69         return false;
70     ld prod = (a - p) * (b - p);
71     return ze(prod) || prod < 0;
72     if (ze(prod)) {
73         //stub: coincides with segment end
74         return true;
75     }
76     return prod < 0;
77 }
78
79 bool checkSegmentIntersection(pt a, pt b, pt c, pt d) {
80     if (ze((a - b) % (c - d))) {
81         if (pointInsideSegment(a, c, d) ||
82             pointInsideSegment(b, c, d) ||
83             pointInsideSegment(c, a, b) ||
84             pointInsideSegment(d, a, b)) {
85             //stub: intersection of parallel segments
86             return true;
87         }
88         return false;
89     }
90     ld s1, s2;
91     for (iter, 2) {

```

16 geometry/svg.cpp

```

92     s1 = (c - a) % (b - a);
93     s2 = (d - a) % (b - a);
94     if (s1 > eps && s2 > eps)
95         return false;
96     if (s1 < -eps && s2 < -eps)
97         return false;
98     swap(a, c), swap(b, d);
99 }
100 return true;
101}
102
103vector<pt> lineCircleIntersection(line l, pt a, ld r) {
104    ld d = l.signedDist(a);
105    pt h = a - l.v * d;
106    if (eq(fabsl(d), r))
107        return {h};
108    else if (fabsl(d) > r)
109        return {};
110    pt w = l.v.rot() * Sqrt(sqr(r) - sqr(d));
111    return {h + w, h - w};
112}
113
114vector<pt> circlesIntersecton(pt a, ld r1, pt b, ld r2) {
115    ld d = (a - b).abs();
116    if (ze(d) && eq(r1, r2)) {
117        //stub: equal circles
118        return {};
119    }
120    // intersection is non-empty iff
121    // triangle with sides r1, r2, d exists
122    ld per = r1 + r2 + d;
123    ld mx = max(max(r1, r2), d);
124    int num = 2;
125    if (eq(mx * 2, per)) {
126        num = 1;
127    } else if (mx * 2 > per)
128        return {};
129    ld part = (sqr(r1) + sqr(d) - sqr(r2)) / ld(2 * d);
130    pt h = a + (b - a) * (part / d);
131    if (num == 1)
132        return {h};
133    ld dh = Sqrt(sqr(r1) - sqr(part));
134    pt w = ((b - a) * (dh / d)).rot();
135    return {h + w, h - w};
136}
137
138vector<pt> circleTangents(pt p, pt a, ld r) {
139    ld d = (p - a).abs();
140    if (eq(r, d))
141        return {p};
142    else if (r > d)
143        return {};
144    ld len = Sqrt(sqr(d) - sqr(r));
145    vector<pt> res;
146    pt vec = (a - p) * (len / sqr(d));
147    for (int sgn: {-1, 1})
148        res.push_back(p + vec.rotCw(pt{len, r * sgn}));
149    return res;
150}
151
152vector<line> circlesBitangents(pt a, ld r1, pt b, ld r2) {
153    ld d = (a - b).abs();
154    if (ze(d) && eq(r1, r2)) {
155        //stub: equal circles
156        return {};
157    }
158
159    vector<line> res;
160    for (int s1: {-1, 1})
161        for (int s2: {-1, 1}) {
162            // inner tangent iff s1 != s2
163            // treat radii as signed
164            ld r = s2 * r2 - s1 * r1;
165            if (eq(fabsl(r), d)) {
166                // incident tangents; need only one copy
167                if (s1 == 1)
168                    continue;
169            } else if (fabsl(r) > d)
170                continue;
171            ld len = Sqrt(sqr(d) - sqr(r));
172            line l(a, a + (b - a).rotCw(pt{len, r}));
173            l.c -= s1 * r1;
174            res.push_back(l);
175        }
176    return res;
177}

```

```

1struct SVG {
2
3    FILE *out;
4    ld sc = 50;
5
6    void open() {
7        out = fopen("image.svg", "w");
8        fprintf(out, "<svg xmlns='http://www.w3.org/2000/svg'
9            ↪ viewBox='-1000 -1000 2000 2000'>\n");
10    }
11
12    void line(pt a, pt b) {
13        a = a * sc, b = b * sc;
14        fprintf(out, "<line x1='%Lf' y1='%Lf' x2='%Lf' y2='%Lf'
15            ↪ stroke='black'/>\n", a.x, -a.y, b.x, -b.y);
16    }
17
18    void circle(pt a, ld r = -1, string col = "red") {
19        r = (r == -1 ? 10 : sc * r);
20        a = a * sc;
21        fprintf(out, "<circle cx='%Lf' cy='%Lf' r='%Lf'
22            ↪ fill='%s'/>\n", a.x, -a.y, r, col.c_str());
23    }
24
25    void text(pt a, string s) {
26        a = a * sc;
27        fprintf(out, "<text x='%Lf' y='%Lf'
28            ↪ font-size='10px'>%s</text>\n", a.x, -a.y,
29            ↪ s.c_str());
30    }
31
32    void close() {
33        fprintf(out, "</svg>\n");
34        fclose(out);
35        out = 0;
36    }
37
38    ~SVG() {
39        if (out)
40            close();
41    }
42} svg;

```


19 graphs/dominator_tree.cpp

```

92         cycle[nc].push_back(u);
93         if (u == to) break;
94     }
95     st.push_back(nc);
96     b[nc] = 1;
97     ++nc;
98 } else {
99     st.push_back(to);
100 }
101 }
102 }
103 forn(i, n) assert(done[i]);
104 assert((int)edges.size() == n-1);
105 cout << res << endl;
106}
107
108void scan() {
109     int m;
110     scanf("%d%d", &n, &m);
111     forn(i, n) out[i].fi = new multiset<Edge>();
112     forn(i, m) {
113         int u, v, w;
114         scanf("%d%d%d", &u, &v, &w);
115         --u, --v;
116         out[v].fi->insert(Edge{v, u, i, w});
117     }
118}

```

```

1 struct Dom {
2     int n;
3     vector<vi> e, re; // graph (on v), reverse graph (on id)
4     vi id, p, sdom, dom, dsu, best;
5     vector<vi> bucket;
6     int dtime = 0;
7
8     Dom() {}
9     Dom(int n) : n(n), e(n), re(n), id(n, -1), p(n),
10         sdom(n), dom(n), dsu(n), best(n), bucket(n)
11     {}
12
13     void find(int v) {
14         if (v != dsu[v]) {
15             find(dsu[v]);
16             if (sdom[best[dsu[v]]] <= sdom[best[v]]) {
17                 best[v] = best[dsu[v]];
18             }
19             dsu[v] = dsu[dsu[v]];
20         }
21     }
22
23     void dfs1(int v) {
24         id[v] = dtime++;
25         for (int to: e[v]) {
26             if (id[to] == -1) {
27                 dfs1(to);
28                 p[id[to]] = id[v];
29             }
30             re[id[to]].push_back(id[v]);
31         }
32     }
33
34     void pre() {
35         dfs1(0);
36         iota(all(best), 0);
37         iota(all(sdom), 0);
38         iota(all(dsu), 0);
39     }
40
41     void run() {
42         pre();
43         for (int v = n-1; v >= 0; --v) {
44             for (int w: bucket[v]) {
45                 find(w);
46                 dom[w] = best[w];
47             }
48             for (int u: re[v]) {
49                 find(u);
50                 sdom[v] = min(sdom[v], sdom[best[u]]);
51             }
52             if (v) {
53                 bucket[sdom[v]].pb(v);
54                 dsu[v] = p[v]; // unite(v, p[v])
55             }
56         }
57
58         for (int v = 1; v < n; ++v) {
59             if (dom[v] != sdom[v]) {
60                 dom[v] = dom[dom[v]];
61             }
62         }
63
64         vi ndom(n), rev(n);
65         forn(i, n) rev[id[i]] = i;
66         forn(i, n) ndom[i] = rev[dom[id[i]]];
67         dom = ndom;
68     }
69};

```

20 graphs/edmonds_matching.cpp

```

1int n;
2vi e[maxn];
3int mt[maxn], p[maxn], base[maxn], b[maxn], blos[maxn];
4int q[maxn];
5int blca[maxn]; // used for lca
6
7int 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
21void 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
30int 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    return -1;
65}
66
67
68int 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[ppv] = v;
78                v = ppv;
79            }
80        }
81    }
82    return res;
83}

```

21 graphs/euler_cycle.cpp

```

1struct Edge {
2    int to, id;
3};
4
5bool usedEdge[maxn];
6vector<Edge> g[maxn];
7int ptr[maxn];
8
9vector<int> cycle;
10void eulerCycle(int u) {
11    while (ptr[u] < sz(g[u]) && usedEdge[g[u][ptr[u]].id])
12        ++ptr[u];
13    if (ptr[u] == sz(g[u]))
14        return;
15    const Edge &e = g[u][ptr[u]];
16    usedEdge[e.id] = true;
17    eulerCycle(e.to);
18    cycle.push_back(e.id);
19    eulerCycle(u);
20}
21
22int edges = 0;
23void addEdge(int u, int v) {
24    g[u].push_back(Edge{v, edges});
25    g[v].push_back(Edge{u, edges++});
26}

```

22 graphs/min_automaton.cpp

```

1 vi inc[maxn][A];
2 int lst[maxn], pos[maxn], part[maxn];
3 int lp[maxn], rp[maxn], nrp[maxn];
4 int upd[maxn], used[maxn], inq[maxn];
5 vector<int> q;
6 int dtime;
7 int np; // number of classes
8 vector<int> toRefine[A];
9
10 void doSwap(int x, int y) {
11     swap(lst[pos[x]], lst[pos[y]]);
12     swap(pos[x], pos[y]);
13 }
14
15 void refine(const vi& a) {
16     ++dtime;
17     vector<int> updated;
18     for (int x: a) {
19         if (used[x] == dtime) continue;
20         used[x] = dtime;
21
22         int p = part[x];
23         if (upd[p] != dtime) {
24             upd[p] = dtime;
25             nrp[p] = rp[p];
26             updated.pb(p);
27         }
28
29         doSwap(x, lst[nrp[p]-1]);
30         --nrp[p];
31     }
32
33     for (int p: updated) {
34         if (lp[p] == nrp[p]) continue;
35         lp[np] = nrp[p];
36         rp[np] = rp[p];
37         rp[p] = nrp[p];
38         for (int i = lp[np]; i < rp[np]; ++i) {
39             part[lst[i]] = np;
40         }
41
42         if (inq[p] || rp[np] - lp[np] < rp[p] - lp[p]) {
43             inq[np] = 1;
44             q.push_back(np);
45         } else {
46             inq[p] = 1;
47             q.push_back(p);
48         }
49
50         ++np;
51     }
52 }
53
54 void solve() {
55     forn(i, n) lst[i] = i;
56     sort(lst, lst+n, [](int i, int j) {
57         return col[i] < col[j];
58     });
59
60     forn(i, n) {
61         if (i && col[lst[i]] != col[lst[i-1]]) {
62             rp[np] = i;
63             lp[++np] = i;
64         }
65         part[lst[i]] = np;
66         pos[lst[i]] = i;
67     }
68     rp[np++] = n;
69
70     forn(i, np) {
71         inq[i] = 1;
72         q.push_back(i);
73     }
74
75     forn(i, q.size()) {
76         int p = q[i];
77         inq[p] = false;
78         forn(c, A) {
79             toRefine[c].clear();
80             for (int id = lp[p]; id < rp[p]; ++id) {
81                 toRefine[c].insert(
82                     toRefine[c].end(), all(inc[lst[id]][c]));
83             }
84         }
85         forn(c, A) if (!toRefine[c].empty()) {
86             refine(toRefine[c]);
87         }
88     }
89
90     forn(i, n) printf("%d\n", part[i] + 1);
91 }

```

23 math/factor.cpp

```

1 //WARNING: only mod <= 1e18
2 ll mul(ll a, ll b, ll mod) {
3     ll res = a * b - (ll(ld(a) * ld(b) / ld(mod)) * mod);
4     while (res < 0)
5         res += mod;
6     while (res >= mod)
7         res -= mod;
8     return res;
9 }
10
11 bool millerRabinTest(ll n, ll a) {
12     if (gcd(n, a) > 1)
13         return false;
14     ll x = n - 1;
15     int l = 0;
16     while (x % 2 == 0) {
17         x /= 2;
18         ++l;
19     }
20     ll c = binpow(a, x, n);
21     for (int i = 0; i < l; ++i) {
22         ll nx = mul(c, c, n);
23         if (nx == 1) {
24             if (c != 1 && c != n - 1)
25                 return false;
26             else
27                 return true;
28         }
29         c = nx;
30     }
31     return c == 1;
32 }
33
34 bool isPrime(ll n) {
35     if (n == 1)
36         return false;
37     if (n % 2 == 0)
38         return n == 2;
39     // < 2^32: 2, 7, 61
40     // < 3e18: 2, 3, 5, 7, 11, 13, 17, 19, 23
41     // < 2^64: 2, 325, 9375, 28178, 450775, 9780504, 1795265022
42     for (ll a = 2; a < min<ll>(8, n); ++a)
43         if (!millerRabinTest(n, a))
44             return false;
45     return true;
46 }
47
48 //WARNING: p is not sorted
49 void factorize(ll x, vector<ll> &p) {
50     if (x == 1)
51         return;
52     if (isPrime(x)) {
53         p.push_back(x);
54         return;
55     }
56     for (ll d: {2, 3, 5})
57         if (x % d == 0) {
58             p.push_back(d);
59             factorize(x / d, p);
60             return;
61         }
62     while (true) {
63         ll x1 = rr() % (x - 1) + 1;
64         ll x2 = (mul(x1, x1, x) + 1) % x;
65         int i1 = 1, i2 = 2;
66         while (true) {
67             ll c = (x1 + x - x2) % x;
68             if (c == 0)
69                 break;
70             ll g = gcd(c, x);
71             if (g > 1) {
72                 factorize(g, p);
73                 factorize(x / g, p);
74                 return;
75             }
76             if (i1 * 2 == i2) {
77                 i1 *= 2;
78                 x1 = x2;
79             }
80             ++i2;
81             x2 = (mul(x2, x2, x) + 1) % x;
82         }
83     }
84 }

```

24 math/fft.cpp

```

1const int LG = 20;
2typedef complex<ld> base;
3
4vector<base> ang[LG + 5];
5
6void init_fft() {
7    int n = 1 << LG;
8    ld e = acos(-1) * 2 / n;
9    ang[LG].resize(n);
10   forn(i, n)
11       ang[LG][i] = polar(ld(1), e * i);
12
13   for (int k = LG - 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
20void fft_rec(base *a, int lg, bool inv) {
21   if (lg == 0)
22       return;
23   int hlen = 1 << (lg - 1);
24   fft_rec(a, lg-1, inv);
25   fft_rec(a + hlen, lg-1, inv);
26
27   forn (i, hlen) {
28       base w = ang[lg][i];
29       if (inv)
30           w = conj(w);
31       base u = a[i];
32       base v = a[i + hlen] * w;
33       a[i] = u + v;
34       a[i + hlen] = u - v;
35   }
36}
37
38void fft(base *a, int lg, bool inv) {
39   int n = 1 << lg;
40   int j = 0, bit;
41   for (int i = 1; i < n; ++i) {
42       for (bit = n >> 1; bit & j; bit >= 1)
43           j ^= bit;
44       j ^= bit;
45       if (i < j)
46           swap(a[i], a[j]);
47   }
48   fft_rec(a, lg, inv);
49   if (inv) {
50       forn(i, n)
51           a[i] /= n;
52   }
53}
54
55void test() {
56   int lg = 3;
57   int n = 1 << lg;
58   init_fft();
59   base a[] = {1,3,5,2,4,6,7,1};
60   fft(a, lg, 0);
61   forn(i, n)
62       cout << a[i].real() << " ";
63   cout << '\n';
64   forn(i, n)
65       cout << a[i].imag() << " ";
66   cout << '\n';
67   // 29 -5.82843 -7 -0.171573 5 -0.171573 -7 -5.82843
68   // 0 -3.41421 6 0.585786 0 -0.585786 -6 3.41421
69}

```

25 math/fft_inv.cpp

```

1const int M = 1 << LG;
2//check: a[0] not zero, lg < LG
3//check: to is of length (1 << (lg + 1))
4base c[M], d[M], e[M];
5void fft_inv(base *a, base *to, int lg) {
6   base r0 = base(1) / a[0];
7   for (int i = 0; i < (1 << lg); ++i)
8       a[i] *= r0;
9   fill(to, to + (1 << lg), 0);
10  to[0] = 1;
11
12  for (int i = 1; i <= lg; ++i) {
13      int n = 1 << i;
14      int n2 = 1 << (i + 1);
15      int hn = 1 << (i - 1);
16
17      fill(c, c + n2, 0);
18      fill(d, d + n2, 0);
19      fill(e, e + n2, 0);
20
21      copy(a, a + n, c);
22      fft(c, i + 1, false);
23
24      copy(to, to + hn, d);
25      fft(d, i + 1, false);
26
27      for (int i = 0; i < n2; ++i)
28          e[i] = c[i] * d[i];
29      fft(e, i + 1, true);
30
31      //cerr << "i = " << i << endl;
32      //assert(abs(e[0] - base(1)) < 1e-9);
33      //for (int i = 1; i < hn; ++i)
34          //assert(abs(e[i]) < 1e-9);
35
36      for (int i = 0; i < hn; ++i) {
37          e[i] = -e[i + hn];
38          e[i + hn] = 0;
39      }
40      for (int i = n; i < n2; ++i)
41          e[i] = 0;
42
43      fft(e, i, false);
44      for (int i = 0; i < n; ++i)
45          e[i] *= d[2 * i];
46      fft(e, i, true);
47      for (int i = 0; i < hn; ++i)
48          to[i + hn] = e[i];
49  }
50  }
51  for (int i = 0; i < (1 << lg); ++i)
52      to[i] *= r0;
53}

```


26 math/golden_search_quad_eq.cpp 27 math/numbers.tex

```

1ld f(ld x) {
2    return 5 * x * x + 100 * x + 1; //-10 is minimum
3}
4
5ld goldenSearch(ld l, ld r) {
6    ld phi = (1 + sqrtl(5)) / 2;
7    ld resphi = 2 - phi;
8    ld x1 = l + resphi * (r - l);
9    ld x2 = r - resphi * (r - l);
10   ld f1 = f(x1);
11   ld f2 = f(x2);
12   forn (iter, 60) {
13       if (f1 < f2) {
14           r = x2;
15           x2 = x1;
16           f2 = f1;
17           x1 = l + resphi * (r - l);
18           f1 = f(x1);
19       } else {
20           l = x1;
21           x1 = x2;
22           f1 = f2;
23           x2 = r - resphi * (r - l);
24           f2 = f(x2);
25       }
26   }
27   return (x1 + x2) / 2;
28}
29
30int main() {
31    std::cout << goldenSearch(-100, 100) << '\n';
32}
33
34vector<ld> sqrRoots(ld a, ld b, ld c) {
35    ld d = b * b - 4 * a * c;
36    if (ze(d))
37        return {-b / (2 * a)};
38    if (d < 0)
39        return {};
40    d = sqrtl(d);
41    if (ze(b)) {
42        ld x1 = -d / (2 * a);
43        ld x2 = d / (2 * a);
44        if (x1 > x2)
45            swap(x1, x2);
46        return {x1, x2};
47    }
48    ld sgn = b > 0 ? 1 : -1;
49    ld x1 = (-b - sgn * d) / (2 * a);
50    ld x2 = c / (a * x1);
51    if (x1 > x2)
52        swap(x1, x2);
53    return {x1, x2};
54}

```

- Simpson and Gauss numerical integration:

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

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

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

- FFT modules:

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

- Fibonacci numbers:

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

- Powers of two

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

- Highly composite numbers

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

- 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: $S = 2\pi R h$, где h — высота.

– Интеграл дуги: $y(x) = \sqrt{r^2 - x^2}, \int y(x)dx = \frac{1}{2}(xy + r^2 \arctan \frac{x}{y}) + C$

- 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

28 math/simplex.cpp

```

1 namespace Simplex {
2
3 ld D[maxm][maxn]; // [n+2][m+2]
4 int B[maxm];
5 int N[maxn];
6 ld x[maxn];
7 int n, m;
8
9 //x >= 0, Ax <= b, c^T x -> max
10 void init(int _n, int _m, ld A[][maxn], ld *b, ld *c) {
11     n = _n, m = _m;
12     forn (i, m)
13         forn (j, n)
14             D[i][j] = -A[i][j];
15     forn (i, m) {
16         D[i][n] = 1;
17         D[i][n + 1] = b[i];
18     }
19     forn (j, n) {
20         D[m][j] = c[j];
21         D[m + 1][j] = 0;
22     }
23     D[m][n + 1] = D[m][n] = D[m + 1][n + 1] = 0;
24     D[m + 1][n] = -1;
25     iota(B, B + m, n);
26     iota(N, N + n, 0);
27     N[n] = -1;
28 }
29
30 void pivot(int b, int nb) {
31     assert(D[b][nb] != 0);
32     ld q = 1. / -D[b][nb];
33     D[b][nb] = -1;
34     forn (i, n + 2)
35         D[b][i] *= q;
36     forn (i, m + 2) {
37         if (i == b)
38             continue;
39         ld coef = D[i][nb];
40         D[i][nb] = 0;
41         forn (j, n + 2)
42             D[i][j] += coef * D[b][j];
43     }
44     swap(B[b], N[nb]);
45 }
46
47 bool betterN(int f, int i, int j) {
48     if (eq(D[f][i], D[f][j]))
49         return N[i] < N[j];
50     return D[f][i] > D[f][j];
51 }
52
53 bool betterB(int nb, int i, int j) {
54     ld ai = D[i][n + 1] / D[i][nb];
55     ld aj = D[j][n + 1] / D[j][nb];
56     if (eq(ai, aj))
57         return B[i] < B[j];
58     return ai > aj;
59 }
60
61 bool simplex(int phase) {
62     int f = phase == 1 ? m : m + 1;
63     while (true) {
64         int nb = -1;
65         forn (i, n + 1) {
66             if (N[i] == -1 && phase == 1)
67                 continue;
68             if (nb == -1 || betterN(f, i, nb))
69                 nb = i;
70         }
71         if (D[f][nb] <= eps)
72             return phase == 1;
73         assert(nb != -1);
74
75         int b = -1;
76         forn (i, m) {
77             if (D[i][nb] >= -eps)
78                 continue;
79             if (b == -1 || betterB(nb, i, b))
80                 b = i;
81         }
82         if (b == -1)
83             return false;
84         pivot(b, nb);
85         if (N[nb] == -1 && phase == 2)
86             return true;
87     }
88 }
89
90 ld solve() {
91     int b = -1;
92     forn (i, m) {
93         if (b == -1 || D[i][n + 1] < D[b][n + 1])
94             b = i;
95     }
96     assert(b != -1);
97     if (D[b][n + 1] < -eps) {
98         pivot(b, n);
99         if (!simplex(2) || D[m + 1][n + 1] < -eps)
100             return -infl;
101     }
102     if (!simplex(1))
103         return infl;
104
105     forn (i, n)
106         x[i] = 0;
107     forn (i, m)
108         if (B[i] < n)
109             x[B[i]] = D[i][n + 1];
110
111     return D[m][n + 1];
112 }
113
114 } // Simplex

```

29 math/stuff.cpp

```

1const int M = 1e6;
2int phi[M];
3void calcPhi() {
4    for (int i = 1; i < M; ++i)
5        phi[i] = i;
6    for (int j = 1; j < M; ++j)
7        for (int i = 2 * j; i < M; i += j)
8            phi[i] -= phi[j];
9}
10int inv[M];
11void calcInv() {
12    inv[1] = 1;
13    for (int i = 2; i < M; ++i) {
14        inv[i] = mul(sub(0, mod / i), inv[mod % i]);
15        assert(mul(i, inv[i]) == 1);
16    }
17}
18int gcd(int a, int b, int &x, int &y) {
19    if (a == 0) {
20        x = 0, y = 1;
21        return b;
22    }
23    int x1, y1;
24    int g = gcd(b % a, a, x1, y1);
25    x = y1 - x1 * (b / a);
26    y = x1;
27    assert(a * x + b * y == g);
28    return g;
29}
30int crt(int mod1, int mod2, int rem1, int rem2) {
31    int r = (rem2 - (rem1 % mod2) + mod2) % mod2;
32    int x, y;
33    int g = gcd(mod1, mod2, x, y);
34    assert(r % g == 0);
35
36    x %= mod2;
37    if (x < 0)
38        x += mod2;
39
40    int ans = (x * (r / g)) % mod2;
41    ans = ans * mod1 + rem1;
42
43    assert(ans % mod1 == rem1);
44    assert(ans % mod2 == rem2);
45    return ans;
46}
47
48// primes to N
49const ll n = 1000000000000LL;
50const ll L = 1000000;
51int small[L+1];
52ll large[L+1];
53void calc_pi() {
54    for (int i = 1; i <= L; ++i) {
55        small[i] = i-1;
56        large[i] = n / i - 1;
57    }
58    for (ll p = 2; p <= L; ++p) {
59        if (small[p] == small[p-1]) continue;
60        int cntp = small[p-1];
61        ll p2 = p*p;
62        ll np = n / p;
63        for (int i = 1; i <= min(L, n / p2); ++i) {
64            ll x = np / i;
65            if (x <= L) {
66                large[i] -= small[x] - cntp;
67            } else {
68                large[i] -= large[p*i] - cntp;
69            }
70        }
71        for (int i = L; i >= p2; --i) {
72            small[i] -= small[i/p] - cntp;
73        }
74    }
75}
76ll pi(ll x) {
77    if (x > L) return small[n/x];
78    else return large[x];
79}
80
81int main() {
82    calcPhi();
83    assert(phi[30] == 1 * 2 * 4);
84    calcInv();
85    int x, y;
86    gcd(3, 5, x, y);
87    gcd(15, 10, x, y);
88    crt(15, 13, 2, 5);
89    crt(17, 3, 15, 2);
90    return 0;
91}

```

30 python/libs.py

```

1""" Decimal """
2from decimal import Decimal as D, getcontext, FloatOperation
3from decimal import ROUND_DOWN
4getcontext().prec = 50
5getcontext().traps[FloatOperation] = True
6getcontext().rounding = ROUND_05UP
7
8a = D('3.14') # Correct
9#a = D(3.14) # Wrong!
10print(a ** D('0.123'))
11print(a % D('1.5'))
12print(D(2).sqrt())
13print(D(1).exp())
14print(D('10').ln())
15print(D('10').log10())
16print(D('3.15').quantize(D('0.1'))) # 3.2
17print(D('3.15').quantize(D('0.1'), rounding=ROUND_DOWN)) # 3.1
18print()
19
20def pi():
21    """Compute Pi to the current precision. """
22    getcontext().prec += 2 # extra digits for intermediate steps
23    three = D(3) # substitute "three=3.0" for regular floats
24    lasts, t, s, n, na, d, da = 0, three, 3, 1, 0, 0, 24
25    while s != lasts:
26        lasts = s
27        n, na = n+na, na+8
28        d, da = d+da, da+32
29        t = (t * n) / d
30        s += t
31    getcontext().prec -= 2
32    return +s # unary plus applies the new precision
33
34def cos(x):
35    """Return the cosine of x as measured in radians.
36    The Taylor series approximation works best for a small x.
37    For larger values, first compute x = x % (2 * pi). """
38    getcontext().prec += 2
39    i, lasts, s, fact, num, sign = 0, 0, 1, 1, 1, 1
40    # sin: i, lasts, s, fact, num, sign = 1, 0, x, 1, x, 1
41    while s != lasts:
42        lasts = s
43        i += 2
44        fact *= i * (i-1)
45        num *= x * x
46        sign *= -1
47        s += num / fact * sign
48    getcontext().prec -= 2
49    return +s
50
51""" Fraction """
52
53from fractions import Fraction as F
54from math import pi
55print(F(16, -10)) # -8/5
56print(F(123)) # 123
57print(F('-.125')) # -1/8
58print(F(pi).limit_denominator(30)) # 22/7
59print(F(1, 2) ** 31) # 1/2147483648

```

31 strings/automaton.cpp

```

1 int t[maxn][26], lnk[maxn], len[maxn];
2 int sz;
3 int last;
4
5 void init() {
6     sz = 3;
7     last = 1;
8     forn(i, 26) t[2][i] = 1;
9     len[2] = -1;
10    lnk[1] = 2;
11}
12
13 void addchar(int c) {
14     int nlast = sz++;
15     len[nlast] = len[last] + 1;
16     int p = last;
17     for (; !t[p][c]; p = lnk[p]) {
18         t[p][c] = nlast;
19     }
20     int q = t[p][c];
21     if (len[p] + 1 == len[q]) {
22         lnk[nlast] = q;
23     } else {
24         int clone = sz++;
25         len[clone] = len[p] + 1;
26         lnk[clone] = lnk[q];
27         lnk[q] = lnk[nlast] = clone;
28         forn(i, 26) t[clone][i] = t[q][i];
29         for (; t[p][c] == q; p = lnk[p]) {
30             t[p][c] = clone;
31         }
32     }
33     last = nlast;
34 }
35
36 bool check(const string& s) {
37     int v = 1;
38     for (int c: s) {
39         c -= 'a';
40         if (!t[v][c]) return false;
41         v = t[v][c];
42     }
43     return true;
44 }
45
46 int main() {
47     string s;
48     cin >> s;
49     init();
50     for (int i: s) {
51         addchar(i - 'a');
52     }
53     forn(i, s.length()) {
54         assert(check(s.substr(i)));
55     }
56     cout << sz << endl;
57     return 0;
58 }

```

32 strings/duval_manacher.cpp

```

1 /*
2  Строка простая, если строго меньше всех суффиксов <=>
3  наименьший циклический сдвиг - первый.
4  Декомпозиция Линдона - разбиение s на w1, w2, ... wk -
5  простые строки такие, что w1 >= w2 >= ... wk.
6 */
7 int duval(string s) {
8     s += s; //remove this to find Lyndon decomposition of s
9     int n = s.size();
10    int i = 0;
11    int ans = 0;
12    //while (i < n) { //for Lyndon decomposition
13    while (i < n / 2) {
14        ans = i;
15        int j = i + 1, k = i;
16        while (j < n && s[k] <= s[j]) {
17            if (s[k] < s[j])
18                k = i;
19            else
20                ++k;
21            ++j;
22        }
23        while (i <= k) {
24            //s.substr(i, j - k) -
25            //next prime string of Lyndon decomposition
26            i += j - k;
27        }
28    }
29    return ans;
30 }
31
32 //actual odd length is (odd[i] * 2 - 1)
33 //actual even length is (even[i] * 2)
34 void manacher(const string& s, vi &odd, vi &even) {
35     int n = s.size();
36     odd.resize(n);
37     int c = -1, r = -1;
38     forn(i, n) {
39         int k = (r <= i ? 0 : min(odd[2 * c - i], r - i));
40         while (i + k < n && i - k >= 0 && s[i + k] == s[i - k])
41             ++k;
42         odd[i] = k;
43         if (i + k > r)
44             r = i + k, c = i;
45     }
46     c = -1, r = -1;
47     even.resize(n - 1);
48     forn(i, n - 1) {
49         int k = (r <= i ? 0 : min(even[2 * c - i], r - i));
50         while (i + k + 1 < n && i - k >= 0 &&
51             s[i + k + 1] == s[i - k])
52             ++k;
53         even[i] = k;
54         if (i + k > r)
55             c = i, r = i + k;
56     }
57 }
58
59 void test() {
60     vector<int> odd, even;
61     string s = "aaaabbbaaaaa";
62     manacher(s, odd, even);
63     for (int x: even)
64         cerr << x << ' ';
65     cerr << '\n';
66     for (int x: odd)
67         cerr << x << ' ';
68     cerr << '\n';
69     // 1 2 1 0 5 0 1 2 2 1
70     // 1 2 2 1 1 1 1 2 3 2 1
71 }
72
73 int main() {
74     cout << duval("ababcabab") << '\n'; // 5
75     test();
76 }

```

33 strings/eertree.cpp

```

1#include <bits/stdc++.h>
2using namespace std;
3const int maxn = 5000100;
4const int inf = 1e9 + 1e5;
5
6char buf[maxn];
7char *s = buf + 1;
8int to[maxn][2];
9int suff[maxn];
10int len[maxn];
11int sz;
12int last;
13
14const int odd = 1;
15const int even = 2;
16const int blank = 3;
17
18inline void go(int &u, int pos) {
19    while (u != blank && s[pos - len[u] - 1] != s[pos])
20        u = suff[u];
21}
22
23void add_char(int pos) {
24    go(last, pos);
25    int u = suff[last];
26    go(u, pos);
27    int c = s[pos] - 'a';
28    if (!to[last][c]) {
29        to[last][c] = sz++;
30        len[sz - 1] = len[last] + 2;
31        assert(to[u][c]);
32        suff[sz - 1] = to[u][c];
33    }
34    last = to[last][c];
35}
36
37void init() {
38    sz = 4;
39    to[blank][0] = to[blank][1] = even;
40    len[blank] = suff[blank] = inf;
41    len[even] = 0, suff[even] = odd;
42    len[odd] = -1, suff[odd] = blank;
43    last = 2;
44}
45
46void build() {
47    init();
48    scanf("%s", s);
49    for (int i = 0; s[i]; ++i)
50        add_char(i);
51}

```

34 strings/suffix_array.cpp

```

1string s;
2int n;
3int sa[maxn], new_sa[maxn], cls[maxn], new_cls[maxn],
4    cnt[maxn], lcp[maxn];
5int n_cls;
6
7void build() {
8    n_cls = 256;
9    forn(i, n) {
10        sa[i] = i;
11        cls[i] = s[i];
12    }
13    for (int d = 0; d < n; d = d ? d*2 : 1) {
14
15        forn(i, n) new_sa[i] = (sa[i] - d + n) % n;
16        forn(i, n_cls) cnt[i] = 0;
17        forn(i, n) ++cnt[cls[i]];
18        forn(i, n_cls) cnt[i+1] += cnt[i];
19        for (int i = n-1; i >= 0; --i)
20            sa[--cnt[cls[new_sa[i]]]] = new_sa[i];
21
22        n_cls = 0;
23        forn(i, n) {
24            if (i && (cls[sa[i]] != cls[sa[i-1]] ||
25                cls[(sa[i]+d)%n] != cls[(sa[i-1]+d)%n])) {
26                ++n_cls;
27            }
28            new_cls[sa[i]] = n_cls;
29        }
30        ++n_cls;
31        forn(i, n) cls[i] = new_cls[i];
32    }
33
34    // cls is also a inv perm of sa if a string is not cyclic
35    // (i.e. a position of i-th lexicographical suffix)
36    int val = 0;
37    forn(i, n) {
38        if (val) --val;
39        if (cls[i] == n-1) continue;
40        int j = sa[cls[i] + 1];
41        while (i+val != n && j+val != n && s[i+val] == s[j+val])
42            ++val;
43        lcp[cls[i]] = val;
44    }
45}
46
47int main() {
48    cin >> s;
49    s += '$';
50    n = s.length();
51    build();
52    forn(i, n) {
53        cout << s.substr(sa[i]) << endl;
54        cout << lcp[i] << endl;
55    }
56}

```

35 strings/ukkonen.cpp

```

1 string s;
2 const int alpha = 26;
3
4 namespace SuffixTree {
5     struct Node {
6         Node *to[alpha];
7         Node *lnk, *par;
8         int l, r;
9
10        Node(int l, int r): l(l), r(r) {
11            memset(to, 0, sizeof(to));
12            lnk = par = 0;
13        }
14    };
15
16    Node *root, *blank, *cur;
17    int pos;
18
19    void init() {
20        root = new Node(0, 0);
21        blank = new Node(0, 0);
22        forn (i, alpha)
23            blank->to[i] = root;
24        root->lnk = root->par = blank->lnk = blank->par = blank;
25        cur = root;
26        pos = 0;
27    }
28
29    int at(int id) {
30        return s[id] - 'a';
31    }
32
33    void goDown(int l, int r) {
34        if (l >= r)
35            return;
36        if (pos == cur->r) {
37            int c = at(l);
38            assert(cur->to[c]);
39            cur = cur->to[c];
40            pos = min(cur->r, cur->l + 1);
41            ++l;
42        } else {
43            int delta = min(r - l, cur->r - pos);
44            l += delta;
45            pos += delta;
46        }
47        goDown(l, r);
48    }
49
50    void goUp() {
51        if (pos == cur->r && cur->lnk) {
52            cur = cur->lnk;
53            pos = cur->r;
54            return;
55        }
56        int l = cur->l, r = pos;
57        cur = cur->par->lnk;
58        pos = cur->r;
59        goDown(l, r);
60    }
61
62    void setParent(Node *a, Node *b) {
63        assert(a);
64        a->par = b;
65        if (b)
66            b->to[at(a->l)] = a;
67    }
68
69    void addLeaf(int id) {
70        Node *x = new Node(id, inf);
71        setParent(x, cur);
72    }
73
74    void splitNode() {
75        assert(pos != cur->r);
76        Node *mid = new Node(cur->l, pos);
77        setParent(mid, cur->par);
78        cur->l = pos;
79        setParent(cur, mid);
80        cur = mid;
81    }
82
83    bool canGo(int c) {
84        if (pos == cur->r)
85            return cur->to[c];
86        return at(pos) == c;
87    }
88
89    void fixLink(Node *&bad, Node *newBad) {
90        if (bad)
91            bad->lnk = cur;
92            bad = newBad;
93    }
94
95    void addCharOnPos(int id) {
96        Node *bad = 0;
97        while (!canGo(at(id))) {
98            if (cur->r != pos) {
99                splitNode();
100                fixLink(bad, cur);
101                bad = cur;
102            } else {
103                fixLink(bad, 0);
104            }
105            addLeaf(id);
106            goUp();
107        }
108        fixLink(bad, 0);
109        goDown(id, id + 1);
110    }
111
112    int cnt(Node *u, int ml) {
113        if (!u)
114            return 0;
115        int res = min(ml, u->r) - u->l;
116        forn (i, alpha)
117            res += cnt(u->to[i], ml);
118        return res;
119    }
120
121    void build(int l) {
122        init();
123        forn (i, l)
124            addCharOnPos(i);
125    }
126};

```

36 structures/centroids.cpp

```

1 const int maxn = 100100;
2 const int LG = 18; // 2*maxn <= 2^LG
3
4 vector<int> g[LG][maxn];
5 int rt[LG][maxn];
6 int from[LG][maxn];
7
8 namespace Cenroids {
9
10 int D;
11 int cnt[maxn];
12 int CENTER, BEST;
13
14 void pre(int u, int prev = -1) {
15     cnt[u] = 1;
16     for (int v: g[D][u]) {
17         if (v == prev)
18             continue;
19         pre(v, u);
20         cnt[u] += cnt[v];
21     }
22 }
23
24 void findCenter(int u, int prev = -1, int up = 0) {
25     int worst = up;
26     for (int v: g[D][u]) {
27         if (v == prev)
28             continue;
29         findCenter(v, u, up + cnt[u] - cnt[v]);
30         worst = max(worst, cnt[v]);
31     }
32     if (worst < BEST) {
33         CENTER = u;
34         BEST = worst;
35     }
36 }
37
38 void markAll(int u, int prev = -1, int subtree = -1) {
39     rt[D][u] = CENTER;
40     from[D][u] = subtree;
41     for (int v: g[D][u]) {
42         if (v == prev)
43             continue;
44         g[D + 1][u].push_back(v);
45         g[D + 1][v].push_back(u);
46         if (subtree == -1)
47             markAll(v, u, v);
48         else
49             markAll(v, u, subtree);
50     }
51 }
52
53 void decompose(int u, int depth = 0) {
54     D = depth;
55     pre(u);
56     CENTER = -1, BEST = 1e9;
57     findCenter(u);
58     assert(CENTER != -1);
59     u = CENTER;
60     markAll(u);
61     D = depth + 1;
62     for (int v: g[D][u]) {
63         auto it = find(g[D][v].begin(), g[D][v].end(), u);
64         assert(it != g[D][v].end());
65         g[D][v].erase(it);
66     }
67     for (int v: g[D][u])
68         decompose(v, depth + 1);
69 }
70
71 };

```

37 structures/heavy_light.cpp

```

1 int n;
2 vi e[maxn];
3
4 namespace HLD {
5 int p[maxn], s[maxn], h[maxn], root[maxn];
6 Rmq rmq[maxn];
7
8 void dfs1(int v, int anc) {
9     s[v] = 1;
10    if (anc != -1) e[v].erase(find(all(e[v]), anc));
11    for (int to: e[v]) {
12        p[to] = v;
13        h[to] = h[v] + 1;
14        dfs1(to, v);
15        s[v] += s[to];
16    }
17 }
18
19 void dfs2(int v, int rt) {
20     root[v] = rt;
21     if (e[v].empty()) {
22         rmq[rt] = Rmq(h[v] - h[rt] + 1);
23         return;
24     }
25     int mxv = e[v][0];
26     for (int to: e[v]) {
27         if (s[to] > s[mxv]) mxv = to;
28     }
29     for (int to: e[v]) {
30         dfs2(to, to == mxv ? rt : to);
31     }
32 }
33
34 int get(int u, int v) {
35     int res = 0;
36     int t;
37     while (root[u] != root[v]) {
38         if (h[root[u]] > h[root[v]]) {
39             t = rmq[root[u]].get(0, h[u] - h[root[u]] + 1);
40             u = p[root[u]];
41         } else {
42             t = rmq[root[v]].get(0, h[v] - h[root[v]] + 1);
43             v = p[root[v]];
44         }
45         res = max(res, t);
46     }
47     int r = root[u];
48     if (h[u] > h[v]) {
49         t = rmq[r].get(h[v] - h[r], h[u] - h[r] + 1);
50     } else {
51         t = rmq[r].get(h[u] - h[r], h[v] - h[r] + 1);
52     }
53     return max(res, t);
54 }
55
56 void put(int v, int x) {
57     rmq[root[v]].put(h[v] - h[root[v]], x);
58 }
59
60 void init() {
61     const int ROOT = 0;
62     h[0] = 0;
63     dfs1(ROOT, -1);
64     dfs2(ROOT, ROOT);
65 }
66 } // namespace HLD

```

38 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 }

```


39 structures/ordered_set.cpp

```

1#include <ext/pb_ds/assoc_container.hpp>
2#include <ext/pb_ds/tree_policy.hpp>
3
4typedef __gnu_pbds::tree<int, __gnu_pbds::null_type,
5    std::less<int>,
6    __gnu_pbds::rb_tree_tag,
7    __gnu_pbds::tree_order_statistics_node_update> oset;
8
9#include <iostream>
10
11int 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}

```

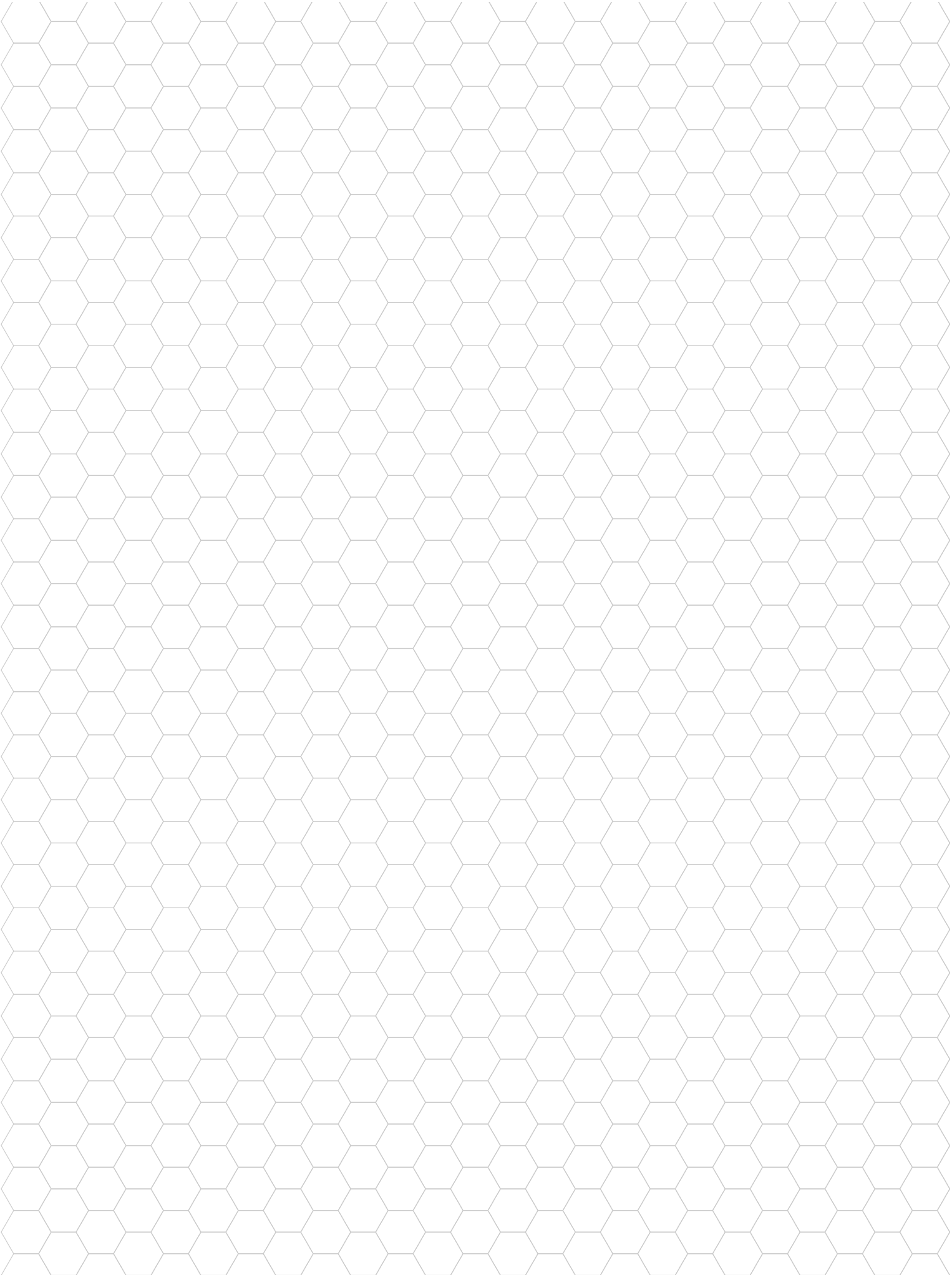
40 structures/treap.cpp

```

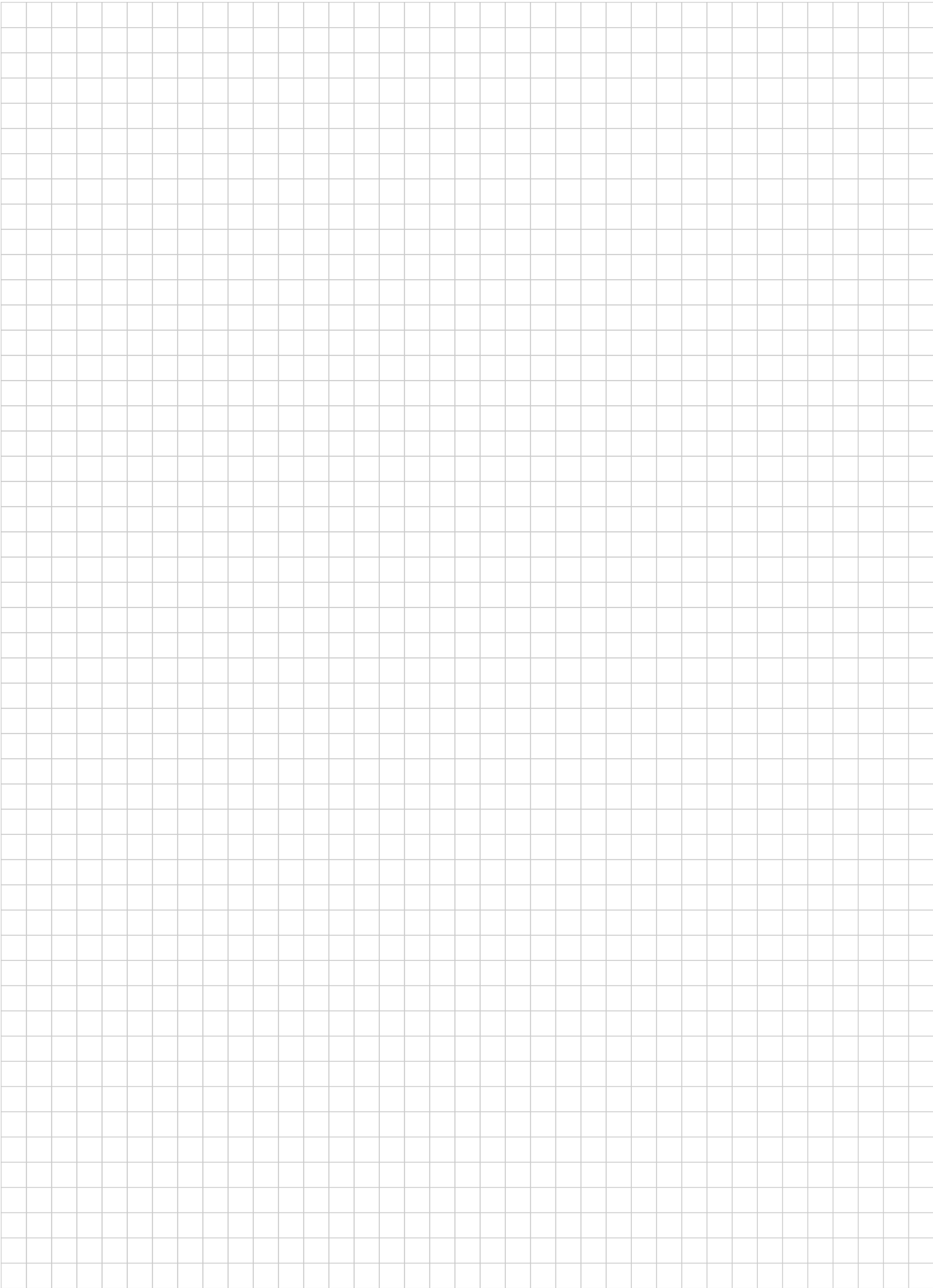
1struct node {
2    int x, y;
3    node *l, *r;
4    node(int x) : x(x), y(rand()), l(r=NULL) {}
5};
6
7void split(node *t, node *&l, node *&r, int x) {
8    if (!t) return (void)(l=r=NULL);
9    if (x <= t->x) {
10        split(t->l, l, t->l, x), r = t;
11    } else {
12        split(t->r, t->r, r, x), l = t;
13    }
14}
15
16node *merge(node *l, node *r) {
17    if (!l) return r;
18    if (!r) return l;
19    if (l->y > r->y) {
20        l->r = merge(l->r, r);
21        return l;
22    } else {
23        r->l = merge(l, r->l);
24        return r;
25    }
26}
27
28node *insert(node *t, node *n) {
29    node *l, *r;
30    split(t, l, r, n->x);
31    return merge(l, merge(n, r));
32}
33
34node *insert(node *t, int x) {
35    return insert(t, new node(x));
36}
37
38node *fast_insert(node *t, node *n) {
39    if (!t) return n;
40    node *root = t;
41    while (true) {
42        if (n->x < t->x) {
43            if (!t->l || t->l->y < n->y) {
44                split(t->l, n->l, n->r, n->x), t->l = n;
45                break;
46            } else {
47                t = t->l;
48            }
49        } else {
50            if (!t->r || t->r->y < n->y) {
51                split(t->r, n->l, n->r, n->x), t->r = n;
52                break;
53            } else {
54                t = t->r;
55            }
56        }
57    }
58    return root;
59}
60
61node *fast_insert(node *t, int x) {
62    return fast_insert(t, new node(x));
63}
64
65int main() {
66    node *t = NULL;
67    forn(i, 1000000) {
68        int x = rand();
69        t = fast_insert(t, x);
70    }
71}

```

41 Сеточка



42 Сеточка



43 Сеточка

