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# 1 Strategy.txt

- 1 - Проверить руками сэмплы
- Подумать как дебагать после написания
- 2 - Выписать сложные формулы и все +-1
- 2 - Проверить имена файлов
- 3 - Прогнать сэмплы
- Переполнения int, переполнения long long
- 3 - 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
- 6 - Прогнать псевдо-максимальный тест(немного чисел,
  - ↳ но очень большие или очень маленькие)
- 7 - Представить что не зайдет и заранее написать
  - ↳ assert'ы, прогнать слегка модифицированные тесты
- 7 - cout.precision: в том числе в интерактивных
  - ↳ задачах
- Удалить debug-output, отсечения для тестов,
  - ↳ вернуть оригинальный тахп, удалить
  - ↳ \_GLIBCXX\_DEBUG
- 9 - 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 = 10010;
3
4   struct Edge {
5     int to, c, f;
6   } es[maxn*2];
7   int ne = 0;
8
9   int n;
10  vector<int> e[maxn];
11  int q[maxn], d[maxn], pos[maxn];
12  int S, T;
13
14  void addEdge(int u, int v, int c) {
15    assert(c <= 1000000000);
16    es[ne] = {v, c, 0};
17    e[u].push_back(ne++);
18    es[ne] = {u, 0, 0};
19    e[v].push_back(ne++);
20  }
21
22  bool bfs() {
23    forn(i, n) d[i] = maxn;
24    d[S] = 0, q[0] = S;
25    int lq = 0, rq = 1;
26    while (lq != rq) {
27      int v = q[lq++];
28      for (int id: e[v]) if (es[id].f < es[id].c) {
29        int to = es[id].to;
30        if (d[to] == maxn)
31          d[to] = d[v] + 1, q[rq++] = to;
32      }
33    }
34    return d[T] != maxn;
35  }
36
37  int dfs(int v, int curf) {
38    if (v == T || curf == 0) return curf;
39    for (int &i = pos[v]; i < (int)e[v].size(); ++i) {
40      int id = e[v][i];
41      int to = es[id].to;
42      if (es[id].f < es[id].c && d[v] + 1 == d[to]) {
43        if (int ret = dfs(to, min(curf, es[id].c-es[id].f))) {
44          es[id].f += ret;
45          es[id^1].f -= ret;
46          return ret;
47        }
48      }
49    }
50  }
51  return 0;
52 }
53
54 i64 dinic(int S, int T) {
55   Dinic::S = S, Dinic::T = T;
56   i64 res = 0;
57   while (bfs()) {
58     forn(i, n) pos[i] = 0;
59     while (int f = dfs(S, 1e9)) {
60       assert(f <= 1000000000);
61       res += f;
62     }
63   }
64   return res;
65 }
66
67 } // namespace Dinic
68
69 void test() {
70   Dinic::n = 4;
71   Dinic::addEdge(0, 1, 1);
72   Dinic::addEdge(0, 2, 2);
73   Dinic::addEdge(2, 1, 1);
74   Dinic::addEdge(1, 3, 2);
75   Dinic::addEdge(2, 3, 1);
76   cout << Dinic::dinic(0, 3) << endl; // 3
77
78 }
79
80 /*
81 LR-поток находит не максимальный поток.
82 Добавим новый сток S' и исток T'. Заменяем ребро (u, v, l, r)
83 LR-сети на ребра (u, T', l), (S', v, l), (u, v, r - l).
84 Добавим ребро (T, S, k). Ставим значение k=inf, пускаем поток.
85 Проверяем, что все ребра из S' насыщены (иначе ответ не
86 существует). Бинарным поиском находим наименьшее k, что величина
87 потока не изменится. Это k - величина МИНИМАЛЬНОГО потока,
88 удовлетворяющего ограничениям. */

```

## 3 flows/globalcut.cpp

```

1 #include <bits/stdc++.h>
2 using namespace std;
3 #define forn(i,n) for (int i = 0; i < int(n); ++i)
4 const int inf = 1e9 + 1e5;
5 #define all(x) (x).begin(), (x).end()
6
7 const int maxn = 505;
8 namespace StoerWagner {
9   int g[maxn][maxn];
10  int dist[maxn];
11  bool used[maxn];
12  int n;
13
14  void addEdge(int u, int v, int c) {
15    g[u][v] += c;
16    g[v][u] += c;
17  }
18
19  int 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
55 int 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

```

1namespace MinCost {
2const ll infc = 1e12;
3
4struct 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
12int N, S, T;
13int totalFlow;
14ll totalCost;
15const int maxn = 505;
16vector<Edge> edge;
17vector<int> g[maxn];
18
19void 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
26ll dist[maxn];
27int fromEdge[maxn];
28
29bool inQueue[maxn];
30bool fordBellman() {
31    forn (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
58ll pot[maxn];
59bool dijkstra() {
60    typedef pair<ll, int> Pair;
61    priority_queue<Pair, vector<Pair>, greater<Pair>> q;
62    forn (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    forn (i, N) {
89        if (dist[i] == infc)
90            continue;
91        pot[i] += dist[i];

```

## 6 geometry/chan.cpp

```

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-1]][w] ^ 1].to;
153         }
154         int k2 = level[w];
155         ll delta = infc;
156         while (k2 > k) {
157             int e = dfrom[k2-1][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[k2-1][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 }

```

```

1 #include <bits/stdc++.h>
2 using namespace std;
3 #define forn(i,n) for (int i = 0; i < int(n); ++i)
4 typedef long double ld;
5
6 const int maxn = 100100;
7 const ld eps = 1e-9;
8
9 mt19937 rr(111);
10 ld rndEps() {
11     return (ld(rr()) / rr.max() - 0.5) / 1e5;
12 }
13
14 bool gt(ld a, ld b) { return a - b > eps; }
15 bool lt(ld a, ld b) { return b - a > eps; }
16 bool eq(ld a, ld b) { return fabs1(a - b) < eps; }
17
18 struct pt {
19     ld x, y, z;
20     ld ox, oy, oz;
21     int pr, nx;
22     bool inHull;
23
24     static pt *NIL;
25
26     pt() {}
27
28     pt(ld x, ld y, ld z): x(x), y(y), z(z) {}
29
30     pt operator-(const pt &p) const {
31         return pt(x - p.x, y - p.y, z - p.z);
32     }
33
34     ld operator*(const pt &p) const {
35         return x * p.x + y * p.y + z * p.z;
36     }
37
38     pt operator%(const pt &p) const {
39         return pt(y * p.z - z * p.y,
40             z * p.x - x * p.z,
41             x * p.y - y * p.x);
42     }
43
44     bool operator==(const pt &a) {
45         return eq(x, a.x) && eq(y, a.y) && eq(z, a.z);
46     }
47
48     void transform(bool rev) {
49         if (rev) {
50             x = ox, y = oy, z = oz;
51         } else {
52             ox = x, oy = y, oz = z;
53             x += rndEps(), y += rndEps(), z += rndEps();
54         }
55     }
56 };
57
58 ostream &operator<<(ostream &out, pt &p) {
59     return out << p.x << ' ' << p.y << ' ' << p.z;
60 }
61
62 istream &operator>>(istream &in, pt &p) {
63     return in >> p.x >> p.y >> p.z;
64 }
65
66 typedef tuple<int, int, int> Facet;
67
68 namespace Chan {
69     int n;
70     pt p[maxn];
71
72     ld turn(int p1, int p2, int p3) {
73         assert(p1 != -1 && p2 != -1 && p3 != -1);
74         return (p[p2].x - p[p1].x) * (p[p3].y - p[p1].y) -
75             (p[p3].x - p[p1].x) * (p[p2].y - p[p1].y);
76     }
77
78 //replace y with z
79     ld turnz(int p1, int p2, int p3) {
80         assert(p1 != -1 && p2 != -1 && p3 != -1);
81         return (p[p2].x - p[p1].x) * (p[p3].z - p[p1].z) -
82             (p[p3].x - p[p1].x) * (p[p2].z - p[p1].z);
83     }
84
85     ld gett(int p1, int p2, int p3) {
86         return turnz(p1, p2, p3) / turn(p1, p2, p3);
87     }
88
89     void act(int i) {
90         if (p[i].inHull) {
91             p[p[i].nx].pr = p[i].pr;

```

```

92     p[p[i].pr].nx = p[i].nx;
93 } else {
94     p[p[i].nx].pr = p[p[i].pr].nx = i;
95 }
96 p[i].inHull ^= 1;
97}
98
99vector<int> buildHull(int l, int r, bool upper) {
100     if (l + 1 >= r) {
101         p[l].pr = p[l].nx = -1;
102         p[l].inHull = true;
103         return {};
104     }
105     int mid = (l + r) / 2;
106     auto L = buildHull(l, mid, upper);
107     auto R = buildHull(mid, r, upper);
108     reverse(L.begin(), L.end());
109     reverse(R.begin(), R.end());
110     int u = mid - 1, v = mid;
111     while (true) {
112         if (p[u].pr != -1 &&
113             ((turn(p[u].pr, u, v) < 0) ^ upper))
114             u = p[u].pr;
115         else if (p[v].nx != -1 &&
116             ((turn(u, v, p[v].nx) < 0) ^ upper))
117             v = p[v].nx;
118         else
119             break;
120     }
121
122     ld T = -1e100;
123     ld t[6];
124     vector<int> A;
125     while (true) {
126         for (i, 6)
127             t[i] = 1e100;
128         if (!L.empty()) {
129             int id = L.back();
130             t[0] = gett(p[id].pr, id, p[id].nx);
131         }
132         if (!R.empty()) {
133             int id = R.back();
134             t[1] = gett(p[id].pr, id, p[id].nx);
135         }
136         if (p[u].pr != -1)
137             t[2] = gett(p[u].pr, u, v);
138         if (p[u].nx != -1)
139             t[3] = gett(u, p[u].nx, v);
140         if (p[v].pr != -1)
141             t[4] = gett(u, p[v].pr, v);
142         if (p[v].nx != -1)
143             t[5] = gett(u, v, p[v].nx);
144         ld nt = 1e100;
145         int type = -1;
146         for (i, 6)
147             if ((t[i] - T >= 1e-15) && t[i] < nt)
148                 nt = t[i], type = i;
149         if (type == -1)
150             break;
151
152         if (type == 0) {
153             act(L.back());
154             if (L.back() < u)
155                 A.push_back(L.back());
156             L.pop_back();
157         } else if (type == 1) {
158             act(R.back());
159             if (R.back() > v)
160                 A.push_back(R.back());
161             R.pop_back();
162         } else if (type == 2) {
163             A.push_back(u);
164             u = p[u].pr;
165         } else if (type == 3) {
166             u = p[u].nx;
167             A.push_back(u);
168         } else if (type == 4) {
169             v = p[v].pr;
170             A.push_back(v);
171         } else if (type == 5) {
172             A.push_back(v);
173             v = p[v].nx;
174         } else
175             assert(false);
176         T = nt;
177     }
178     assert(L.empty() && R.empty());
179
180     p[u].nx = v, p[v].pr = u;
181     for (int i = u + 1; i < v; ++i)
182         p[i].inHull = false;
183     for (int i = int(A.size()) - 1; i >= 0; --i) {
184         int id = A[i];
185         if (id <= u || id >= v) {
186             if (u == id)
187                 u = p[u].pr;
188             if (v == id)
189                 v = p[v].nx;
190             act(id);
191         } else {
192             p[id].pr = u, p[id].nx = v;
193             act(id);
194             if (id >= mid)
195                 v = id;
196             else
197                 u = id;
198         }
199     }
200     return A;
201 }
202
203 //facets are oriented ccw if look from the outside
204 vector<Facet> getFacets() {
205     for (i, n)
206         p[i].transform(false);
207     //WARNING: original order of points is changed
208     sort(p, p + n, [](const pt &a, const pt &b) {
209         return a.x < b.x;
210     });
211
212     vector<Facet> facets;
213     for (q, 2) {
214         auto movie = buildHull(0, n, q);
215         for (auto x: movie) {
216             if (!p[x].inHull)
217                 facets.emplace_back(p[x].pr, x, p[x].nx);
218             else
219                 facets.emplace_back(p[x].pr, p[x].nx, x);
220             act(x);
221         }
222     }
223     for (i, n)
224         p[i].transform(true);
225     return facets;
226 }
227
228 //namespace Chan
229
230 int main() {
231     int n;
232     cin >> n;
233     Chan::n = n;
234     for (i, n)
235         cin >> Chan::p[i];
236     auto facets = Chan::getFacets();
237     set<int> nodes;
238     for (auto f: facets) {
239         nodes.insert(get<0>(f));
240         nodes.insert(get<1>(f));
241         nodes.insert(get<2>(f));
242     }
243     assert(nodes.size() * 2 == facets.size() + 4);
244     ld V = 0, S = 0;
245     for (auto f: facets) {
246         pt v1 = Chan::p[get<1>(f)] - Chan::p[get<0>(f)];
247         pt v2 = Chan::p[get<2>(f)] - Chan::p[get<0>(f)];
248         pt v3 = Chan::p[get<0>(f)];
249         pt vv = v1 % v2;
250         for (i, n) {
251             pt v4 = Chan::p[i] - Chan::p[get<0>(f)];
252             assert(v4 * vv < 0.1);
253         }
254         S += sqrtl(vv.x * vv.x + vv.y * vv.y + vv.z * vv.z) / 2;
255         V += vv * v3 / 6;
256     }
257     cout.precision(10);
258     cout << fixed;
259     cout << S << ' ' << V << '\n';
260 }

```

## 7 geometry/convex\_hull.cpp

```

1#include <bits/stdc++.h>
2using namespace std;
3#define forn(i, n) for (int i = 0; i < int(n); ++i)
4#define sz(x) ((int) (x).size())
5
6#include "primitives.cpp"
7
8bool cmpAngle(const pt &a, const pt &b) {
9    bool ar = a.right(), br = b.right();
10    if (ar ^ br)
11        return ar;
12    return gt(a % b, 0);
13}
14
15struct Hull {
16    vector<pt> top, bot;
17
18    void append(pt p) {
19        while (bot.size() > 1 && ge((p - bot.back())
20            % (bot.back() - *next(bot.rbegin()))), 0))
21            bot.pop_back();
22        bot.push_back(p);
23        while (top.size() > 1 && ge(0, (p - top.back())
24            % (top.back() - *next(top.rbegin()))))
25            top.pop_back();
26        top.push_back(p);
27    }
28
29    void build(vector<pt> h) {
30        sort(h.begin(), h.end());
31        h.erase(unique(h.begin(), h.end()), h.end());
32        top.clear(), bot.clear();
33        for (pt p: h)
34            append(p);
35    }
36
37    pt kth(int k) {
38        if (k < sz(bot))
39            return bot[k];
40        else
41            return top[sz(top) - (k - sz(bot)) - 2];
42    }
43
44    pt mostDistant(pt dir) {
45        if (bot.empty()) {
46            //empty hull
47            return pt{1e18, 1e18};
48        }
49        if (bot.size() == 1)
50            return bot.back();
51        dir = dir.rot();
52        int n = sz(top) + sz(bot) - 2;
53        int L = -1, R = n;
54        while (L + 1 < R) {
55            int C = (L + R) / 2;
56            pt v = kth((C + 1) % n) - kth(C);
57            if (cmpAngle(dir, v)) //finds upper bound
58                R = C;
59            else
60                L = C;
61        }
62        return kth(R % n);
63    }
64};

```

## 8 geometry/halfplanes.cpp

```

1#include <bits/stdc++.h>
2using namespace std;
3#define forn(i, n) for (int i = 0; i < int(n); ++i)
4#define forab(i, a, b) for (int i = int(a); i < int(b); ++i)
5#include "primitives.cpp"
6
7ld det3x3(line &l1, line &l2, line &l3) {
8    return l1.a * (l2.b * l3.c - l2.c * l3.b) +
9        l1.b * (l2.c * l3.a - l2.a * l3.c) +
10        l1.c * (l2.a * l3.b - l2.b * l3.a);
11}
12
13vector<pt> halfplanesInterseccion(vector<line> lines) {
14    sort(lines.begin(), lines.end(),
15        [](const line &a, const line &b) {
16            bool ar = a.right(), br = b.right();
17            if (ar ^ br)
18                return ar;
19            ld prod = (pt{a.a, a.b} % pt{b.a, b.b});
20            if (!eq(prod, 0))
21                return prod > 0;
22            return a.c < b.c;
23        });
24    vector<line> lines2;
25    pt pr;
26    forn (i, lines.size()) {
27        pt cur{lines[i].a, lines[i].b};
28        if (i == 0 || cur != pr)
29            lines2.push_back(lines[i]);
30        pr = cur;
31    }
32    lines = lines2;
33    int n = lines.size();
34    forn (i, n)
35        lines[i].id = i;
36    vector<line> hull;
37    forn (i, 2 * n) {
38        line l = lines[i % n];
39        while ((int) hull.size() >= 2) {
40            ld D = det3x3(*next(hull.rbegin()), hull.back(), l);
41            if (ge(D, 0))
42                break;
43            hull.pop_back();
44        }
45        hull.push_back(l);
46    }
47    vector<int> firstTime(n, -1);
48    vector<line> v;
49    forn (i, hull.size()) {
50        int cid = hull[i].id;
51        if (firstTime[cid] == -1) {
52            firstTime[cid] = i;
53            continue;
54        }
55        forab(j, firstTime[cid], i)
56            v.push_back(hull[j]);
57        break;
58    }
59    n = v.size();
60    if (v.empty()) {
61        //empty intersection
62        return {};
63    }
64    v.push_back(v[0]);
65    vector<pt> res;
66    pt center{0, 0};
67    forn (i, n) {
68        res.push_back(linesIntersection(v[i], v[i + 1]));
69        center = center + res.back();
70    }
71    center = center / n;
72    for (auto l: lines)
73        if (gt(0, l.signedDist(center))) {
74            //empty intersection
75            return {};
76        }
77    return res;
78}

```



## 9 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}

```

## 10 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//p must be oriented counterclockwise
13 bool segmentInsidePolygon(pt a, pt b, pt *p, int n) {
14     if (!pointInsidePolygon((a + b) / 2, p, n))
15         return false;
16     if (a == b)
17         return true;
18     forn(i, n) {
19         pt c = p[i];
20         if (eq((a - c) % (b - c), 0) &&
21             gt(0, (a - c) * (b - c))) {
22             //point on segment
23             pt pr = p[(i + n - 1) % n];
24             pt nx = p[(i + 1) % n];
25             if (gt((c - pr) % (nx - c), 0))
26                 return false;
27             ld s1 = (pr - a) % (b - a);
28             ld s2 = (nx - a) % (b - a);
29             if ((gt(s1, 0) || gt(s2, 0)) &&
30                 (gt(0, s1) || gt(0, s2)))
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 (ge(s1, 0) && ge(s2, 0))
38             continue;
39         if (ge(0, s1) && ge(0, s2))
40             continue;
41
42         s1 = (c - a) % (b - a);
43         s2 = (d - a) % (b - a);
44         if (ge(s1, 0) && ge(s2, 0))
45             continue;
46         if (ge(0, s1) && ge(0, s2))
47             continue;
48
49         return false;
50     }
51     return true;
52}

```

# 11 geometry/primitives.cpp

```

1//WARNING! do not forget to normalize vector (a,b)
2struct line {
3    ld a, b, c;
4    int id;
5
6    line(pt p1, pt p2) {
7        gassert(p1 != p2);
8        pt n = (p2 - p1).rot();
9        n /= n.abs();
10       a = n.x, b = n.y;
11       c = -(n * p1);
12    }
13
14    bool right() const {
15        return gt(a, 0) || (eq(a, 0) && gt(b, 0));
16    }
17
18    line(ld _a, ld _b, ld _c): a(_a), b(_b), c(_c) {
19        ld d = pt{a, b}.abs();
20        gassert(!eq(d, 0));
21        a /= d, b /= d, c /= d;
22    }
23
24    ld signedDist(pt p) {
25        return p * pt{a, b} + c;
26    }
27};
28
29ld pointSegmentDist(pt p, pt a, pt b) {
30    ld res = min((p - a).abs(), (p - b).abs());
31    if (a != b && ge((p - a) * (b - a), 0) &&
32        ge((p - b) * (a - b), 0))
33        res = min(res,
34            fabsl((p - a) * (b - a) / (b - a).abs()));
35    return res;
36}
37
38pt linesIntersection(line l1, line l2) {
39    ld D = l1.a * l2.b - l1.b * l2.a;
40    if (eq(D, 0)) {
41        if (eq(l1.c, l2.c)) {
42            //equal lines
43        } else {
44            //no intersection
45        }
46    }
47    ld dx = -l1.c * l2.b + l1.b * l2.c;
48    ld dy = -l1.a * l2.c + l1.c * l2.a;
49    pt res{dx / D, dy / D};
50    //gassert(eq(l1.signedDist(res), 0));
51    //gassert(eq(l2.signedDist(res), 0));
52    return res;
53}
54
55bool pointInsideSegment(pt p, pt a, pt b) {
56    if (!eq((p - a) * (b - a), 0))
57        return false;
58    return ge(0, (a - p) * (b - p));
59}
60
61bool checkSegmentIntersection(pt a, pt b, pt c, pt d) {
62    if (eq((a - b) * (c - d), 0)) {
63        if (pointInsideSegment(a, c, d) ||
64            pointInsideSegment(b, c, d) ||
65            pointInsideSegment(c, a, b) ||
66            pointInsideSegment(d, a, b)) {
67            //intersection of parallel segments
68            return true;
69        }
70        return false;
71    }
72
73    ld s1, s2;
74
75    s1 = (c - a) * (b - a);
76    s2 = (d - a) * (b - a);
77    if (gt(s1, 0) && gt(s2, 0))
78        return false;
79    if (gt(0, s1) && gt(0, s2))
80        return false;
81
82    swap(a, c), swap(b, d);
83
84    s1 = (c - a) * (b - a);
85    s2 = (d - a) * (b - a);
86    if (gt(s1, 0) && gt(s2, 0))
87        return false;
88    if (gt(0, s1) && gt(0, s2))
89        return false;
90
91    return true;
92}
93
94// WARNING! run checkSegmentIntersection before and process
95// parallel case manually
96pt segmentsIntersection(pt a, pt b, pt c, pt d) {
97    ld S = (b - a) * (d - c);
98    ld s1 = (c - a) * (d - a);
99    return a + (b - a) / S * s1;
100}
101
102vector<pt> circlesIntersection(pt a, ld r1, pt b, ld r2) {
103    ld d2 = (a - b).abs2();
104    ld d = (a - b).abs();
105
106    if (a == b && eq(r1, r2)) {
107        //equal circles
108    }
109    if (gt(d2, sqr(r1 + r2)) || gt(sqr(r1 - r2), d2)) {
110        //empty intersection
111        return {};
112    }
113    int num = 2;
114    if (eq(sqr(r1 + r2), d2) || eq(sqr(r1 - r2), d2))
115        num = 1;
116    ld cosa = (sqr(r1) + d2 - sqr(r2)) / ld(2 * r1 * d);
117    ld oh = cosa * r1;
118    pt h = a + ((b - a) / d * oh);
119    if (num == 1)
120        return {h};
121    ld hp = sqrtl(max(0.L, 1 - cosa * cosa)) * r1;
122
123    pt w = ((b - a) / d * hp).rot();
124    return {h + w, h - w};
125}
126
127//a is circle center, p is point
128vector<pt> circleTangents(pt a, ld r, pt p) {
129    ld d2 = (a - p).abs2();
130    ld d = (a - p).abs();
131
132    if (gt(sqr(r), d2)) {
133        //no tangents
134        return {};
135    }
136    if (eq(sqr(r), d2)) {
137        //point lies on circle - one tangent
138        return {p};
139    }
140
141    pt B = p - a;
142    pt H = B * sqr(r) / d2;
143    ld h = sqrtl(d2 - sqr(r)) * ld(r) / d;
144    pt w = (B / d * h).rot();
145    H = H + a;
146    return {H + w, H - w};
147}
148
149vector<pt> lineCircleIntersection(line l, pt a, ld r) {
150    ld d = l.signedDist(a);
151    if (gt(fabsl(d), r))
152        return {};
153    pt h = a - pt{l.a, l.b} * d;
154    if (eq(fabsl(d), r))
155        return {h};
156    pt w{pt{l.a, l.b}.rot() * sqrtl(max<ld>(0, sqr(r)-sqr(d)))};
157    return {h + w, h - w};
158}
159
160//modified magic from e-maxx
161vector<line> commonTangents(pt a, ld r1, pt b, ld r2) {
162    if (a == b && eq(r1, r2)) {
163        //equal circles
164        return {};
165    }
166    vector<line> res;
167    pt c = b - a;
168    ld z = c.abs2();
169    for (int i = -1; i <= 1; i += 2)
170        for (int j = -1; j <= 1; j += 2) {
171            ld r = r2 * j - r1 * i;
172            ld d = z - sqr(r);
173            if (gt(0, d))
174                continue;
175            d = sqrtl(max<ld>(0, d));
176            pt magic = pt{r, d} / z;
177            line l(magic * c, magic * c, r1 * i);
178            l.c -= pt{l.a, l.b} * a;
179            res.push_back(l);
180        }
181    return res;
182}

```



## 12 geometry/svg.cpp

```

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

```

## 13 graphs/2sat.cpp

```

1 const int maxn = 200100; //2 x number of variables
2
3 namespace TwoSAT {
4     int n; //number of variables
5     bool used[maxn];
6     vector<int> g[maxn];
7     vector<int> gr[maxn];
8     int comp[maxn];
9     int res[maxn];
10
11     void addEdge(int u, int v) { //u or v
12         g[u].push_back(v ^ 1);
13         g[v].push_back(u ^ 1);
14         gr[u ^ 1].push_back(v);
15         gr[v ^ 1].push_back(u);
16     }
17
18     vector<int> ord;
19     void dfs1(int u) {
20         used[u] = true;
21         for (int v: g[u]) {
22             if (used[v])
23                 continue;
24             dfs1(v);
25         }
26         ord.push_back(u);
27     }
28
29     int COL = 0;
30     void dfs2(int u) {
31         used[u] = true;
32         comp[u] = COL;
33         for (int v: gr[u]) {
34             if (used[v])
35                 continue;
36             dfs2(v);
37         }
38     }
39
40     void mark(int u) {
41         res[u / 2] = u % 2;
42         used[u] = true;
43         for (int v: g[u]) {
44             if (used[v])
45                 continue;
46             mark(v);
47         }
48     }
49
50     bool run() {
51         fill(res, res + 2 * n, -1);
52         fill(used, used + 2 * n, false);
53         for (i, 2 * n)
54             if (!used[i])
55                 dfs1(i);
56         reverse(ord.begin(), ord.end());
57         assert((int) ord.size() == (2 * n));
58         fill(used, used + 2 * n, false);
59         for (int u: ord) if (!used[u]) {
60             dfs2(u);
61             ++COL;
62         }
63         for (i, n)
64             if (comp[i * 2] == comp[i * 2 + 1])
65                 return false;
66
67         reverse(ord.begin(), ord.end());
68         fill(used, used + 2 * n, false);
69         for (int u: ord) {
70             if (res[u / 2] != -1) {
71                 continue;
72             }
73             mark(u);
74         }
75         return true;
76     }
77 }
78
79 int main() {
80     TwoSAT::n = 2;
81     TwoSAT::addEdge(0, 2); //x or y
82     TwoSAT::addEdge(0, 3); //x or !y
83     TwoSAT::addEdge(3, 3); //!y or !y
84     assert(TwoSAT::run());
85     cout << TwoSAT::res[0] << ' ' << TwoSAT::res[1] << '\n';
86     //1 0
87 }

```

## 14 graphs/directed\_mst.cpp

```

1// WARNING: this code wasn't submitted anywhere
2
3namespace TwoChinese {
4
5struct Edge {
6    int to, w, id;
7    bool operator<(const Edge& other) const {
8        return to < other.to || (to == other.to && w < other.w);
9    }
10};
11typedef vector<vector<Edge>> Graph;
12
13const int maxn = 2050;
14
15// global, for supplementary algorithms
16int b[maxn];
17int tin[maxn], tup[maxn];
18int dtime; // counter for tin, tout
19vector<int> st;
20int nc; // number of strongly connected components
21int q[maxn];
22
23int answer;
24
25void tarjan(int v, const Graph& e, vector<int>& comp) {
26    b[v] = 1;
27    st.push_back(v);
28    tin[v] = tup[v] = dtime++;
29
30    for (Edge t: e[v]) if (t.w == 0) {
31        int to = t.to;
32        if (b[to] == 0) {
33            tarjan(to, e, comp);
34            tup[v] = min(tup[v], tup[to]);
35        } else if (b[to] == 1) {
36            tup[v] = min(tup[v], tin[to]);
37        }
38    }
39
40    if (tin[v] == tup[v]) {
41        while (true) {
42            int t = st.back();
43            st.pop_back();
44            comp[t] = nc;
45            b[t] = 2;
46            if (t == v) break;
47        }
48        ++nc;
49    }
50}
51
52vector<Edge> bfs(
53    const Graph& e, const vi& init, const vi& comp)
54{
55    int n = e.size();
56    forn(i, n) b[i] = 0;
57    int lq = 0, rq = 0;
58    for (int v: init) b[v] = 1, q[rq++] = v;
59
60    vector<Edge> result;
61
62    while (lq != rq) {
63        int v = q[lq++];
64        for (Edge t: e[v]) if (t.w == 0) {
65            int to = t.to;
66            if (b[to]) continue;
67            if (!comp.empty() && comp[v] != comp[to]) continue;
68            b[to] = 1;
69            q[rq++] = to;
70            result.push_back(t);
71        }
72    }
73
74    return result;
75}
76
77// warning: check that each vertex is reachable from root
78vector<Edge> run(Graph e, int root) {
79    int n = e.size();
80
81    // find minimum incoming weight for each vertex
82    vector<int> minw(n, inf);
83    forn(v, n) for (Edge t: e[v]) {
84        minw[t.to] = min(minw[t.to], t.w);
85    }
86    forn(v, n) for (Edge &t: e[v]) if (t.to != root) {
87        t.w -= minw[t.to];
88    }
89    forn(i, n) if (i != root) answer += minw[i];
90
91    // 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    int oldnc = nc;
112
113    // run recursively on compressed graph
114    vector<Edge> subres = run(ne, comp[root]);
115
116    // find incoming edge id for each component, init queue
117    // if there is an edge (u, v) between different components
118    // than v is added to queue
119    nc = oldnc;
120    vector<int> incomingId(nc);
121    for (Edge e: subres) {
122        incomingId[e.to] = e.id;
123    }
124
125    vector<Edge> result;
126    vector<int> init;
127    init.push_back(root);
128    forn(v, n) for (Edge t: e[v]) {
129        if (incomingId[comp[t.to]] == t.id) {
130            result.push_back(t);
131            init.push_back(t.to);
132        }
133    }
134
135    // run bfs to add edges inside components and return answer
136    vector<Edge> innerEdges = bfs(e, init, comp);
137    result.insert(result.end(), all(innerEdges));
138
139    assert((int)result.size() + 1 == n);
140    return result;
141}
142
143} // namespace TwoChinese
144
145void test () {
146    auto res = TwoChinese::run({
147        {{1,5,0},{2,5,1}},
148        {{3,1,2}},
149        {{1,2,3},{4,1,4}},
150        {{1,1,5},{4,2,6}},
151        {{2,1,7}}},
152        0);
153    cout << TwoChinese::answer << endl;
154    for (auto e: res) cout << e.id << " ";
155    cout << endl;
156    // 9    0 6 2 7
157}

```

## 15 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}

```

## 16 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}

```

## 17 math/factor.cpp

```

1//WARNING: only mod <= 1e18
2ll 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
11bool 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
34bool isPrime(ll n) {
35    if (n == 1)
36        return false;
37    if (n % 2 == 0)
38        return n == 2;
39    for (ll a = 2; a < min<ll>(8, n); ++a)
40        if (!millerRabinTest(n, a))
41            return false;
42    return true;
43}
44
45//WARNING: p is not sorted
46void factorize(ll x, vector<ll> &p) {
47    if (x == 1)
48        return;
49    if (isPrime(x)) {
50        p.push_back(x);
51        return;
52    }
53    for (ll d: {2, 3, 5})
54        if (x % d == 0) {
55            p.push_back(d);
56            factorize(x / d, p);
57            return;
58        }
59    while (true) {
60        ll x1 = rr() % (x - 1) + 1;
61        ll x2 = (mul(x1, x1, x) + 1) % x;
62        int i1 = 1, i2 = 2;
63        while (true) {
64            ll c = (x1 + x - x2) % x;
65            if (c == 0)
66                break;
67            ll g = gcd(c, x);
68            if (g > 1) {
69                factorize(g, p);
70                factorize(x / g, p);
71                return;
72            }
73            if (i1 * 2 == i2) {
74                i1 *= 2;
75                x1 = x2;
76            }
77            ++i2;
78            x2 = (mul(x2, x2, x) + 1) % x;
79        }
80    }
81}

```

## 18 math/fft.cpp

```

1const int maxlg = 20;
2
3vector<base> ang[maxlg + 5];
4
5void 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
21void 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
42void 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
60const int maxn = 1050000;
61
62int n;
63base a[maxn];
64base b[maxn];
65
66void 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}

```

## 19 math/fft\_inv.cpp

```

1 vector<int> mul(vector<int> a, vector<int> b,
2     bool carry = true) {
3     int n = sz(a);
4     if (carry) {
5         a.resize(n * 2);
6         b.resize(n * 2);
7     }
8     fft(a.data(), a.size(), false);
9     fft(b.data(), b.size(), false);
10    for (int i = 0; i < sz(a); ++i)
11        a[i] = mul(a[i], b[i]);
12    fft(a.data(), a.size(), true);
13    a.resize(n);
14    return a;
15}
16
17 vector<int> inv(vector<int> v) {
18     int n = 1;
19     while (n < sz(v))
20         n <= 1;
21     v.resize(n, 0);
22     vector<int> res(1, binpow(v[0], mod - 2));
23     for (int k = 1; k < n; k <= 1) {
24         vector<int> A(k * 2, 0);
25         copy(v.begin(), v.begin() + k, A.begin());
26         vector<int> C = res;
27         C.resize(k * 2, 0);
28         A = mul(A, C, false);
29         for (int i = 0; i < 2 * k; ++i)
30             A[i] = sub(0, A[i]);
31         A[0] = sum(A[0], 1);
32         for (int i = 0; i < k; ++i)
33             assert(A[i] == 0);
34         copy(A.begin() + k, A.end(), A.begin());
35         A.resize(k);
36         vector<int> B(k);
37         copy(v.begin() + k, v.begin() + 2 * k, B.begin());
38         C.resize(k);
39         B = mul(B, C);
40         for (int i = 0; i < k; ++i)
41             A[i] = sub(A[i], B[i]);
42         A = mul(A, C);
43         res.resize(k * 2);
44         copy(A.begin(), A.end(), res.begin() + k);
45     }
46     return res;
47}

```

## 20 math/golden\_search.cpp

```

1 ld f(ld x) {
2     return 5 * x * x + 100 * x + 1; // -10 is minimum
3 }
4
5 ld goldenSearch(ld l, ld r) {
6     ld phi = (1 + sqrt(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
30 int main() {
31     std::cout << goldenSearch(-100, 100) << '\n';
32}

```

## 21 math/numbers.tex

- 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:

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

- 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

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

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

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

## 22 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}

```



## 23 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}

```

## 24 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("ababcbab") << '\n'; // 5
75     test();
76}

```

## 25 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}

```

## 26 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}

```

## 27 strings/ukkonen.cpp

```

1string s;
2const int alpha = 26;
3
4namespace 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];
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};

```

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

```

## 29 structures/convex\_hull\_trick.cpp

```

1 /*
2     WARNING!!!
3     - finds maximum of A*x+B
4     - double check max coords for int/long long overflow
5     - set min x query in put function
6     - add lines with non-descending A coefficient
7 */
8 struct FastHull {
9     int a[maxn];
10    int b[maxn];
11    int p[maxn];
12    int c;
13
14    FastHull(): c(0) {}
15
16    ll get(int x) {
17        if (c == 0)
18            return -inf;
19        int pos = upper_bound(p, p + c, x) - p - 1;
20        assert(pos >= 0);
21        return (ll) a[pos] * x + b[pos];
22    }
23
24    ll divideCeil(ll p, ll q) {
25        assert(q > 0);
26        if (p >= 0)
27            return (p + q - 1) / q;
28        return -((-p) / q);
29    }
30
31    void put(int A, ll B) {
32        while (c > 0) {
33            if (a[c - 1] == A && b[c - 1] >= B)
34                return;
35            ll pt = p[c - 1];
36            if (a[c - 1] * pt + b[c - 1] < A * pt + B) {
37                --c;
38                continue;
39            }
40            ll q = A - a[c - 1];
41            ll np = divideCeil(b[c - 1] - B, q);
42            p[c] = np;
43            a[c] = A;
44            b[c] = B;
45            ++c;
46            return;
47        }
48        if (c == 0) {
49            a[c] = A, b[c] = B;
50            p[c] = -1e9; //min x query
51            ++c;
52            return;
53        }
54    }
55 };
56
57 struct SlowHull {
58     vector<pair<int, ll>> v;
59
60     void put(int a, ll b) {
61         v.emplace_back(a, b);
62     }
63
64     ll get(ll x) {
65         ll best = -inf;
66         for (auto p: v)
67             best = max(best, p.first * x + p.second);
68         return best;
69     }
70 };
71
72
73 int main() {
74     FastHull hull1;
75     SlowHull hull2;
76     vector<int> as;
77     forn (ii, 10000)
78         as.push_back(rand() % int(1e8));
79     sort(as.begin(), as.end());
80     forn (ii, 10000) {
81         int b = rand() % int(1e8);
82         hull1.put(as[ii], b);
83         hull2.put(as[ii], b);
84         int x = rand() % int(2e8 + 1) - int(1e8);
85         assert(hull1.get(x) == hull2.get(x));
86     }
87 }

```

## 30 structures/heavy\_light.cpp

```

1const int maxn = 100500;
2const int maxd = 17;
3
4vector<int> g[maxn];
5
6struct Tree {
7    vector<int> t;
8    int base;
9
10    Tree(): base(0) {
11    }
12
13    Tree(int n) {
14        base = 1;
15        while (base < n)
16            base *= 2;
17        t = vector<int>(base * 2, 0);
18    }
19
20    void put(int v, int delta) {
21        assert(v < base);
22        v += base;
23        t[v] += delta;
24        while (v > 1) {
25            v /= 2;
26            t[v] = max(t[v * 2], t[v * 2 + 1]);
27        }
28    }
29
30    //Careful here: cr = 2 * maxn
31    int get(int l, int r, int v=1, int cl=0, int cr = 2*maxn) {
32        cr = min(cr, base);
33        if (l <= cl && cr <= r)
34            return t[v];
35        if (r <= cl || cr <= l)
36            return 0;
37        int cc = (cl + cr) / 2;
38        return max(get(l, r, v * 2, cl, cc),
39                  get(l, r, v * 2 + 1, cc, cr));
40    }
41};
42
43namespace HLD {
44    int h[maxn];
45    int timer;
46    int in[maxn], out[maxn], cnt[maxn];
47    int p[maxd][maxn];
48    int vroot[maxn];
49    int vpos[maxn];
50    int ROOT;
51    Tree tree[maxn];
52
53    void dfs1(int u, int prev) {
54        p[0][u] = prev;
55        in[u] = timer++;
56        cnt[u] = 1;
57        for (int v: g[u]) {
58            if (v == prev)
59                continue;
60            h[v] = h[u] + 1;
61            dfs1(v, u);
62            cnt[u] += cnt[v];
63        }
64        out[u] = timer;
65    }
66
67    int dfs2(int u, int prev) {
68        int to = -1;
69        for (int v: g[u]) {
70            if (v == prev)
71                continue;
72            if (to == -1 || cnt[v] > cnt[to])
73                to = v;
74        }
75        int len = 1;
76        for (int v: g[u]) {
77            if (v == prev)
78                continue;
79            if (to == v) {
80                vpos[v] = vpos[u] + 1;
81                vroot[v] = vroot[u];
82                len += dfs2(v, u);
83            }
84            else {
85                vroot[v] = v;
86                vpos[v] = 0;
87                dfs2(v, u);
88            }
89        }
90        if (vroot[u] == u)
91            tree[u] = Tree(len);
92
93        return len;
94    }
95
96    void init(int n) {
97        timer = 0;
98        h[ROOT] = 0;
99        dfs1(ROOT, ROOT);
100        for (d, maxd - 1)
101            for (i, n)
102                p[d + 1][i] = p[d][p[d][i]];
103        vroot[ROOT] = ROOT;
104        vpos[ROOT] = 0;
105        dfs2(ROOT, ROOT);
106        //WARNING: init all trees
107    }
108
109    bool isPrev(int u, int v) {
110        return in[u] <= in[v] && out[v] <= out[u];
111    }
112
113    int lca(int u, int v) {
114        for (int d = maxd - 1; d >= 0; --d)
115            if (!isPrev(p[d][u], v))
116                u = p[d][u];
117            if (!isPrev(u, v))
118                u = p[0][u];
119        return u;
120    }
121
122    //for each v: h[v] >= toh
123    int getv(int u, int toh) {
124        int res = 0;
125        while (h[u] >= toh) {
126            int rt = vroot[u];
127            int l = max(0, toh - h[rt]), r = vpos[u] + 1;
128            res = max(res, tree[rt].get(l, r));
129            if (rt == ROOT)
130                break;
131            u = p[0][rt];
132        }
133        return res;
134    }
135
136    int get(int u, int v) {
137        int w = lca(u, v);
138        return max(getv(u, h[w]), getv(v, h[w] + 1));
139    }
140
141    void put(int u, int val) {
142        int rt = vroot[u];
143        int pos = vpos[u];
144        tree[rt].put(pos, val);
145    }
146};

```

## 31 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 }

```



## 32 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}

```

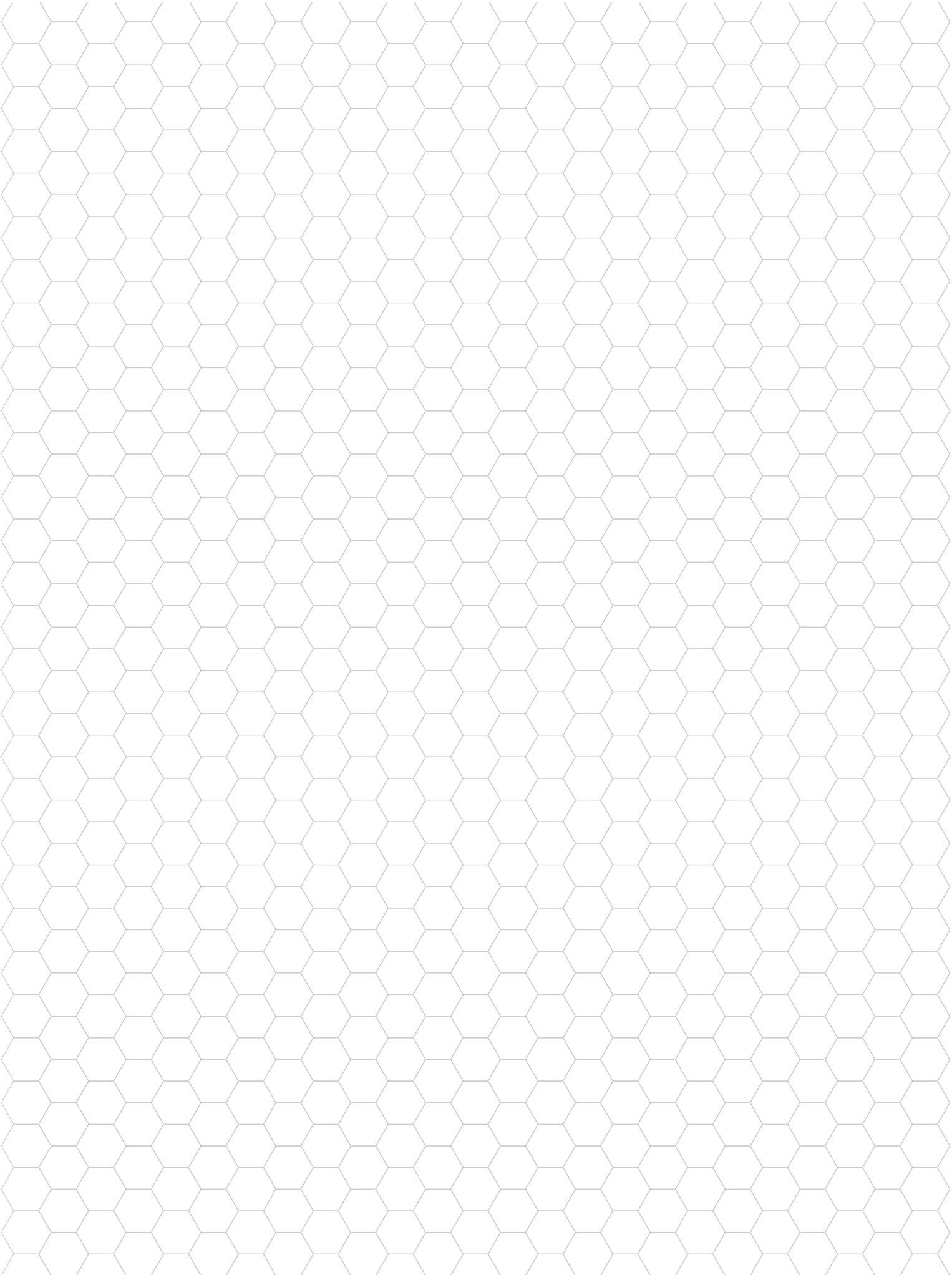
## 33 structures/treap.cpp

```

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}

```

34 Сеточка



35 Сеточка

