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1 Теория чисел

1.1 КТО

```

1 int gcd(int a, int b, int &x, int &y) {
2     if (b==0) { x = 1; y = 0; return a; }
3     int d = gcd(b, a%b, y, x);
4     y-=a/b*x;
5     return d;
6 }
7 int inv(int r, int m) {
8     int x, y;
9     gcd(r, m, x, y);
10    return (x+m)%m;
11 }
12 int crt(int r, int n, int c, int m) { return r + ((
    c - r) % m + m) * inv(n, m) % m * n; }
```

1.2 Алгоритм Миллера — Рабина

```

1 __int128 one=1;
2 int po(int a, int b, int p)
3 {
4     int res=1;
5     while(b) {if(b & 1) {res=(res*one*a)%p;--b;} else
6         {a=(a*one*a)%p;b>>=1;}} return res;
7 }
8 bool chprime(int n) ///miller-rabin
9 {
10    if(n==2) return true;
11    if(n<=1 || n%2==0) return false;
12    int h=n-1; int d=0; while(h%2==0) {h/=2;++d;}
13    for(int a:{2, 3, 5, 7, 11, 13, 17, 19, 23, 29,
14        31, 37})
15    {
16        if(a==n) return true;
17        int u=po(a, h, n); bool ok=0;
18        if(u%n==1) continue;
19        for(int c=0; c<d; ++c)
20        {
21            if((u+1)%n==0) {ok=1; break;}
22            u=(u*one*u)%n;
23        }
24        if(!ok) return false;
25    }
26    return true;
27 }
```

1.3 Алгоритм Берлекэмпа — Мессе

<https://mzhang2021.github.io/cp-blog/berlekamp-massey/>

```

1 template<typename T>
2 vector<T> berlekampMassey(const vector<T> &s) {
3     int n = s.size(), l = 0, m = 1;
4     vector<T> b(n), c(n);
5     T ld = b[0] = c[0] = 1;
6     for (int i=0; i<n; i++, m++) {
7         T d = s[i];
8         for (int j=1; j<=l; j++)
9             d += c[j] * s[i-j];
10        if (d == 0) continue;
11        vector<T> temp = c;
12        T coef = d / ld;
13        for (int j=m; j<n; j++) c[j] -= coef * b[j-m];
14        if (2 * l <= i) {
15            l = i + 1 - l;
16            b = temp;
17            ld = d;
18            m = 0;
19        }
20    }
21    c.resize(l + 1);
22    c.erase(c.begin());
23    for (T &x : c)
24        x = -x;
25    return c;
26 }
```

2 Графы

2.1 SCC и 2-SAT

Алгоритм ищет сильносвязные компоненты в графе g , если есть путь $i \rightarrow j$, то $scc[i] \leq scc[j]$

В случае 2-SAT рёбра $i \Rightarrow j$ и $(j \oplus 1) \Rightarrow (i \oplus 1)$ должны быть добавлены одновременно.

```

1 vector<vector<int>> g(2 * n);
2 vector<vector<int>> r(g.size());
3 for (int i = 0; i < g.size(); ++i) {
4     for (int j : g[i]) r[j].push_back(i);
5 }
6 vector<int> used(g.size()), tout(g.size());
7 int time = 0;
8 auto dfs = [&](auto dfs, int cur) -> void {
9     if (used[cur]) return;
10    used[cur] = 1;
11    for (int nxt : g[cur]) {
12        dfs(dfs, nxt);
13    }
14    // used[cur] = 2;
15    tout[cur] = time++;
16 };
17 for (int i = 0; i < g.size(); ++i) if (!used[i])
18     dfs(dfs, i);
19 vector<int> ind(g.size());
20 iota(ind.begin(), ind.end(), 0);
21 sort(all(ind), [&](int i, int j){return tout[i] >
22     tout[j];});
23 vector<int> scc(g.size(), -1);
24 auto go = [&](auto go, int cur, int color) -> void
25 {
26     if (scc[cur] != -1) return;
27     scc[cur] = color;
28     for (int nxt : r[cur]) {
29         go(go, nxt, color);
30     }
31 };
32 int color = 0;
33 for (int i : ind) {
34     if (scc[i] == -1) go(go, i, color++);
35 }
36 for (int i = 0; i < g.size() / 2; ++i) {
37     if (scc[2 * i] == scc[2 * i + 1]) "IMPOSSIBLE"
38     if (scc[2 * i] < scc[2 * i + 1]) {
39         // !i => i, assign i = true
40     } else {
41         // i => !i, assign i = false
42     }
43 }

```

2.2 Эйлеров цикл

```

1 vector<vector<pair<int, int>>> g(n); // pair{nxt,
2     idx}
3 vector<pair<int, int>> e(p.size());
4 // build graph
5 vector<int> in(n), out(n);
6 for (auto [u, v] : e) in[v]++, out[u]++;
7 vector<int> used(m), it(n), cycle;
8 auto dfs = [&](auto dfs, int cur) -> void {
9     while (true) {
10        while (it[cur] < g[cur].size() && used[g[cur][
11            it[cur]].second]) it[cur]++;
12        if (it[cur] == g[cur].size()) return;
13        auto [nxt, idx] = g[cur][it[cur]];
14        used[idx] = true;
15        dfs(dfs, nxt);
16        cycle.push_back(idx);
17    }
18 };
19 int cnt = 0, odd = -1;
20 for (int i = 0; i < n; ++i){
21     if (out[i] && odd == -1) odd = i;
22     if (in[i] != out[i]) {
23         if (in[i] + 1 == out[i]) odd = i;
24         if (abs(in[i] - out[i]) > 1) return {}; // must
25             hold

```

```

23     cnt++;
24 }
25 }
26 if (cnt != 0 && cnt != 2) return {}; // must hold
27 // for undirected find odd vertex (and count that #
28     of odd is 0 or 2)
29 dfs(dfs, odd);
30 reverse(cycle.begin(), cycle.end());
31 if (cycle.size() != m) return {};

```

2.3 Компоненты вершинной двусвязности

```

1 int n, m;
2 cin >> n >> m;
3 vector <vector <int> > g(n + 1);
4 map <pair <int, int>, int> comp, col;
5 for (int i = 0; i < m; ++i) {
6     int u, v, c; cin >> u >> v >> c; c--;
7     col[{u,v}] = col[{v,u}] = c;
8     g[u].push_back(v);
9     g[v].push_back(u);
10 }
11 vector <int> used(n + 1);
12 vector <int> newCompWithoutParent(n + 1), h(n + 1),
13     up(n + 1);
14 auto findCutPoints = [&](auto self, int u, int p)
15     -> void {
16     used[u] = 1;
17     up[u] = h[u];
18     for (int v : g[u]) {
19         if (!used[v]) {
20             h[v] = h[u] + 1;
21             self(self, v, u);
22             up[u] = min(up[u], up[v]);
23             if (up[v] >= h[u]) {
24                 newCompWithoutParent[v] = 1;
25             }
26         }
27         else {
28             up[u] = min(up[u], h[v]);
29         }
30     }
31 };
32 for (int u = 1; u <= n; ++u) {
33     if (!used[u]) {
34         findCutPoints(findCutPoints, u, u);
35     }
36 }
37 int ptr = 0;
38 vector <map <int, int> > colors(m);
39 auto markComponents = [&](auto self, int u, int
40     cur) -> void {
41     used[u] = 1;
42     for (int v : g[u]) {
43         if (!used[v]) {
44             if (newCompWithoutParent[v]) {
45                 ptr++;
46                 self(self, v, ptr - 1);
47             }
48             else {
49                 self(self, v, cur);
50             }
51         }
52         else if (h[v] < h[u]) {
53             comp[{u,v}] = comp[{v,u}] = cur;
54             int c = col[{u,v}];
55             colors[cur][u] |= 1 << c;
56             colors[cur][v] |= 1 << c;
57         }
58     }
59 };
60 used.assign(n + 1, 0);
61 for (int u = 1; u <= n; ++u) {
62     if (!used[u]) {
63         markComponents(markComponents, u, -1);
64     }
65 }
66 for (int comp = 0; comp < m; ++comp) {
67     vector <int> cnt(4);

```

```

65 int tot = 0;
66 for (auto [u, mask] : colors[comp]) {
67     tot |= mask;
68     cnt[bp(mask)]++;
69 }
70 if (bp(tot)<3) {
71     continue;
72 }
73 if (cnt[2] || cnt[3]>2) {
74     cout << "Yes" << endl;
75     return;
76 }
77 }
78 cout << "No" << endl;

```

3 xor, and, or-свёртки

```

1 const int p = 998244353;
2 vector<int> band(vector<int> a, vector<int> b)
3 {
4     int n=0; while((1<<n)<a.size()) ++n;
5     a.resize(1<<n); b.resize(1<<n);
6     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(mask & (1<<i)) {a[mask-(1<<i)]+=a[mask]; a[mask-(1<<i)]%=p;}
7     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(mask & (1<<i)) {b[mask-(1<<i)]+=b[mask]; b[mask-(1<<i)]%=p;}
8     vector<int> c(1<<n, 0);
9     for(int mask=0; mask<(1<<n); ++mask) {c[mask]=a[mask]*b[mask]; c[mask]%=p;}
10    for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(!(mask & (1<<i))) {c[mask]-=c[mask+(1<<i)]; c[mask]%=p;}
11    return c;
12 }
13 vector<int> bor(vector<int> a, vector<int> b)
14 {
15     int n=0; while((1<<n)<a.size()) ++n;
16     a.resize(1<<n); b.resize(1<<n);
17     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(!(mask & (1<<i))) {a[mask+(1<<i)]+=a[mask]; a[mask+(1<<i)]%=p;}
18     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(!(mask & (1<<i))) {b[mask+(1<<i)]+=b[mask]; b[mask+(1<<i)]%=p;}
19     vector<int> c(1<<n, 0);
20     for(int mask=0; mask<(1<<n); ++mask) {c[mask]=a[mask]*b[mask]; c[mask]%=p;}
21     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(mask & (1<<i)) {c[mask]-=c[mask-(1<<i)]; c[mask]%=p;}
22     return c;
23 }
24 vector<int> bxor(vector<int> a, vector<int> b)
25 {
26     assert(p%2==1); int inv2=(p+1)/2;
27     int n=0; while((1<<n)<a.size()) ++n;
28     a.resize(1<<n); b.resize(1<<n);
29     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(!(mask & (1<<i))) {int u=a[mask], v=a[mask+(1<<i)]; a[mask+(1<<i)]=(u+v)%p; a[mask]=(u-v)%p;}
30     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(!(mask & (1<<i))) {int u=b[mask], v=b[mask+(1<<i)]; b[mask+(1<<i)]=(u+v)%p; b[mask]=(u-v)%p;}
31     vector<int> c(1<<n, 0);
32     for(int mask=0; mask<(1<<n); ++mask) {c[mask]=a[mask]*b[mask]; c[mask]%=p;}
33     for(int i=0; i<n; ++i) for(int mask=0; mask<(1<<n); ++mask) if(!(mask & (1<<i))) {int u=c[mask], v=c[mask+(1<<i)]; c[mask+(1<<i)]=((u-u)*inv2)%p; c[mask]=((u+v)*inv2)%p;}
34     return c;
35 }

```

4 Структуры данных

4.1 Дерево Фенвика

```

1 int fe[maxn]; /// fenwick tree
2 void pl(int pos, int val) {while(pos<maxn) {fe[pos]+=val; pos+=(pos+1);}}
3 int get(int pos) {int ans=0; while(pos>=0) {ans+=fe[pos]; pos&=(pos+1); --pos;} return ans;} /// [0, pos] - vkluchitelno!!!
4 int get(int l, int r) {return get(r-1)-get(l-1);} // / summa na [l,r)

```

4.2 Дерево отрезков

```

1 template<typename Data, typename Mod, typename UniteData, typename UniteMod, typename Apply>
2 struct MassSegmentTree {
3     int h, n;
4     Data zd;
5     Mod zm;
6     vector<Data> data;
7     vector<Mod> mod;
8
9     UniteData ud; // Data (Data, Data)
10    UniteMod um; // Mod (Mod, Mod);
11    Apply a; // Data (Data, Mod, int); last argument is the length of current segment (could be used for range += and sum counting, for instance)
12
13    template<typename I>
14    MassSegmentTree(int sz, Data zd, Mod zm, UniteData ud, UniteMod um, Apply a, I init) : h(_lg(sz > 1 ? sz - 1 : 1) + 1), n(1 << h), zm(zm), zd(zd), data(2 * n, zd), mod(n, zm), ud(ud), um(um), a(a) {
15        for (int i = 0; i < sz; ++i) data[i + n] = init(i);
16        for (int i = n - 1; i > 0; --i) data[i] = ud(data[2 * i], data[2 * i + 1]);
17    }
18
19    MassSegmentTree(int sz, Data zd, Mod zm, UniteData ud, UniteMod um, Apply a) : h(_lg(sz > 1 ? sz - 1 : 1) + 1), n(1 << h), zm(zm), zd(zd), data(2 * n, zd), mod(n, zm), ud(ud), um(um), a(a) {}
20
21    void push(int i) {
22        if (mod[i] == zm) return;
23        apply(2 * i, mod[i]);
24        apply(2 * i + 1, mod[i]);
25        mod[i] = zm;
26    }
27
28    // is used only for apply
29    int length(int i) { return 1 << (h - _lg(i)); }
30
31    // is used only for descent
32    int left(int i) {
33        int lvl = _lg(i);
34        return (i & ((1 << lvl) - 1)) * (1 << (h - lvl));
35    }
36
37    // is used only for descent
38    int right(int i) {
39        int lvl = _lg(i);
40        return ((i & ((1 << lvl) - 1)) + 1) * (1 << (h - lvl));
41    }
42
43    template<typename S>
44    void apply(int i, S x) {
45        data[i] = a(data[i], x, length(i));
46        if (i < n) mod[i] = um(mod[i], x);
47    }
48
49    void update(int i) {

```

```

50     if (mod[i] != zm) return;
51     data[i] = ud(data[2 * i], data[2 * i + 1]);
52 }
53
54 template<typename S>
55 void update(int l, int r, S x) { // [l; r)
56     l += n, r += n;
57     for (int shift = h; shift > 0; --shift) {
58         push(l >> shift);
59         push((r - 1) >> shift);
60     }
61     for (int lf = l, rg = r; lf < rg; lf /= 2, rg
62         /= 2) {
63         if (lf & 1) apply(lf++, x);
64         if (rg & 1) apply(--rg, x);
65     }
66     for (int shift = 1; shift <= h; ++shift) {
67         update(l >> shift);
68         update((r - 1) >> shift);
69     }
70 }
71
72 Data get(int l, int r) { // [l; r)
73     l += n, r += n;
74     for (int shift = h; shift > 0; --shift) {
75         push(l >> shift);
76         push((r - 1) >> shift);
77     }
78     Data leftRes = zd, rightRes = zd;
79     for (; l < r; l /= 2, r /= 2) {
80         if (l & 1) leftRes = ud(leftRes, data[l++]);
81         if (r & 1) rightRes = ud(data[--r], rightRes);
82     }
83     return ud(leftRes, rightRes);
84 }
85
86 // l \in [0; n) && ok(get(l, l), l);
87 // returns last r: ok(get(l, r), r)
88 template<typename C>
89 int lastTrue(int l, C ok) {
90     l += n;
91     for (int shift = h; shift > 0; --shift) push(l
92 >> shift);
93     Data cur = zd;
94     do {
95         l >>= __builtin_ctz(l);
96         Data with1;
97         with1 = ud(cur, data[l]);
98         if (ok(with1, right(l))) {
99             cur = with1;
100             ++l;
101         } else {
102             while (l < n) {
103                 push(l);
104                 Data with2;
105                 with2 = ud(cur, data[2 * l]);
106                 if (ok(with2, right(2 * l))) {
107                     cur = with2;
108                     l = 2 * l + 1;
109                 } else {
110                     l = 2 * l;
111                 }
112             }
113             return l - n;
114         }
115     } while (l & (l - 1));
116     return n;
117 }
118
119 // r \in [0; n) && ok(get(r, r), r);
120 // returns first l: ok(get(l, r), l)
121 template<typename C>
122 int firstTrue(int r, C ok) {
123     r += n;
124     for (int shift = h; shift > 0; --shift) push((r
125 - 1) >> shift);
126     Data cur = zd;
127     while (r & (r - 1)) {
128         r >>= __builtin_ctz(r);

```

```

126     Data with1;
127     with1 = ud(data[--r], cur);
128     if (ok(with1, left(r))) {
129         cur = with1;
130     } else {
131         while (r < n) {
132             push(r);
133             Data with2;
134             with2 = ud(data[2 * r + 1], cur);
135             if (ok(with2, left(2 * r))) {
136                 cur = with2;
137                 r = 2 * r;
138             } else {
139                 r = 2 * r + 1;
140             }
141         }
142         return r - n + 1;
143     }
144 }
145 return 0;
146 }
147 };

```

4.2.1 Примеры использования

- Взятие максимума и прибавление константы

```

1 MassSegmentTree segtree(n, 0LL, 0LL,
2 [](int x, int y) { return max(x, y); },
3 [](int x, int y) { return x + y; },
4 [](int x, int y, int len) { return x + y; });

```

- Взятие суммы и прибавление константы

```

1 MassSegmentTree segtree(n, 0LL, 0LL,
2 [](int x, int y) { return x + y; },
3 [](int x, int y) { return x + y; },
4 [](int x, int y, int len) { return x + y * len;
5 });

```

- Взятие суммы и присвоение

```

1 MassSegmentTree segtree(n, 0LL, -1LL,
2 [](int x, int y) { return x + y; },
3 [](int x, int y) { return y; },
4 [](int x, int y, int len) { return y * len; });

```

4.3 Ordered set

```

1 #include <ext/pb_ds/assoc_container.hpp>
2 #include <ext/pb_ds/tree_policy.hpp>
3
4 using namespace __gnu_pbds;
5 using namespace std;
6
7 using ordered_set = tree<int, null_type, less<>,
8     rb_tree_tag, tree_order_statistics_node_update
9 >;

```

4.4 Convex hull trick

```

1 int div_up(int a, int b) { return a/b+((a^b)>0&&a%b
2 ); } // divide a by b rounded up
3 const int LQ = ..., RQ = ...; //leftmost query,
4 rightmost query
5 int in(ii L, int x) {
6     return L.x * x + L.y;
7 }
8 struct Hull {
9     vector <pair <int, int> > lines;
10    vector <int> borders;
11    void push(ii L) {
12        while (lines.size() && in(L, borders.back()) <
13            in(lines.back(), borders.back())) {
14            lines.pop_back();
15            borders.pop_back();
16        }
17        lines.push_back({L.x, L.y});
18        borders.push_back(L.x);
19    }
20    if (lines.empty()) {

```

```

15     lines = {L};
16     borders = {LQ};
17 }
18 else if (lines.back().x > L.x) {
19     int x = div_up(L.y - lines.back().y, lines.
back().x - L.x);
20     if (x <= RQ) {
21         lines.app(L);
22         borders.app(x);
23     }
24 }
25 }
26 Hull (){}
27 Hull (vector <ii> a) {
28     auto comp = [&] (ii u, ii v) {
29         return u.x > v.x || (u.x == v.x && u.y < v.
y);
30     };
31     sort(all(a), comp);
32     for (auto L : a) {
33         push(L);
34     }
35 }
36 int get(int x) {
37     int pos = upper_bound(all(borders), x) -
borders.begin();
38     assert(pos>0);
39     pos--;
40     return in(lines[pos],x);
41 }
42 };

```

4.5 Центроидная декомпозиция

```

1 vector<int> sz(n), lvl(n, -1);
2 auto dfs = [&](auto dfs, int cur, int prev) -> int
{
3     if (lvl[cur] != -1) return 0;
4     sz[cur] = 1;
5     for (auto [nxt, w] : g[cur]) {
6         if (nxt != prev) sz[cur] += dfs(dfs, nxt,
cur);
7     }
8     return sz[cur];
9 };
10 auto find = [&](auto find, int cur, int prev, int
tot) -> int {
11     int bch = -1, bsz = 0;
12     for (auto [nxt, w] : g[cur]) {
13         if (nxt == prev || lvl[nxt] != -1) continue
;
14         if (sz[nxt] > bsz) {
15             bch = nxt;
16             bsz = sz[nxt];
17         }
18     }
19     if (bsz + bsz <= tot) return cur;
20     return find(find, bch, cur, tot);
21 };
22 dfs(dfs, 0, 0);
23 auto c = find(find, 0, 0, sz[0]);
24 vector<pair<int, int>> stack{{c, 0}};
25 int ans = INF;
26 while (!stack.empty()) {
27     auto [centroid, l] = stack.back();
28     stack.pop_back();
29     lvl[centroid] = 1;
30     for (auto [nxt, w] : g[centroid]) {
31         if (lvl[nxt] != -1) continue;
32         dfs(dfs, nxt, centroid);
33         int new_centroid = find(find, nxt, centroid
, sz[nxt]);
34         stack.push_back({new_centroid, lvl[centroid
] + 1});
35     }
36 }

```

5 Строковые алгоритмы

5.1 Префикс-функция

```

1 vector<int> prefix_function(string s) {
2     vector<int> p(s.size());
3     for (int i = 1; i < s.size(); ++i) {
4         p[i] = p[i - 1];
5         while (p[i] && s[p[i]] != s[i]) p[i] = p[p[i] -
1];
6         p[i] += s[i] == s[p[i]];
7     }
8     return p;
9 }

```

5.2 Z-функция

```

1 vector<int> z_function (string s) { // z[i] - lcp
of s and s[i:]
2     int n = (int) s.length();
3     vector<int> z (n);
4     for (int i=1, l=0, r=0; i<n; ++i) {
5         if (i <= r)
6             z[i] = min (r-i+1, z[i-l]);
7         while (i+z[i] < n && s[z[i]] == s[i+z[i]])
8             ++z[i];
9         if (i+z[i]-1 > r)
10             l = i, r = i+z[i]-1;
11     }
12     return z;
13 }

```

5.3 Алгоритм Манакера

```

1 vector<int> manacher_odd(const string &s) {
2     vector<int> man(s.size(), 0);
3     int l = 0, r = 0;
4     int n = s.size();
5     for (int i = 1; i < n; i++) {
6         if (i <= r) {
7             man[i] = min(r - i, man[l + r - i]);
8         }
9         while (i + man[i] + 1 < n && i - man[i] - 1 >=
0 && s[i + man[i] + 1] == s[i - man[i] - 1]) {
10             man[i]++;
11         }
12         if (i + man[i] > r) {
13             l = i - man[i];
14             r = i + man[i];
15         }
16     }
17     return man;
18 }
19 // abacaba : (0 1 0 3 0 1 0)
20 // abbaa : (0 0 0 0 0)
21
22 vector <int> manacher_even(const string &s) {
23     assert(s.size());
24     string t;
25     for (int i = 0; i + 1 < s.size(); ++i) {
26         t += s[i];
27         t += '#';
28     }
29     t += s.back();
30     auto odd = manacher_odd(t);
31     vector <int> ans;
32     for (int i = 1; i < odd.size(); i += 2) {
33         ans.push_back((odd[i]+1)/2);
34     }
35     return ans;
36 }
37 // abacaba : (0 0 0 0 0 0)
38 // abbaa : (0 2 0 1)
39
40 auto pal = [&] (int l, int len) {
41     if (len & 1) {
42         int m = l + len/2;
43         return odd[m] >= len/2;
44     }
45     else {
46         int m = l + len/2 - 1;
47         return even[m] >= len/2;

```

```

48     }
49 };

```

5.4 Суфмассив

Переработанный китайский суфмассив

```

1  const int inf = 1e9;
2  struct rmq {
3      int n;
4      vector<int> a;
5      void build(const vector<int> &x) {
6          assert(x.size() == n);
7          for (int i = 0; i < n; ++i) a[n + i] = x[i];
8          for (int i = n - 1; i > 0; --i) a[i] = min(a[2
9              * i], a[2 * i + 1]);
10     }
11     rmq(int n) : n(n), a(2 * n, inf) {}
12     void put(int i, int x) {
13         a[i + n] = min(a[i + n], x);
14         for (i = (i + n) / 2; i > 0; i /= 2) {
15             a[i] = min(a[i * 2], a[i * 2 + 1]);
16         }
17     }
18     int getMin(int l, int r) { // [l; r)
19         assert(l < r);
20         int res = inf;
21         for (l += n, r += n; l < r; l /= 2, r /= 2) {
22             if (l & 1) res = min(res, a[l++]);
23             if (r & 1) res = min(res, a[--r]);
24         }
25         return res;
26     };
27     template <typename T>
28     struct suar {
29         vector<int> sa, lcp, rank; rmq t;
30         suar(T s, int lim=256) : t((int)s.size() - 1)
31         { // s must be nonempty, 0 < s[i] < lim!
32             int n = (int)s.size() + 1, k = 0, a, b; s.
33             app(0);
34             vector<int> x(s.begin(), s.end()), y(n),
35             ws(max(n, lim)); rank.resize(n);
36             sa = lcp = y, iota(sa.begin(), sa.end(), 0)
37             ;
38             for (int j = 0, p = 0; p < n; j = max(1ll,
39                 j * 2), lim = p) {
40                 p = j, iota(y.begin(), y.end(), n - j);
41                 for (int i = 0; i < n; i++) if (sa[i]
42                     >= j) y[p++] = sa[i] - j;
43                 fill(ws.begin(), ws.end(), 0);
44                 for (int i = 0; i < n; i++) ws[x[i]]++;
45                 for (int i = 1; i < lim; i++) ws[i] +=
46                     ws[i - 1];
47                 for (int i = n; i--;) sa[--ws[x[y[i]
48                     ]]] = y[i];
49                 swap(x, y), p = 1, x[sa[0]] = 0;
50                 for (int i = 1; i < n; i++) a = sa[i -
51                     1], b = sa[i], x[b] = (y[a] == y[b] && y[a + j]
52                     == y[b + j]) ? p - 1 : p++;
53                 for (int i = 1; i < n; i++) rank[sa[i]] = i
54                 ;
55                 for (int i = 0, j; i < n - 1; lcp[rank[i
56                     ++]] = k)
57                     for (k && k--, j = sa[rank[i] - 1];
58                         s[i + k] == s[j + k]; k++);
59                 sa.erase(sa.begin()); lcp.erase(lcp.begin()
60                     ); lcp.erase(lcp.begin());
61                 t.build(lcp);
62                 for (auto &e : rank) {
63                     e--;
64                 }
65             }
66     }
67     int getLcp(int i, int j) {
68         i = rank[i]; j = rank[j];
69         if (j < i) {
70             swap(i, j);
71         }
72         if (i == j) {

```

```

60         return inf;
61     }
62     else {
63         return t.getMin(i, j);
64     }
65 }
66 };

```

5.5 Алгоритм Ахо — Корасик

```

1  struct node{
2      int next[alpha] = {}, link[alpha] = {};
3      int suf = 0;
4      ll visited = 0, ans = 0;
5      vector<int> term;
6      node() {}
7  };
8
9  vector<node> mem;
10
11 int get_next(int nd, char c) {
12     if (!mem[nd].next[c - a]) { mem[nd].next[c - a] =
13         mem.size(); mem.emplace_back(); }
14     return mem[nd].next[c - a];
15 }
16
17 void find(string s, vector<string> t) {
18     mem.reserve(1e6 + 100); mem.clear();
19     mem.emplace_back(); mem.emplace_back();
20     // 0th element is nullptr, 1st is the root
21     int q = t.size();
22     for (int j = 0; j < q; ++j) {
23         int cur = 1;
24         for (char c : ts[j]) cur = get_next(cur, c);
25         mem[cur].term.push_back(j);
26     }
27     vector<int> bfs_order;
28     queue<int> bfs;
29     {
30         node &root = mem[1];
31         root.suf = 1;
32         for (char c = a; c < a + alpha; ++c) {
33             root.link[c - a] = (root.next[c - a] ?
34                 root.next[c - a] : 1);
35         }
36         bfs.push(1);
37     }
38     while (!bfs.empty()) {
39         int cur_idx = bfs.front();
40         bfs.pop();
41         node &cur = mem[cur_idx];
42         bfs_order.push_back(cur_idx);
43         for (char c = a; c < a + alpha; ++c) {
44             int nxt_idx = cur.next[c - a];
45             if (!nxt_idx) continue;
46             node &nxt = mem[nxt_idx];
47             nxt.suf = (cur_idx == 1 ? 1 : mem[cur.suf].
48                 link[c - a]);
49             for (char c = a; c < a + alpha; ++c) {
50                 nxt.link[c - a] = (nxt.next[c - a] ? nxt.
51                     next[c - a] : mem[nxt.suf].link[c - a]);
52             }
53             bfs.push(nxt_idx);
54         }
55     }
56     // do something
57 }

```

5.6 Дерево палиндромов

```

1  struct palindromic{
2      int n;
3      vector<int> p, suf{0, 0}, len{-1, 0};
4      vector<array<int, alpha>> to{{}, {}};
5      int sz = 2;
6
7      palindromic(const string &s) : n(s.size()), p(n +
8          1, 1) {
9          suf.reserve(n);

```

```

9     len.reserve(n);
10    for (int i = 0; i < n; ++i) {
11        auto check = [&](int l) { return i > 1 && s[i]
12        ] == s[i - 1 - 1]; };
13        int par = p[i];
14        while (!check(len[par])) par = suf[par];
15        if (to[par][s[i] - a]) {
16            p[i + 1] = to[par][s[i] - a];
17            continue;
18        }
19        p[i + 1] = sz++;
20        to[par][s[i] - a] = p[i + 1];
21        to.emplace_back();
22        len.emplace_back(len[par] + 2);
23        do {
24            par = suf[par];
25        } while (!check(len[par]));
26        int link = to[par][s[i] - a];
27        if (link == p[i + 1]) link = 1;
28        suf.emplace_back(link);
29    }
30 };

```

6 Потоки

6.1 Алгоритм Диница

```

1  #define pb push_back
2  struct Dinic{
3      struct edge{
4          int to, flow, cap;
5      };
6
7      const static int N = 555; //count of vertices
8
9      vector<edge> e;
10     vector<int> g[N + 7];
11     int dp[N + 7];
12     int ptr[N + 7];
13
14     void clear(){
15         for (int i = 0; i < N + 7; i++) g[i].clear();
16         e.clear();
17     }
18
19     void addEdge(int a, int b, int cap){
20         g[a].pb(e.size());
21         e.pb({b, 0, cap});
22         g[b].pb(e.size());
23         e.pb({a, 0, 0});
24     }
25
26     int minFlow, start, finish;
27
28     bool bfs(){
29         for (int i = 0; i < N; i++) dp[i] = -1;
30         dp[start] = 0;
31         vector<int> st;
32         int uk = 0;
33         st.pb(start);
34         while(uk < st.size()){
35             int v = st[uk++];
36             for (int to : g[v]){
37                 auto ed = e[to];
38                 if (ed.cap - ed.flow >= minFlow && dp[ed.to]
39                 == -1){
40                     dp[ed.to] = dp[v] + 1;
41                     st.pb(ed.to);
42                 }
43             }
44             return dp[finish] != -1;
45         }
46
47     int dfs(int v, int flow){
48         if (v == finish) return flow;
49         for (; ptr[v] < g[v].size(); ptr[v]++){
50             int to = g[v][ptr[v]];
51             edge ed = e[to];

```

```

52         if (ed.cap - ed.flow >= minFlow && dp[ed.to] ==
53         dp[v] + 1){
54             int add = dfs(ed.to, min(flow, ed.cap - ed.
55             flow));
56             if (add){
57                 e[to].flow += add;
58                 e[to ^ 1].flow -= add;
59                 return add;
60             }
61         }
62         return 0;
63     }
64     int dinic(int start, int finish){
65         Dinic::start = start;
66         Dinic::finish = finish;
67         int flow = 0;
68         for (minFlow = (1 << 30); minFlow; minFlow >>= 1)
69             {
70                 while(bfs()){
71                     for (int i = 0; i < N; i++) ptr[i] = 0;
72                     while(int now = dfs(start, (int)2e9 + 7))
73                         flow += now;
74                 }
75             }
76         return flow;
77     }
78     int dinic;

```

6.2 Mincost k-flow

6.2.1 Строим граф

```

1  struct edge {
2      int next, capacity, cost, flow = 0;
3
4      edge() = default;
5
6      edge(int next, int capacity, int cost) : next(
7      next), capacity(capacity), cost(cost) {}
8
9      int rem() const { return capacity - flow; }
10
11     int operator+=(int f) { return flow += f; }
12
13     int operator-=(int f) { return flow -= f; }
14 };
15
16 auto addEdge = [&](auto from, auto next, auto
17 capacity, int cost) {
18     g[from].push_back(e.size());
19     e.emplace_back(next, capacity, cost);
20     g[next].push_back(e.size());
21     e.emplace_back(from, 0, -cost);
22 };

```

Если граф ориентированный, то addEdge вызываем один раз. Если неориентированный, то два, вот так:

```

1 addEdge(u, v, capacity, cost);
2 addEdge(v, u, capacity, cost);

```

6.2.2 Запускаем Форда — Беллмана

```

1 vector<ll> phi(n, 0);
2 auto fordBellman = [&](int s, int t) {
3     phi.assign(n, 0);
4     for (int iter = 0; iter < n; ++iter) {
5         bool changed = false;
6         for (int u = 0; u < n; ++u) {
7             for (auto index : g[u]) {
8                 auto edge = e[index];
9                 if (edge.rem() > 0 && phi[edge.next] > phi[
10                 u] + edge.cost) {
11                     phi[edge.next] = phi[u] + edge.cost;
12                     changed = true;
13                 }
14             }
15             if (!changed) break;

```

```

16 }
17 };
18 fordBellman(s, t);

```

6.2.3 Ищем кратчайший путь Дейкстры с потенциалами

```

1 vector<ll> dist;
2 vector<int> from;
3 vector<bool> cnt;
4 auto dijkstra = [&](int s, int t) {
5     dist.assign(n, 1e18);
6     from.assign(n, -1);
7     cnt.assign(n, false);
8     dist[s] = 0;
9     set<pair<int, int>> se;
10    se.insert({0, s});
11    while ((int)(se.size())) {
12        int cur = se.begin()->y;
13        se.erase(se.begin());
14        cnt[cur] = true;
15        for (int index : g[cur]) {
16            auto &edge = e[index];
17            if (edge.rem() == 0) continue;
18            ll weight = edge.cost + phi[cur] - phi[edge.
19            next];
20            if (dist[edge.next] > dist[cur] + weight) {
21                se.erase({dist[edge.next], edge.next});
22                dist[edge.next] = dist[cur] + weight;
23                se.insert({dist[edge.next], edge.next});
24                from[edge.next] = cur;
25            }
26        }
27        if (dist[t] == (ll) 1e18) return -1LL;
28        ll cost = 0;
29        for (int p = t; p != s; p = from[p]) {
30            for (auto index : g[from[p]]) {
31                auto &edge = e[index];
32                ll weight = edge.cost + phi[from[p]] - phi[
33                edge.next];
34                if (edge.rem() > 0 && edge.next == p && dist[
35                edge.next] == dist[from[p]] + weight) {
36                    edge += 1;
37                    e[index ^ 1] -= 1;
38                    cost += edge.cost;
39                    break;
40                }
41            }
42            for (int i = 0; i < n; ++i) {
43                phi[i] += dist[i];
44            }
45            return cost;
46        }
47        ll cost = 0;
48        for (int flow = 0; flow < k; ++flow) {
49            ll a = dijkstra(s, t);
50            if (a == -1) {
51                cout << "-1\n";
52                return;
53            }
54            cost += a;
55        }

```

6.2.4 Восстанавливаем ответ

```

1 auto findPath = [&](int s, int t) {
2     vector<int> ans;
3     int cur = s;
4     while (cur != t) {
5         for (auto index : g[cur]) {
6             auto &edge = e[index];
7             if (edge.flow <= 0) continue;
8             edge -= 1;
9             e[index ^ 1] += 1;
10            ans.push_back(index / 4);
11            // index / 4 because each edge has 4 copies
12            cur = edge.next;
13            break;

```

```

14 }
15 }
16 return ans;
17 };
18 for (int flow = 0; flow < k; ++flow) {
19     auto p = findPath(s, t);
20     cout << p.size() << ' ';
21     for (int x : p) cout << x + 1 << ' ';
22     cout << '\n';
23 }

```

7 FFT & co

7.1 NTT & co

```

1 #define int long long
2 using namespace std;
3 typedef long long ll;
4 const int p=998244353;
5 int po(int a,int b){if(b==0) return 1; if(b==1)
6 // 1, 1/4, 1/8, 1/16, 5/16, 3/16, 7/16, ...
7 return a; if(b%2==0){int u=po(a,b/2);return (u
8 *1LL*u)%p;} else {int u=po(a,b-1);return (a*1LL
9 *u)%p;}}
10 int inv(int x){return po(x,p-2);}
11 template<int M, int K, int G> struct Fft {
12     // 1, 1/4, 1/8, 1/16, 5/16, 3/16, 7/16, ...
13     int g[1 << (K - 1)];
14     Fft() : g() { //if t1 constexpr...
15         static_assert(K >= 2, "Fft: K >= 2 must hold");
16         g[0] = 1;
17         g[1 << (K - 2)] = G;
18         for (int l = 1 << (K - 2); l >= 2; l >>= 1) {
19             g[l >> 1] = (g[l] * 1LL * g[l]) % M;
20         }
21         assert((g[1]*1LL * g[1]) % M == M - 1);
22         for (int l = 2; l <= 1 << (K - 2); l <<= 1) {
23             for (int i = 1; i < l; ++i) {
24                 g[l + i] = (g[l] * 1LL * g[i]) % M;
25             }
26         }
27     }
28     void fft(vector<int> &x) const {
29         const int n = x.size();
30         assert(n <= 1 << K);
31         for (int h = __builtin_ctz(n); h--;) {
32             const int l = (1 << h);
33             for (int i = 0; i < n >> (h+1); ++i) {
34                 for (int j = i << (h+1); j < (((i << 1) +
35                 1) << h); ++j) {
36                     const int t = (g[i] * 1LL * x[j | l]) % M;
37                     x[j | l] = x[j] - t;
38                     if (x[j|l] < 0) x[j | l] += M;
39                     x[j]+=t;
40                     if (x[j] >= M) x[j] -= M;
41                 }
42             }
43         }
44         for (int i = 0, j = 0; i < n; ++i) {
45             if (i < j) std::swap(x[i], x[j]);
46             for (int l = n; (l >>= 1) && !((j ^= 1) & 1);
47             ) {}
48         }
49     }
50     vector<int> convolution(const vector<int> &a,
51         const vector<int> &b) const {
52         if(a.empty() || b.empty()) return {};
53         const int na = a.size(), nb = b.size();
54         int n, invN = 1;
55         for (n = 1; n < na + nb - 1; n <= 1) invN = ((
56         invN & 1) ? (invN + M) : invN) >> 1;
57         vector<int> x(n, 0), y(n, 0);
58         std::copy(a.begin(), a.end(), x.begin());
59         std::copy(b.begin(), b.end(), y.begin());
60         fft(x);
61         fft(y);
62         for (int i = 0; i < n; ++i) x[i] = (((
63         static_cast<long long>(x[i]) * y[i]) % M) *
64         invN) % M;
65         std::reverse(x.begin() + 1, x.end());

```



```

56     fft(x);
57     x.resize(na + nb - 1);
58     return x;
59 }
60 };
61 Fft<998244353,23,31> muls;
62 vector<int> form(vector<int> v,int n)
63 {
64     while(v.size()<n) v.push_back(0);
65     while(v.size()>n) v.pop_back();
66     return v;
67 }
68 vector<int> operator *(vector<int> v1,vector<int>
    v2)
69 {
70     return muls.convolution(v1,v2);
71 }
72 vector<int> operator +(vector<int> v1,vector<int>
    v2)
73 {
74     while(v2.size()<v1.size()) v2.push_back(0); while
    (v1.size()<v2.size()) v1.push_back(0);
75     for(int i=0;i<v1.size();++i) {v1[i]+=v2[i];if(v1[
    i]>=p) v1[i]-=p; else if(v1[i]<0) v1[i]+=p;}
76     return v1;
77 }
78 vector<int> operator -(vector<int> v1,vector<int>
    v2)
79 {
80     int sz=max(v1.size(),v2.size());while(v1.size()<
    sz) v1.push_back(0); while(v2.size()<sz) v2.
    push_back(0);
81     for(int i=0;i<sz;++i) {v1[i]-=v2[i];if(v1[i]<0)
    v1[i]+=p; else if(v1[i]>=p) v1[i]-=p;} return
    v1;
82 }
83 vector<int> trmi(vector<int> v)
84 {
85     for(int i=1;i<v.size();i+=2) {if(v[i]>0) v[i]=p-v
    [i]; else v[i]=(-v[i]);}
86     return v;
87 }
88 vector<int> deriv(vector<int> v)
89 {
90     if(v.empty()) return{};
91     vector<int> ans(v.size()-1);
92     for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i
    %p;
93     return ans;
94 }
95 vector<int> integ(vector<int> v)
96 {
97     vector<int> ans(v.size()+1);ans[0]=0;
98     for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i
    %p;
99     return ans;
100 }
101 vector<int> mul(vector<vector<int> > v)
102 {
103     if(v.size()==1) return v[0];
104     vector<vector<int> > v1,v2;for(int i=0;i<v.size()
    /2;++i) v1.push_back(v[i]); for(int i=v.size()
    /2;i<v.size();++i) v2.push_back(v[i]);
105     return muls.convolution(mul(v1),mul(v2));
106 }
107 vector<int> inv1(vector<int> v,int n)
108 {
109     assert(v[0]!=0);
110     int sz=1;v=form(v,n);vector<int> a={inv(v[0])};
111     while(sz<n)
112     {
113         vector<int> vsz;for(int i=0;i<min(n,2*sz);++i)
        vsz.push_back(v[i]);
114         vector<int> b=((vector<int>) {1})-muls.
        convolution(a,vsz);
115         for(int i=0;i<sz;++i) assert(b[i]==0);
116         b.erase(b.begin(),b.begin()+sz);
117         vector<int> c=muls.convolution(b,a);
118         for(int i=0;i<sz;++i) a.push_back(c[i]);
119         sz*=2;

```

```

120     }
121     return form(a,n);
122 }

```

7.2 старое доброе FFT

```

1 using cd = complex<double>;
2 const double PI = acos(-1);
3
4 void fft(vector<cd> & a, bool invert) {
5     int n = a.size();
6
7     for (int i = 1, j = 0; i < n; i++) {
8         int bit = n >> 1;
9         for (; j & bit; bit >>= 1)
10             j ^= bit;
11         j ^= bit;
12
13         if (i < j)
14             swap(a[i], a[j]);
15     }
16
17     for (int len = 2; len <= n; len <= 1) {
18         double ang = 2 * PI / len * (invert ? -1 : 1);
19         cd wlen(cos(ang), sin(ang));
20         for (int i = 0; i < n; i += len) {
21             cd w(1);
22             for (int j = 0; j < len / 2; j++) {
23                 cd u = a[i+j], v = a[i+j+len/2] * w;
24                 a[i+j] = u + v;
25                 a[i+j+len/2] = u - v;
26                 w *= wlen;
27             }
28         }
29     }
30
31     if (invert) {
32         for (cd & x : a)
33             x /= n;
34     }
35 }
36 vector<int> multiply(vector<int> const& a, vector<
    int> const& b) {
37     vector<cd> fa(a.begin(), a.end()), fb(b.begin(),
    b.end());
38     int n = 1;
39     while (n < a.size() + b.size())
40         n <= 1;
41     fa.resize(n);
42     fb.resize(n);
43
44     fft(fa, false);
45     fft(fb, false);
46     for (int i = 0; i < n; i++)
47         fa[i] *= fb[i];
48     fft(fa, true);
49
50     vector<int> result(n);
51     for (int i = 0; i < n; i++)
52         result[i] = round(fa[i].real());
53     while(!result.empty() && !result.back()) result.
    pop_back();
54     return result;
55 }

```

8 Геометрия

8.1 Касательные

```

1 auto max = [&] (auto cmp) {
2     int k = 0;
3     for (int lg = 18; lg >= 0; --lg) {
4         int i = k + (1 << lg), j = k - (1 << lg)
    );
5         i = (i % n + n) % n;
6         j = (j % n + n) % n;
7         array<int, 3> ind{i, j, k};
8         sort(all(ind), cmp);

```

```

9         k = ind[2];
10     }
11     return k;
12 };
13 auto uppert = [&](Point p) { //last vertex in
counterclockwise order about p
14     auto cmp = [&](int i, int j) {return (a[i]
- p) < (a[j] - p); };
15     return max(cmp);
16 };
17 auto lowert = [&](Point p) { //first vertex in
counterclockwise order about p
18     auto cmp = [&](int i, int j) {return (a[i]
- p) > (a[j] - p); };
19     return max(cmp);
20 };
21 auto uppertinf = [&](Point p) { //upper tangent
line parallel to vector p
22     swap(p.x, p.y);
23     p.x = -p.x;
24     auto cmp = [&](int i, int j) { return a[i]
% p < a[j] % p; };
25     return max(cmp);
26 };
27 auto lowertinf = [&](Point p) { //lower tangent
line parallel to vector p
28     swap(p.x, p.y);
29     p.x = -p.x;
30     auto cmp = [&](int i, int j) { return a[i]
% p > a[j] % p; };
31     return max(cmp);
32 };

```

8.2 Примитивы

```

1 struct Point {
2     int x, y;
3     Point(){}
4     Point (int x_, int y_) {
5         x = x_; y = y_;
6     }
7     Point operator + (Point p) {
8         return Point(x+p.x,y+p.y);
9     }
10    Point operator - (Point p) {
11        return Point(x - p.x, y - p.y);
12    }
13    int operator * (Point p) {
14        return x * p.y - y * p.x;
15    }
16    int operator % (Point p) {
17        return x * p.x + y * p.y;
18    }
19    bool operator < (Point v) {
20        return (*this) * v > 0;
21    }
22    bool operator > (Point v) {
23        return v < (*this);
24    };
25    bool operator <= (Point v) {
26        return (*this) * v >= 0;
27    }
28 };
29 bool line(Point a, Point b, Point c) {
30     return (b-a)*(c-b)==0;
31 }
32 bool ord(Point a, Point p, Point b) {
33     return (p - a)%(p - b)<0;
34 }

```

8.3 Точка нестрого внутри выпуклости

```

1 auto inT = [&](Point a, Point b, Point c,
Point p) {
2     a = a-p; b = b-p; c = c-p;
3     return abs(a*b)+abs(b*c)+abs(c*a) == abs(a*
b+b*c+c*a);
4 };
5 auto inP = [&](Point p) { //a must be in
counterclockwise order!
6     int l = 1, r = n - 1;

```

```

7     while (l < r - 1) {
8         int m = (l + r) / 2;
9         if ((a[m] - a[0]) < (p - a[0])) {
10             l = m;
11         }
12         else {
13             r = m;
14         }
15     }
16     return inT(a[l], a[0], a[r], p);
17 };

```

9 Разное

9.1 Флаги компиляции

```

-DLOCAL -Wall -Wextra -pedantic -Wshadow -Wformat=2
-Wfloat-equal -Wconversion -Wlogical-op -Wshift-overflow=2
-Wduplicated-cond -Wcast-qual -Wcast-align -D_GLIBCXX_DEBUG
-D_GLIBCXX_DEBUG_PEDANTIC -D_FORTIFY_SOURCE=2
-fsanitize=address -fsanitize=undefined -fno-sanitize-recover
-fstack-protector -std=c++2a

```

9.1.1 Сеточка в vim

<https://codeforces.com/blog/entry/122540>

```

1 i|<esc>25A      |<esc>
2 o+<esc>25A---+<esc>
3 Vky35Pdd

```

9.2 Что сделать на пробном туре

- Убедиться, что работают все IDE. Разобраться, как настраи-
вать в них LOCAL.
- В системе ML — это ML или RE?
- Максимальный размер файла
- Можно посмотреть на время работы серверов позапуская Флой-
да — Варшалла

9.3 Шаблон

```

1 #include<bits/stdc++.h>
2
3 using namespace std;
4
5 #define int long long
6 #define app push_back
7 #define all(x) x.begin(), x.end()
8 #ifdef LOCAL
9 #define debug(...) [](auto...a){ ((cout << a <<
' '), ...) << endl; }(#__VA_ARGS__, ":",
__VA_ARGS__)
10 #else
11 #define debug(...)
12 #endif
13
14 int32_t main() {
15     cin.tie(0);ios_base::sync_with_stdio(0);
16 }

```

...