



Notebook - Maratona de Programação

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1 Algoritmos

1.1 Cdq

```
1 // LIS 3D problem
2
3 struct Segtree{
4     vi t;
5     int n;
6
7     Segtree(int n){
8         this->n = n;
9         t.assign(2*n, 0);
10    }
11
12    int merge(int a, int b){
13        return max(a, b);
14    }
15
16    void build(){
17        for(int i=n-1;i>0;i--){
18            t[i] = merge(t[i<<1], t[i<<1|1]);
19        }
20
21    int query(int l, int r){
22        int resl = -INF, resr = -INF;
23        for(l+=n, r+=n+1; l<r; l>>=1, r>>=1){
24            if(l&1) resl = merge(resl, t[l++]);
25            if(r&1) resr = merge(t[--r], resr);
26        }
27        return merge(resl, resr);
28    }
29
30    void update(int p, int value){
31        p+=n;
32        for(t[p]=max(t[p], value); p>>=1;){
33            t[p] = merge(t[p<<1], t[p<<1|1]);
34        }
35    };
36
37    struct point{
38        int x, y, z, id;
39        bool left;
40        point(int x=0, int y=0, int z=0): x(x), y(y), z(z){
41            left = false;
42        }
43        bool operator<(const point &o){
44            if(x != o.x) return x < o.x;
45            if(y != o.y) return y > o.y;
46            return z < o.z;
47        }
48    };
49
50    void cdq(int l, int r, vector<point> &a, vi &dp){
51        if(l==r) return;
52
53        int mid = (l+r) / 2;
54
55        cdq(l, mid, a, dp);
56
57        // compress z
58        set<int> uz; map<int, int> idz;
59        for(int i=l;i<=r;i++) uz.insert(a[i].z);
60        int id = 0;
61        for(auto z: uz) idz[z] = id++;
62
63        vector<point> tmp;
64        for(int i=l;i<=r;i++){
65            tmp.pb(a[i]);
66            tmp.back().x = 0;
67
```

```
68            tmp.back().z = idz[tmp.back().z];
69            if(i<=mid)
70                tmp.back().left = true;
71        }
72
73        Segtree st(id);
74
75        sort(tmp.rbegin(), tmp.rend());
76
77        for(auto t: tmp){
78            if(t.left){
79                st.update(t.z, dp[t.id]);
80            }else{
81                dp[t.id] = max(dp[t.id], st.query(0, t.z
82                    -1)+1);
83            }
84        }
85        cdq(mid+1, r, a, dp);
86    }
87
88    int32_t main()
89    {sws;
90
91
92        int n; cin >> n;
93
94        vector<point> vet(n);
95        for(int i=0;i<n;i++){
96            cin >> vet[i].x >> vet[i].y >> vet[i].z;
97        }
98
99        sort(vet.begin(), vet.end());
100
101        for(int i=0;i<n;i++)
102            vet[i].id = i;
103
104        vi dp(n, 1);
105
106        cdq(0, n-1, vet, dp);
107
108        int ans = 0;
109        for(int i=0;i<n;i++)
110            ans = max(ans, dp[i]);
111
112        cout << ans << endl;
113
114        return 0;
115    }
116 }
```

1.2 Histogram Rectangle

```
1 ll bestRectangle(vector<int> hist){
2     int n = hist.size();
3     stack<ll> s;
4     s.push(-1);
5     ll ans = hist[0];
6     vector<ll> left_smaller(n, -1), right_smaller(n,
7         n);
8     for(int i=0;i<n;i++){
9         while(!s.empty() and s.top() != -1 and hist[s.
10             top()]>hist[i]){
11             right_smaller[s.top()] = i;
12             s.pop();
13         }
14         if(i>0 and hist[i]==hist[i-1])
15             left_smaller[i] = left_smaller[i-1];
16         else
17             left_smaller[i] = s.top();
18         s.push(i);
19     }
20 }
```

```

19     for(int j=0;j<n;j++){
20         ll area = hist[j]*(right_smaller[j]-
left_smaller[j]-1);
21         ans = max(ans, area);
22     }
23     return ans;
24 }

```

1.3 Mst Xor

```

1 // omg why just 2 seconds
2 #include <bits/stdc++.h>
3 // #define int long long
4 #define ff first
5 #define ss second
6 #define ll long long
7 #define ld long double
8 #define pb push_back
9 #define eb emplace_back
10 #define pii pair<int, int>
11 #define pll pair<ll, ll>
12 #define ti tuple<int, int, int>
13 #define vi vector<int>
14 #define vl vector<ll>
15 #define vii vector<pii>
16 #define sws ios_base::sync_with_stdio(false);cin.tie(
NULL);cout.tie(NULL);
17 #define endl '\n'
18 #define teto(a, b) (((a)+(b)-1)/(b))
19 #define all(x) x.begin(), x.end()
20 #define forn(i, n) for(int i = 0; i < (int)n; i++)
21 #define forne(i, a, b) for(int i = a; i <= b; i++)
22 #define dbg(msg, var) cerr << msg << " " << var <<
endl;
23
24 using namespace std;
25
26 const int MAX = 6e6+10;
27 const ll MOD = 1e9+7;
28 const int INF = 0x3f3f3f3f;
29 const ll LLINF = 0x3f3f3f3f3f3f3f3f;
30 const ld EPS = 1e-6;
31 const ld PI = acos(-1);
32
33 // End Template //
34
35 const int N = 2e5+10;
36
37 struct DSU {
38     int n;
39     map<int, int> parent;
40     map<int, vi> comp;
41
42     int find(int v) {
43         if(v==parent[v])
44             return v;
45         return parent[v]=find(parent[v]);
46     }
47
48     void join(int a, int b) {
49         a = find(a);
50         b = find(b);
51         if(a!=b) {
52             if((int)comp[a].size()<(int)comp[b].size
53             ())
54                 swap(a, b);
55             for(auto v: comp[b])
56                 comp[a].pb(v);
57             comp[b].clear();
58             parent[b]=a;
59         }
60

```

```

61     }
62 };
63
64 int trie[MAX][2];
65 set<int> idx[MAX];
66 int finish[MAX];
67 int nxt = 1;
68
69 void add(int s){
70     int node = 0;
71     for(int i=30;i>=0;i--){
72         bool c = (s & (1<<i));
73         if(trie[node][c] == 0)
74             node = trie[node][c] = nxt++;
75         else
76             node = trie[node][c];
77         finish[node]++;
78     }
79 }
80
81 void remove(int s){
82     int node = 0;
83     for(int i=30;i>=0;i--){
84         bool c = (s & (1<<i));
85         node = trie[node][c];
86         finish[node]--;
87     }
88 }
89
90 int min_xor(int s){
91     int node = 0;
92     int ans = 0;
93     for(int i=30;i>=0;i--){
94         bool c = (s & (1<<i));
95         if(finish[trie[node][c]] != 0)
96             node = trie[node][c];
97         else{
98             ans ^= 1 << i;
99             node = trie[node][!c];
100         }
101     }
102     return ans;
103 }
104
105
106 int32_t main()
107 {sws;
108
109     int n;
110     cin >> n;
111     vi x(n);
112     for(int i=0;i<n;i++)
113         cin >> x[i];
114
115     sort(x.begin(), x.end());
116     x.erase(unique(x.begin(), x.end()), x.end());
117     n = x.size();
118
119     DSU dsu;
120
121     ll mstsum = 0;
122
123     vi pais;
124     for(int i=0;i<n;i++){
125         add(x[i]);
126         dsu.parent[x[i]] = x[i];
127         dsu.comp[x[i]].pb(x[i]);
128         pais.pb(x[i]);
129     }
130
131     while((int)pais.size()!=1){
132         vector<ti> edges;
133         for(auto p: pais){

```

```

134     vi &nodes = dsu.comp[p];
135     // erase
136     for(auto u: nodes) remove(u);
137
138     // query
139     ti ed = {LLINF, 0, 0};
140     for(auto u: nodes){
141         int xr = min_xor(u);
142         ed = min(ed, {xr, u, xr^u});
143     }
144     edges.pb(ed);
145
146     // add back
147     for(auto u: nodes) add(u);
148 }
149
150 for(auto [xr, u, v]: edges){
151     if(dsu.find(u)!=dsu.find(v)){
152         // u, v -> mst
153         // cout << "mst = " << u << " " << v
154         mstsum += xr;
155         dsu.join(u, v);
156     }
157 }
158 vi pais2;
159 for(auto p: pais)
160     if(p==dsu.find(p))
161         pais2.pb(p);
162 swap(pais, pais2);
163 }
164
165 cout << mstsum << endl;
166
167 return 0;
168 }

```

1.4 Ternary Search

```

1 // Ternary
2 ld l = -1e4, r = 1e4;
3 int iter = 100;
4 while(iter--){
5     ld m1 = (2*l + r) / 3;
6     ld m2 = (l + 2*r) / 3;
7     if(check(m1) > check(m2))
8         l = m1;
9     else
10        r = m2;
11 }

```

2 DP

2.1 Aliens

```

1 // Solves https://codeforces.com/contest/1279/problem
  /F
2
3 // dado um vetor de inteiros, escolha k subsegmentos
  disjuntos de soma máxima
4 // em vez de rodar a dp[i][k] = melhor soma éat i
  usando k segmentos,
5 // vc roda uma dp[i] adicionando um custo W toda vez
  que usa um novo subsegmento,
6 // e faz busca binária nesse W pra achar o custo
  mínimo que usa exatamente K intervalos
7
8 ll n, k, L;
9 pll check(ll w, vl& v){
10     vector<pll> dp(n+1);

```

```

11     dp[0] = {0,0};
12     for(int i=1;i<=n;i++){
13         dp[i] = dp[i-1];
14         dp[i].ff += v[i];
15         if(i-L>=0){
16             pll t = {dp[i-L].ff + w, dp[i-L].ss + 1};
17             dp[i] = min(dp[i], t);
18         }
19     }
20
21     return dp[n];
22 }
23
24 ll solve(vl v){
25     ll l=-1, r=n+1, ans=-1;
26     while(l<=r){
27         ll mid = (l+r)/2;
28         pll c = check(mid, v);
29         if(c.ss <= k){
30             r = mid - 1;
31             ans = mid;
32         }else{
33             l = mid + 1;
34         }
35     }
36
37     pll c = check(ans, v);
38
39     if(ans < 0) return 0;
40
41     // we can simply use k insted of c.ss ~magic~
42     return c.ff - ans*k;
43 }
44
45 int32_t main()
46 {sws;
47
48     string s;
49     cin >> n >> k >> L;
50     cin >> s;
51
52     vl upper(n+1, 0), lower(n+1, 0);
53     for(int i=0;i<n;i++){
54         if('A'<= s[i] and s[i] <= 'Z')
55             upper[i+1] = 1;
56     }
57     for(int i=0;i<n;i++){
58         if('a'<= s[i] and s[i] <= 'z')
59             lower[i+1] = 1;
60
61     cout << min(solve(lower),
62                 solve(upper)) << endl;
63
64     return 0;
65 }

```

2.2 Divide Conquer

```

1 ll cost(int l, int r) {
2     return ?;
3 }
4
5 void process(int l, int r, int optl, int optr) {
6     if (l > r) return;
7     int opt = optl;
8     int mid = (l + r) / 2;
9     for (int i=optl;i<=min(mid-1, optr);i++) {
10         if (dp[i] + cost(i+1, mid) < dp2[mid]) {
11             opt = i;
12             dp2[mid] = dp[i] + cost(i+1, mid);
13         }
14     }
15     process(l, mid-1, optl, opt);
16     process(mid+1, r, opt, optr);

```

```

17 }
18
19 int main() {
20     for (int i=0;i<n;i++) {
21         dp[i] = cost(0, i);
22         dp2[i] = LLINF;
23     }
24
25     for (int i=0;i<k-1;i++) {
26         process(0, n-1, 0, n-1);
27         swap(dp, dp2);
28         dp2.assign(N, LLINF);
29     }
30 }

```

2.3 Dp Digitos

```

1 // dp de quantidade de numeros <= r com ate qt
  digitos diferentes de 0
2 ll dp(int idx, string& r, bool menor, int qt, vector<
  vector<vi>>& tab) {
3     if(qt > 3) return 0;
4     if(idx >= r.size()) {
5         return 1;
6     }
7     if(tab[idx][menor][qt] != -1)
8         return tab[idx][menor][qt];
9
10    ll res = 0;
11    for(int i = 0; i <= 9; i++) {
12        if(menor or i <= r[idx]-'0') {
13            res += dp(idx+1, r, menor or i < (r[idx]-
14                '0'), qt+(i>0), tab);
15        }
16    }
17    return tab[idx][menor][qt] = res;
18 }

```

2.4 Knuth

```

1 for (int i=1;i<=n;i++) {
2     opt[i][i] = i;
3     dp[i][i] = ?; // initialize
4 }
5 auto cost = [&](int l, int r) {
6     return ?;
7 };
8
9 for (int l=n-1;l>=1;l--) {
10    for (int r=l+1;r<=n;r++) {
11        ll ans = LLINF;
12        for (int k=opt[l][r-1]; k<=min(r-1, opt[l+1][
13            r]); k++) {
14            ll best = dp[l][k] + dp[k+1][r];
15            if (ans > best) {
16                ans = best;
17                opt[l][r] = k;
18            }
19            dp[l][r] = ans + cost(l, r);
20        }
21    }
22 }
23 cout << dp[1][n] << endl;

```

2.5 Largest Ksubmatrix

```

1 int n, m;
2 int a[MAX][MAX];
3 // Largest K such that exists a block K*K with equal
  numbers

```

```

4 int largestKSubmatrix(){
5     int dp[n][m];
6     memset(dp, 0, sizeof(dp));
7
8     int result = 0;
9     for(int i = 0 ; i < n ; i++){
10        for(int j = 0 ; j < m ; j++){
11            if(!i or !j)
12                dp[i][j] = 1;
13            else if(a[i][j] == a[i-1][j] and
14                a[i][j] == a[i][j-1] and
15                a[i][j] == a[i-1][j-1])
16                dp[i][j] = min(min(dp[i-1][j], dp[i][
17                    j-1]),
18                                dp[i-1][j-1]) + 1;
19            else dp[i][j] = 1;
20
21            result = max(result, dp[i][j]);
22        }
23    }
24    return result;
25 }

```

2.6 Lis

```

1 multiset<int> S;
2 for(int i=0;i<n;i++){
3     auto it = S.upper_bound(vet[i]); // low for inc
4     if(it != S.end())
5         S.erase(it);
6     S.insert(vet[i]);
7 }
8 // size of the lis
9 int ans = S.size();
10
11 ////////////////////////////////////////////////// see that later
12 // https://codeforces.com/blog/entry/13225?#comment
  -180208
13
14 vi LIS(const vi &elements){
15     auto compare = [&](int x, int y) {
16         return elements[x] < elements[y];
17     };
18     set< int, decltype(compare) > S(compare);
19
20     vi previous( elements.size(), -1 );
21     for(int i=0; i<int( elements.size() ); ++i){
22         auto it = S.insert(i).first;
23         if(it != S.begin())
24             previous[i] = *prev(it);
25         if(*it == i and next(it) != S.end())
26             S.erase(next(it));
27     }
28
29     vi answer;
30     answer.push_back( *S.rbegin() );
31     while ( previous[answer.back()] != -1 )
32         answer.push_back( previous[answer.back()] );
33     reverse( answer.begin(), answer.end() );
34     return answer;
35 }

```

2.7 Partition Problem

```

1 // Partition Problem DP O(n2)
2 bool findPartition(vi &arr){
3     int sum = 0;
4     int n = arr.size();
5
6     for(int i=0;i<n;i++)
7         sum += arr[i];

```

```

8
9     if(sum&1) return false;
10
11     bool part[sum/2+1][n+1];
12
13     for(int i=0;i<=n;i++){
14         part[0][i] = true;
15
16     for(int i=1;i<=sum/2;i++){
17         part[i][0] = false;
18
19     for(int i=1;i<=sum/2;i++){
20         for(int j=1;j<=n;j++){
21             part[i][j] = part[i][j-1];
22             if(i >= arr[j-1])
23                 part[i][j] |= part[i - arr[j-1]][j
24 -1];
25         }
26     }
27     return part[sum / 2][n];

```

3 ED

3.1 Bit

```

1 struct FT {
2     vi bit; // indexado em 1
3     int n;
4
5     FT(int n) {
6         this->n = n+5;
7         bit.assign(n+2, 0);
8     }
9
10    int sum(int idx) {
11        int ret = 0;
12        for(++idx; idx > 0; idx -= idx & -idx)
13            ret += bit[idx];
14        return ret;
15    }
16
17    int sum(int l, int r) { // [l, r]
18        return sum(r) - sum(l - 1);
19    }
20
21    void add(int idx, int delta) {
22        for(++idx; idx < n; idx += idx & -idx)
23            bit[idx] += delta;
24    }
25 };

```

3.2 Bit Kth

```

1 struct FT {
2     vector<int> bit; // indexado em 1
3     int n;
4
5     FT(int n) {
6         this->n = n + 1;
7         bit.assign(n + 1, 0);
8     }
9
10    int kth(int x){
11        int resp = 0;
12        x--;
13        for(int i=26;i>=0;i--){
14            if(resp + (1<<i) >= n) continue;
15            if(bit[resp + (1<<i)] <= x){
16                x -= bit[resp + (1<<i)];
17                resp += (1<<i);

```

```

18        }
19    }
20    return resp + 1;
21 }
22
23 void upd(int pos, int val){
24     for(int i = pos; i < n; i += (i&-i))
25         bit[i] += val;
26 }
27 };

```

3.3 Cht

```

1 const ll is_query = -LLINF;
2 struct Line{
3     ll m, b;
4     mutable function<const Line*> succ;
5     bool operator<(const Line& rhs) const{
6         if(rhs.b != is_query) return m < rhs.m;
7         const Line* s = succ();
8         if(!s) return 0;
9         ll x = rhs.m;
10        return b - s->b < (s->m - m) * x;
11    }
12 };
13 struct Cht : public multiset<Line>{ // maintain max m
14     *x+b
15     bool bad(iterator y){
16         auto z = next(y);
17         if(y == begin()){
18             if(z == end()) return 0;
19             return y->m == z->m && y->b <= z->b;
20         }
21         auto x = prev(y);
22         if(z == end()) return y->m == x->m && y->b <=
23             x->b;
24         return (ld)(x->b - y->b)*(z->m - y->m) >= (ld)
25             (y->b - z->b)*(y->m - x->m);
26     }
27     void insert_line(ll m, ll b){ // min -> insert (-
28         m, -b) -> -eval()
29         auto y = insert({ m, b });
30         y->succ = [=]{ return next(y) == end() ? 0 :
31             &*next(y); };
32         if(bad(y)){ erase(y); return; }
33         while(next(y) != end() && bad(next(y))) erase
34             (next(y));
35         while(y != begin() && bad(prev(y))) erase(
36             prev(y));
37     }
38     ll eval(ll x){
39         auto l = *lower_bound((Line) { x, is_query })
40         ;
41         return l.m * x + l.b;
42     }
43 };

```

3.4 Color Update

```

1 #define ti tuple<int, int, int>
2 struct Color{
3     set<ti> inter; // l, r, color
4     vector<ti> update(int l, int r, int c){
5         if(inter.empty()){ inter.insert({l, r, c});
6         return {}; }
7         vector<ti> removed;
8         auto it = inter.lower_bound({l+1, 0, 0});
9         it = prev(it);
10        while(it != inter.end()){
11            auto [l1, r1, c1] = *it;
12            if((l1<=l and l1<=r) or (l1<=r1 and r1<=r)
13                or (l1<=l and r<=r1)){

```

```

12         removed.pb({l1, r1, c1});
13     }else if(l1 > r)
14         break;
15     it = next(it);
16 }
17 for(auto [l1, r1, c1]: removed){
18     inter.erase({l1, r1, c1});
19     if(l1<l) inter.insert({l1, min(r1, l-1),
20 c1});
21     if(r<r1) inter.insert({max(l1, r+1), r1,
22 c1});
23 }
24 if(c != 0) inter.insert({l, r, c});
25 return removed;
26 }
27 ti query(int i){
28     if(inter.empty()) return {INF, INF, INF};
29     return *prev(inter.lower_bound({i+1, 0, 0}));
30 };

```

3.5 Dsu Queue

```

1 // DSU with queue rollback
2 // Normal DSU implementation with queue-like rollback
3 // find(x) - O(logn)
4 // join(a, b) - O(logn)
5 // pop() - (log^2n) amortized
6
7 struct event {
8     int a, b; // original operation
9     int fa, fb; // fa turned into fb's father
10    bool type; // 1 = inverted, 0 = normal
11 };
12
13 struct DSU {
14     int n;
15     vector<int> parent, size;
16     vector<event> st; int qnt_inv;
17     DSU(int n): n(n), parent(n), size(n, 1), qnt_inv
18 (0) {
19         for (int i=0;i<n;i++) parent[i] = i;
20     }
21     int find(int a) {
22         if (parent[a] == a) return a;
23         return find(parent[a]);
24     }
25     void join(int a, int b, bool inverted=false) {
26         int fa = find(a), fb = find(b);
27         if (size[fa] < size[fb]) swap(fa, fb);
28         st.push_back({a, b, fa, fb, inverted});
29         if (inverted == 1) qnt_inv++;
30         if (fa != fb) {
31             parent[fb] = fa;
32             size[fa] += size[fb];
33         }
34     }
35     void roll_back() {
36         auto [a, b, fa, fb, type] = st.back(); st.
37 pop_back();
38         if (type == 1) qnt_inv--;
39         if (fa != fb) {
40             parent[fb] = fb;
41             size[fa] -= size[fb];
42         }
43     }
44     void pop() {

```

```

47     auto lsb = [](int x) { return x&-x; };
48     if (qnt_inv == 0) { // invert all elements
49         vector<event> normal;
50         while (!st.empty()) {
51             normal.push_back(st.back());
52             roll_back();
53         }
54         for (auto [a, b, fa, fb, type]: normal) {
55             join(a, b, true);
56         }
57     } else if (st.back().type == 0) { // need to
58 reallocate
59         int qnt = lsb(qnt_inv);
60         vector<event> normal, inverted;
61         while (qnt > 0) {
62             event e = st.back();
63             if (e.type == 1) {
64                 inverted.push_back(e);
65                 qnt --;
66             } else {
67                 normal.push_back(e);
68             }
69             roll_back();
70         }
71         while (!normal.empty()) {
72             auto [a, b, fa, fb, type] = normal.
73 back(); normal.pop_back();
74             join(a, b);
75         }
76         while (!inverted.empty()) {
77             auto [a, b, fa, fb, type] = inverted.
78 back(); inverted.pop_back();
79             join(a, b, true);
80         }
81     }
82     // remove the last element
83     roll_back();
84 }
85 };

```

3.6 Minqueue

```

1 struct MinQ {
2     stack<pair<ll,ll>> in;
3     stack<pair<ll,ll>> out;
4
5     void add(ll val) {
6         ll minimum = in.empty() ? val : min(val, in.
7 top().ss);
8         in.push({val, minimum});
9     }
10    ll pop() {
11        if(out.empty()) {
12            while(!in.empty()) {
13                ll val = in.top().ff;
14                in.pop();
15                ll minimum = out.empty() ? val : min(
16 val, out.top().ss);
17                out.push({val, minimum});
18            }
19            ll res = out.top().ff;
20            out.pop();
21            return res;
22        }
23    }
24    ll minn() {
25        ll minimum = LLINF;
26        if(in.empty() || out.empty())
27            minimum = in.empty() ? (ll)out.top().ss :
28 (ll)in.top().ss;

```



```

28         else
29             minimum = min((ll)in.top().ss, (ll)out.
30 top().ss);
31         return minimum;
32     }
33
34     ll size() {
35         return in.size() + out.size();
36     }
37 };

```

3.7 Segtree Implicita

```

1 // SegTree Implicita O(nlogMAX)
2
3 struct node{
4     int val;
5     int l, r;
6     node(int a=0, int b=0, int c=0){
7         l=a;r=b;val=c;
8     }
9 };
10
11 int idx=2; // 1-> root / 0-> zero element
12 node t[8600010];
13 int N;
14
15 int merge(int a, int b){
16     return a + b;
17 }
18
19 void update(int pos, int x, int i=1, int j=N, int no
20 =1){
21     if(i==j){
22         t[no].val+=x;
23         return;
24     }
25     int meio = (i+j)/2;
26
27     if(pos<=meio){
28         if(t[no].l==0) t[no].l=idx++;
29         update(pos, x, i, meio, t[no].l);
30     }
31     else{
32         if(t[no].r==0) t[no].r=idx++;
33         update(pos, x, meio+1, j, t[no].r);
34     }
35
36     t[no].val=merge(t[t[no].l].val, t[t[no].r].val);
37 }
38
39 int query(int A, int B, int i=1, int j=N, int no=1){
40     if(B<i or j<A)
41         return 0;
42     if(A<=i and j<=B)
43         return t[no].val;
44
45     int mid = (i+j)/2;
46
47     int ans1 = 0, ansr = 0;
48
49     if(t[no].l!=0) ans1 = query(A, B, i, mid, t[no].l
50 );
51     if(t[no].r!=0) ansr = query(A, B, mid+1, j, t[no
52 ].r);
53
54     return merge(ans1, ansr);
55 }

```

3.8 Segtree Implicita Lazy

```

1 struct node{
2     pll val;
3     ll lazy;
4     ll l, r;
5     node(){
6         l=-1;r=-1;val={0,0};lazy=0;
7     }
8 };
9
10 node tree[40*MAX];
11 int id = 2;
12 ll N=1e9+10;
13
14 pll merge(pll A, pll B){
15     if(A.ff==B.ff) return {A.ff, A.ss+B.ss};
16     return (A.ff<B.ff ? A:B);
17 }
18
19 void prop(ll l, ll r, int no){
20     ll mid = (l+r)/2;
21     if(l!=r){
22         if(tree[no].l==-1){
23             tree[no].l = id++;
24             tree[tree[no].l].val = {0, mid-l+1};
25         }
26         if(tree[no].r==-1){
27             tree[no].r = id++;
28             tree[tree[no].r].val = {0, r-(mid+1)+1};
29         }
30         tree[tree[no].l].lazy += tree[no].lazy;
31         tree[tree[no].r].lazy += tree[no].lazy;
32     }
33     tree[no].val.ff += tree[no].lazy;
34     tree[no].lazy=0;
35 }
36
37 void update(int a, int b, int x, ll l=0, ll r=2*N, ll
38 no=1){
39     prop(l, r, no);
40     if(a<=l and r<=b){
41         tree[no].lazy += x;
42         prop(l, r, no);
43         return;
44     }
45     if(r<a or b<l) return;
46     int m = (l+r)/2;
47     update(a, b, x, l, m, tree[no].l);
48     update(a, b, x, m+1, r, tree[no].r);
49
50     tree[no].val = merge(tree[tree[no].l].val, tree[
51 tree[no].r].val);
52 }
53
54 pll query(int a, int b, int l=0, int r=2*N, int no=1)
55 {
56     prop(l, r, no);
57     if(a<=l and r<=b) return tree[no].val;
58     if(r<a or b<l) return {INF, 0};
59     int m = (l+r)/2;
60     int left = tree[no].l, right = tree[no].r;
61
62     return tree[no].val = merge(query(a, b, l, m,
63 left),
64 query(a, b, m+1, r,
65 right));
66 }

```

3.9 Segtree Iterative

```

1 struct Segtree{
2     int n; vector<int> t;
3     Segtree(int n): n(n), t(2*n, 0) {}
4 }

```

```

5   int f(int a, int b) { return max(a, b); }
6
7   void build(){
8       for(int i=n-1; i>0; i--)
9           t[i] = f(t[i<<1], t[i<<1|1]);
10  }
11
12  int query(int l, int r) { // [l, r]
13      int resl = -INF, resr = -INF;
14      for(l+=n, r+=n+1; l<r; l>>=1, r>>=1) {
15          if(l&1) resl = f(resl, t[l++]);
16          if(r&1) resr = f(t[--r], resr);
17      }
18      return f(resl, resr);
19  }
20
21  void update(int p, int value) {
22      for(t[p+=n]=value; p >>= 1;)
23          t[p] = f(t[p<<1], t[p<<1|1]);
24  }
25 };

```

3.10 Segtree Maxsubarray

```

1 // Subarray with maximum sum
2 struct no{
3     ll p, s, t, b; // prefix, suffix, total, best
4     no(ll x=0): p(x), s(x), t(x), b(x){}
5 };
6
7 struct Segtree{
8     vector<no> t;
9     int n;
10
11     Segtree(int n){
12         this->n = n;
13         t.assign(2*n, no(0));
14     }
15
16     no merge(no l, no r){
17         no ans;
18         ans.p = max(OLL, max(l.p, l.t+r.p));
19         ans.s = max(OLL, max(r.s, l.s+r.t));
20         ans.t = l.t+r.t;
21         ans.b = max(max(l.b, r.b), l.s+r.p);
22         return ans;
23     }
24
25     void build(){
26         for(int i=n-1; i>0; i--)
27             t[i]=merge(t[i<<1], t[i<<1|1]);
28     }
29
30     no query(int l, int r){ // idx 0
31         no a(0), b(0);
32         for(l+=n, r+=n+1; l<r; l>>=1, r>>=1){
33             if(l&1)
34                 a=merge(a, t[l++]);
35             if(r&1)
36                 b=merge(t[--r], b);
37         }
38         return merge(a, b);
39     }
40
41     void update(int p, int value){
42         for(t[p+=n] = no(value); p >>= 1;)
43             t[p] = merge(t[p<<1], t[p<<1|1]);
44     }
45 };
46 };

```

3.11 Segtree Pa

```

1 int N;
2 vl t(4*MAX, 0);
3 vl v(MAX, 0);
4 vector<pll> lazy(4*MAX, {0,0});
5 // [x, x+y, x+2y...] //
6
7 inline ll merge(ll a, ll b){
8     return a + b;
9 }
10
11 void build(int l=0, int r=N-1, int no=1){
12     if(l == r){ t[no] = v[l]; return; }
13     int mid = (l + r) / 2;
14     build(l, mid, 2*no);
15     build(mid+1, r, 2*no+1);
16     t[no] = merge(t[2*no], t[2*no+1]);
17 }
18
19 inline pll sum(pll a, pll b){ return {a.ff+b.ff, a.ss
20     +b.ss}; }
21
22 inline void prop(int l, int r, int no){
23     auto [x, y] = lazy[no];
24     if(x==0 and y==0) return;
25     ll len = (r-l+1);
26     t[no] += (x + x + y*(len-1))*len / 2;
27     if(l != r){
28         int mid = (l + r) / 2;
29         lazy[2*no] = sum(lazy[2*no], lazy[no]);
30         lazy[2*no+1] = sum(lazy[2*no+1], {x + (mid-1
31             +1)*y, y});
32     }
33     lazy[no] = {0,0};
34 }
35
36 ll query(int a, int b, int l=0, int r=N-1, int no=1){
37     prop(l, r, no);
38     if(r<a or b<l) return 0;
39     if(a<=l and r<=b) return t[no];
40     int mid = (l + r) / 2;
41     return merge(
42         query(a, b, l, mid, 2*no),
43         query(a, b, mid+1, r, 2*no+1)
44     );
45 }
46
47 void update(int a, int b, ll x, ll y, int l=0, int r=
48     N-1, int no=1){
49     prop(l, r, no);
50     if(r<a or b<l) return;
51     if(a<=l and r<=b){
52         lazy[no] = {x, y};
53         prop(l, r, no);
54         return;
55     }
56     int mid = (l + r) / 2;
57     update(a, b, x, y, l, mid, 2*no);
58     update(a, b, x + max((mid-max(l, a)+1)*y, OLL), y
59         , mid+1, r, 2*no+1);
60     t[no] = merge(t[2*no], t[2*no+1]);
61 }

```

3.12 Segtree Recursive

```

1 vector<ll> t(4*N, 0);
2 vector<ll> lazy(4*N, 0);
3
4 inline ll f(ll a, ll b) {
5     return a + b;
6 }
7
8 void build(vector<int> &v, int lx=0, int rx=N-1, int
9     x=1) {

```

```

9     if (lx == rx) { if (lx < v.size()) t[x] = v[lx];
10    return; }
11    int mid = (lx + rx) / 2;
12    build(v, lx, mid, 2*x);
13    build(v, mid+1, rx, 2*x+1);
14    t[x] = f(t[2*x], t[2*x+1]);
15 }
16 void prop(int lx, int rx, int x) {
17     if (lazy[x] != 0) {
18         t[x] += lazy[x] * (rx-lx+1);
19         if (lx != rx) {
20             lazy[2*x] += lazy[x];
21             lazy[2*x+1] += lazy[x];
22         }
23         lazy[x] = 0;
24     }
25 }
26
27 ll query(int l, int r, int lx=0, int rx=N-1, int x=1)
28 {
29     prop(lx, rx, x);
30     if (r < lx or rx < l) return 0;
31     if (l <= lx and rx <= r) return t[x];
32     int mid = (lx + rx) / 2;
33     return f(
34         query(l, r, lx, mid, 2*x),
35         query(l, r, mid+1, rx, 2*x+1)
36     );
37 }
38 void update(int l, int r, ll val, int lx=0, int rx=N-1, int x=1) {
39     prop(lx, rx, x);
40     if (r < lx or rx < l) return;
41     if (l <= lx and rx <= r) {
42         lazy[x] += val;
43         prop(lx, rx, x);
44         return;
45     }
46     int mid = (lx + rx) / 2;
47     update(l, r, val, lx, mid, 2*x);
48     update(l, r, val, mid+1, rx, 2*x+1);
49     t[x] = f(t[2*x], t[2*x+1]);
50 }

```

3.13 Sparse Table

```

1 int logv[N+1];
2 void make_log() {
3     logv[1] = 0; // pre-comutar tabela de log
4     for (int i = 2; i <= N; i++)
5         logv[i] = logv[i/2] + 1;
6 }
7 struct Sparse {
8     int n;
9     vector<vector<int>> st;
10
11     Sparse(vector<int>& v) {
12         n = v.size();
13         int k = logv[n];
14         st.assign(n+1, vector<int>(k+1, 0));
15
16         for (int i=0; i<n; i++) {
17             st[i][0] = v[i];
18         }
19
20         for (int j = 1; j <= k; j++) {
21             for (int i = 0; i + (1 << j) <= n; i++) {
22                 st[i][j] = f(st[i][j-1], st[i + (1 <<
23                 (j-1))][j-1]);
24             }
25         }
26     }

```

```

25 }
26
27 int f(int a, int b) {
28     return min(a, b);
29 }
30
31 int query(int l, int r) {
32     int k = logv[r-l+1];
33     return f(st[l][k], st[r - (1 << k) + 1][k]);
34 }
35 };
36
37 struct Sparse2d {
38     int n, m;
39     vector<vector<vector<int>>> st;
40
41     Sparse2d(vector<vector<int>> mat) {
42         n = mat.size();
43         m = mat[0].size();
44         int k = logv[min(n, m)];
45
46         st.assign(n+1, vector<vector<int>>(m+1,
47         vector<int>(k+1)));
48         for (int i = 0; i < n; i++)
49             for (int j = 0; j < m; j++)
50                 st[i][j][0] = mat[i][j];
51
52         for (int j = 1; j <= k; j++) {
53             for (int x1 = 0; x1 < n; x1++) {
54                 for (int y1 = 0; y1 < m; y1++) {
55                     int delta = (1 << (j-1));
56                     if (x1+delta >= n or y1+delta >= m)
57                         continue;
58
59                     st[x1][y1][j] = st[x1][y1][j-1];
60                     st[x1][y1][j] = f(st[x1][y1][j],
61                     st[x1+delta][y1][j-1]);
62                     st[x1][y1][j] = f(st[x1][y1][j],
63                     st[x1+delta][y1+delta][j-1]);
64                 }
65             }
66         }
67
68         // so funciona para quadrados
69         int query(int x1, int y1, int x2, int y2) {
70             assert(x2-x1+1 == y2-y1+1);
71             int k = logv[x2-x1+1];
72             int delta = (1 << k);
73
74             int res = st[x1][y1][k];
75             res = f(res, st[x2 - delta+1][y1][k]);
76             res = f(res, st[x1][y2 - delta+1][k]);
77             res = f(res, st[x2 - delta+1][y2 - delta+1][k]);
78         }
79         return res;
80     }
81
82     int f(int a, int b) {
83         return a | b;
84     }
85 };

```

3.14 Treap

```

1 mt19937 rng(chrono::steady_clock::now().
2     time_since_epoch().count()); // mt19937_64
3 uniform_int_distribution<int> distribution(1, INF);

```

```

4  const int N = 2e5+10;
5  int nxt = 0;
6  int X[N], Y[N], L[N], R[N], sz[N], idx[N];
7  bool flip[N];
8
9  //! Call this before anything else
10 void build() {
11     iota(Y+1, Y+N, 1);
12     shuffle(Y+1, Y+N, rng); // rng :: mt19937
13 }
14
15 int new_node(int x, int id) {
16     int u = ++nxt;
17     idx[u] = id;
18     sz[u] = 1;
19     X[u] = x;
20     return u;
21 }
22
23 void push(int u) { // also known as unlaze
24     if(!u) return;
25     if (flip[u]) {
26         flip[u] = false;
27         flip[L[u]] ^= 1;
28         flip[R[u]] ^= 1;
29         swap(L[u], R[u]);
30     }
31 }
32
33 void pull(int u) { // also known as fix
34     if (!u) return;
35     sz[u] = sz[L[u]] + 1 + sz[R[u]];
36 }
37
38 // root = merge(l, r);
39 int merge(int l, int r) {
40     push(l); push(r);
41     int u;
42     if (!l || !r) {
43         u = l ? l : r;
44     } else if (Y[l] < Y[r]) {
45         u = l;
46         R[u] = merge(R[u], r);
47     } else {
48         u = r;
49         L[u] = merge(l, L[u]);
50     }
51     pull(u);
52     return u;
53 }
54
55 // (s elements, N - s elements)
56 pair<int, int> splitsz(int u, int s) {
57     if (!u) return {0, 0};
58     push(u);
59     if (sz[L[u]] >= s) {
60         auto [l, r] = splitsz(L[u], s);
61         L[u] = r;
62         pull(u);
63         return {l, u};
64     } else {
65         auto [l, r] = splitsz(R[u], s - sz[L[u]] - 1);
66         R[u] = l;
67         pull(u);
68         return {u, r};
69     }
70 }
71
72 // (<= x, > x)
73 pair<int, int> splitval(int u, int x) {
74     if (!u) return {0, 0};
75     push(u);

```

```

76     if (X[u] > x) {
77         auto [l, r] = splitval(L[u], x);
78         L[u] = r;
79         pull(u);
80         return {l, u};
81     } else {
82         auto [l, r] = splitval(R[u], x);
83         R[u] = l;
84         pull(u);
85         return {u, r};
86     }
87 }
88
89 int insert(int u, int node) {
90     push(u);
91     if (!u) return node;
92     if (Y[node] < Y[u]) {
93         tie(L[node], R[node]) = splitval(u, X[node]);
94         u = node;
95     }
96     else if (X[node] < X[u]) L[u] = insert(L[u], node);
97     else R[u] = insert(R[u], node);
98     pull(u);
99     return u;
100 }
101
102 int find(int u, int x) {
103     return u == 0 ? 0 :
104         x == X[u] ? u :
105         x < X[u] ? find(L[u], x) :
106             find(R[u], x);
107 }
108
109 void free(int u) { /* node u can be deleted, maybe
110     put in a pool of free IDs */ }
111
112 int erase(int u, int key) {
113     push(u);
114     if (!u) return 0;
115     if (X[u] == key) {
116         int v = merge(L[u], R[u]);
117         free(u);
118         u = v;
119     } else u = erase(key < X[u] ? L[u] : R[u], key);
120     pull(u);
121     return u;

```

3.15 Virtual Tree

```

1  bool initialized = false;
2  int original_root = 1;
3  const int E = 2 * N;
4  vector<int> vt[N]; // virtual tree edges
5  int in[N], out[N], T, t[E<<1];
6  void dfs_time(int u, int p = 0) {
7      in[u] = ++T;
8      t[T + E] = u;
9      for (int v : g[u]) if (v != p) {
10         dfs_time(v, u);
11         t[++T + E] = u;
12     }
13     out[u] = T;
14 }
15
16 int take(int u, int v) { return in[u] < in[v] ? u : v; }
17
18 bool cmp_in(int u, int v) { return in[u] < in[v]; }
19 void build_st() {
20     in[0] = 0x3f3f3f3f;
21     for (int i = E-1; i > 0; i--)
22         t[i] = take(t[i<<1], t[i<<1+1]);

```

```

22 }
23
24 int query(int l, int r) {
25     int ans = 0;
26     for (l+=E, r+=E; l < r; l>>=1, r>>=1) {
27         if (l&1) ans = take(ans, t[l++]);
28         if (r&1) ans = take(ans, t[--r]);
29     }
30     return ans;
31 }
32
33 int get_lca(int u, int v) {
34     if (in[u] > in[v]) swap(u, v);
35     return query(in[u], out[v]+1);
36 }
37
38 int covers(int u, int v) { // does u cover v?
39     return in[u] <= in[v] && out[u] >= out[v];
40 }
41
42 int build_vt(vector<int>& vnodes) {
43     assert(initialized);
44
45     sort(all(vnodes), cmp_in);
46     int n = vnodes.size();
47     for (int i = 0; i < n-1; i++) {
48         int u = vnodes[i], v = vnodes[i+1];
49         vnodes.push_back(get_lca(u, v));
50     }
51     sort(all(vnodes), cmp_in);
52     vnodes.erase(unique(all(vnodes)), vnodes.end());
53
54     for (int u : vnodes)
55         vt[u].clear();
56
57     stack<int> s;
58     for (int u : vnodes) {
59         while (!s.empty() && !covers(s.top(), u))
60             s.pop();
61         if (!s.empty()) vt[s.top()].push_back(u);
62         s.push(u);
63     }
64     return vnodes[0]; // root
65 }
66
67 void initialize() {
68     initialized = true;
69     dfs_time(original_root);
70     build_st();
71 }

```

4 Geometria

4.1 2d

```

1 #define vp vector<point>
2 #define ld long double
3 const ld EPS = 1e-6;
4 const ld PI = acos(-1);
5
6 typedef ld T;
7 bool eq(T a, T b){ return abs(a - b) <= EPS; }
8
9 struct point{
10     T x, y;
11     int id;
12     point(T x=0, T y=0): x(x), y(y){}
13
14     point operator+(const point &o) const{ return {x
15         + o.x, y + o.y}; }
16     point operator-(const point &o) const{ return {x
17         - o.x, y - o.y}; }

```

```

16     point operator*(T t) const{ return {x * t, y * t
17 }; }
18     point operator/(T t) const{ return {x / t, y / t
19 }; }
20     T operator*(const point &o) const{ return x * o.x
21         + y * o.y; }
22     T operator^(const point &o) const{ return x * o.y
23         - y * o.x; }
24     bool operator<(const point &o) const{
25         return (eq(x, o.x) ? y < o.y : x < o.x);
26     }
27     bool operator==(const point &o) const{
28         return eq(x, o.x) and eq(y, o.y);
29     }
30     friend ostream& operator<<(ostream& os, point p)
31     {
32         return os << "(" << p.x << "," << p.y << ")";
33     }
34 };
35
36 int ccw(point a, point b, point e){ // -1=dir; 0=
37     collinear; 1=esq;
38     T tmp = (b-a) ^ (e-a); // vector from a to b
39     return (tmp > EPS) - (tmp < -EPS);
40 }
41
42 ld norm(point a){ // Modulo
43     return sqrt(a * a);
44 }
45
46 T norm2(point a){
47     return a * a;
48 }
49
50 bool nulo(point a){
51     return (eq(a.x, 0) and eq(a.y, 0));
52 }
53
54 point rotccw(point p, ld a){
55     // a = PI*a/180; // graus
56     return point((p.x*cos(a)-p.y*sin(a)), (p.y*cos(a)
57         +p.x*sin(a)));
58 }
59
60 point rot90cw(point a) { return point(a.y, -a.x); };
61 point rot90ccw(point a) { return point(-a.y, a.x); };
62
63 ld proj(point a, point b){ // a sobre b
64     return a*b/norm(b);
65 }
66
67 ld angle(point a, point b){ // em radianos
68     ld ang = a*b / norm(a) / norm(b);
69     return acos(max(min(ang, (ld)1), (ld)-1));
70 }
71
72 ld angle_vec(point v){
73     // return 180/PI*atan2(v.x, v.y); // graus
74     return atan2(v.x, v.y);
75 }
76
77 ld order_angle(point a, point b){ // from a to b ccw
78     (a in front of b)
79     ld aux = angle(a,b)*180/PI;
80     return ((a^b)<=0 ? aux:360-aux);
81 }
82
83 bool angle_less(point a1, point b1, point a2, point
84     b2){ // ang(a1,b1) <= ang(a2,b2)
85     point p1((a1*b1), abs((a1^b1)));
86     point p2((a2*b2), abs((a2^b2)));
87     return (p1^p2) <= 0;
88 }
89
90 ld area(vp &p){ // (points sorted)
91     ld ret = 0;
92     for(int i=2;i<(int)p.size();i++)
93         ret += (p[i]-p[0])^(p[i-1]-p[0]);
94     return abs(ret/2);
95 }
96
97 ld areaT(point &a, point &b, point &c){

```

```

79     return abs((b-a)^(c-a))/2.0;
80 }
81
82 point center(vp &A){
83     point c = point();
84     int len = A.size();
85     for(int i=0;i<len;i++){
86         c=c+A[i];
87     }
88     return c/len;
89 }
90
91 point forca_mod(point p, ld m){
92     ld cm = norm(p);
93     if(cm<EPS) return point();
94     return point(p.x*m/cm,p.y*m/cm);
95 }
96
97 ld param(point a, point b, point v){
98     // v = t*(b-a) + a // return t;
99     // assert(line(a, b).inside_seg(v));
100    return ((v-a) * (b-a)) / ((b-a) * (b-a));
101 }
102
103 bool simetric(vp &a){ //ordered
104     int n = a.size();
105     point c = center(a);
106     if(n&1) return false;
107     for(int i=0;i<n/2;i++){
108         if(ccw(a[i], a[i+n/2], c) != 0)
109             return false;
110     }
111     return true;
112 }
113
114 point mirror(point m1, point m2, point p){
115     // mirror point p around segment m1m2
116     point seg = m2-m1;
117     ld t0 = ((p-m1)*seg) / (seg*seg);
118     point ort = m1 + seg*t0;
119     point pm = ort-(p-ort);
120     return pm;
121 }
122
123 // Line
124
125
126 struct line{
127     point p1, p2;
128     T a, b, c; // ax+by+c = 0;
129     // y-y1 = ((y2-y1)/(x2-x1))(x-x1)
130     line(point p1=0, point p2=0): p1(p1), p2(p2){
131         a = p1.y - p2.y;
132         b = p2.x - p1.x;
133         c = p1 ^ p2;
134     }
135     line(T a=0, T b=0, T c=0): a(a), b(b), c(c){
136         // Gera os pontos p1 p2 dados os coeficientes
137         // isso aqui eh um lixo mas quebra um galho
138         kkkkkk
139         if(b==0){
140             p1 = point(1, -c/a);
141             p2 = point(0, -c/a);
142         }else{
143             p1 = point(1, (-c-a*1)/b);
144             p2 = point(0, -c/b);
145         }
146     }
147     T eval(point p){
148         return a*p.x+b*p.y+c;
149     }
150     bool inside(point p){

```

```

151         return eq(eval(p), 0);
152     }
153     point normal(){
154         return point(a, b);
155     }
156 }
157
158 bool inside_seg(point p){
159     return (
160         ((p1-p) ^ (p2-p)) == 0 and
161         ((p1-p) * (p2-p)) <= 0
162     );
163 }
164 };
165
166 // be careful with precision error
167 vp inter_line(line l1, line l2){
168     ld det = l1.a*l2.b - l1.b*l2.a;
169     if(det==0) return {};
170     ld x = (l1.b*l2.c - l1.c*l2.b)/det;
171     ld y = (l1.c*l2.a - l1.a*l2.c)/det;
172     return {point(x, y)};
173 }
174
175 // segments not collinear
176 vp inter_seg(line l1, line l2){
177     vp ans = inter_line(l1, l2);
178     if(ans.empty() or !l1.inside_seg(ans[0]) or !l2.
179         inside_seg(ans[0]))
180         return {};
181     return ans;
182 }
183
184 bool seg_has_inter(line l1, line l2){
185     return ccw(l1.p1, l1.p2, l2.p1) * ccw(l1.p1, l1.
186         p2, l2.p2) < 0 and
187         ccw(l2.p1, l2.p2, l1.p1) * ccw(l2.p1, l2.
188         p2, l1.p2) < 0;
189 }
190
191 ld dist_seg(point p, point a, point b){ // point -
192     seg
193     if((p-a)*(b-a) < EPS) return norm(p-a);
194     if((p-b)*(a-b) < EPS) return norm(p-b);
195     return abs((p-a)^(b-a)) / norm(b-a);
196 }
197
198 ld dist_line(point p, line l){ // point - line
199     return abs(l.eval(p))/sqrt(1.a*1.a + 1.b*1.b);
200 }
201
202 line bisector(point a, point b){
203     point d = (b-a)*2;
204     return line(d.x, d.y, a*a - b*b);
205 }
206
207 line perpendicular(line l, point p){ // passes
208     through p
209     return line(l.b, -l.a, -l.b*p.x + l.a*p.y);
210 }
211
212 // Circle
213
214 struct circle{
215     point c; T r;
216     circle() : c(0, 0), r(0){}
217     circle(const point o) : c(o), r(0){}
218     circle(const point a, const point b){
219         c = (a+b)/2;
220         r = norm(a-c);
221     }

```

```

219 circle(const point a, const point b, const point cc){
220     assert(ccw(a, b, cc) != 0);
221     c = inter_line(bisector(a, b), bisector(b, c))[0];
222     r = norm(a-c);
223 }
224 bool inside(const point &a) const{
225     return norm(a - c) <= r + EPS;
226 }
227 };
228
229 pair<point, point> tangent_points(circle cr, point p){
230     {
231         ld d1 = norm(p-cr.c), theta = asin(cr.r/d1);
232         point p1 = rotccw(cr.c-p, -theta);
233         point p2 = rotccw(cr.c-p, theta);
234         assert(d1 >= cr.r);
235         p1 = p1 * (sqrt(d1*d1-cr.r*cr.r) / d1) + p;
236         p2 = p2 * (sqrt(d1*d1-cr.r*cr.r) / d1) + p;
237     }
238     return {p1, p2};
239 }
240 circle incircle(point p1, point p2, point p3){
241     ld m1 = norm(p2-p3);
242     ld m2 = norm(p1-p3);
243     ld m3 = norm(p1-p2);
244     point c = (p1*m1 + p2*m2 + p3*m3)*(1/(m1+m2+m3));
245     ld s = 0.5*(m1+m2+m3);
246     ld r = sqrt(s*(s-m1)*(s-m2)*(s-m3)) / s;
247     return circle(c, r);
248 }
249
250 circle circumcircle(point a, point b, point c) {
251     circle ans;
252     point u = point((b-a).y, -(b-a).x);
253     point v = point((c-a).y, -(c-a).x);
254     point n = (c-b)*0.5;
255     ld t = (u^v)/(v^u);
256     ans.c = ((a+c)*0.5) + (v*t);
257     ans.r = norm(ans.c-a);
258     return ans;
259 }
260
261 vp inter_circle_line(circle C, line L){
262     point ab = L.p2 - L.p1, p = L.p1 + ab * ((C.c-L.p1)*(ab) / (ab*ab));
263     ld s = (L.p2-L.p1)^(C.c-L.p1), h2 = C.r*C.r - s*s / (ab*ab);
264     if (h2 < -EPS) return {};
265     if (eq(h2, 0)) return {p};
266     point h = (ab/norm(ab)) * sqrt(h2);
267     return {p - h, p + h};
268 }
269
270 vp inter_circle(circle c1, circle c2){
271     if (c1.c == c2.c) { assert(c1.r != c2.r); return {}; }
272     point vec = c2.c - c1.c;
273     ld d2 = vec * vec, sum = c1.r + c2.r, dif = c1.r - c2.r;
274     ld p = (d2 + c1.r * c1.r - c2.r * c2.r) / (2 * d2);
275     ld h2 = c1.r * c1.r - p * p * d2;
276     if (sum * sum < d2 or dif * dif > d2) return {};
277     point mid = c1.c + vec * p, per = point(-vec.y, vec.x) * sqrt(fmax(0, h2) / d2);
278     if (eq(per.x, 0) and eq(per.y, 0)) return {mid};
279     return {mid + per, mid - per};
280 }
281
282 // minimum circle cover O(n) amortizado

```

```

283 circle min_circle_cover(vp v){
284     random_shuffle(v.begin(), v.end());
285     circle ans;
286     int n = v.size();
287     for(int i=0;i<n;i++) if(!ans.inside(v[i])){
288         ans = circle(v[i]);
289         for(int j=0;j<i;j++) if(!ans.inside(v[j])){
290             ans = circle(v[i], v[j]);
291             for(int k=0;k<j;k++) if(!ans.inside(v[k])){
292                 ans = circle(v[i], v[j], v[k]);
293             }
294         }
295     }
296     return ans;
297 }

```

4.2 3d

```

1 // typedef ll cod;
2 // bool eq(cod a, cod b){ return (a==b); }
3
4 const ld EPS = 1e-6;
5 #define vp vector<point>
6 typedef ld cod;
7 bool eq(cod a, cod b){ return fabs(a - b) <= EPS; }
8
9 struct point
10 {
11     cod x, y, z;
12     point(cod x=0, cod y=0, cod z=0): x(x), y(y), z(z) {}
13
14     point operator+(const point &o) const {
15         return {x+o.x, y+o.y, z+o.z};
16     }
17     point operator-(const point &o) const {
18         return {x-o.x, y-o.y, z-o.z};
19     }
20     point operator*(cod t) const {
21         return {x*t, y*t, z*t};
22     }
23     point operator/(cod t) const {
24         return {x/t, y/t, z/t};
25     }
26     bool operator==(const point &o) const {
27         return eq(x, o.x) and eq(y, o.y) and eq(z, o.z);
28     }
29     cod operator*(const point &o) const { // dot
30         return x*o.x + y*o.y + z*o.z;
31     }
32     point operator^(const point &o) const { // cross
33         return point(y*o.z - z*o.y,
34                     z*o.x - x*o.z,
35                     x*o.y - y*o.x);
36     }
37 };
38
39 ld norm(point a) { // Modulo
40     return sqrt(a * a);
41 }
42 cod norm2(point a) {
43     return a * a;
44 }
45 bool nulo(point a) {
46     return (eq(a.x, 0) and eq(a.y, 0) and eq(a.z, 0));
47 }
48 ld proj(point a, point b) { // a sobre b
49     return (a*b)/norm(b);
50 }
51 ld angle(point a, point b) { // em radianos

```

```

52     return acos((a*b) / norm(a) / norm(b));
53 }
54
55 cod triple(point a, point b, point c) {
56     return (a * (b^c)); // Area do paralelepipedo
57 }
58
59 point normilize(point a) {
60     return a/norm(a);
61 }
62
63 struct plane {
64     cod a, b, c, d;
65     point p1, p2, p3;
66     plane(point p1=0, point p2=0, point p3=0): p1(p1)
67     , p2(p2), p3(p3) {
68         point aux = (p1-p3)^(p2-p3);
69         a = aux.x; b = aux.y; c = aux.z;
70         d = -a*p1.x - b*p1.y - c*p1.z;
71     }
72     plane(point p, point normal) {
73         normal = normilize(normal);
74         a = normal.x; b = normal.y; c = normal.z;
75         d = -(p*normal);
76     }
77     // ax+by+cz+d = 0;
78     cod eval(point &p) {
79         return a*p.x + b*p.y + c*p.z + d;
80     }
81 };
82
83 cod dist(plane pl, point p) {
84     return fabs(pl.a*p.x + pl.b*p.y + pl.c*p.z + pl.d
85 ) / sqrt(pl.a*pl.a + pl.b*pl.b + pl.c*pl.c);
86 }
87
88 point rotate(point v, point k, ld theta) {
89     // Rotaciona o vetor v theta graus em torno do
90     eixo k
91     // theta *= PI/180; // graus
92     return (
93         v*cos(theta)) +
94         ((k^v)*sin(theta)) +
95         (k*(k^v))*(1-cos(theta))
96 );
97
98 // 3d line inter / mindistance
99 cod d(point p1, point p2, point p3, point p4) {
100     return (p2-p1) * (p4-p3);
101 }
102
103 vector<point> inter3d(point p1, point p2, point p3,
104 point p4) {
105     cod mua = ( d(p1, p3, p4, p3) * d(p4, p3, p2, p1)
106 - d(p1, p3, p2, p1) * d(p4, p3, p4, p3) )
107 / ( d(p2, p1, p2, p1) * d(p4, p3, p4, p3)
108 - d(p4, p3, p2, p1) * d(p4, p3, p2, p1) );
109     cod mub = ( d(p1, p3, p4, p3) + mua * d(p4, p3,
110 p2, p1) ) / d(p4, p3, p4, p3);
111     point pa = p1 + (p2-p1) * mua;
112     point pb = p3 + (p4-p3) * mub;
113     if (pa == pb) return {pa};
114     return {};
115 }

```

4.3 Convex Hull

```

1 vp convex_hull(vp P)
2 {
3     sort(P.begin(), P.end());
4     vp L, U;
5     for(auto p: P){

```

```

6         while(L.size()>=2 and ccw(L.end()[-2], L.back
7         (), p)!=1)
8             L.pop_back();
9             L.push_back(p);
10     }
11     reverse(P.begin(), P.end());
12     for(auto p: P){
13         while(U.size()>=2 and ccw(U.end()[-2], U.back
14         (), p)!=1)
15             U.pop_back();
16             U.push_back(p);
17     }
18     L.pop_back();
19     L.insert(L.end(), U.begin(), U.end()-1);
20     return L;
21 }

```

4.4 Delaunay

```

1 cod areaT2(point &a, point &b, point &c){
2     return abs((b-a)^(c-a));
3 }
4
5 typedef struct QuadEdge* Q;
6 struct QuadEdge {
7     int id;
8     point o;
9     Q rot, nxt;
10    bool used;
11
12    QuadEdge(int id_ = -1, point o_ = point(INF, INF)
13    ) :
14        id(id_), o(o_), rot(nullptr), nxt(nullptr),
15        used(false) {}
16
17    Q rev() const { return rot->rot; }
18    Q next() const { return rot->nxt; }
19    Q prev() const { return rot->nxt->rot; }
20    point dest() const { return rev()->o; }
21 };
22
23 Q edge(point from, point to, int id_from, int id_to)
24 {
25     Q e1 = new QuadEdge(id_from, from);
26     Q e2 = new QuadEdge(id_to, to);
27     Q e3 = new QuadEdge;
28     Q e4 = new QuadEdge;
29     tie(e1->rot, e2->rot, e3->rot, e4->rot) = {e3, e4
30     , e2, e1};
31     tie(e1->nxt, e2->nxt, e3->nxt, e4->nxt) = {e1, e2
32     , e4, e3};
33     return e1;
34 }
35
36 void splice(Q a, Q b) {
37     swap(a->nxt->rot->nxt, b->nxt->rot->nxt);
38     swap(a->nxt, b->nxt);
39 }
40
41 void del_edge(Q& e, Q ne) { // delete e and assign e
42     <- ne
43     splice(e, e->prev());
44     splice(e->rev(), e->rev()->prev());
45     delete e->rev()->rot, delete e->rev();
46     delete e->rot; delete e;
47     e = ne;
48 }
49
50 Q conn(Q a, Q b) {
51     Q e = edge(a->dest(), b->o, a->rev()->id, b->id);
52     splice(e, a->rev()->prev());
53     splice(e->rev(), b);
54     return e;
55 }

```



```

49 }
50
51 bool in_c(point a, point b, point c, point p) { // p
52     ta na circunf. (a, b, c) ?
53     __int128 p2 = p*p, A = a*a - p2, B = b*b - p2, C
54     = c*c - p2;
55     return areaT2(p, a, b) * C + areaT2(p, b, c) * A
56     + areaT2(p, c, a) * B > 0;
57 }
58
59 pair<Q, Q> build_tr(vector<point>& p, int l, int r) {
60     if (r-l+1 <= 3) {
61         Q a = edge(p[l], p[l+1], l, l+1), b = edge(p[
62         l+1], p[r], l+1, r);
63         if (r-l+1 == 2) return {a, a->rev()};
64         splice(a->rev(), b);
65         ll ar = areaT2(p[l], p[l+1], p[r]);
66         Q c = ar ? conn(b, a) : 0;
67         if (ar >= 0) return {a, b->rev()};
68         return {c->rev(), c};
69     }
70     int m = (l+r)/2;
71     auto [la, ra] = build_tr(p, l, m);
72     auto [lb, rb] = build_tr(p, m+1, r);
73     while (true) {
74         if (ccw(lb->o, ra->o, ra->dest())) ra = ra->
75         rev()->prev();
76         else if (ccw(lb->o, ra->o, lb->dest())) lb =
77         lb->rev()->next();
78         else break;
79     }
80     Q b = conn(lb->rev(), ra);
81     auto valid = [&](Q e) { return ccw(e->dest(), b->
82     dest(), b->o); };
83     if (ra->o == la->o) la = b->rev();
84     if (lb->o == rb->o) rb = b;
85     while (true) {
86         Q L = b->rev()->next();
87         if (valid(L)) while (in_c(b->dest(), b->o, L
88         ->dest(), L->next()->dest()))
89             del_edge(L, L->next());
90         Q R = b->prev();
91         if (valid(R)) while (in_c(b->dest(), b->o, R
92         ->dest(), R->prev()->dest()))
93             del_edge(R, R->prev());
94         if (!valid(L) and !valid(R)) break;
95         if (!valid(L) or (valid(R) and in_c(L->dest()
96         , L->o, R->o, R->dest())))
97             b = conn(R, b->rev());
98         else b = conn(b->rev(), L->rev());
99     }
100     return {la, rb};
101 }
102
103 vector<vector<int>>> delaunay(vp v) {
104     int n = v.size();
105     auto tmp = v;
106     vector<int> idx(n);
107     iota(idx.begin(), idx.end(), 0);
108     sort(idx.begin(), idx.end(), [&](int l, int r) {
109         return v[l] < v[r]; });
110     for (int i = 0; i < n; i++) v[i] = tmp[idx[i]];
111     assert(unique(v.begin(), v.end()) == v.end());
112     vector<vector<int>>> g(n);
113     bool col = true;
114     for (int i = 2; i < n; i++) if (areaT2(v[i], v[i
115     -1], v[i-2])) col = false;
116     if (col) {
117         for (int i = 1; i < n; i++)
118             g[idx[i-1]].push_back(idx[i]), g[idx[i]].
119             push_back(idx[i-1]);
120         return g;
121     }
122 }
123
124 Q e = build_tr(v, 0, n-1).first;
125 vector<Q> edg = {e};
126 for (int i = 0; i < edg.size(); i = edg[i++]) {
127     for (Q at = e; !at->used; at = at->next()) {
128         at->used = true;
129         g[idx[at->id]].push_back(idx[at->rev()->
130         id]);
131         edg.push_back(at->rev());
132     }
133 }
134 return g;
135 }
136
137 4.5 Halfplane Inter
138
139 struct Halfplane {
140     point p, pq;
141     ld angle;
142     Halfplane() {}
143     Halfplane(const point &a, const point &b) : p(a),
144     pq(b - a) {
145         angle = atan2l(pq.y, pq.x);
146     }
147
148     bool out(const point &r) { return (pq ^ (r - p))
149     < -EPS; }
150     bool operator<(const Halfplane &e) const { return
151     angle < e.angle; }
152
153     friend point inter(const Halfplane &s, const
154     Halfplane &t) {
155         ld alpha = ((t.p - s.p) ^ t.pq) / (s.pq ^ t.
156         pq);
157         return s.p + (s.pq * alpha);
158     }
159 }
160
161 vp hp_intersect(vector<Halfplane> &H) {
162     point box[4] = {
163         point(LLINF, LLINF),
164         point(-LLINF, LLINF),
165         point(-LLINF, -LLINF),
166         point(LLINF, -LLINF)
167     };
168     for(int i = 0; i < 4; i++) {
169         Halfplane aux(box[i], box[(i+1) % 4]);
170         H.push_back(aux);
171     }
172
173     sort(H.begin(), H.end());
174     deque<Halfplane> dq;
175     int len = 0;
176     for(int i = 0; i < (int)H.size(); i++) {
177         while (len > 1 && H[i].out(inter(dq[len-1],
178         dq[len-2]))) {
179             dq.pop_back();
180             --len;
181         }
182         while (len > 1 && H[i].out(inter(dq[0], dq
183         [1]))) {
184             dq.pop_front();
185             --len;
186         }
187         if (len > 0 && fabs1((H[i].pq ^ dq[len-1].pq)
188         ) < EPS) {
189             if ((H[i].pq * dq[len-1].pq) < 0.0)
190                 return vp();
191         }
192     }
193 }

```

```

51         if (H[i].out(dq[len-1].p)) {
52             dq.pop_back();
53             --len;
54         }
55         else continue;
56     }
57     dq.push_back(H[i]);
58     ++len;
59 }
60
61 while (len > 2 && dq[0].out(inter(dq[len-1], dq[
62 len-2]))) {
63     dq.pop_back();
64     --len;
65 }
66
67 while (len > 2 && dq[len-1].out(inter(dq[0], dq
68 [1]))) {
69     dq.pop_front();
70     --len;
71 }
72
73 if (len < 3) return vp();
74
75 vp ret(len);
76 for(int i = 0; i+1 < len; i++) {
77     ret[i] = inter(dq[i], dq[i+1]);
78 }
79 ret.back() = inter(dq[len-1], dq[0]);
80 return ret;
81 }
82 // O(n3)
83 vp half_plane_intersect(vector<line> &v){
84     vp ret;
85     int n = v.size();
86     for(int i=0; i<n; i++){
87         for(int j=i+1; j<n; j++){
88             point crs = inter(v[i], v[j]);
89             if(crs.x == INF) continue;
90             bool bad = 0;
91             for(int k=0; k<n; k++){
92                 if(v[k].eval(crs) < -EPS){
93                     bad = 1;
94                     break;
95                 }
96             }
97             if(!bad) ret.push_back(crs);
98         }
99     }
100     return ret;
101 }

```

4.6 Inside Polygon

```

1 // Convex O(logn)
2
3 bool insideT(point a, point b, point c, point e){
4     int x = ccw(a, b, e);
5     int y = ccw(b, c, e);
6     int z = ccw(c, a, e);
7     return !((x==1 or y==1 or z==1) and (x==-1 or y
8 ==-1 or z==-1));
9 }
10
11 bool inside(vp &p, point e){ // ccw
12     int l=2, r=(int)p.size()-1;
13     while(l<r){
14         int mid = (l+r)/2;
15         if(ccw(p[0], p[mid], e) == 1)
16             l=mid+1;
17         else{

```

```

17             r=mid;
18         }
19     }
20     // bordo
21     // if(r==(int)p.size()-1 and ccw(p[0], p[r], e)
22 ==0) return false;
23     // if(r==2 and ccw(p[0], p[1], e)==0) return
24 false;
25     // if(ccw(p[r], p[r-1], e)==0) return false;
26     return insideT(p[0], p[r-1], p[r], e);
27 }
28 // Any O(n)
29
30 int inside(vp &p, point pp){
31     // 1 - inside / 0 - boundary / -1 - outside
32     int n = p.size();
33     for(int i=0; i<n; i++){
34         int j = (i+1)%n;
35         if(line({p[i], p[j]}).inside_seg(pp))
36             return 0;
37     }
38     int inter = 0;
39     for(int i=0; i<n; i++){
40         int j = (i+1)%n;
41         if(p[i].x <= pp.x and pp.x < p[j].x and ccw(p
42 [i], p[j], pp)==1)
43             inter++; // up
44         else if(p[j].x <= pp.x and pp.x < p[i].x and
45 ccw(p[i], p[j], pp)==-1)
46             inter++; // down
47     }
48     if(inter%2==0) return -1; // outside
49     else return 1; // inside
50 }

```

4.7 Intersect Polygon

```

1 bool intersect(vector<point> A, vector<point> B) //
2 Ordered ccw
3 {
4     for(auto a: A)
5         if(inside(B, a))
6             return true;
7     for(auto b: B)
8         if(inside(A, b))
9             return true;
10
11     if(inside(B, center(A)))
12         return true;
13
14     return false;
15 }

```

4.8 Kdtree

```

1 bool on_x(const point& a, const point& b) { return a.
2 x < b.x; }
3 bool on_y(const point& a, const point& b) { return a.
4 y < b.y; }
5 bool on_z(const point& a, const point& b) { return a.
6 z < b.z; }
7
8 struct Node {
9     point pt; // if this is a leaf, the single point
10     in it
11     cod x0 = LLINF, x1 = -LLINF, y0 = LLINF, y1 = -
12     LLINF, z0 = LLINF, z1 = -LLINF; // bounds
13     Node *first = 0, *second = 0;
14 }

```

```

10     cod distance(const point &p) { // min squared
11     distance to a point
12         cod x = (p.x < x0 ? x0 : p.x > x1 ? x1 : p.x)
13         ;
14         cod y = (p.y < y0 ? y0 : p.y > y1 ? y1 : p.y)
15         ;
16         cod z = (p.z < z0 ? z0 : p.z > z1 ? z1 : p.z)
17         ;
18         return norm(point(x,y,z) - p);
19     }
20
21     Node(vp&& p) : pt(p[0]) {
22         for (point pi : p) {
23             x0 = min(x0, pi.x); x1 = max(x1, pi.x);
24             y0 = min(y0, pi.y); y1 = max(y1, pi.y);
25             z0 = min(z0, pi.z); z1 = max(z1, pi.z);
26         }
27         if (p.size() > 1) {
28             auto cmp = (x1-x0 >= y1-y0 and x1-x0 >=
29             z1-z0 ? on_x : (y1-y0 >= z1-z0 ? on_y: on_z));
30             sort(p.begin(), p.end(), cmp);
31             // divide by taking half the array for
32             each child (not
33             // best performance with many duplicates
34             in the middle)
35             int half = p.size() / 2;
36             first = new Node({p.begin(), p.begin() +
37             half});
38             second = new Node({p.begin() + half, p.
39             end()});
40         }
41     }
42 };
43
44 struct KDTree {
45     Node* root;
46     KDTree(const vp& p) : root(new Node({p.begin(), p
47     .end()})) {}
48
49     pair<cod, point> search(Node *node, const point&
50     p) {
51         if (!node->first) {
52             // uncomment if we should not find the
53             point itself:
54             if (p == node->pt) return {LLINF, point()}
55         };
56         return make_pair(norm(p - node->pt), node
57         ->pt);
58     }
59
60     Node *f = node->first, *s = node->second;
61     cod bfirst = f->distance(p), bsec = s->
62     distance(p);
63     if (bfirst > bsec) swap(bsec, bfirst), swap(f
64     , s);
65
66     auto best = search(f, p);
67     if (bsec < best.first)
68         best = min(best, search(s, p));
69     return best;
70 }
71
72 // find nearest point to a point, and its squared
73 distance
74 // (requires an arbitrary operator< for Point)
75 pair<cod, point> nearest(const point& p) {
76     return search(root, p);
77 }
78 };
79
80 4.9 Lichao
81
82 struct Lichao { // min
83
84     struct line {
85         ll a, b;
86         array<int, 2> ch;
87         line(ll a_ = 0, ll b_ = LLINF) : a(a_), b(b_)
88         , ch({-1, -1}) {}
89         ll operator()(ll x) { return a * x + b; }
90     };
91     vector<line> ln;
92
93     int ch(int p, int d) {
94         if (ln[p].ch[d] == -1) {
95             ln[p].ch[d] = ln.size();
96             ln.emplace_back();
97         }
98         return ln[p].ch[d];
99     }
100     Lichao() { ln.emplace_back(); }
101
102     void add(line s, ll l=-N, ll r=N, int p=0) {
103         ll m = (l+r)/2;
104         bool L = s(l) < ln[p](l);
105         bool M = s(m) < ln[p](m);
106         bool R = s(r) < ln[p](r);
107         if (M) swap(ln[p], s), swap(ln[p].ch, s.ch);
108         if (s.b == LLINF) return;
109         if (L != M) add(s, l, m-1, ch(p, 0));
110         else if (R != M) add(s, m+1, r, ch(p, 1));
111     }
112     ll query(int x, ll l=-N, ll r=N, int p=0) {
113         ll m = (l + r) / 2, ret = ln[p](x);
114         if (ret == LLINF) return ret;
115         if (x < m) return min(ret, query(x, l, m-1,
116         ch(p, 0)));
117         return min(ret, query(x, m+1, r, ch(p, 1)));
118     }
119 };
120
121 4.10 Linear Transformation
122
123 // Apply linear transformation (p -> q) to r.
124 point linear_transformation(point p0, point p1, point
125     q0, point q1, point r) {
126     point dp = p1-p0, dq = q1-q0, num((dp^dq), (dp^dq
127     ));
128     return q0 + point((r-p0)^(num), (r-p0)*(num))/(dp
129     *dp);
130 }
131
132 4.11 Mindistpair
133
134 ll MinDistPair(vp &vet){
135     int n = vet.size();
136     sort(vet.begin(), vet.end());
137     set<point> s;
138
139     ll best_dist = LLINF;
140     int j=0;
141     for(int i=0;i<n;i++){
142         ll d = ceil(sqrt(best_dist));
143         while(j<n and vet[i].x-vet[j].x >= d){
144             s.erase(point(vet[j].y, vet[j].x));
145             j++;
146         }
147
148         auto it1 = s.lower_bound({vet[i].y - d, vet[i]
149         }.x});
150         auto it2 = s.upper_bound({vet[i].y + d, vet[i]
151         }.x});
152
153         for(auto it=it1; it!=it2; it++){
154             ll dx = vet[i].x - it->y;
155             ll dy = vet[i].y - it->x;
156         }
157     }
158 }

```

```

21         if(best_dist > dx*dx + dy*dy){
22             best_dist = dx*dx + dy*dy;
23             // vet[i] e inv(it)
24         }
25     }
26
27     s.insert(point(vet[i].y, vet[i].x));
28 }
29 return best_dist;
30 }

```

4.12 Minkowski Sum

```

1 vp minkowski(vp p, vp q){
2     int n = p.size(), m = q.size();
3     auto reorder = [&](vp &p) {
4         // set the first vertex must be the lowest
5         int id = 0;
6         for(int i=1;i<p.size();i++){
7             if(p[i].y < p[id].y or (p[i].y == p[id].y
8             and p[i].x < p[id].x))
9                 id = i;
10        }
11        rotate(p.begin(), p.begin() + id, p.end());
12    };
13    reorder(p); reorder(q);
14    p.push_back(p[0]);
15    q.push_back(q[0]);
16    vp ans; int i = 0, j = 0;
17    while(i < n or j < m){
18        ans.push_back(p[i] + q[j]);
19        cod cross = (p[i+1] - p[i]) ^ (q[j+1] - q[j])
20        ;
21        if(cross >= 0) i ++;
22        if(cross <= 0) j ++;
23    }
24    return ans;
25 }

```

4.13 Numintersectionline

```

1 int main()
2 {
3     int lim = 1e6;
4     Segtree st(lim+100);
5     int n, m, y, x, l, r;
6     cin >> n >> m;
7
8     int open=-1, close=INF; // open -> check -> close
9     vector< pair<int, pii> > sweep;
10
11     ll ans = 0;
12     for(int i=0;i<n;i++){ // horizontal
13         cin >> y >> l >> r;
14         sweep.pb({l, {open, y}});
15         sweep.pb({r, {close, y}});
16     }
17     for(int i=0;i<m;i++){ // vertical
18         cin >> x >> l >> r;
19         sweep.pb({x, {l, r}});
20     }
21     sort(sweep.begin(), sweep.end());
22
23     // set<int> on;
24     for(auto s: sweep){
25         if(s.ss.ff==open){
26             st.update(s.ss.ss, 1);
27             // on.insert(s.ss.ss);
28         }
29         else if(s.ss.ff==close){
30             st.update(s.ss.ss, -1);
31         }
32     }
33 }

```

```

31         // on.erase(s.ss.ss);
32     }
33     else{
34         ans += st.query(s.ss.ff, s.ss.ss);
35         // auto it1 = on.lower_bound(s.ss.ff);
36         // auto it2 = on.upper_bound(s.ss.ss);
37         // for(auto it = it1; it!=it2; it++){
38             // intersection -> (s.ff, it);
39         // }
40     }
41 }
42
43 cout << ans << endl;
44
45 return 0;
46 }
47 }

```

4.14 Polygon Cut Length

```

1 // Polygon Cut length
2 ld solve(vp &p, point a, point b){ // ccw
3     int n = p.size();
4     ld ans = 0;
5
6     for(int i=0;i<n;i++){
7         int j = (i+1) % n;
8
9         int signi = ccw(a, b, p[i]);
10        int signj = ccw(a, b, p[j]);
11
12        if(signi == 0 and signj == 0){
13            if((b-a) * (p[j]-p[i]) > 0){
14                ans += param(a, b, p[j]);
15                ans -= param(a, b, p[i]);
16            }
17        }else if(signi <= 0 and signj > 0){
18            ans -= param(a, b, inter_line({a, b}, {p[
19            i], p[j]}[0]));
20        }else if(signi > 0 and signj <= 0){
21            ans += param(a, b, inter_line({a, b}, {p[
22            i], p[j]}[0]));
23        }
24    }
25    return abs(ans * norm(b-a));
26 }

```

4.15 Polygon Diameter

```

1 pair<point, point> polygon_diameter(vp p) {
2     p = convex_hull(p);
3     int n = p.size(), j = n<2 ? 0:1;
4     pair<ll, vp> res({0, {p[0], p[0]}});
5     for (int i=0;i<j;i++){
6         for (; j = (j+1) % n) {
7             res = max(res, {norm2(p[i] - p[j]), {p[i]
8             ], p[j]}});
9             if ((p[(j + 1) % n] - p[j]) ^ (p[i + 1] -
10             p[i]) >= 0)
11                 break;
12         }
13     }
14     return res.second;
15 }
16
17 double diameter(const vector<point> &p) {
18     vector<point> h = convexHull(p);
19     int m = h.size();
20     if (m == 1)
21         return 0;
22     if (m == 2)
23         return h[1] - h[0];
24 }

```

```

21     return dist(h[0], h[1]);
22     int k = 1;
23     while (area(h[m - 1], h[0], h[(k + 1) % m]) >
24            area(h[m - 1], h[0], h[k]))
25         ++k;
26     double res = 0;
27     for (int i = 0, j = k; i <= k && j < m; i++) {
28         res = max(res, dist(h[i], h[j]));
29         while (j < m && area(h[i], h[(i + 1) % m], h
30            [(j + 1) % m]) > area(h[i], h[(i + 1) % m], h[j]))
31             j++;
32     }
33     return res;
34 }

```

4.16 Rotating Callipers

```

1  int N;
2
3  int sum(int i, int x){
4      if(i+x>N-1) return (i+x-N);
5      return i+x;
6  }
7
8  ld rotating_callipers(vp &vet){
9      N = vet.size();
10     ld ans = 0;
11     // 2 triangulos (p1, p3, p4) (p1, p2, p3);
12     for(int i=0;i<N;i++){ // p1
13         int p2 = sum(i, 1); // p2
14         int p4 = sum(i, 3); // p4
15         for(int j=sum(i, 2);j!=i;j=sum(j, 1)){ // p3
16             if(j==p2) p2 = sum(p2, 1);
17             while(sum(p2, 1)!=j and areaT(vet[p2],
18                vet[i], vet[j]) < areaT(vet[sum(p2, 1)], vet[i],
19                vet[j]))
20                 p2 = sum(p2, 1);
21             while(sum(p4, 1)!=i and areaT(vet[p4],
22                vet[i], vet[j]) < areaT(vet[sum(p4, 1)], vet[i],
23                vet[j]))
24                 p4 = sum(p4, 1);
25
26             ans = max(ans, area(vet[i], vet[p2], vet[
27                j], vet[p4]));
28         }
29     }
30     return ans;
31 }

```

4.17 Sort By Angle

```

1  // Comparator function for sorting points by angle
2
3  int ret[2][2] = {{3, 2},{4, 1}};
4  inline int quad(point p) {
5      return ret[p.x >= 0][p.y >= 0];
6  }
7
8  bool comp(point a, point b) { // ccw
9      int qa = quad(a), qb = quad(b);
10     return (qa == qb ? (a ^ b) > 0 : qa < qb);
11 }
12
13 // only vectors in range [x+0, x+180)
14 bool comp(point a, point b){
15     return (a ^ b) > 0; // ccw
16     // return (a ^ b) < 0; // cw

```

```

17 }

```

4.18 Tetrahedron Distance3d

```

1  bool nulo(point a){
2      return (eq(a.x, 0) and eq(a.y, 0) and eq(a.z, 0))
3      ;
4  }
5  ld misto(point p1, point p2, point p3){
6      return (p1^p2)*p3;
7  }
8
9  ld dist_pt_face(point p, vp v){
10     assert(v.size()==3);
11
12     point v1 = v[1]-v[0];
13     point v2 = v[2]-v[0];
14     point n = (v1^v2);
15
16     for(int i=0;i<3;i++){
17         point va = p-v[i];
18         point vb = v[(i+1)%3]-v[i];
19         point ve = vb^n;
20         ld d = ve*v[i];
21         //se ponto coplanar com um dos lados do
22         //prisma (va^vb eh nulo),
23         //ele esta dentro do prisma (poderia
24         //desconsiderar pois distancia
25         //vai ser a msm da distancia do ponto ao
26         //segmento)
27         if(!nulo(va^vb) and (v[(i+2)%3]*ve>d) ^ (p*ve
28            >d)) return LLINF;
29     }
30
31     //se ponto for coplanar ao triangulo (e dentro do
32     //triangulo)
33     //vai retornar zero corretamente
34     return fabs(misto(p-v[0],v1,v2)/norm(n));
35 }
36
37 ld dist_pt_seg(point p, vp li){
38     return norm((li[1]-li[0])^(p-li[0]))/norm(li[1]-
39        li[0]);
40 }
41
42 ld dist_line(vp l1, vp l2){
43     point n = (l1[1]-l1[0])^(l2[1]-l2[0]);
44     if(nulo(n)) //retas paralelas - dist ponto a reta
45         return dist_pt_seg(l2[0],l1);
46
47     point o1o2 = l2[0]-l1[0];
48     return fabs((o1o2*n)/norm(n));
49 }
50
51 // retas paralelas e intersecao nao nula
52 ld dist_seg(vp l1, vp l2){
53
54     assert(l2.size()==2);
55     assert(l1.size()==2);
56
57     //pontos extremos do segmento
58     ld ans = LLINF;
59     for(int i=0;i<2;i++){
60         for(int j=0;j<2;j++){
61             ans = min(ans, norm(l1[i]-l2[j]));
62         }
63     }
64
65     //verificando distancia de ponto extremo com
66     //ponto interno dos segs
67     for(int t=0;t<2;t++){
68         for(int i=0;i<2;i++){
69             bool c=true;
70             for(int k=0;k<2;k++){
71                 point va = l1[i]-l2[k];

```

```

62         point vb = l2[!k]-l2[k];
63         ld ang = atan2(norm((vb~va)), vb*va);
64         if(ang>PI/2) c = false;
65     }
66     if(c)
67         ans = min(ans,dist_pt_seg(l1[i],l2));
68 }
69 swap(l1,l2);
70 }
71
72 //ponto interno com ponto interno dos segmentos
73 point v1 = l1[1]-l1[0], v2 = l2[1]-l2[0];
74 point n = v1~v2;
75 if(!nulo(n)){
76     bool ok = true;
77     for(int t=0;t<2;t++){
78         point n2 = v2~n;
79         point oio2 = l2[0]-l1[0];
80         ld escalar = (oio2*n2)/(v1*n2);
81         if(escalar<0 or escalar>1) ok = false;
82         swap(l1,l2);
83         swap(v1,v2);
84     }
85     if(ok) ans = min(ans,dist_line(l1,l2));
86 }
87
88 return ans;
89 }
90
91 ld ver(vector<vp> &vet){
92     ld ans = LLINF;
93     // vertice - face
94     for(int k=0;k<2;k++){
95         for(int pt=0;pt<4;pt++){
96             for(int i=0;i<4;i++){
97                 vp v;
98                 for(int j=0;j<4;j++){
99                     if(i!=j) v.pb(vet[!k][j]);
100             }
101             ans = min(ans, dist_pt_face(vet[k][pt
102 ], v));
103         }
104     }
105     // edge - edge
106     for(int i1=0;i1<4;i1++){
107         for(int j1=0;j1<i1;j1++){
108             for(int i2=0;i2<4;i2++){
109                 for(int j2=0;j2<i2;j2++){
110                     ans = min(ans, dist_seg({vet[0][
111 i1], vet[0][j1]},
112 {vet[1][
113 i2], vet[1][j2]}));
114
115 return ans;
116 }
117 }

```

4.19 Voronoi

```

1 bool polygonIntersection(line &seg, vp &p) {
2     long double l = -1e18, r = 1e18;
3     for(auto ps : p) {
4         long double z = seg.eval(ps);
5         l = max(l, z);
6         r = min(r, z);
7     }
8     return l - r > EPS;
9 }
10
11 int w, h;
12
13 line getBisector(point a, point b) {
14     line ans(a, b);
15     swap(ans.a, ans.b);

```

```

16     ans.b *= -1;
17     ans.c = ans.a * (a.x + b.x) * 0.5 + ans.b * (a.y
18 + b.y) * 0.5;
19     return ans;
20 }
21
22 vp cutPolygon(vp poly, line seg) {
23     int n = (int) poly.size();
24     vp ans;
25     for(int i = 0; i < n; i++) {
26         double z = seg.eval(poly[i]);
27         if(z > -EPS) {
28             ans.push_back(poly[i]);
29         }
30         double z2 = seg.eval(poly[(i + 1) % n]);
31         if((z > EPS && z2 < -EPS) || (z < -EPS && z2
32 > EPS)) {
33             ans.push_back(inter_line(seg, line(poly[i
34 ], poly[(i + 1) % n]))[0]);
35         }
36     }
37     return ans;
38 }
39
40 // BE CAREFUL!
41 // the first point may be any point
42 // O(N^3)
43 vp getCell(vp pts, int i) {
44     vp ans;
45     ans.emplace_back(0, 0);
46     ans.emplace_back(1e6, 0);
47     ans.emplace_back(1e6, 1e6);
48     ans.emplace_back(0, 1e6);
49     for(int j = 0; j < (int) pts.size(); j++) {
50         if(j != i) {
51             ans = cutPolygon(ans, getBisector(pts[i],
52 pts[j]));
53         }
54     }
55     return ans;
56 }
57
58 // O(N^2) expected time
59 vector<vp> getVoronoi(vp pts) {
60     // assert(pts.size() > 0);
61     int n = (int) pts.size();
62     vector<int> p(n, 0);
63     for(int i = 0; i < n; i++) {
64         p[i] = i;
65     }
66     shuffle(p.begin(), p.end(), rng);
67     vector<vp> ans(n);
68     ans[0].emplace_back(0, 0);
69     ans[0].emplace_back(w, 0);
70     ans[0].emplace_back(w, h);
71     ans[0].emplace_back(0, h);
72     for(int i = 1; i < n; i++) {
73         ans[i] = ans[0];
74     }
75     for(auto i : p) {
76         for(auto j : p) {
77             if(j == i) break;
78             auto bi = getBisector(pts[j], pts[i]);
79             if(!polygonIntersection(bi, ans[j]))
80                 continue;
81             ans[j] = cutPolygon(ans[j], getBisector(
82 pts[j], pts[i]));
83             ans[i] = cutPolygon(ans[i], getBisector(
84 pts[i], pts[j]));
85         }
86     }
87     return ans;
88 }

```

5 Grafos

5.1 2sat

```
1 #define rep(i,l,r) for (int i = (l); i < (r); i++)
2 struct TwoSat { // copied from kth-competitive-
   programming/kactl
3   int N;
4   vector<vi> gr;
5   vi values; // 0 = false, 1 = true
6   TwoSat(int n = 0) : N(n), gr(2*n) {}
7   int addVar() { // (optional)
8     gr.emplace_back();
9     gr.emplace_back();
10    return N++;
11  }
12  void either(int f, int j) {
13    f = max(2*f, -1-2*f);
14    j = max(2*j, -1-2*j);
15    gr[f].push_back(j^1);
16    gr[j].push_back(f^1);
17  }
18  void atMostOne(const vi& li) { // (optional)
19    if ((int)li.size() <= 1) return;
20    int cur = ~li[0];
21    rep(i,2,(int)li.size()) {
22      int next = addVar();
23      either(cur, ~li[i]);
24      either(cur, next);
25      either(~li[i], next);
26      cur = ~next;
27    }
28    either(cur, ~li[1]);
29  }
30  vi _val, comp, z; int time = 0;
31  int dfs(int i) {
32    int low = _val[i] = ++time, x; z.push_back(i)
33    ;
34    for(int e : gr[i]) if (!comp[e])
35      low = min(low, _val[e]?: dfs(e));
36    if (low == _val[i]) do {
37      x = z.back(); z.pop_back();
38      comp[x] = low;
39      if (values[x>>1] == -1)
40        values[x>>1] = x&1;
41    } while (x != i);
42    return _val[i] = low;
43  }
44  bool solve() {
45    values.assign(N, -1);
46    _val.assign(2*N, 0); comp = _val;
47    rep(i,0,2*N) if (!comp[i]) dfs(i);
48    rep(i,0,N) if (comp[2*i] == comp[2*i+1])
49      return 0;
50    return 1;
51  }
52 };
```

5.2 Block Cut Tree

```
1 // Block-Cut Tree do brunomaletta
2 // art[i] responde o numero de novas componentes
   conexas
3 // criadas apos a remocao de i do grafo g
4 // Se art[i] >= 1, i eh ponto de articulacao
5 //
6 // Para todo i <= blocks.size()
7 // blocks[i] eh uma componente 2-vertice-conexa
   maximal
8 // edgblocks[i] sao as arestas do bloco i
9 // tree[i] eh um vertice da arvore que corresponde ao
   bloco i
```

```
10 //
11 // pos[i] responde a qual vertice da arvore vertice i
   pertence
12 // Arvore tem no maximo 2n vertices
13
14 struct block_cut_tree {
15   vector<vector<int>> g, blocks, tree;
16   vector<vector<pair<int, int>>> edgblocks;
17   stack<int> s;
18   stack<pair<int, int>> s2;
19   vector<int> id, art, pos;
20
21   block_cut_tree(vector<vector<int>> g_) : g(g_) {
22     int n = g.size();
23     id.resize(n, -1), art.resize(n), pos.resize(n)
24   };
25   build();
26
27   int dfs(int i, int& t, int p = -1) {
28     int lo = id[i] = t++;
29     s.push(i);
30
31     if (p != -1) s2.emplace(i, p);
32     for (int j : g[i]) if (j != p and id[j] !=
33       -1) s2.emplace(i, j);
34
35     for (int j : g[i]) if (j != p) {
36       if (id[j] == -1) {
37         int val = dfs(j, t, i);
38         lo = min(lo, val);
39
40         if (val >= id[i]) {
41           art[i]++;
42           blocks.emplace_back(1, i);
43           while (blocks.back().back() != j)
44             blocks.back().push_back(s.top
45               ()), s.pop();
46
47           edgblocks.emplace_back(1, s2.top
48             ()), s2.pop();
49           while (edgblocks.back().back() !=
50             pair(j, i))
51             edgblocks.back().push_back(s2
52               .top()), s2.pop();
53         }
54         // if (val > id[i]) aresta i-j eh
55         ponte
56       }
57       else lo = min(lo, id[j]);
58     }
59
60     if (p == -1 and art[i]) art[i]--;
61     return lo;
62   }
63
64   void build() {
65     int t = 0;
66     for (int i = 0; i < g.size(); i++) if (id[i]
67       == -1) dfs(i, t, -1);
68
69     tree.resize(blocks.size());
70     for (int i = 0; i < g.size(); i++) if (art[i]
71       )
72       pos[i] = tree.size(), tree.emplace_back()
73     ;
74
75     for (int i = 0; i < blocks.size(); i++) for (
76       int j : blocks[i]) {
77       if (!art[j]) pos[j] = i;
78       else tree[i].push_back(pos[j]), tree[pos[
79         j]].push_back(i);
80     }
81   }
```

```

70     }
71 };

```

5.3 Centroid Decomp

```

1  vector<int> g[N];
2  int sz[N], rem[N];
3
4  void dfs(vector<int>& path, int u, int d=0, int p=-1)
5  {
6      path.push_back(d);
7      for (int v : g[u]) if (v != p and !rem[v]) dfs(
8          path, v, d+1, u);
9  }
10
11 int dfs_sz(int u, int p=-1) {
12     sz[u] = 1;
13     for (int v : g[u]) if (v != p and !rem[v]) sz[u]
14         += dfs_sz(v, u);
15     return sz[u];
16 }
17
18 int centroid(int u, int p, int size) {
19     for (int v : g[u]) if (v != p and !rem[v] and sz[
20         v] > size / 2)
21         return centroid(v, u, size);
22     return u;
23 }
24
25 ll decomp(int u, int k) {
26     int c = centroid(u, u, dfs_sz(u));
27     rem[c] = true;
28
29     ll ans = 0;
30     vector<int> cnt(sz[u]);
31     cnt[0] = 1;
32     for (int v : g[c]) if (!rem[v]) {
33         vector<int> path;
34         dfs(path, v);
35         // d1 + d2 + 1 == k
36         for (int d : path) if (0 <= k-d-1 and k-d-1 <
37             sz[u])
38             ans += cnt[k-d-1];
39         for (int d : path) cnt[d+1]++;
40     }
41
42     for (int v : g[c]) if (!rem[v]) ans += decomp(v,
43         k);
44     return ans;
45 }

```

5.4 Dfs Tree

```

1  int desce[N], sobe[N], vis[N], h[N];
2  int backedges[N], pai[N];
3
4  // backedges[u] = backedges que comecam embaixo de (
5  // ou =) u e sobem pra cima de u; backedges[u] == 0
6  // => u eh ponte
7  void dfs(int u, int p) {
8      if(vis[u]) return;
9      pai[u] = p;
10     h[u] = h[p]+1;
11     vis[u] = 1;
12
13     for(auto v : g[u]) {
14         if(p == v or vis[v]) continue;
15         dfs(v, u);
16         backedges[u] += backedges[v];
17     }
18     for(auto v : g[u]) {
19         if(h[v] > h[u]+1)

```

```

18         desce[u]++;
19         else if(h[v] < h[u]-1)
20             sobe[u]++;
21     }
22     backedges[u] += sobe[u] - desce[u];
23 }

```

5.5 Dinic

```

1  const int N = 300;
2
3  struct Dinic {
4      struct Edge{
5          int from, to; ll flow, cap;
6      };
7      vector<Edge> edge;
8
9      vector<int> g[N];
10     int ne = 0;
11     int lvl[N], vis[N], pass;
12     int qu[N], px[N], qt;
13
14     ll run(int s, int sink, ll minE) {
15         if(s == sink) return minE;
16
17         ll ans = 0;
18
19         for(; px[s] < (int)g[s].size(); px[s]++) {
20             int e = g[s][ px[s] ];
21             auto &v = edge[e], &rev = edge[e^1];
22             if(lvl[v.to] != lvl[s]+1 || v.flow >= v.
23                 cap)
24                 continue; // v.cap - v.flow
25             < lim
26             ll tmp = run(v.to, sink, min(minE, v.cap-v
27                 .flow));
28             v.flow += tmp, rev.flow -= tmp;
29             ans += tmp, minE -= tmp;
30             if(minE == 0) break;
31         }
32         return ans;
33     }
34     bool bfs(int source, int sink) {
35         qt = 0;
36         qu[qt++] = source;
37         lvl[source] = 1;
38         vis[source] = ++pass;
39         for(int i = 0; i < qt; i++) {
40             int u = qu[i];
41             px[u] = 0;
42             if(u == sink) return true;
43             for(auto& ed : g[u]) {
44                 auto v = edge[ed];
45                 if(v.flow >= v.cap || vis[v.to] ==
46                     pass)
47                     continue; // v.cap - v.flow < lim
48                 vis[v.to] = pass;
49                 lvl[v.to] = lvl[u]+1;
50                 qu[qt++] = v.to;
51             }
52         }
53         return false;
54     }
55     ll flow(int source, int sink) {
56         reset_flow();
57         ll ans = 0;
58         //for(lim = (1LL << 62); lim >= 1; lim /= 2)
59         while(bfs(source, sink))
60             ans += run(source, sink, LLINF);
61         return ans;
62     }
63     void addEdge(int u, int v, ll c, ll rc) {
64         Edge e = {u, v, 0, c};

```



```

61     edge.pb(e);
62     g[u].push_back(ne++);
63
64     e = {v, u, 0, rc};
65     edge.pb(e);
66     g[v].push_back(ne++);
67 }
68 void reset_flow() {
69     for(int i = 0; i < ne; i++)
70         edge[i].flow = 0;
71     memset(lvl, 0, sizeof(lvl));
72     memset(vis, 0, sizeof(vis));
73     memset(qu, 0, sizeof(qu));
74     memset(px, 0, sizeof(px));
75     qt = 0; pass = 0;
76 }
77 vector<pair<int, int>> cut() {
78     vector<pair<int, int>> cuts;
79     for (auto [from, to, flow, cap]: edge) {
80         if (flow == cap and vis[from] == pass and
81             vis[to] < pass and cap > 0) {
82             cuts.pb({from, to});
83         }
84     }
85     return cuts;
86 };

```

5.6 Dominator Tree

```

1 // Dominator Tree
2 // idom[x] = immediate dominator of x
3
4 vector<int> g[N], gt[N], T[N];
5 vector<int> S;
6 int dsu[N], label[N];
7 int sdom[N], idom[N], dfs_time, id[N];
8
9 vector<int> bucket[N];
10 vector<int> down[N];
11
12 void prep(int u){
13     S.push_back(u);
14     id[u] = ++dfs_time;
15     label[u] = sdom[u] = dsu[u] = u;
16
17     for(int v : g[u]){
18         if(!id[v])
19             prep(v), down[u].push_back(v);
20         gt[v].push_back(u);
21     }
22 }
23
24 int fnd(int u, int flag = 0){
25     if(u == dsu[u]) return u;
26     int v = fnd(dsu[u], 1), b = label[ dsu[u] ];
27     if(id[ sdom[b] ] < id[ sdom[ label[u] ] ])
28         label[u] = b;
29     dsu[u] = v;
30     return flag ? v : label[u];
31 }
32
33 void build_dominator_tree(int root, int sz){
34     // memset(id, 0, sizeof(int) * (sz + 1));
35     // for(int i = 0; i <= sz; i++) T[i].clear();
36     prep(root);
37     reverse(S.begin(), S.end());
38
39     int w;
40     for(int u : S){
41         for(int v : gt[u]){
42             w = fnd(v);
43             if(id[ sdom[w] ] < id[ sdom[u] ])

```

```

44         sdom[u] = sdom[w];
45     }
46     gt[u].clear();
47
48     if(u != root) bucket[ sdom[u] ].push_back(u);
49
50     for(int v : bucket[u]){
51         w = fnd(v);
52         if(sdom[w] == sdom[v]) idom[v] = sdom[v];
53         else idom[v] = w;
54     }
55     bucket[u].clear();
56
57     for(int v : down[u]) dsu[v] = u;
58     down[u].clear();
59 }
60
61 reverse(S.begin(), S.end());
62 for(int u : S) if(u != root){
63     if(idom[u] != sdom[u]) idom[u] = idom[ idom[u]
64 ] ];
65     T[ idom[u] ].push_back(u);
66 }
67 S.clear();
68 }

```

5.7 Ford

```

1 const int N = 2000010;
2
3 struct Ford {
4     struct Edge {
5         int to, f, c;
6     };
7
8     int vis[N];
9     vector<int> adj[N];
10    vector<Edge> edges;
11    int cur = 0;
12
13    void addEdge(int a, int b, int cap, int rcap) {
14        Edge e;
15        e.to = b; e.c = cap; e.f = 0;
16        edges.pb(e);
17        adj[a].pb(cur++);
18
19        e = Edge();
20        e.to = a; e.c = rcap; e.f = 0;
21        edges.pb(e);
22        adj[b].pb(cur++);
23    }
24
25    int dfs(int s, int t, int f, int tempo) {
26        if(s == t)
27            return f;
28        vis[s] = tempo;
29
30        for(int e : adj[s]) {
31            if(vis[edges[e].to] < tempo and (edges[e
32 ].c - edges[e].f) > 0) {
33                if(int a = dfs(edges[e].to, t, min(f,
34 edges[e].c - edges[e].f), tempo)) {
35                    edges[e].f += a;
36                    edges[e^1].f -= a;
37                    return a;
38                }
39            }
40        }
41        return 0;
42    }
43
44    int flow(int s, int t) {
45        int mflow = 0, tempo = 1;

```

```

44     while(int a = dfs(s, t, INF, tempo)) {
45         mflow += a;
46         tempo++;
47     }
48     return mflow;
49 }
50 };

```

5.8 Hld Aresta

```

1 // Use it together with recursive_segtree
2 const int N = 3e5+10;
3 vector<vector<pair<int, int>>> g(N, vector<pair<int,
4     int>>());
5 vector<int> in(N), inv(N), sz(N);
6 vector<int> peso(N), pai(N);
7 vector<int> head(N), tail(N), h(N);
8 int tin;
9
10 void dfs(int u, int p=-1, int depth=0){
11     sz[u] = 1; h[u] = depth;
12     for(auto &i: g[u]) if(i.ff != p){
13         auto [v, w] = i;
14         dfs(v, u, depth+1);
15         pai[v] = u; sz[u] += sz[v]; peso[v] = w;
16         if (sz[v] > sz[g[u][0].ff) or g[u][0].ff == p swap(i, g[u][0]);
17     }
18 }
19 void build_hld(int u, int p = -1) {
20     v[in[u] = tin++] = peso[u]; tail[u] = u;
21     inv[tin-1] = u;
22     for(auto &i: g[u]) if(i.ff != p) {
23         int v = i.ff;
24         head[v] = (i == g[u][0] ? head[u] : v);
25         build_hld(v, u);
26     }
27     if(g[u].size() > 1) tail[u] = tail[g[u][0].ff];
28 }
29 void init_hld(int root = 0) {
30     dfs(root);
31     tin = 0;
32     build_hld(root);
33     build();
34 }
35 void reset(){
36     g.assign(N, vector<pair<int,int>>());
37     in.assign(N, 0), sz.assign(N, 0);
38     peso.assign(N, 0), pai.assign(N, 0);
39     head.assign(N, 0); tail.assign(N, 0);
40     h.assign(N, 0); inv.assign(N, 0);
41
42     t.assign(4*N, 0); v.assign(N, 0);
43     lazy.assign(4*N, 0);
44 }
45 ll query_path(int a, int b) {
46     if (a == b) return 0;
47     if(in[a] < in[b]) swap(a, b);
48
49     if(head[a] == head[b]) return query(in[b]+1, in[a]
50     );
51     return merge(query(in[head[a]], in[a]),
52     query_path(pai[head[a]], b));
53 }
54 void update_path(int a, int b, int x) {
55     if (a == b) return;
56     if(in[a] < in[b]) swap(a, b);
57
58     if(head[a] == head[b]) return (void)update(in[b]
59     +1, in[a], x);
60     update(in[head[a]], in[a], x); update_path(pai[
61     head[a]], b, x);

```

```

58 }
59 ll query_subtree(int a) {
60     if(sz[a] == 1) return 0;
61     return query(in[a]+1, in[a]+sz[a]-1);
62 }
63 void update_subtree(int a, int x) {
64     if(sz[a] == 1) return;
65     update(in[a]+1, in[a]+sz[a]-1, x);
66 }
67 int lca(int a, int b) {
68     if(in[a] < in[b]) swap(a, b);
69     return head[a] == head[b] ? b : lca(pai[head[a]],
70     b);
71 }

```

5.9 Hld Vertice

```

1 // Use it together with recursive_segtree
2 const int N = 3e5+10;
3 vector<vector<int>> g(N, vector<int>());
4 vector<int> in(N), inv(N), sz(N);
5 vector<int> peso(N), pai(N);
6 vector<int> head(N), tail(N), h(N);
7 int tin;
8
9 void dfs(int u, int p=-1, int depth=0){
10     sz[u] = 1; h[u] = depth;
11     for(auto &v: g[u]) if(v != p){
12         dfs(v, u, depth+1);
13         pai[v] = u; sz[u] += sz[v];
14         if (sz[v] > sz[g[u][0]] or g[u][0] == p) swap
15         (v, g[u][0]);
16     }
17 }
18 void build_hld(int u, int p = -1) {
19     v[in[u] = tin++] = peso[u]; tail[u] = u;
20     inv[tin-1] = u;
21     for(auto &v: g[u]) if(v != p) {
22         head[v] = (v == g[u][0] ? head[u] : v);
23         build_hld(v, u);
24     }
25     if(g[u].size() > 1) tail[u] = tail[g[u][0]];
26 }
27 void init_hld(int root = 0) {
28     dfs(root);
29     tin = 0;
30     build_hld(root);
31     build();
32 }
33 void reset(){
34     g.assign(N, vector<int>());
35     in.assign(N, 0), sz.assign(N, 0);
36     peso.assign(N, 0), pai.assign(N, 0);
37     head.assign(N, 0); tail.assign(N, 0);
38     h.assign(N, 0); inv.assign(N, 0);
39
40     t.assign(4*N, 0); v.assign(N, 0);
41     lazy.assign(4*N, 0);
42 }
43 ll query_path(int a, int b) {
44     if(in[a] < in[b]) swap(a, b);
45
46     if(head[a] == head[b]) return query(in[b], in[a])
47     ;
48     return merge(query(in[head[a]], in[a]),
49     query_path(pai[head[a]], b));
50 }
51 void update_path(int a, int b, int x) {
52     if(in[a] < in[b]) swap(a, b);
53
54     if(head[a] == head[b]) return (void)update(in[b],
55     in[a], x);
56     update(in[head[a]], in[a], x); update_path(pai[
57     head[a]], b, x);

```

```

53     update(in[head[a]], in[a], x); update_path(pai[
54     head[a]], b, x);
55 }
56 ll query_subtree(int a) {
57     return query(in[a], in[a]+sz[a]-1);
58 }
59 void update_subtree(int a, int x) {
60     update(in[a], in[a]+sz[a]-1, x);
61 }
62 int lca(int a, int b) {
63     if(in[a] < in[b]) swap(a, b);
64     return head[a] == head[b] ? b : lca(pai[head[a]],
65     b);
66 }

```

5.10 Hungarian

```

1 // Hungarian Algorithm
2 //
3 // Assignment problem
4 // Put the edges in the 'a' matrix (negative or
5 // positive)
6 // assignment() returns a pair with the min
7 // assignment,
8 // and the column chosen by each row
9 // assignment() - O(n^3)
10
11 template<typename T>
12 struct hungarian {
13     int n, m;
14     vector<vector<T>> a;
15     vector<T> u, v;
16     vector<int> p, way;
17     T inf;
18
19     hungarian(int n_, int m_) : n(n_), m(m_), u(m+1),
20     v(m+1), p(m+1), way(m+1) {
21         a = vector<vector<T>>(n, vector<T>(m));
22         inf = numeric_limits<T>::max();
23     }
24     pair<T, vector<int>> assignment() {
25         for (int i = 1; i <= n; i++) {
26             p[0] = i;
27             int j0 = 0;
28             vector<T> minv(m+1, inf);
29             vector<int> used(m+1, 0);
30             do {
31                 used[j0] = true;
32                 int i0 = p[j0], j1 = -1;
33                 T delta = inf;
34                 for (int j = 1; j <= m; j++) if (!
35                 used[j]) {
36                     T cur = a[i0-1][j-1] - u[i0] - v[
37                     j];
38                     if (cur < minv[j]) minv[j] = cur,
39                     j1 = j;
40                     if (minv[j] < delta) delta = minv
41                     [j], j1 = j;
42                 }
43                 for (int j = 0; j <= m; j++)
44                     if (used[j]) u[p[j]] += delta, v[
45                     j] -= delta;
46                 else minv[j] -= delta;
47                 j0 = j1;
48             } while (p[j0] != 0);
49             do {
50                 int j1 = way[j0];
51                 p[j0] = p[j1];
52                 j0 = j1;
53             } while (j0);
54             vector<int> ans(m);
55         }
56     }
57 }

```

```

48     for (int j = 1; j <= m; j++) ans[p[j]-1] = j
49     -1;
50     return make_pair(-v[0], ans);
51 }
52 };

```

5.11 Kosaraju

```

1 vector<int> g[N], gi[N]; // grafo invertido
2 int vis[N], comp[N]; // componente conexo de cada
3 // vertice
4 stack<int> S;
5
6 void dfs(int u){
7     vis[u] = 1;
8     for(auto v: g[u]) if(!vis[v]) dfs(v);
9     S.push(u);
10 }
11
12 void scc(int u, int c){
13     vis[u] = 1; comp[u] = c;
14     for(auto v: gi[u]) if(!vis[v]) scc(v, c);
15 }
16
17 void kosaraju(int n){
18     for(int i=0;i<n;i++) vis[i] = 0;
19     for(int i=0;i<n;i++) if(!vis[i]) dfs(i);
20     for(int i=0;i<n;i++) vis[i] = 0;
21     while(S.size()){
22         int u = S.top();
23         S.pop();
24         if(!vis[u]) scc(u, u);
25     }
26 }

```

5.12 Lca

```

1 template<typename T> struct rmq {
2     vector<T> v;
3     int n; static const int b = 30;
4     vector<int> mask, t;
5
6     int op(int x, int y) { return v[x] < v[y] ? x : y
7     ; }
8     int msb(int x) { return __builtin_clz(1)-
9     __builtin_clz(x); }
10    rmq() {}
11    rmq(const vector<T>& v_) : v(v_), n(v.size()),
12    mask(n), t(n) {
13        for (int i = 0, at = 0; i < n; mask[i++] = at
14        |= 1) {
15            at = (at<<1)&((1<<b)-1);
16            while (at and op(i, i-msb(at&-at)) == i)
17                at ^= at&-at;
18            for (int i = 0; i < n/b; i++) t[i] = b*i+b-1-
19            msb(mask[b*i+b-1]);
20            for (int j = 1; (1<<j) <= n/b; j++) for (int
21            i = 0; i+(1<<j) <= n/b; i++)
22                t[n/b*j+i] = op(t[n/b*(j-1)+i], t[n/b*(j
23                -1)+i+(1<<(j-1))]);
24        }
25        int small(int r, int sz = b) { return r-msb(mask[
26        r]&((1<<sz)-1)); }
27        T query(int l, int r) {
28            if (r-l+1 <= b) return small(r, r-l+1);
29            int ans = op(small(l+b-1), small(r));
30            int x = l/b+1, y = r/b-1;
31            if (x <= y) {
32                int j = msb(y-x+1);
33                ans = op(ans, op(t[n/b*j+x], t[n/b*j+y
34                -(1<<j)+1]));
35            }
36        }
37    }
38 }

```

```

26     }
27     return ans;
28 }
29 };
30
31 namespace lca {
32     vector<int> g[MAX];
33     int v[2*MAX], pos[MAX], dep[2*MAX];
34     int t;
35     rmq<int> RMQ;
36
37     void dfs(int i, int d = 0, int p = -1) {
38         v[t] = i, pos[i] = t, dep[t++] = d;
39         for (int j : g[i]) if (j != p) {
40             dfs(j, d+1, i);
41             v[t] = i, dep[t++] = d;
42         }
43     }
44     void build(int n, int root) {
45         t = 0;
46         dfs(root);
47         RMQ = rmq<int>(vector<int>(dep, dep+2*n-1));
48     }
49     int lca(int a, int b) {
50         a = pos[a], b = pos[b];
51         return v[RMQ.query(min(a, b), max(a, b))];
52     }
53     int dist(int a, int b) {
54         return dep[pos[a]] + dep[pos[b]] - 2*dep[pos[lca(a, b)]];
55     }
56 }
57
58 // binary lift
59
60 const int LOG = 22;
61 vector<vector<int>> g(N);
62 int t, n;
63 vector<int> in(N), height(N);
64 vector<vector<int>> up(LOG, vector<int>(N));
65 void dfs(int u, int h=0, int p=-1) {
66     up[0][u] = p;
67     in[u] = t++;
68     height[u] = h;
69     for (auto v : g[u]) if (v != p) dfs(v, h+1, u);
70 }
71
72 void blift() {
73     up[0][0] = 0;
74     for (int i=1; i<LOG; i++) {
75         for (int j=0; j<n; j++) {
76             up[i][j] = up[i-1][up[i-1][j]];
77         }
78     }
79 }
80
81 int lca(int u, int v) {
82     if (u == v) return u;
83     if (in[u] < in[v]) swap(u, v);
84     for (int i=LOG-1; i>=0; i--) {
85         int u2 = up[i][u];
86         if (in[u2] > in[v])
87             u = u2;
88     }
89     return up[0][u];
90 }
91
92 t = 0;
93 dfs(0);
94 blift();

```

5.13 Mcmf

```

1 template <class T = int>
2 class MCMF {
3 public:
4     struct Edge {
5         Edge(int a, T b, T c) : to(a), cap(b), cost(c) {}
6         int to;
7         T cap, cost;
8     };
9
10    MCMF(int size) {
11        n = size;
12        edges.resize(n);
13        pot.assign(n, 0);
14        dist.resize(n);
15        visit.assign(n, false);
16    }
17
18    std::pair<T, T> mcmf(int src, int sink) {
19        std::pair<T, T> ans(0, 0);
20        if (!SPFA(src, sink)) return ans;
21        fixPot();
22        // can use dijkstra to speed up depending on
the graph
23        while (SPFA(src, sink)) {
24            auto flow = augment(src, sink);
25            ans.first += flow.first;
26            ans.second += flow.first * flow.second;
27            fixPot();
28        }
29        return ans;
30    }
31
32    void addEdge(int from, int to, T cap, T cost) {
33        edges[from].push_back(list.size());
34        list.push_back(Edge(to, cap, cost));
35        edges[to].push_back(list.size());
36        list.push_back(Edge(from, 0, -cost));
37    }
38 private:
39     int n;
40     std::vector<std::vector<int>> edges;
41     std::vector<Edge> list;
42     std::vector<int> from;
43     std::vector<T> dist, pot;
44     std::vector<bool> visit;
45
46     /*bool dij(int src, int sink) {
47         T INF = std::numeric_limits<T>::max();
48         dist.assign(n, INF);
49         from.assign(n, -1);
50         visit.assign(n, false);
51         dist[src] = 0;
52         for (int i = 0; i < n; i++) {
53             int best = -1;
54             for (int j = 0; j < n; j++) {
55                 if (visit[j]) continue;
56                 if (best == -1 || dist[best] > dist[j])
57                     best = j;
58             }
59             if (dist[best] >= INF) break;
60             visit[best] = true;
61             for (auto e : edges[best]) {
62                 auto ed = list[e];
63                 if (ed.cap == 0) continue;
64                 T toDist = dist[best] + ed.cost + pot
[best] - pot[ed.to];
65                 assert(toDist >= dist[best]);
66                 if (toDist < dist[ed.to]) {
67                     dist[ed.to] = toDist;
68                     from[ed.to] = e;
69                 }

```

```

70     }
71     return dist[sink] < INF;
72 }*/
73
74 std::pair<T, T> augment(int src, int sink) {
75     std::pair<T, T> flow = {list[from[sink]].cap,
76     0};
77     for(int v = sink; v != src; v = list[from[v]
78     ^1].to) {
79         flow.first = std::min(flow.first, list[
80     from[v]].cap);
81         flow.second += list[from[v]].cost;
82     }
83     for(int v = sink; v != src; v = list[from[v]
84     ^1].to) {
85         list[from[v]].cap -= flow.first;
86         list[from[v]^1].cap += flow.first;
87     }
88     return flow;
89 }
90
91 std::queue<int> q;
92 bool SPFA(int src, int sink) {
93     T INF = std::numeric_limits<T>::max();
94     dist.assign(n, INF);
95     from.assign(n, -1);
96     q.push(src);
97     dist[src] = 0;
98     while(!q.empty()) {
99         int on = q.front();
100         q.pop();
101         visit[on] = false;
102         for(auto e : edges[on]) {
103             auto ed = list[e];
104             if(ed.cap == 0) continue;
105             T toDist = dist[on] + ed.cost + pot[
106     on] - pot[ed.to];
107             if(toDist < dist[ed.to]) {
108                 dist[ed.to] = toDist;
109                 from[ed.to] = e;
110                 if(!visit[ed.to]) {
111                     visit[ed.to] = true;
112                     q.push(ed.to);
113                 }
114             }
115         }
116     }
117     return dist[sink] < INF;
118 }
119
120 void fixPot() {
121     T INF = std::numeric_limits<T>::max();
122     for(int i = 0; i < n; i++) {
123         if(dist[i] < INF) pot[i] += dist[i];
124     }
125 }

```

5.14 Mcmf Quirino

```

1 struct Dinitz {
2     struct Edge {
3         int v, u, cap, flow=0, cost;
4         Edge(int v, int u, int cap, int cost) : v(v), u(u
5         ), cap(cap), cost(cost) {}
6     };
7     int n, s, t;
8     Dinitz(int n, int s, int t) : n(n), s(s), t(t) {
9         adj.resize(n);
10    }
11
12    vector<Edge> edges;

```

```

13    vector<vector<int>> adj;
14    void add_edge(int v, int u, int cap, int cost) {
15        edges.eb(v, u, cap, cost);
16        adj[v].pb(sz(edges)-1);
17        edges.eb(u, v, 0, -cost);
18        adj[u].pb(sz(edges)-1);
19    }
20
21    vector<int> dist;
22    bool spfa() {
23        dist.assign(n, LLINF);
24
25        queue<int> Q;
26        vector<bool> inqueue(n, false);
27
28        dist[s] = 0;
29        Q.push(s);
30        inqueue[s] = true;
31
32        vector<int> cnt(n);
33
34        while (!Q.empty()) {
35            int v = Q.front(); Q.pop();
36            inqueue[v] = false;
37
38            for (auto eid : adj[v]) {
39                auto const& e = edges[eid];
40                if (e.cap - e.flow <= 0) continue;
41                if (dist[e.u] > dist[e.v] + e.cost) {
42                    dist[e.u] = dist[e.v] + e.cost;
43                    if (!inqueue[e.u]) {
44                        Q.push(e.u);
45                        inqueue[e.u] = true;
46                    }
47                }
48            }
49        }
50
51        return dist[t] != LLINF;
52    }
53
54    int cost = 0;
55    vector<int> ptr;
56    int dfs(int v, int f) {
57        if (v == t || f == 0) return f;
58        for (auto &cid = ptr[v]; cid < sz(adj[v]);) {
59            auto eid = adj[v][cid];
60            auto &e = edges[eid];
61            cid++;
62            if (e.cap - e.flow <= 0) continue;
63            if (dist[e.v] + e.cost != dist[e.u]) continue;
64            int newf = dfs(e.u, min(f, e.cap-e.flow));
65            if (newf == 0) continue;
66            e.flow += newf;
67            edges[eid^1].flow -= newf;
68            cost += e.cost * newf;
69            return newf;
70        }
71        return 0;
72    }
73
74    int total_flow = 0;
75    int flow() {
76        while (spfa()) {
77            ptr.assign(n, 0);
78            while (int newf = dfs(s, LLINF))
79                total_flow += newf;
80        }
81        return total_flow;
82    }
83 };

```

6 Math

6.1 Berlekamp Massey

```
1
2 #define SZ 233333
3
4 ll qp(ll a, ll b)
5 {
6     ll x=1; a%=MOD;
7     while(b)
8     {
9         if(b&1) x=x*a%MOD;
10        a=a*a%MOD; b>>=1;
11    }
12    return x;
13 }
14 namespace linear_seq {
15
16 inline vector<int> BM(vector<int> x)
17 {
18     //ls: (shortest) relation sequence (after filling
19     zeroes) so far
20     //cur: current relation sequence
21     vector<int> ls, cur;
22     //lf: the position of ls (t')
23     //ldt: delta of ls (v')
24     int lf=0, ldt=0;
25     for(int i=0; i<int(x.size()); ++i)
26     {
27         ll t=0;
28         //evaluate at position i
29         for(int j=0; j<int(cur.size()); ++j)
30             t=(t+x[i-j-1]*(ll)cur[j])%MOD;
31         if((t-x[i])%MOD==0) continue; //good so far
32         //first non-zero position
33         if(!cur.size())
34         {
35             cur.resize(i+1);
36             lf=i; ldt=(t-x[i])%MOD;
37             continue;
38         }
39         //cur=cur-c/ldt*(x[i]-t)
40         ll k=-(x[i]-t)*qp(ldt, MOD-2)%MOD/*1/ldt*/;
41         vector<int> c(i-lf-1); //add zeroes in front
42         c.pb(k);
43         for(int j=0; j<int(ls.size()); ++j)
44             c.pb(-ls[j]*k%MOD);
45         if(c.size()<cur.size()) c.resize(cur.size());
46         for(int j=0; j<int(cur.size()); ++j)
47             c[j]=(c[j]+cur[j])%MOD;
48         //if cur is better than ls, change ls to cur
49         if(i-lf+(int)ls.size()>=(int)cur.size())
50             ls=cur, lf=i, ldt=(t-x[i])%MOD;
51         cur=c;
52     }
53     for(int i=0; i<int(cur.size()); ++i)
54         cur[i]=(cur[i]%MOD+MOD)%MOD;
55     return cur;
56 }
57 int m; //length of recurrence
58 //a: first terms
59 //h: relation
60 ll a[SZ], h[SZ], t_[SZ], s[SZ], t[SZ];
61 //calculate p*q mod f
62 inline void mull(ll*p, ll*q)
63 {
64     for(int i=0; i<m+m; ++i) t_[i]=0;
65     for(int i=0; i<m; ++i) if(p[i])
66         for(int j=0; j<m; ++j)
67             t_[i+j]=(t_[i+j]+p[i]*q[j])%MOD;
68     for(int i=m+m-1; i>=m; --i) if(t_[i])
```

```
68         //miuns t_[i]x^{i-m}(x^{m-1}\sum_{j=0}^{m-1} x^{
69         m-j-1}h_j)
70         for(int j=m-1; ~j; --j)
71             t_[i-j-1]=(t_[i-j-1]+t_[i]*h[j])%MOD;
72     }
73     inline ll calc(ll K)
74     {
75         for(int i=m; ~i; --i)
76             s[i]=t[i]=0;
77         //init
78         s[0]=1; if(m!=1) t[1]=1; else t[0]=h[0];
79         //binary-exponentiation
80         while(K)
81         {
82             if(K&1) mull(s, t);
83             mull(t, t); K>>=1;
84         }
85         ll su=0;
86         for(int i=0; i<m; ++i) su=(su+s[i]*a[i])%MOD;
87         return (su%MOD+MOD)%MOD;
88     }
89     inline int work(vector<int> x, ll n)
90     {
91         if(n<int(x.size())) return x[n];
92         vector<int> v=BM(x); m=v.size(); if(!m) return 0;
93         for(int i=0; i<m; ++i) h[i]=v[i], a[i]=x[i];
94         return calc(n);
95     }
96 }
97 }
98 using linear_seq::work;
```

6.2 Bigmod

```
1 ll mod(string a, ll p) {
2     ll res = 0, b = 1;
3     reverse(all(a));
4
5     for(auto c : a) {
6         ll tmp = (((ll)c-'0')*b) % p;
7         res = (res + tmp) % p;
8
9         b = (b * 10) % p;
10    }
11
12    return res;
13 }
```

6.3 Crt

```
1 tuple<ll, ll, ll> ext_gcd(ll a, ll b) {
2     if (!a) return {b, 0, 1};
3     auto [g, x, y] = ext_gcd(b%a, a);
4     return {g, y - b/a*x, x};
5 }
6
7 struct crt {
8     ll a, m;
9
10    crt() : a(0), m(1) {}
11    crt(ll a_, ll m_) : a(a_), m(m_) {}
12    crt operator * (crt C) {
13        auto [g, x, y] = ext_gcd(m, C.m);
14        if ((a - C.a) % g) a = -1;
15        if (a == -1 || C.a == -1) return crt(-1, 0);
16        ll lcm = m/g*C.m;
17        ll ans = a + (x*(C.a-a)/g % (C.m/g))*m;
18        return crt((ans % lcm + lcm) % lcm, lcm);
19    }
20 };
```

6.4 Division Trick

```
1 for(int l = 1, r; l <= n; l = r + 1) {
2     r = n / (n / l);
3     // n / i has the same value for l <= i <= r
4 }
```

6.5 Fft Mod Tfg

```
1 // usar vector<int> p(ms, 0);
2
3 const int me = 20;
4 const int ms = 1 << me;
5
6 ll fexp(ll x, ll e, ll mod = MOD) {
7     ll ans = 1;
8     x %= mod;
9     for(; e > 0; e /= 2) {
10         if(e & 1) {
11             ans = ans * x % mod;
12         }
13         x = x * x % mod;
14     }
15     return ans;
16 }
17
18 //is n primitive root of p ?
19 bool test(ll x, ll p) {
20     ll m = p - 1;
21     for(int i = 2; i * i <= m; ++i) if(m % i == 0) {
22         if(fexp(x, i, p) == 1) return false;
23         if(fexp(x, m / i, p) == 1) return false;
24     }
25     return true;
26 }
27
28 //find the largest primitive root for p
29 int search(int p) {
30     for(int i = p - 1; i >= 2; --i) if(test(i, p))
31         return i;
32     return -1;
33 }
34
35 #define add(x, y, mod) (x+y>=mod?x+y-mod:x+y)
36
37 const int gen = search(MOD);
38 int bits[ms], r[ms + 1];
39
40 void pre(int n) {
41     int LOG = 0;
42     while(1 << (LOG + 1) < n) {
43         LOG++;
44     }
45     for(int i = 1; i < n; i++) {
46         bits[i] = (bits[i >> 1] >> 1) | ((i & 1) << LOG);
47     }
48 }
49
50 void pre(int n, int root, int mod) {
51     pre(n);
52     r[0] = 1;
53     for(int i = 1; i <= n; i++) {
54         r[i] = (ll) r[i - 1] * root % mod;
55     }
56 }
57
58 vector<int> fft(vector<int> a, int mod, bool inv =
59     false) {
60     int root = gen;
61     if(inv) {
62         root = fexp(root, mod - 2, mod);
63     }
```

```
61 }
62 int n = a.size();
63 root = fexp(root, (mod - 1) / n, mod);
64 pre(n, root, mod);
65 for(int i = 0; i < n; i++) {
66     int to = bits[i];
67     if(i < to) {
68         swap(a[i], a[to]);
69     }
70 }
71 for(int len = 1; len < n; len *= 2) {
72     for(int i = 0; i < n; i += len * 2) {
73         int cur_root = 0;
74         int delta = n / (2 * len);
75         for(int j = 0; j < len; j++) {
76             int u = a[i + j], v = (ll) a[i + j +
77 len] * r[cur_root] % mod;
78             a[i + j] = add(u, v, mod);
79             a[i + j + len] = add(u, mod - v, mod);
80             cur_root += delta;
81         }
82     }
83 }
84 if(inv) {
85     int rev = fexp(n, mod - 2, mod);
86     for(int i = 0; i < n; i++)
87         a[i] = (ll) a[i] * rev % mod;
88 }
89 return a;
90 }
```

6.6 Fft Simple

```
1 #define ld long double
2 const ld PI = acos(-1);
3
4 struct num{
5     ld a {0.0}, b {0.0};
6     num(){}
7     num(ld na) : a{na}{}
8     num(ld na, ld nb) : a{na}, b{nb} {}
9     const num operator+(const num &c) const{
10         return num(a + c.a, b + c.b);
11     }
12     const num operator-(const num &c) const{
13         return num(a - c.a, b - c.b);
14     }
15     const num operator*(const num &c) const{
16         return num(a*c.a - b*c.b, a*c.b + b*c.a);
17     }
18     const num operator/(const int &c) const{
19         return num(a/c, b/c);
20     }
21 };
22
23 void fft(vector<num> &a, bool invert){
24     int n = a.size();
25     for(int i=1,j=0;i<n;i++){
26         int bit = n>>1;
27         for(; j&bit; bit>>=1)
28             j^=bit;
29         j^=bit;
30         if(i<j)
31             swap(a[i], a[j]);
32     }
33     for(int len = 2; len <= n; len <= 1){
34         ld ang = 2 * PI / len * (invert ? -1 : 1);
35         num wlen(cos(ang), sin(ang));
36         for(int i=0;i<n;i+=len){
37             num w(1);
38             for (int j=0;j<len/2;j++){
39                 num u = a[i+j], v = a[i+j+len/2] * w;
```

```

40         a[i+j] = u + v;
41         a[i+j+len/2] = u - v;
42         w = w * wlen;
43     }
44 }
45 }
46 if(invert)
47     for(num &x: a)
48         x = x/n;
49 }
50 }
51
52 vector<ll> multiply(vector<int> const& a, vector<int>
53     const& b){
54     vector<num> fa(a.begin(), a.end());
55     vector<num> fb(b.begin(), b.end());
56     int n = 1;
57     while(n < int(a.size() + b.size()) )
58         n <= 1;
59     fa.resize(n);
60     fb.resize(n);
61     fft(fa, false);
62     fft(fb, false);
63     for(int i=0; i<n; i++)
64         fa[i] = fa[i]*fb[i];
65     fft(fa, true);
66     vector<ll> result(n);
67     for(int i=0; i<n; i++)
68         result[i] = round(fa[i].a);
69     while(result.back()==0) result.pop_back();
70     return result;
71 }

```

6.7 Fft Tourist

```

1 struct num{
2     ld x, y;
3     num() { x = y = 0; }
4     num(ld x, ld y) : x(x), y(y) {}
5 };
6
7 inline num operator+(num a, num b) { return num(a.x +
8     b.x, a.y + b.y); }
9 inline num operator-(num a, num b) { return num(a.x -
10     b.x, a.y - b.y); }
11 inline num operator*(num a, num b) { return num(a.x *
12     b.x - a.y * b.y, a.x * b.y + a.y * b.x); }
13 inline num conj(num a) { return num(a.x, -a.y); }
14
15 int base = 1;
16 vector<num> roots = {{0, 0}, {1, 0}};
17 vector<int> rev = {0, 1};
18 const ld PI = acos(-1);
19
20 void ensure_base(int nbase){
21     if(nbase <= base)
22         return;
23     rev.resize(1 << nbase);
24     for(int i = 0; i < (1 << nbase); i++)
25         rev[i] = (rev[i >> 1] >> 1) + ((i & 1) << (
26             nbase - 1));
27
28     roots.resize(1 << nbase);
29
30     while(base < nbase){
31         ld angle = 2*PI / (1 << (base + 1));
32         for(int i = 1 << (base - 1); i < (1 << base);
33             i++){
34             roots[i << 1] = roots[i];
35             ld angle_i = angle * (2 * i + 1 - (1 <<
36                 base));

```

```

32         roots[(i << 1) + 1] = num(cos(angle_i),
33             sin(angle_i));
34     }
35     base++;
36 }
37
38 void fft(vector<num> &a, int n = -1){
39     if(n == -1)
40         n = a.size();
41
42     assert((n & (n-1)) == 0);
43     int zeros = __builtin_ctz(n);
44     ensure_base(zeros);
45     int shift = base - zeros;
46     for(int i = 0; i < n; i++)
47         if(i < (rev[i] >> shift))
48             swap(a[i], a[rev[i] >> shift]);
49
50     for(int k = 1; k < n; k <= 1)
51         for(int i = 0; i < n; i += 2 * k)
52             for(int j = 0; j < k; j++){
53                 num z = a[i+j+k] * roots[j+k];
54                 a[i+j+k] = a[i+j] - z;
55                 a[i+j] = a[i+j] + z;
56             }
57 }
58
59 vector<num> fa, fb;
60 vector<ll> multiply(vector<ll> &a, vector<ll> &b){
61     int need = a.size() + b.size() - 1;
62     int nbase = 0;
63     while((1 << nbase) < need) nbase++;
64     ensure_base(nbase);
65     int sz = 1 << nbase;
66     if(sz > (int) fa.size())
67         fa.resize(sz);
68
69     for(int i = 0; i < sz; i++){
70         int x = (i < (int) a.size() ? a[i] : 0);
71         int y = (i < (int) b.size() ? b[i] : 0);
72         fa[i] = num(x, y);
73     }
74     fft(fa, sz);
75     num r(0, -0.25 / sz);
76     for(int i = 0; i <= (sz >> 1); i++){
77         int j = (sz - i) & (sz - 1);
78         num z = (fa[j] * fa[j] - conj(fa[i] * fa[i]))
79             * r;
80         if(i != j) {
81             fa[j] = (fa[i] * fa[i] - conj(fa[j] * fa[
82                 j])) * r;
83             fa[i] = z;
84         }
85     }
86     fft(fa, sz);
87     vector<ll> res(need);
88     for(int i = 0; i < need; i++)
89         res[i] = round(fa[i].x);
90     return res;
91 }
92
93 vector<ll> multiply_mod(vector<ll> &a, vector<ll> &b,
94     int m, int eq = 0){
95     int need = a.size() + b.size() - 1;
96     int nbase = 0;
97     while((1 << nbase) < need) nbase++;
98     ensure_base(nbase);
99     int sz = 1 << nbase;
100     if(sz > (int) fa.size())
        fa.resize(sz);

```



```

101 for(int i=0;i<(int)a.size();i++){
102     int x = (a[i] % m + m) % m;
103     fa[i] = num(x & ((1 << 15) - 1), x >> 15);
104 }
105 fill(fa.begin() + a.size(), fa.begin() + sz, num
106 {0, 0});
107 fft(fa, sz);
108 if(sz > (int) fb.size())
109     fb.resize(sz);
110 if(eq)
111     copy(fa.begin(), fa.begin() + sz, fb.begin());
112 else{
113     for(int i = 0; i < (int) b.size(); i++){
114         int x = (b[i] % m + m) % m;
115         fb[i] = num(x & ((1 << 15) - 1), x >> 15);
116     }
117     fill(fb.begin() + b.size(), fb.begin() + sz,
118 num {0, 0});
119     fft(fb, sz);
120 ld ratio = 0.25 / sz;
121 num r2(0, -1);
122 num r3(ratio, 0);
123 num r4(0, -ratio);
124 num r5(0, 1);
125 for(int i=0;i<=(sz >> 1);i++) {
126     int j = (sz - i) & (sz - 1);
127     num a1 = (fa[i] + conj(fa[j]));
128     num a2 = (fa[i] - conj(fa[j])) * r2;
129     num b1 = (fb[i] + conj(fb[j])) * r3;
130     num b2 = (fb[i] - conj(fb[j])) * r4;
131     if(i != j){
132         num c1 = (fa[j] + conj(fa[i]));
133         num c2 = (fa[j] - conj(fa[i])) * r2;
134         num d1 = (fb[j] + conj(fb[i])) * r3;
135         num d2 = (fb[j] - conj(fb[i])) * r4;
136         fa[i] = c1 * d1 + c2 * d2 * r5;
137         fb[i] = c1 * d2 + c2 * d1;
138     }
139     fa[j] = a1 * b1 + a2 * b2 * r5;
140     fb[j] = a1 * b2 + a2 * b1;
141 }
142 fft(fa, sz);
143 fft(fb, sz);
144 vector<ll> res(need);
145 for(int i=0;i<need;i++){
146     ll aa = round(fa[i].x);
147     ll bb = round(fb[i].x);
148     ll cc = round(fa[i].y);
149     res[i] = (aa + ((bb % m) << 15) + ((cc % m)
150 << 30)) % m;
151 }
152 }

```

6.8 Frac

```

1 struct frac {
2     ll num, den;
3     frac(ll num=0, ll den=1) : num(num), den(den) {}
4     frac operator+(const frac &o) const { return {num
5 *o.den + o.num*den, den*o.den}; }
6     frac operator-(const frac &o) const { return {num
7 *o.den - o.num*den, den*o.den}; }
8     frac operator*(const frac &o) const { return {num
9 *o.num, den*o.den}; }
10    frac operator/(const frac &o) const { return {num
11 *o.den, den*o.num}; }
12    bool operator<(const frac &o) const { return num*
13 o.den < den*o.num; }

```

```
9 };
```

6.9 Fwht

```

1 // Fast Walsh Hadamard Transform
2 //
3 // FWHT<'|'>(f) eh SOS DP
4 // FWHT<'&'>(f) eh soma de superset DP
5 // Se chamar com ^, usar tamanho potencia de 2!!
6 //
7 // O(n log(n))
8
9 template<char op, class T> vector<T> FWHT(vector<T> f
10 , bool inv = false) {
11     int n = f.size();
12     for (int k = 0; (n-1)>>k; k++) for (int i = 0; i
13 < n; i++) if (i>>k&1) {
14         int j = i^(1<<k);
15         if (op == '^') f[j] += f[i], f[i] = f[j] - 2*
16 f[i];
17         if (op == '|' ) f[i] += (inv ? -1 : 1) * f[j];
18         if (op == '&') f[j] += (inv ? -1 : 1) * f[i];
19     }
20     if (op == '^' and inv) for (auto& i : f) i /= n;
21     return f;
22 }

```

6.10 Gaussxor

```

1 struct Gauss {
2     array<ll, LOG_MAX> vet;
3     int size;
4     Gauss() : size(0) {
5         fill(vet.begin(), vet.end(), 0);
6     }
7     Gauss(vector<ll> vals) : size(0) {
8         fill(vet.begin(), vet.end(), 0);
9         for(ll val : vals) add(val);
10    }
11    bool add(ll val) {
12        for(int i = LOG_MAX-1; i >= 0; i--) if(val &
13 (1LL << i)) {
14            if(vet[i] == 0) {
15                vet[i] = val;
16                size++;
17                return true;
18            }
19            val ^= vet[i];
20        }
21        return false;
22    }
23 }

```

6.11 Inverso Mult

```

1 // gcd(a, m) = 1 para existir solucao
2 // ax + my = 1, ou a*x = 1 (mod m)
3 ll inv(ll a, ll m) { // com gcd
4     ll x, y;
5     gcd(a, m, x, y);
6     return ((x % m) + m) % m;
7 }
8
9 ll inv(ll a, ll phm) { // com phi(m), se m for primo
10    entao phi(m) = p-1
11    ll e = phm-1;
12    return fexp(a, e);

```

6.12 Kitamasa

```

1 using poly = vector<mint>; // mint = int mod P with
2 operators +, - and *

```

```

2 inline int len(const poly& a) { return a.size(); } // 20
   get rid of the annoying "hey a.size() is
   unsigned" warning
3
4 poly pmul(const poly& a, const poly& b) {
5     poly c(len(a) + len(b) - 1, 0);
6     for (int i = 0; i < len(a); i++)
7         for (int j = 0; j < len(b); j++)
8             c[i+j] = c[i+j] + a[i] * b[j];
9     return c;
10 }
11
12 // only works if b.back() == 1
13 poly pmod(const poly& a, const poly& b) {
14     poly c(a.begin(), a.end());
15     for (int i = len(c) - 1; i >= len(b) - 1; i--) {
16         int k = i - (len(b) - 1); // index of the
           quotient term
17         for (int j = 0; j < len(b); j++)
18             c[j+k] = c[j+k] - c[i] * b[j];
19     }
20     c.resize(len(b) - 1);
21     return c;
22 }
23
24 poly ppwr(poly x, ll e, poly f) {
25     poly ans = { 1 };
26     for (; e > 0; e /= 2) {
27         if (e & 1) ans = pmod(pmul(ans, x), f);
28         x = pmod(pmul(x, x), f);
29     }
30     return ans;
31 }
32
33 // values = { A0, A1, ..., An }. recurrence = C0 * A0
   + C1 * A1 + ... + Cn * An generates A{n+1}
34 mint kitamasa(const poly& values, const poly&
   recurrence, ll n) {
35     poly f(len(recurrence) + 1);
36     f.back() = 1;
37     for (int i = 0; i < len(recurrence); i++)
38         f[i] = mint(0) - recurrence[i];
39
40     auto d = ppwr(poly{0, 1}, n, f); // x^N mod f(x)
41
42     mint ans = 0;
43     for (int i = 0; i < len(values); i++)
44         ans = ans + d[i] * values[i];
45     return ans;
46 }

```

6.13 Linear Diophantine Equation

```

1 // Linear Diophantine Equation
2 int gcd(int a, int b, int &x, int &y)
3 {
4     if (a == 0)
5     {
6         x = 0; y = 1;
7         return b;
8     }
9     int x1, y1;
10    int d = gcd(b%a, a, x1, y1);
11    x = y1 - (b / a) * x1;
12    y = x1;
13    return d;
14 }
15
16 bool find_any_solution(int a, int b, int c, int &x0,
   int &y0, int &g)
17 {
18     g = gcd(abs(a), abs(b), x0, y0);
19     if (c % g)

```

```

           return false;
20
21
22     x0 *= c / g;
23     y0 *= c / g;
24     if (a < 0) x0 = -x0;
25     if (b < 0) y0 = -y0;
26     return true;
27 }
28
29 // All solutions
30 // x = x0 + k*b/g
31 // y = y0 - k*a/g

```

6.14 Matrix Exponentiation

```

1 struct Matrix {
2     vector<vl> m;
3     int r, c;
4
5     Matrix(vector<vl> mat) {
6         m = mat;
7         r = mat.size();
8         c = mat[0].size();
9     }
10
11     Matrix(int row, int col, bool ident=false) {
12         r = row; c = col;
13         m = vector<vl>(r, vl(c, 0));
14         if(ident) {
15             for(int i = 0; i < min(r, c); i++) {
16                 m[i][i] = 1;
17             }
18         }
19     }
20
21     Matrix operator*(const Matrix &o) const {
22         assert(c == o.r); // garantir que da pra
           multiplicar
23         vector<vl> res(r, vl(o.c, 0));
24
25         for(int i = 0; i < r; i++) {
26             for(int k = 0; k < c; k++) {
27                 for(int j = 0; j < o.c; j++) {
28                     res[i][j] = (res[i][j] + m[i][k]*
                       o.m[k][j]) % MOD;
29                 }
30             }
31         }
32
33         return Matrix(res);
34     }
35 };
36
37 Matrix fexp(Matrix b, int e, int n) {
38     if(e == 0) return Matrix(n, n, true); //
           identidade
39     Matrix res = fexp(b, e/2, n);
40     res = (res * res);
41     if(e%2) res = (res * b);
42
43     return res;
44 }

```

6.15 Miller Habin

```

1 ll mul(ll a, ll b, ll m) {
2     return (a*b-ll(a*(long double)b/m+0.5)*m+m)%m;
3 }
4
5 ll expo(ll a, ll b, ll m) {
6     if (!b) return 1;
7     ll ans = expo(mul(a, a, m), b/2, m);

```

```

8     return b%2 ? mul(a, ans, m) : ans;
9 }
10
11 bool prime(ll n) {
12     if (n < 2) return 0;
13     if (n <= 3) return 1;
14     if (n % 2 == 0) return 0;
15
16     ll d = n - 1;
17     int r = 0;
18     while (d % 2 == 0) {
19         r++;
20         d /= 2;
21     }
22
23     // com esses primos, o teste funciona garantido
24     // para n <= 2^64
25     // funciona para n <= 3*10^24 com os primos ate
26     // 41
27     for (int i : {2, 325, 9375, 28178, 450775,
28         9780504, 795265022}) {
29         if (i >= n) break;
30         ll x = expo(i, d, n);
31         if (x == 1 or x == n - 1) continue;
32
33         bool deu = 1;
34         for (int j = 0; j < r - 1; j++) {
35             x = mul(x, x, n);
36             if (x == n - 1) {
37                 deu = 0;
38                 break;
39             }
40         }
41         if (deu) return 0;
42     }
43     return 1;
44 }

```

6.16 Mint

```

1 struct mint {
2     int x;
3     mint(int _x = 0) : x(_x) { }
4     mint operator +(const mint &o) const { return x +
5         o.x >= MOD ? x + o.x - MOD : x + o.x; }
6     mint operator *(const mint &o) const { return
7         mint((ll)x * o.x % MOD); }
8     mint operator -(const mint &o) const { return *
9         this + (MOD - o.x); }
10    mint inv() { return pwr(MOD - 2); }
11    mint pwr(ll e) {
12        mint ans = 1;
13        for (mint b=x; e; e >>= 1, b = b * b)
14            if (e & 1) ans = ans * b;
15        return ans;
16    }
17 };
18
19 mint fac[N], ifac[N];
20 void build_fac() {
21     fac[0] = 1;
22     for (int i=1; i<N; i++)
23         fac[i] = fac[i-1] * i;
24     ifac[N-1] = fac[N-1].inv();
25     for (int i=N-2; i>=0; i--)
26         ifac[i] = ifac[i+1] * (i+1);
27 }
28
29 mint c(ll n, ll k) {
30     if (k > n) return 0;
31     return fac[n] * ifac[k] * ifac[n-k];
32 }

```

6.17 Mobius

```

1 vi mobius(int n) {
2     // g(n) = sum{f(d)} => f(n) = sum{mu(d)*g(n/d)}
3     vi mu(n+1);
4     mu[1] = 1; mu[0] = 0;
5     for(int i = 1; i <= n; i++)
6         for(int j = i + i; j <= n; j += i)
7             mu[j] -= mu[i];
8
9     return mu;
10 }

```

6.18 Mulmod

```

1 ll mulmod(ll a, ll b) {
2     if(a == 0) {
3         return 0LL;
4     }
5     if(a%2 == 0) {
6         ll val = mulmod(a/2, b);
7         return (val + val) % MOD;
8     }
9     else {
10        ll val = mulmod((a-1)/2, b);
11        val = (val + val) % MOD;
12        return (val + b) % MOD;
13    }
14 }

```

6.19 Pollard Rho

```

1 ll mul(ll a, ll b, ll m) {
2     ll ret = a*b - ((ll)((ld)1/m*a*b+0.5)*m);
3     return ret < 0 ? ret+m : ret;
4 }
5
6 ll pow(ll a, ll b, ll m) {
7     ll ans = 1;
8     for (; b > 0; b /= 2ll, a = mul(a, a, m)) {
9         if (b % 2ll == 1)
10             ans = mul(ans, a, m);
11    }
12    return ans;
13 }
14
15 bool prime(ll n) {
16     if (n < 2) return 0;
17     if (n <= 3) return 1;
18     if (n % 2 == 0) return 0;
19
20     ll r = __builtin_ctzll(n - 1), d = n >> r;
21     for (int a : {2, 325, 9375, 28178, 450775,
22         9780504, 795265022}) {
23         ll x = pow(a, d, n);
24         if (x == 1 or x == n - 1 or a % n == 0)
25             continue;
26
27         for (int j = 0; j < r - 1; j++) {
28             x = mul(x, x, n);
29             if (x == n - 1) break;
30         }
31         if (x != n - 1) return 0;
32     }
33     return 1;
34 }
35
36 ll rho(ll n) {
37     if (n == 1 or prime(n)) return n;
38     auto f = [n](ll x) {return mul(x, x, n) + 1;};
39
40     ll x = 0, y = 0, t = 30, prd = 2, x0 = 1, q;

```

```

39 while (t % 40 != 0 or gcd(prd, n) == 1) {
40     if (x==y) x = ++x0, y = f(x);
41     q = mul(prd, abs(x-y), n);
42     if (q != 0) prd = q;
43     x = f(x), y = f(f(y)), t++;
44 }
45 return gcd(prd, n);
46 }
47
48 vector<ll> fact(ll n) {
49     if (n == 1) return {};
50     if (prime(n)) return {n};
51     ll d = rho(n);
52     vector<ll> l = fact(d), r = fact(n / d);
53     l.insert(l.end(), r.begin(), r.end());
54     return l;
55 }

```

6.20 Poly

```

1  const int MOD = 998244353;
2  const int me = 15;
3  const int ms = 1 << me;
4
5  #define add(x, y) x+y>=MOD?x+y-MOD:x+y
6
7  const int gen = 3; // use search() from PrimitiveRoot
8  .cpp if MOD isn't 998244353
9  int bits[ms], root[ms];
10
11 void initFFT() {
12     root[1] = 1;
13     for(int len = 2; len < ms; len += len) {
14         int z = (int) fexp(gen, (MOD - 1) / len / 2);
15         for(int i = len / 2; i < len; i++) {
16             root[2 * i] = root[i];
17             root[2 * i + 1] = (int)((long long) root[i] * z % MOD);
18         }
19     }
20 }
21
22 void pre(int n) {
23     int LOG = 0;
24     while(1 << (LOG + 1) < n) {
25         LOG++;
26     }
27     for(int i = 1; i < n; i++) {
28         bits[i] = (bits[i >> 1] >> 1) | ((i & 1) << LOG);
29     }
30 }
31
32 std::vector<int> fft(std::vector<int> a, bool inv = false) {
33     int n = (int) a.size();
34     pre(n);
35     if(inv) {
36         std::reverse(a.begin() + 1, a.end());
37     }
38     for(int i = 0; i < n; i++) {
39         int to = bits[i];
40         if(i < to) { std::swap(a[i], a[to]); }
41     }
42     for(int len = 1; len < n; len *= 2) {
43         for(int i = 0; i < n; i += len * 2) {
44             for(int j = 0; j < len; j++) {
45                 int u = a[i + j], v = (int)((long long) a[i + j + len] * root[len + j] % MOD);
46                 a[i + j] = add(u, v);
47                 a[i + j + len] = add(u, MOD - v);
48             }
49         }
50     }
51 }

```

```

49 }
50 if(inv) {
51     long long rev = fexp(n, MOD-2, MOD);
52     for(int i = 0; i < n; i++)
53         a[i] = (int)(a[i] * rev % MOD);
54 }
55 return a;
56 }
57
58 std::vector<int> shift(const std::vector<int> &a, int s) {
59     int n = std::max(0, s + (int) a.size());
60     std::vector<int> b(n, 0);
61     for(int i = std::max(-s, 0); i < (int) a.size(); i++) {
62         b[i + s] = a[i];
63     }
64     return b;
65 }
66
67 std::vector<int> cut(const std::vector<int> &a, int n) {
68     std::vector<int> b(n, 0);
69     for(int i = 0; i < (int) a.size() && i < n; i++) {
70         b[i] = a[i];
71     }
72     return b;
73 }
74
75 std::vector<int> operator +(std::vector<int> a, const std::vector<int> &b) {
76     int sz = (int) std::max(a.size(), b.size());
77     a.resize(sz, 0);
78     for(int i = 0; i < (int) b.size(); i++) {
79         a[i] = add(a[i], b[i]);
80     }
81     return a;
82 }
83
84 std::vector<int> operator -(std::vector<int> a, const std::vector<int> &b) {
85     int sz = (int) std::max(a.size(), b.size());
86     a.resize(sz, 0);
87     for(int i = 0; i < (int) b.size(); i++) {
88         a[i] = add(a[i], MOD - b[i]);
89     }
90     return a;
91 }
92
93 std::vector<int> operator *(std::vector<int> a, std::vector<int> b) {
94     while(!a.empty() && a.back() == 0) a.pop_back();
95     while(!b.empty() && b.back() == 0) b.pop_back();
96     if(a.empty() || b.empty()) return std::vector<int> >(0, 0);
97     int n = 1;
98     while(n-1 < (int) a.size() + (int) b.size() - 2) n += n;
99     a.resize(n, 0);
100    b.resize(n, 0);
101    a = fft(a, false);
102    b = fft(b, false);
103    for(int i = 0; i < n; i++) {
104        a[i] = (int) ((long long) a[i] * b[i] % MOD);
105    }
106    return fft(a, true);
107 }
108
109 std::vector<int> inverse(const std::vector<int> &a, int k) {
110     assert(!a.empty() && a[0] != 0);
111     if(k == 0) {

```

```

112     return std::vector<int>(1, (int) fexp(a[0],
MOD - 2));
113 } else {
114     int n = 1 << k;
115     auto c = inverse(a, k-1);
116     return cut(c * cut(std::vector<int>(1, 2) -
cut(a, n) * c, n), n);
117 }
118 }
119
120 std::vector<int> operator /(std::vector<int> a, std::
vector<int> b) {
121     // NEED TO TEST!
122     while(!a.empty() && a.back() == 0) a.pop_back();
123     while(!b.empty() && b.back() == 0) b.pop_back();
124     assert(!b.empty());
125     if(a.size() < b.size()) return std::vector<int>
>(1, 0);
126     std::reverse(a.begin(), a.end());
127     std::reverse(b.begin(), b.end());
128     int n = (int) a.size() - (int) b.size() + 1;
129     int k = 0;
130     while((1 << k) - 1 < n) k++;
131     a = cut(a * inverse(b, k), (int) a.size() - (int)
b.size() + 1);
132     std::reverse(a.begin(), a.end());
133     return a;
134 }
135
136 std::vector<int> log(const std::vector<int> &a, int k
) {
137     assert(!a.empty() && a[0] != 0);
138     int n = 1 << k;
139     std::vector<int> b(n, 0);
140     for(int i = 0; i+1 < (int) a.size() && i < n; i
++) {
141         b[i] = (int)((i + 1LL) * a[i+1] % MOD);
142     }
143     b = cut(b * inverse(a, k), n);
144     assert((int) b.size() == n);
145     for(int i = n - 1; i > 0; i--) {
146         b[i] = (int) (b[i-1] * fexp(i, MOD - 2) % MOD
);
147     }
148     b[0] = 0;
149     return b;
150 }
151
152 std::vector<int> exp(const std::vector<int> &a, int k
) {
153     assert(!a.empty() && a[0] == 0);
154     if(k == 0) {
155         return std::vector<int>(1, 1);
156     } else {
157         auto b = exp(a, k-1);
158         int n = 1 << k;
159         return cut(b * cut(std::vector<int>(1, 1) +
cut(a, n) - log(b, k), n), n);
160     }
161 }

```

6.21 Primitiveroot

```

1 long long fexp(long long x, long long e, long long
mod = MOD) {
2     long long ans = 1;
3     x %= mod;
4     for(; e > 0; e /= 2, x = x * x % mod) {
5         if(e & 1) ans = ans * x % mod;
6     }
7     return ans;
8 }
9 //is n primitive root of p ?

```

```

10 bool test(long long x, long long p) {
11     long long m = p - 1;
12     for(int i = 2; i * i <= m; ++i if(!(m % i)) {
13         if(fexp(x, i, p) == 1) return false;
14         if(fexp(x, m / i, p) == 1) return false;
15     }
16     return true;
17 }
18 //find the smallest primitive root for p
19 int search(int p) {
20     for(int i = 2; i < p; i++) if(test(i, p)) return
i;
21     return -1;
22 }

```

6.22 Raiz Primitiva

```

1 ll fexp(ll b, ll e, ll mod) {
2     if(e == 0) return 1LL;
3     ll res = fexp(b, e/2LL, mod);
4     res = (res*res)%mod;
5     if(e%2LL)
6         res = (res*b)%mod;
7     return res%mod;
8 }
9
10
11 vl fatorar(ll n) { // fatora em primos
12     vl fat;
13     for(int i = 2; i*i <= n; i++) {
14         if(n%i == 0) {
15             fat.pb(i);
16             while(n%i == 0)
17                 n /= i;
18         }
19     }
20     return fat;
21 }
22
23 // O(log(n) ^ 2)
24 bool raiz_prim(ll a, ll mod, ll phi, vl fat) {
25     if(__gcd(a, mod) != 1 or fexp(a, phi/2, mod) ==
1) // phi de euler sempre eh PAR
26         return false;
27
28     for(auto f : fat) {
29         if(fexp(a, phi/f, mod) == 1)
30             return false;
31     }
32
33     return true;
34 }
35
36 // mods com raizes primitivas: 2, 4, p^k, 2*p^k, p eh
primo impar, k inteiro --- O(n log^2(n))
37 ll achar_raiz(ll mod, ll phi) {
38     if(mod == 2) return 1;
39     vl fat, elementos;
40     fat = fatorar(phi);
41
42     for(ll i = 2; i <= mod-1; i++) {
43         if(raiz_prim(i, mod, phi, fat))
44             return i;
45     }
46
47     return -1; // retorna -1 se nao existe
48 }
49
50 vl todas_raizes(ll mod, ll phi, ll raiz) {
51     vl raizes;
52     if(raiz == -1) return raizes;
53     ll r = raiz;
54     for(ll i = 1; i <= phi-1; i++) {

```

```

55         if(__gcd(i, phi) == 1) {
56             raizes.pb(r);
57         }
58         r = (r * raiz) % mod;
59     }
60
61     return raizes;
62 }

```

6.23 Randommod

```

1 int randommod() {
2     auto primo = [](int num) {
3         for(int i = 2; i*i <= num; i++) {
4             if(num%i == 0) return false;
5         }
6         return true;
7     };
8     uniform_int_distribution<int> distribution
9     (1000000007, 1500000000);
10    int num = distribution(rng);
11    while(!primo(num)) num++;
12    return num;
13 }

```

6.24 Totient

```

1 // phi(p^k) = (p^(k-1))*(p-1) com p primo
2 // O(sqrt(m))
3 ll phi(ll m){
4     ll res = m;
5     for(ll d=2; d*d<=m; d++){
6         if(m % d == 0){
7             res = (res/d)*(d-1);
8             while(m%d == 0)
9                 m /= d;
10        }
11    }
12    if(m > 1) {
13        res /= m;
14        res *= (m-1);
15    }
16    return res;
17 }
18
19 // modificacao do crivo, O(n*log(log(n)))
20 vector<ll> phi_to_n(ll n){
21     vector<bool> isprime(n+1, true);
22     vector<ll> tot(n+1);
23     tot[0] = 0; tot[1] = 1;
24     for(ll i=1; i<=n; i++){
25         tot[i] = i;
26     }
27
28     for(ll p=2; p<=n; p++){
29         if(isprime[p]){
30             tot[p] = p-1;
31             for(ll i=p+p; i<=n; i+=p){
32                 isprime[i] = false;
33                 tot[i] = (tot[i]/p)*(p-1);
34             }
35         }
36     }
37     return tot;
38 }

```

7 Misc

7.1 Bitwise

```

1 // Least significant bit (lsb)

```

```

2 int lsb(int x) { return x&-x; }
3 int lsb(int x) { return __builtin_ctz(x); } //
4 // Most significant bit (msb)
5 int msb(int x) { return 32-1-__builtin_clz(x); }
6 // bit position
7 // Power of two
8 bool isPowerOfTwo(int x){ return x && (!(x&(x-1)))
9 }; }
10 // floor(log2(x))
11 int flog2(int x) { return 32-1-__builtin_clz(x); }
12 int flog2ll(ll x) { return 64-1-__builtin_clzll(x); }
13
14 // Built-in functions
15 // Number of bits 1
16 __builtin_popcount()
17 __builtin_popcountll()
18
19 // Number of leading zeros
20 __builtin_clz()
21 __builtin_clzll()
22
23 // Number of trailing zeros
24 __builtin_ctz()
25 __builtin_ctzll()

```

7.2 Ordered Set

```

1 #include <bits/extc++.h>
2 using namespace __gnu_pbds; // or pb_ds;
3 template<typename T, typename B = null_type>
4 using ordered_set = tree<T, B, less<T>, rb_tree_tag,
5     tree_order_statistics_node_update>;
6
7 // order_of_key(k) : Number of items strictly
8 // smaller than k
9 // find_by_order(k) : K-th element in a set (counting
10 // from zero)
11
12 // to swap two sets, use a.swap(b);

```

7.3 Rand

```

1 mt19937 rng(chrono::steady_clock::now().
2     time_since_epoch().count()); // mt19937_64
3 uniform_int_distribution<int> distribution(1,n);
4
5 num = distribution(rng); // num no range [1, n]
6 shuffle(vec.begin(), vec.end(), rng); // shuffle
7
8 using ull = unsigned long long;
9 ull mix(ull o){
10     o+=0x9e3779b97f4a7c15;
11     o=(o^(o>>30))*0xbf58476d1ce4e5b9;
12     o=(o^(o>>27))*0x94d049bb133111eb;
13     return o^(o>>31);
14 }
15 ull hash(pii a) {return mix(a.first ^ mix(a.second))
16 };

```

7.4 Submask

```

1 // O(3^n)
2 for (int m = 0; m < (1<<n); m++) {
3     for (int s = m; s; s = (s-1) & m) {
4         // s is every submask of m
5     }
6 }
7
8 // O(2^n * n) SOS dp like

```

```

9 for (int b = n-1; b >= 0; b--) {
10     for (int m = 0; m < (1 << n); m++) {
11         if (j & (1 << b)) {
12             // propagate info through submasks
13             amount[j ^ (1 << b)] += amount[j];
14         }
15     }
16 }

```

7.5 Template

```

1 #include <bits/stdc++.h>
2 #define sws cin.tie(0)->sync_with_stdio(false);
3 #define ll long long
4 #define ff first
5 #define ss second
6 #define pb push_back
7 #define endl '\n'
8
9 using namespace std;
10
11 const int INF = 0x3f3f3f3f;
12
13 int main() {
14     sws;
15
16     return 0;
17 }

```

8 Numeric

8.1 Lagrange Interpolation

```

1 // Lagrange's interpolation O(n^2)
2 ld interpolate(vector<pair<int, int>> d, ld x){
3     ld y = 0;
4     int n = d.size();
5     for(int i=0; i<n; i++){
6         ld yi = d[i].ss;
7         for(int j=0; j<n; j++){
8             if(j!=i)
9                 yi = yi*(x - d[j].ff)/(ld)(d[i].ff - d
10                    [j].ff);
11         }
12         y += yi;
13     }
14     return y;
15 }
16 // O(n)
17
18 template<typename T = mint>
19 struct Lagrange {
20     vector<T> y, den, l, r;
21     int n;
22     Lagrange(const vector<T>& _y) : y(_y), n(_y.size
23        ()) {
24         den.resize(n, 0);
25         l.resize(n, 0); r.resize(n, 0);
26
27         for (int i = 0; i < n; i++) {
28             den[i] = ifac[i] * ifac[n - 1 - i];
29             if ((n - 1 - i) % 2 == 1) den[i] = -den[i]
30         }
31     }
32
33     T eval(T x) {
34         l[0] = 1;
35         for (int i = 1; i < n; i++)
36             l[i] = l[i-1] * (x + -T(i-1));
37     }
38 }

```

```

36
37     r[n - 1] = 1;
38     for (int i = n - 2; i >= 0; i--)
39         r[i] = r[i+1] * (x + -T(i+1));
40
41     T ans = 0;
42     for (int i = 0; i < n; i++) {
43         T num = l[i] * r[i];
44         ans = ans + y[i] * num * den[i];
45     }
46     return ans;
47 }
48 };

```

8.2 Newton Raphson

```

1 // Newton Raphson
2
3 ld f(x){ return x*2 + 2; }
4 ld fd(x){ return 2; } // derivada
5
6 ld root(ld x){
7     // while(f(x)>EPS)
8     for(int i=0; i<20; i++){
9         if(fd(x)<EPS)
10             x = LLINF;
11         else
12             x = x - f(x)/fd(x);
13     }
14     return x;
15 }

```

8.3 Simpson's Formula

```

1 inline ld simpson(ld fl, ld fr, ld fmid, ld l, ld r){
2     return (fl+fr+4*fmid)*(r-l)/6;
3 }
4
5 ld rsimpson(ld slr, ld fl, ld fr, ld fmid, ld l, ld r
6     )
7 {
8     ld mid = (l+r)/2;
9     ld fml = f((l+mid)/2), fmr = f((mid+r)/2);
10    ld slm = simpson(fl, fmid, fml, l, mid);
11    ld smr = simpson(fmid, fr, fmr, mid, r);
12    if(fabs(slr-slm-smr) < EPS) return slm+smr; //
13    aprox. good enough
14    return rsimpson(slm, fl, fmid, fml, l, mid)+rsimpson(
15        smr, fmid, fr, fmr, mid, r);
16 }
17
18 ld integrate(ld l, ld r)
19 {
20     ld mid = (l+r)/2;
21     ld fl = f(l), fr = f(r);
22     ld fmid = f(mid);
23     return rsimpson(simpson(fl, fr, fmid, l, r), fl, fr,
24         fmid, l, r);
25 }

```

9 Strings

9.1 Aho Corasick

```

1 // https://github.com/joseleite19/icpc-notebook/blob/
2   master/code/string/aho_corasick.cpp
3 const int A = 26;
4 int to[N][A];
5 int ne = 2, fail[N], term[N];
6 void add_string(string str, int id){
7     int p = 1;
8 }

```

```

7     for(auto c: str){
8         int ch = c - 'a'; // !
9         if(!to[p][ch]) to[p][ch] = ne++;
10        p = to[p][ch];
11    }
12    term[p]++;
13 }
14 void init(){
15     for(int i = 0; i < ne; i++) fail[i] = 1;
16     queue<int> q; q.push(1);
17     int u, v;
18     while(!q.empty()){
19         u = q.front(); q.pop();
20         for(int i = 0; i < A; i++){
21             if(to[u][i]){
22                 v = to[u][i]; q.push(v);
23                 if(u != 1){
24                     fail[v] = to[ fail[u] ][i];
25                     term[v] += term[ fail[v] ];
26                 }
27             }
28             else if(u != 1) to[u][i] = to[ fail[u] ][i];
29             else to[u][i] = 1;
30         }
31     }
32 }

```

9.2 Edit Distance

```

1 int edit_distance(int a, int b, string& s, string& t)
2 {
3     // indexado em 0, transforma s em t
4     if(a == -1) return b+1;
5     if(b == -1) return a+1;
6     if(tab[a][b] != -1) return tab[a][b];
7
8     int ins = INF, del = INF, mod = INF;
9     ins = edit_distance(a-1, b, s, t) + 1;
10    del = edit_distance(a, b-1, s, t) + 1;
11    mod = edit_distance(a-1, b-1, s, t) + (s[a] != t[b]);
12
13    return tab[a][b] = min(ins, min(del, mod));
14 }

```

9.3 Eertree

```

1 // heavily based on https://ideone.com/YQX9jv,
2 // which adamant cites here https://codeforces.com/
3 // blog/entry/139597#comment-196033
4 struct Eertree {
5     int s[N];
6     int n, last, sz;
7
8     int len[N], link[N];
9     int to[N][A];
10
11     Eertree() {
12         s[n++] = -1;
13         len[1] = -1, link[1] = 1; // "backspace" root
14         is 1
15         len[0] = 0, link[0] = 1; // empty root is 0
16         (to[backspace root][any char] = empty root)
17         last = 2;
18         sz = 2;
19     }
20
21     int get_link(int u) {
22         while (s[n - len[u] - 2] != s[n - 1]) u =
23         link[u];
24         return u;
25     }
26 }

```

```

21     }
22
23     void push(int c) {
24         s[n++] = c;
25         int p = get_link(last);
26         if (!to[p][c]) {
27             int u = ++sz;
28             len[u] = len[p] + 2;
29             link[u] = to[get_link(link[p])][c]; //
30             may be 0 (empty), but never 1 (backspace)
31             to[p][c] = u;
32         }
33         last = to[p][c];
34     }
35 }

```

9.4 Hash

```

1 // String Hash template
2 // constructor(s) - O(|s|)
3 // query(l, r) - returns the hash of the range [l,r]
4 // from left to right - O(1)
5 // query_inv(l, r) from right to left - O(1)
6 struct Hash {
7     const ll P = 31;
8     int n; string s;
9     vector<ll> h, hi, p;
10    Hash() {}
11    Hash(string s): s(s), n(s.size()), h(n), hi(n), p
12    (n) {
13        for (int i=0;i<n;i++) p[i] = (i ? P*p[i-1]:1)
14        % MOD;
15        for (int i=0;i<n;i++)
16            h[i] = (s[i] + (i ? h[i-1]:0) * P) % MOD;
17        for (int i=n-1;i>=0;i--)
18            hi[i] = (s[i] + (i+1<n ? hi[i+1]:0) * P)
19            % MOD;
20    }
21    int query(int l, int r) {
22        ll hash = (h[r] - (l ? h[l-1]*p[r-l+1]%MOD :
23        0));
24        return hash < 0 ? hash + MOD : hash;
25    }
26    int query_inv(int l, int r) {
27        ll hash = (hi[l] - (r+1 < n ? hi[r+1]*p[r-
28        1+1] % MOD : 0));
29        return hash < 0 ? hash + MOD : hash;
30    }
31 }
32 };

```

9.5 Kmp

```

1 string p;
2 int neighbor[N];
3 int walk(int u, char c) { // leader after inputting '
4     c'
5     while (u != -1 && (u+1 >= (int)p.size() || p[u +
6     1] != c)) // leader doesn't match
7         u = neighbor[u];
8     return p[u + 1] == c ? u+1 : u;
9 }
10 void build() {
11     neighbor[0] = -1; // -1 is the leftmost state
12     for (int i = 1; i < (int)p.size(); i++)
13         neighbor[i] = walk(neighbor[i-1], p[i]);
14 }

```

9.6 Lcs

```

1 string LCSUBSTR(string X, string Y)
2 {

```



```

3   int m = X.size();
4   int n = Y.size();
5
6   int result = 0, end;
7   int len[2][n];
8   int currRow = 0;
9
10  for(int i=0;i<=m;i++){
11      for(int j=0;j<=n;j++){
12          if(i==0 || j==0)
13              len[currRow][j] = 0;
14          else if(X[i-1] == Y[j-1]){
15              len[currRow][j] = len[1-currRow][j-1]
16              + 1;
17              if(len[currRow][j] > result){
18                  result = len[currRow][j];
19                  end = i - 1;
20              }
21          }
22          else
23              len[currRow][j] = 0;
24      }
25      currRow = 1 - currRow;
26  }
27
28  if(result==0)
29      return string();
30
31  return X.substr(end - result + 1, result);
32 }

```

9.7 Lcsubseq

```

1 // Longest Common Subsequence
2 string lcs(string x, string y){
3     int n = x.size(), m = y.size();
4     vector<vi> dp(n+1, vi(m+1, 0));
5
6     for(int i=0;i<=n;i++){
7         for(int j=0;j<=m;j++){
8             if(!i or !j)
9                 dp[i][j]=0;
10            else if(x[i-1] == y[j-1])
11                dp[i][j]=dp[i-1][j-1]+1;
12            else
13                dp[i][j]=max(dp[i-1][j], dp[i][j-1]);
14        }
15    }
16
17    // int len = dp[n][m];
18    string ans="";
19
20    // recover string
21    int i = n-1, j = m-1;
22    while(i>=0 and j>=0){
23        if(x[i] == y[j]){
24            ans.pb(x[i]);
25            i--; j--;
26        }else if(dp[i][j+1]>dp[i+1][j])
27            i--;
28        else
29            j--;
30    }
31
32    reverse(ans.begin(), ans.end());
33
34    return ans;
35 }

```

9.8 Manacher

```

1 // O(n), d1 -> palindromo impar, d2 -> palindromo par
   (centro da direita)
2 void manacher(string &s, vector<int> &d1, vector<int>
   &d2) {
3     int n = s.size();
4     for(int i = 0, l = 0, r = -1; i < n; i++) {
5         int k = (i > r) ? 1 : min(d1[l + r - i], r -
6         i + 1);
7         while(0 <= i - k && i + k < n && s[i - k] ==
8         s[i + k]) {
9             k++;
10        }
11        d1[i] = k--;
12        if(i + k > r) {
13            l = i - k;
14            r = i + k;
15        }
16    }
17
18    for(int i = 0, l = 0, r = -1; i < n; i++) {
19        int k = (i > r) ? 0 : min(d2[l + r - i + 1],
20        r - i + 1);
21        while(0 <= i - k - 1 && i + k < n && s[i - k
22        - 1] == s[i + k]) {
23            k++;
24        }
25        d2[i] = k--;
26        if(i + k > r) {
27            l = i - k - 1;
28            r = i + k;
29        }
30    }
31 }

```

9.9 Suffix Array

```

1 vector<int> suffix_array(string s) {
2     s += "!";
3     int n = s.size(), N = max(n, 260);
4     vector<int> sa(n), ra(n);
5     for (int i = 0; i < n; i++) sa[i] = i, ra[i] = s[
6     i];
7
8     for (int k = 0; k < n; k ? k *= 2 : k++) {
9         vector<int> nsa(sa), nra(n), cnt(N);
10
11        for (int i = 0; i < n; i++) nsa[i] = (nsa[i] -
12        k+n)%n, cnt[ra[i]]++;
13        for (int i = 1; i < N; i++) cnt[i] += cnt[i
14        -1];
15        for (int i = n-1; i+1; i--) sa[--cnt[ra[nsa[i
16        ]]]] = nsa[i];
17
18        for (int i = 1, r = 0; i < n; i++) nra[sa[i]]
19        = r += ra[sa[i]] !=
20        ra[sa[i-1]] or ra[(sa[i]+k)%n] != ra[(sa[
21        i-1]+k)%n];
22        ra = nra;
23        if (ra[sa[n-1]] == n-1) break;
24    }
25    return vector<int>(sa.begin()+1, sa.end());
26 }
27
28 vector<int> kasai(string s, vector<int> sa) {
29     int n = s.size(), k = 0;
30     vector<int> ra(n), lcp(n);
31     for (int i = 0; i < n; i++) ra[sa[i]] = i;
32
33     for (int i = 0; i < n; i++, k -= !k) {
34         if (ra[i] == n-1) { k = 0; continue; }
35         int j = sa[ra[i]+1];
36         while (i+k < n and j+k < n and s[i+k] == s[j+
37         k]) k++;
38     }
39 }

```

```

31     lcp[ra[i]] = k;
32 }
33 return lcp;
34 }

```

9.10 Suffix Array Radix

```

1 #define pii pair<int, int>
2
3 void radix_sort(vector<pii>& rnk, vi& ind) {
4     auto counting_sort = [](vector<pii>& rnk, vi& ind
5 ) {
6         int n = ind.size(), maxx = -1;
7         for(auto p : rnk) maxx = max(maxx, p.ff);
8
9         vi cnt(maxx+1, 0), pos(maxx+1), ind_new(n);
10        for(auto p : rnk) cnt[p.ff]++;
11        pos[0] = 0;
12
13        for(int i = 1; i <= maxx; i++) {
14            pos[i] = pos[i-1] + cnt[i-1];
15        }
16
17        for(auto idx : ind) {
18            int val = rnk[idx].ff;
19            ind_new[pos[val]] = idx;
20            pos[val]++;
21        }
22
23        swap(ind, ind_new);
24    };
25
26    for(int i = 0; i < (int)rnk.size(); i++) swap(rnk
27 [i].ff, rnk[i].ss);
28    counting_sort(rnk, ind);
29 }
30
31 vi suffix_array(const string& s) {
32     int n = s.size();
33     vector<pii> rnk(n, {0, 0});
34     vi ind(n);
35     for(int i=0; i<n; i++) {
36         rnk[i].ff = (s[i] == '$') ? 0 : s[i]-'a'+1;
37         // manter '$' como 0
38         ind[i] = i;
39     }
40
41     for(int k = 1; k <= n; k = (k << 1)) {
42         for(int i = 0; i < n; i++) {
43             if(ind[i]+k >= n) {
44                 rnk[ind[i]].ss = 0;
45             }
46             else {
47                 rnk[ind[i]].ss = rnk[ind[i]+k].ff;
48             }
49         }
50         radix_sort(rnk, ind); // sort(all(rnk), cmp)
51         pra n*log(n), cmp com rnk[i] < rnk[j]
52
53         vector<pii> tmp = rnk;
54         tmp[ind[0]] = {1, 0}; // rnk.ff comecar em 1
55         pois '$' eh o 0
56         for(int i = 1; i < n; i++) {
57             tmp[ind[i]].ff = tmp[ind[i-1]].ff;
58             if(rnk[ind[i]] != rnk[ind[i-1]]) {
59                 tmp[ind[i]].ff++;
60             }
61         }
62         swap(rnk, tmp);
63     }
64     return ind;
65 }

```

```

62 }
63
64
65 vi lcp_array(const string& s, const vi& sarray) {
66     vi inv(s.size());
67     for(int i = 0; i < (int)s.size(); i++) {
68         inv[sarray[i]] = i;
69     }
70     vi lcp(s.size());
71     int k = 0;
72     for(int i = 0; i < (int)s.size()-1; i++) {
73         int pi = inv[i];
74         if(pi-1 < 0) continue;
75         int j = sarray[pi-1];
76
77         while(s[i+k] == s[j+k]) k++;
78         lcp[pi] = k;
79         k = max(k-1, 0);
80     }
81
82     return vi(lcp.begin()+1, lcp.end()); // LCP(i, j)
83     = min(lcp[i], ..., lcp[j-1])
84 }

```

9.11 Suffix Automaton

```

1 const int SA = 2*N; // Node 1 is the initial node of
   the automaton
2 int last = 1;
3 #define link my_link
4 int len[SA], link[SA];
5 array<int, 26> to[SA]; // maybe map<int, int>
6 int lastID = 1;
7 void push(int c) {
8     int u = ++lastID;
9     len[u] = len[last] + 1;
10
11     int p = last;
12     last = u; // update last immediately
13     for (; p > 0 && !to[p][c]; p = link[p])
14         to[p][c] = u;
15
16     if (p == 0) { link[u] = 1; return; }
17
18     int q = to[p][c];
19     if (len[q] == len[p] + 1) { link[u] = q; return; }
20
21     int clone = ++lastID;
22     len[clone] = len[p] + 1;
23     link[clone] = link[q];
24     link[q] = link[u] = clone;
25     to[clone] = to[q];
26     for (int pp = p; to[pp][c] == q; pp = link[pp])
27         to[pp][c] = clone;
28 }

```

9.12 Z Func

```

1 vector<int> Z(string s) {
2     int n = s.size();
3     vector<int> z(n);
4     int x = 0, y = 0;
5     for (int i = 1; i < n; i++) {
6         z[i] = max(0, min(z[i - x], y - i + 1));
7         while (i + z[i] < n and s[z[i]] == s[i + z[i]
8 ])) {
9             x = i; y = i + z[i]; z[i]++;
10        }
11    }
12    return z;
13 }

```