

# Competitive Programming Notebook

Programadores Roblox

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# 1 String

## 1.1 Trie

```

1 // Trie por array
2 int trie[MAXN][26];
3 int tot_nos = 0;
4 vector<bool> acaba(MAXN, false);
5 vector<int> contador(MAXN, 0);
6
7 void insere(string s) {
8     int no = 0;
9     for(auto &c : s) {
10         if(trie[no][c - 'a'] == 0) {
11             trie[no][c - 'a'] = ++tot_nos;
12         }
13         no = trie[no][c - 'a'];
14         contador[no]++;
15     }
16     acaba[no] = true;
17 }
18
19 bool busca(string s) {
20     int no = 0;
21     for(auto &c : s) {
22         if(trie[no][c - 'a'] == 0) {
23             return false;
24         }
25         no = trie[no][c - 'a'];
26     }
27     return acaba[no];
28 }
29
30 int isPref(string s) {
31     int no = 0;
32     for(auto &c : s) {
33         if(trie[no][c - 'a'] == 0){
34             return -1;
35         }
36         no = trie[no][c - 'a'];
37     }
38     return contador[no];
39 }
```

## 1.2 Hashing

```

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 // patrocinado por tiagodfs
7
8 mt19937 rng(time(nullptr));
9
10 struct Hash {
11     const int X = rng();
12     const int MOD = 1e9+7;
13     int n; string s;
14     vector<int> h, hi, p;
15     Hash() {}
16     Hash(string s): s(s), n(s.size()), h(n), hi(n), p(n) {
17         for (int i=0;i<n;i++) p[i] = (i ? X*p[i-1]:1) % MOD;
18         for (int i=0;i<n;i++)
19             h[i] = (s[i] + (i ? h[i-1]:0) * X) % MOD;
20         for (int i=n-1;i>=0;i--)
21             hi[i] = (s[i] + (i+1<n ? hi[i+1]:0) * X) % MOD;
22     }
23     int query(int l, int r) {
```

```

23         int hash = (h[r] - (l ? h[l-1]*p[r-1+1]%MOD : 0));
24         return hash < 0 ? hash + MOD : hash;
25     }
26     int query_inv(int l, int r) {
27         int hash = (hi[l] - (r+1 < n ? hi[r+1]*p[r-1+1] % MOD : 0));
28         return hash < 0 ? hash + MOD : hash;
29     }
30 };
```

## 1.3 Z Function

```

1 vector<int> z_function(string s) {
2     int n = s.size();
3     vector<int> z(n);
4     int l = 0, r = 0;
5     for(int i = 1; i < n; i++) {
6         if(i < r) {
7             z[i] = min(r - i, z[i - 1]);
8         }
9         while(i + z[i] < n && s[z[i]] == s[i + z[i]]) {
10             z[i]++;
11         }
12         if(i + z[i] > r) {
13             l = i;
14             r = i + z[i];
15         }
16     }
17     return z;
18 }
```

## 1.4 Kmp

```

1 vector<int> kmp(string &s) {
2     int m = s.size();
3     vector<int> lsp(m, 0);
4     for (int i = 1, j = 0; i < m; i++) {
5         while (j > 0 && s[j] != s[i]) j = lsp[j - 1];
6         if (s[i] == s[j]) j++;
7         lsp[i] = j;
8     }
9     return lsp;
10 }
```

# 2 DS

## 2.1 Seg Lazy Pa

```

/* Notas
PA eh da forma a0 (a) e razão (d)
na hora de propagar o lazy
aplica no no S = (a0 + (a0 + (n - 1) * d)) * n / 2
(variante da soma total do no)
pros filhos, o da esquerda eh normal
lazy_a[esq] += lazy_a[x]
lazy_d[esq] += lazy_d[x]
pro da direita tem que mudar o a (que eh o elemento
inicial naquele no da direita)
lazy_a[dir] += a + len_esq * (d)
lazy_d[dir] += lazy_d[x]

int gauss(int n, int a, int d) {
// (a0 + an) * n / 2
if (n <= 0)
    return 0;
return (a + (a + (n - 1) * d)) * n / 2;
}
```

```

20 struct SegTree {
21     int n;
22     vector<int> v, lazy_a, lazy_d, tree;
23     SegTree(vector<int> &a) : v(a), n(a.size()) {
24         tree.resize(4 * n);
25         lazy_a.resize(4 * n, 0);
26         lazy_d.resize(4 * n, 0);
27         build(1, 0, n - 1);
28     }
29     void build(int x, int lx, int rx) {
30         if (lx == rx) {
31             tree[x] = v[lx];
32             return;
33         }
34         int mid = (lx + rx) / 2;
35         build(2 * x, lx, mid);
36         build(2 * x + 1, mid + 1, rx);
37         tree[x] = tree[2 * x] + tree[2 * x + 1];
38     }
39     int query(int x, int lx, int rx, int l, int r) {
40         push(x, lx, rx);
41         if (lx >= l && rx <= r)
42             return tree[x];
43         if (lx > r || rx < l)
44             return 0;
45         int mid = (lx + rx) / 2;
46         return query(2 * x, lx, mid, l, r) + query(2 * x
47             + 1, mid + 1, rx, l, r);
48     }
49     int query(int l, int r) {
50         return query(1, 0, n - 1, l, r);
51     }
52     void push(int x, int lx, int rx) {
53         if (lazy_a[x] && lazy_d[x]) {
54             int tam = rx - lx + 1;
55             tree[x] += gauss(tam, lazy_a[x], lazy_d[x]);
56             if (lx != rx) {
57                 int mid = (lx + rx) / 2;
58                 int tam_esq = mid - lx + 1;
59                 lazy_a[2 * x] += lazy_a[x];
60                 lazy_d[2 * x] += lazy_d[x];
61                 lazy_a[2 * x + 1] += (lazy_a[x] + tam_esq *
62                     lazy_d[x]);
63                 lazy_d[2 * x + 1] += lazy_d[x];
64             }
65             lazy_a[x] = lazy_d[x] = 0;
66         }
67     }
68     void update(int x, int lx, int rx, int l, int r,
69                 int a, int d) {
70         push(x, lx, rx);
71         if (lx >= l && rx <= r) {
72             lazy_a[x] += a + (lx - 1) * d;
73             lazy_d[x] += d;
74             push(x, lx, rx);
75             return;
76         }
77         int mid = (lx + rx) / 2;
78         update(2 * x, lx, mid, l, r, a, d);
79         update(2 * x + 1, mid + 1, rx, l, r, a, d);
80         tree[x] = tree[2 * x] + tree[2 * x + 1];
81     }
82     void update(int l, int r, int a, int d) {
83         update(1, 0, n - 1, l, r, a, d);
84     }
85 };

```

```

3 // range query e point update
4 template <typename T>
5 struct SegTree {
6     int n;
7     vector<T> tree;
8     T neutral_value = 0;
9     T combine(T a, T b) {
10         return a + b;
11     }
12
13     SegTree(const vector<T>& data) {
14         n = data.size();
15         tree.resize(2 * n, neutral_value);
16
17         for (int i = 0; i < n; i++)
18             tree[n + i] = data[i];
19
20         for (int i = n - 1; i > 0; --i)
21             tree[i] = combine(tree[i * 2], tree[i * 2
+ 1]);
22     }
23     T range_query(int l, int r) {
24         T res_l = neutral_value, res_r =
neutral_value;
25
26         for (l += n, r += n + 1; l < r; l >>= 1, r
>>= 1) {
27             if (l & 1) res_l = combine(res_l, tree[l
++]);
28             if (r & 1) res_r = combine(tree[-r],
res_r);
29         }
30
31         return combine(res_l, res_r);
32     }
33     void update(int pos, T new_val) {
34         tree[pos += n] = new_val;
35         for (pos >= 1; pos > 0; pos >>= 1)
36             tree[pos] = combine(tree[2 * pos], tree[2
* pos + 1]);
37     }
38 };

```

## 2.3 Merge Sort Tree

```

1 #define all(x) x.begin(), x.end()
2
3 struct MST {
4     int n;
5     vector<vector<int>> tree;
6     MST(vector<int> &a) {
7         n = a.size();
8         tree.resize(4 * n);
9         build(1, 0, n - 1, a);
10    }
11    void build(int x, int lx, int rx, vector<int> &a) {
12        if (lx == rx) {
13            tree[x] = {a[lx]};
14            return;
15        }
16        int mid = lx + (rx - lx) / 2;
17        build(2 * x, lx, mid, a);
18        build(2 * x + 1, mid + 1, rx, a);
19        auto &L = tree[2 * x], &R = tree[2 * x + 1];
20        tree[x].resize(L.size() + R.size());
21        merge(all(L), all(R), tree[x].begin());
22    }
23    int query(int x, int lx, int rx, int l, int r, int
val) {
24        if (lx > r || rx < l) return 0;
25        if (lx >= l && rx <= r) {
26            auto &v = tree[x];
27            return lower_bound(all(v), val) - v.begin();
28        }
29        int mid = lx + (rx - lx) / 2;
30        int L = query(2 * x, lx, mid, l, r, val);
31        int R = query(2 * x + 1, mid + 1, rx, l, r, val);
32        return L + R;
33    }
34 };

```

## 2.2 Segtree Iterativa

```
1 // Exemplo de uso:  
2 // SegTree<int> st(vetor);
```

```

28     }
29     int mid = lx + (rx - lx) / 2;
30     return query(2 * x, lx, mid, l, r, val) + query(2
31     * x + 1, mid + 1, rx, l, r, val);
32   }
33   int query(int l, int r, int val) {
34     if (l > r) return 0;
35     return query(1, 0, n - 1, l, r, val);
36   }
37 }
38 /* mst.query(l, r, 1) retorna quantos caras distintos
39   no range
40   map<int, int> last;
41   for (int i = 0; i < n; i++) {
42     if (last.count(a[i])) {
43       esq[i] = last[a[i]];
44     } else {
45       esq[i] = -1;
46     }
47   last[a[i]] = i;
48 }
49 MST mst(esq);
50 jogar vetor de ultima aparicao na seg
51 */

```

## 2.4 Ordered Set E Map

```

1
2 #include<ext/pb_ds/assoc_container.hpp>
3 #include<ext/pb_ds/tree_policy.hpp>
4 using namespace __gnu_pbds;
5 using namespace std;
6
7 template<typename T> using ordered_multiset = tree<T,
8   null_type, less_equal<T>, rb_tree_tag,
9   tree_order_statistics_node_update>;
10 template <typename T> using o_set = tree<T, null_type
11 , less<T>, rb_tree_tag,
12 tree_order_statistics_node_update>;
13 template <typename T, typename R> using o_map = tree<
14   T, R, less<T>, rb_tree_tag,
15   tree_order_statistics_node_update>;
16
17 int main() {
18   int i, j, k, n, m;
19   o_set<int> st;
20   st.insert(1);
21   st.insert(2);
22   cout << *st.find_by_order(0) << endl; // k-esimo
23   cout << st.order_of_key(2) << endl; // numero de
24   elementos menores que k
25   o_map<int, int> mp;
26   mp.insert({1, 10});
27   mp.insert({2, 20});
28   cout << mp.find_by_order(0)->second << endl; // k-
29   esimo elemento
30   cout << mp.order_of_key(2) << endl; // numero de
31   elementos (chave) menores que k
32   return 0;
33 }

```

## 2.5 Sparse Table

```

1 // 0-index, O(1)
2 struct SparseTable {
3   vector<vector<int>> st;
4   int max_log;
5   SparseTable(vector<int>& arr) {
6     int n = arr.size();
7     max_log = floor(log2(n)) + 1;

```

```

8     st.resize(n, vector<int>(max_log));
9     for (int i = 0; i < n; i++) {
10       st[i][0] = arr[i];
11     }
12     for (int j = 1; j < max_log; j++) {
13       for (int i = 0; i + (1 << j) <= n; i++) {
14         st[i][j] = max(st[i][j - 1], st[i +
15         (1 << (j - 1))][j - 1]);
16       }
17     }
18   }
19   int query(int L, int R) {
20     int tamanho = R - L + 1;
21     int k = floor(log2(tamanho));
22     return max(st[L][k], st[R - (1 << k) + 1][k]);
23   }

```

## 2.6 Psum 2d

```

1 vector<vector<int>> psum(h+1, vector<int>(w+1, 0));
2 for (int i=1; i<=h; i++){
3   for (int j=1; j<=w; j++){
4     cin >> psum[i][j];
5     psum[i][j] += psum[i-1][j]+psum[i][j-1]-psum[
6     i-1][j-1];
7   }
8 // retorna a psum2d do intervalo inclusivo [(a, b), (
9 int retangulo(int a, int b, int c, int d){
10   c = min(c, h), d = min(d, w);
11   a = max(0LL, a-1), b = max(0LL, b-1);
12   return v[c][d]-v[a][d]-v[c][b]+v[a][b];
13 }

```

## 2.7 Segtree Sum

```

1 struct SegTree {
2   vector<int> tree;
3   vector<int> lazy;
4   int n;
5   SegTree(int N) {
6     n = N;
7     tree.resize(4 * n);
8     lazy.resize(4 * n, 0);
9     // build(a);
10 }
11 void push(int lx, int rx, int x) {
12   if (lazy[x] == 0) {
13     return;
14   }
15   // tree[x] += lazy[x];
16   tree[x] += (rx - lx + 1) * lazy[x];
17   if (lx != rx) {
18     lazy[2 * x] += lazy[x];
19     lazy[2 * x + 1] += lazy[x];
20   }
21   lazy[x] = 0;
22 }
23 void build(vector<int> &a) {
24   build(0, n - 1, 1, a);
25 }
26 void build(int lx, int rx, int x, vector<int> &a)
27 {
28   if (lx == rx) {
29     tree[x] = a[lx];
30     return;
31   }
32   int mid = lx + (rx - lx) / 2;
33   build(lx, mid, 2 * x, a);

```

```

33     build(mid + 1, rx, 2 * x + 1, a);
34     tree[x] = tree[2 * x] + tree[2 * x + 1];
35 }
36 void update(int l, int r, int val) {
37     update(0, n - 1, 1, l, r, val);
38 }
39 void update(int lx, int rx, int x, int l, int r,
40             int val) {
41     push(lx, rx, x);
42     if (rx < l || lx > r) {
43         return;
44     }
45     if (lx >= l && rx <= r) {
46         lazy[x] += val;
47         push(lx, rx, x);
48         return;
49     }
50     int mid = lx + (rx - lx) / 2;
51     update(lx, mid, 2 * x, l, r, val);
52     update(mid + 1, rx, 2 * x + 1, l, r, val);
53     tree[x] = tree[2 * x] + tree[2 * x + 1];
54 }
55 int query(int l, int r) {
56     return query(0, n - 1, 1, l, r);
57 }
58 int query(int lx, int rx, int x, int l, int r) {
59     push(lx, rx, x);
60     if (rx < l || lx > r) {
61         return 0;
62     }
63     if (lx >= l && rx <= r) {
64         return tree[x];
65     }
66     int mid = lx + (rx - lx) / 2;
67     int s1 = query(lx, mid, 2 * x, l, r);
68     int s2 = query(mid + 1, rx, 2 * x + 1, l, r);
69     return s1 + s2;
70 }

```

## 2.8 Dsu

```

1 struct DSU {
2     vector<int> par, rank, sz;
3     int c;
4     DSU(int n) : par(n + 1), rank(n + 1, 0), sz(n +
5         1, 1), c(n) {
6         for (int i = 1; i <= n; ++i) par[i] = i;
7     }
8     int find(int i) {
9         return (par[i] == i ? i : (par[i] = find(par[i])));
10    }
11    bool same(int i, int j) {
12        return find(i) == find(j);
13    }
14    int get_size(int i) {
15        return sz[find(i)];
16    }
17    int count() {
18        return c; // quantos componentes conexos
19    }
20    int merge(int i, int j) {
21        if ((i = find(i)) == (j = find(j))) return
22            -1;
23        else --c;
24        if (rank[i] > rank[j]) swap(i, j);
25        par[i] = j;
26        sz[j] += sz[i];
27        if (rank[i] == rank[j]) rank[j]++;
28        return j;
29    }
30 };

```

## 2.9 Bit

```

1 struct BIT {
2     int n;
3     vector<int> bit;
4     BIT(int n = 0): n(n), bit(n + 1, 0) {}
5     void add(int i, int delta) {
6         for(; i <= n; i += i & -i) bit[i] += delta;
7     }
8     int sum(int i) {
9         int r = 0;
10        for(; i > 0; i -= i & -i) r += bit[i];
11        return r;
12    }
13    int range_sum(int l, int r){
14        if (r < l) return 0;
15        return sum(r) - sum(l - 1);
16    }
17 };

```

## 3 Search and sort

### 3.1 Merge Sort

```

1 int mergeAndCount(vector<int>& v, int l, int m, int r
2 ) {
3     int x = m - l + 1;
4     int y = r - m;
5     vector<int> left(x), right(y);
6     for (int i = 0; i < x; i++) left[i] = v[l + i];
7     for (int j = 0; j < y; j++) right[j] = v[m + 1 +
8         j];
9     int i = 0, j = 0, k = l;
10    int swaps = 0;
11    while (i < x && j < y) {
12        if (left[i] <= right[j]) {
13            v[k++] = left[i++];
14        } else {
15            v[k++] = right[j++];
16            swaps += (x - i);
17        }
18    }
19    while (i < x) v[k++] = left[i++];
20    while (j < y) v[k++] = right[j++];
21    return swaps;
22 }
23 int mergeSort(vector<int>& v, int l, int r) {
24     int swaps = 0;
25     if (l < r) {
26         int m = l + (r - 1) / 2;
27         swaps += mergeSort(v, l, m);
28         swaps += mergeSort(v, m + 1, r);
29         swaps += mergeAndCount(v, l, m, r);
30     }
31     return swaps;
32 }

```

### 3.2 Monotonic Stack

```

1 vector<int> find_esq(vector<int> &v, bool maior) {
2     int n = v.size();
3     vector<int> result(n);
4     stack<int> s;
5
6     for (int i = 0; i < n; i++) {
7         while (!s.empty() && (maior ? v[s.top()] <= v
8 [i] : v[s.top()] >= v[i])) {
9             s.pop();
10        }
11        if (s.empty()) {
12            result[i] = -1;
13        }
14    }
15    return result;
16 }

```

```

12     } else {
13         result[i] = v[s.top()];
14     }
15     s.push(i);
16 }
17 return result;
18 }

19 vector<int> find_dir(vector<int> &v, bool maior) {
20     int n = v.size();
21     vector<int> result(n);
22     stack<int> s;
23     for (int i = n - 1; i >= 0; i--) {
24         while (!s.empty() && (maior ? v[s.top()] <= v
25 [i] : v[s.top()] >= v[i])) {
26             s.pop();
27         }
28         if (s.empty()) {
29             result[i] = -1;
30         } else {
31             result[i] = v[s.top()];
32         }
33         s.push(i);
34     }
35     return result;
36 }

```

4 Stress

## 4.1 Gen

```
1 // pre-compilar os headers:  
2 // compilar template com g++ -H e procurar onde esta  
    stdc++.h  
3 // criar a pasta bits e incluir com "" ou inves de <>  
4 // compilar stress com: g++ -pipe -O3 -flto -march=  
    native -mtune=native gen.ccp  
5 // faz bastante diferenÃ§a no runtime  
6  
7 #include <bits/stdc++.h>  
8 #include <cstdlib>  
9 #include <ctime>  
10 using namespace std;  
11  
12 int randi(int L, int R) { return L + rand() % (R - L  
    + 1); }  
13 char randc(char L, char R) { return char(L + rand() %  
    (R - L + 1)); }  
14  
15 int main(int argc, char** argv) {  
16     if (argc > 1) srand(atoi(argv[1]));  
17     else srand(time(0));  
18  
19     int n = randi(1, 100);  
20     cout << n << '\n';  
21     for (int i = 0; i < n; i++) {  
22         cout << randi(-10, 20) << ' ';  
23     }  
24     cout << '\n';  
25 }
```

5 Math

## 5.1 Combinatorics

```
1 const int MAXN_FATORIAL = 200005;
2 const int MOD = 1e9 + 7;
3 // DEFINE INT LONG LONG PLMDS
4 int fat[MAXN_FATORIAL], fati[MAXN_FATORIAL];
```

## 5.2 Equação Diofantina

```

1 int extended_gcd(int a, int b, int& x, int& y) {
2     if (a == 0) {
3         x = 0;
4         y = 1;
5         return b;
6     }
7     int x1, y1;
8     int gcd = extended_gcd(b % a, a, x1, y1);
9     x = y1 - (b / a) * x1;
10    y = x1;
11    return gcd;
12 }
13
14 bool solve(int a, int b, int c, int& x0, int& y0) {
15     int x, y;
16     int g = extended_gcd(abs(a), abs(b), x, y);
17     if (c % g != 0) {
18         return false;
19     }
20     x0 = x * (c / g);
21     y0 = y * (c / g);
22     if (a < 0) x0 = -x0;
23     if (b < 0) y0 = -y0;
24     return true;
25 }
```

### 5.3 Multiplicacao Matriz

```

1 // multiplica matrizes de tamanhos variados,
   resultado em uma matrix N*M
2 vector<vector<int>> mm(vector<vector<int>> A, vector<
   vector<int>> B) {
3     int N = A.size(), M = B[0].size(), K = B.size();
4     vector<vector<int>> C(N, vector<int>(M));

```

```

6     for (int i = 0; i < N; ++i)
7         for (int j = 0; j < M; ++j)
8             for (int k = 0; k < K; ++k)
9                 C[i][j] = (C[i][j]+A[i][k] * B[k][j]
10                % mod)%mod;
11
12 }  


```

## 5.4 Discrete Log

```

1 // returns minimum x for which a^x = b (mod m), a and
2 // m are coprime.
3 // if the answer dont need to be greater than some
4 // value, the vector<int> can be removed
5 int discrete_log(int a, int b, int m) {
6     a %= m, b %= m;
7     int n = sqrt(m) + 1;
8
9     int an = 1;
10    for (int i = 0; i < n; ++i)
11        an = (an * 111 * a) % m;
12
13    unordered_map<int, vector<int>> vals;
14    for (int q = 0, cur = b; q <= n; ++q) {
15        vals[cur].push_back(q);
16        cur = (cur * 111 * a) % m;
17    }
18
19    int res = LLONG_MAX;
20
21    for (int p = 1, cur = 1; p <= n; ++p) {
22        cur = (cur * 111 * an) % m;
23        if (vals.count(cur)) {
24            for (int q: vals[cur]) {
25                int ans = n * p - q;
26                res = min(res, ans);
27            }
28        }
29    }
30
31    return res;
32 }  


```

## 5.5 Segment Sieve

```

1 // Retorna quantos primos tem entre [l, r] (inclusivo)
2
3 int seg_sieve(int l, int r){
4     if (l > r) return 0;
5     vector<bool> is_prime(r - l + 1, true);
6     if (l == 1) is_prime[0] = false;
7
8     for (int p : primos){
9         if (p * p > r) break;
10        int start = max(p * p, (l + p - 1) / p * p);
11        for (int j = start; j <= r; j += p){
12            if (j >= l) {
13                is_prime[j - 1] = false;
14            }
15        }
16    }
17
18    return accumulate(all(is_prime), 0ll);;
19 }  


```

## 5.6 Totient

```

1 // phi(n) = n * (1 - 1/p1) * (1 - 1/p2) * ...
2 int phi(int n) {
3     int result = n;
4     for (int i = 2; i * i <= n; i++) {  


```

```

5         if (n % i == 0) {
6             while (n % i == 0)
7                 n /= i;
8             result -= result / i;
9         }
10    }
11    if (n > 1) // SE n sobrou, ele Ã' um fator primo
12        result -= result / n;
13    return result;
14 }
15
16 // crivo phi
17 const int MAXN_PHI = 1000001;
18 int phiv[MAXN_PHI];
19 void phi_sieve() {
20     for (int i = 0; i < MAXN_PHI; i++) phiv[i] = i;
21     for (int i = 2; i < MAXN_PHI; i++) {
22         if (phiv[i] == i) {
23             for (int j = i; j < MAXN_PHI; j += i)
24                 phiv[j] -= phiv[j] / i;
25         }
26     }
27 }  


```

## 5.7 Menor Fator Primo

```

1 const int MAXN = 1000001;
2 int spf[MAXN];
3 vector<int> primos;
4
5 void crivo() {
6     for (int i = 0; i < MAXN; i++) spf[i] = [i];
7     for (int i = 2; i * i < MAXN; i++) {
8         if (spf[i] == i) {
9             for (int j = i * i; j < MAXN; j += i) {
10                if (spf[j] == j) {
11                    spf[j] = i;
12                }
13            }
14        }
15    }
16    for (int i = 2; i < MAXN; i++) {
17        if (spf[i] == i) {
18            primos.push_back(i);
19        }
20    }
21 }
22
23 map<int, int> fatora(int n) {
24     map<int, int> fatores;
25     while (n > 1) {
26         fatores[spf[n]]++;
27         n /= spf[n];
28     }
29     return fatores;
30 }
31
32 int numero_de_divisores(int n) {
33     if (n == 1) return 1;
34     map<int, int> fatores = fatorar(n);
35     int nod = 1;
36     for (auto &[primo, expoente] : fatores) nod *= (expoente + 1);
37     return nod;
38 }
39
40 // DEFINE INT LONG LONG
41 int soma_dos_divisores(int n) {
42     if (n == 1) return 1;
43     map<int, int> fatores = fatorar(n);
44     int sod = 1;
45     for (auto &[primo, expoente] : fatores) {
46         int termo_soma = 1;  


```

```

47     int potencia_primo = 1;
48     for (int i = 0; i < expoente; i++) {
49         potencia_primo *= primo;
50         termo_soma += potencia_primo;
51     }
52     sod *= termo_soma;
53 }
54 return sod;
55 }
```

## 5.8 Exgcd

```

1 // 0 retorno da funcao eh {n, m, g}
2 // e significa que gcd(a, b) = g e
3 // n e m sao inteiros tais que an + bm = g
4 array<ll, 3> exgcd(int a, int b) {
5     if(b == 0) return {1, 0, a};
6     auto [m, n, g] = exgcd(b, a % b);
7     return {n, m - a / b * n, g};
8 }
```

## 5.9 Fexp

```

1 // a^e mod m
2 // O(log n)
3
4 int fexp(int a, int e, int m) {
5     a %= m;
6     int ans = 1;
7     while (e > 0){
8         if (e & 1) ans = ans*a % m;
9         a = a*a % m;
10        e /= 2;
11    }
12    return ans%m;
13 }
```

## 5.10 Divisores

```

1 // Retorna um vetor com os divisores de x
2 // eh preciso ter o crivo implementado
3 // O(divisores)
4
5 vector<int> divs(int x){
6     vector<int> ans = {1};
7     vector<array<int, 2>> primos; // {primo, expoente}
8 }
9
10 while (x > 1) {
11     int p = crivo[x], cnt = 0;
12     while (x % p == 0) cnt++, x /= p;
13     primos.push_back({p, cnt});
14 }
15 for (int i=0; i<primos.size(); i++){
16     int cur = 1, len = ans.size();
17
18     for (int j=0; j<primos[i][1]; j++){
19         cur *= primos[i][0];
20         for (int k=0; k<len; k++)
21             ans.push_back(cur*ans[k]);
22     }
23 }
24
25 return ans;
26 }
```

## 5.11 Crivo

```
1 // O(n*log(log(n)))
```

```

2 bool composto[MAX]
3 for(int i = 1; i <= n; i++) {
4     if(composto[i]) continue;
5     for(int j = 2*i; j <= n; j += i)
6         composto[j] = 1;
7 }
```

## 5.12 Mod Inverse

```

1 array<int, 2> extended_gcd(int a, int b) {
2     if (b == 0) return {1, 0};
3     auto [x, y] = extended_gcd(b, a % b);
4     return {y, x - (a / b) * y};
5 }
6
7 int mod_inverse(int a, int m) {
8     auto [x, y] = extended_gcd(a, m);
9     return (x % m + m) % m;
10 }
```

## 5.13 Base Calc

```

1 int char_to_val(char c) {
2     if (c >= '0' && c <= '9') return c - '0';
3     else return c - 'A' + 10;
4 }
5
6 char val_to_char(int val) {
7     if (val >= 0 && val <= 9) return val + '0';
8     else return val - 10 + 'A';
9 }
10
11 int to_base_10(string &num, int bfrom) {
12     int result = 0;
13     int pot = 1;
14     for (int i = num.size() - 1; i >= 0; i--) {
15         if (char_to_val(num[i]) >= bfrom) return -1;
16         result += char_to_val(num[i]) * pot;
17         pot *= bfrom;
18     }
19     return result;
20 }
21
22 string from_base_10(int n, int bto) {
23     if (n == 0) return "0";
24     string result = "";
25     while (n > 0) {
26         result += val_to_char(n % bto);
27         n /= bto;
28     }
29     reverse(result.begin(), result.end());
30     return result;
31 }
32
33 string convert_base(string &num, int bfrom, int bto)
34 {
35     int n_base_10 = to_base_10(num, bfrom);
36     return from_base_10(n_base_10, bto);
37 }
```

## 5.14 Fft

```

1 // multiplica dois polinomios em O(NlogN)
2
3 using cd = complex<double>;
4 const double PI = acos(-1);
5
6 void fft(vector<cd> &A, bool invert) {
7     int N = size(A);
8
9     for (int i = 1, j = 0; i < N; i++) {
10         int bit = N >> 1;
```

```

11     for ( ; j & bit; bit >>= 1)
12         j ^= bit;
13     j ^= bit;
14
15     if (i < j)
16         swap(A[i], A[j]);
17 }
18
19 for (int len = 2; len <= N; len <= 1) {
20     double ang = 2 * PI / len * (invert ? -1 : 1);
21     cd wlen(cos(ang), sin(ang));
22     for (int i = 0; i < N; i += len) {
23         cd w(1);
24         for (int j = 0; j < len/2; j++) {
25             cd u = A[i+j], v = A[i+j+len/2] * w;
26             A[i+j] = u + v;
27             A[i+j+len/2] = u-v;
28             w *= wlen;
29         }
30     }
31
32     if (invert) {
33         for (auto &x : A)
34             x /= N;
35     }
36 }
37
38 vector<int> multiply(vector<int> const& A, vector<int>
39 > const& B) {
40     vector<cd> fa(begin(A), end(A)), fb(begin(B), end(B));
41     int N = 1;
42     while (N < size(A) + size(B))
43         N <= 1;
44     fa.resize(N);
45     fb.resize(N);
46
47     fft(fa, false);
48     fft(fb, false);
49     for (int i = 0; i < N; i++)
50         fa[i] *= fb[i];
51     fft(fa, true);
52
53     vector<int> result(N);
54     for (int i = 0; i < N; i++)
55         result[i] = round(fa[i].real());
56     return result;
57 }
```

## 6 Graph

### 6.1 Dijkstra

```

1 // SSP com pesos positivos.
2 // O((V + E) log V).
3
4 vector<int> dijkstra(int S) {
5     vector<bool> vis(MAXN, 0);
6     vector<ll> dist(MAXN, LLONG_MAX);
7     dist[S] = 0;
8     priority_queue<pii, vector<pii>, greater<pii> pq
9     ;
10    pq.push({0, S});
11    while(pq.size()) {
12        ll v = pq.top().second;
13        pq.pop();
14        if(vis[v]) continue;
15        vis[v] = 1;
16        for(auto &[peso, vizinho] : adj[v]) {
17            if(dist[vizinho] > dist[v] + peso) {
18                dist[vizinho] = dist[v] + peso;
19                pq.push({dist[vizinho], vizinho});
20            }
21        }
22    }
23 }
```

```

18                 pq.push({dist[vizinho], vizinho});
19             }
20         }
21     }
22     return dist;
23 }
```

### 6.2 Floyd Warshall

```

1 // SSP e acha ciclos.
2 // Bom com constraints menores.
3 // O(n^3)
4
5 int dist[501][501];
6
7 void floydWarshall() {
8     for(int k = 0; k < n; k++) {
9         for(int i = 0; i < n; i++) {
10             for(int j = 0; j < n; j++) {
11                 dist[i][j] = min(dist[i][j], dist[i][
k] + dist[k][j]);
12             }
13         }
14     }
15 }
16
17 void solve() {
18     int m, q;
19     cin >> n >> m >> q;
20     for(int i = 0; i < n; i++) {
21         for(int j = i; j < n; j++) {
22             if(i == j) {
23                 dist[i][j] = dist[j][i] = 0;
24             } else {
25                 dist[i][j] = dist[j][i] = lINF;
26             }
27         }
28         for(int i = 0; i < m; i++) {
29             int u, v, w;
30             cin >> u >> v >> w;
31             dist[u][v] = min(dist[u][v], w);
32             dist[v][u] = min(dist[v][u], w);
33         }
34     }
35     floydWarshall();
36     while(q--) {
37         int u, v;
38         cin >> u >> v;
39         if(dist[u][v] == lINF) cout << -1 << '\n';
40         else cout << dist[u][v] << '\n';
41     }
42 }
```

### 6.3 Eulerian Path

```

1 /**
2  * versao que assume: #define int long long
3  *
4  * Retorna um caminho/ciclo euleriano em um grafo (se
5  * existir).
6  * - g: lista de adjacencia (vector<vector<int>>).
7  * - directed: true se o grafo for dirigido.
8  * - s: vertice inicial.
9  * - e: vertice final (opcional). Se informado, tenta
10   caminho de s ate e.
11  * - O(Nlog(N))
12  * Retorna vetor com a sequencia de vertices, ou
13   vazio se impossivel.
14 */
15
16 vector<int> eulerian_path(const vector<vector<int>>&
17 g, bool directed, int s, int e = -1) {
18     int n = (int)g.size();
19     // copia das adjacencias em multiset para
20     // permitir remoção especifica
```

```

15     vector<multiset<int>> h(n);
16     vector<int> in_degree(n, 0);
17     vector<int> result;
18     stack<int> st;
19     // preencher h e indegrees
20     for (int u = 0; u < n; ++u) {
21         for (auto v : g[u]) {
22             ++in_degree[v];
23             h[u].emplace(v);
24         }
25     }
26     st.emplace(s);
27     if (e != -1) {
28         int out_s = (int)h[s].size();
29         int out_e = (int)h[e].size();
30         int diff_s = in_degree[s] - out_s;
31         int diff_e = in_degree[e] - out_e;
32         if (diff_s * diff_e != -1) return {};
33         impossible;
34     }
35     for (int u = 0; u < n; ++u) {
36         if (e != -1 && (u == s || u == e)) continue;
37         int out_u = (int)h[u].size();
38         if (in_degree[u] != out_u || (!directed && (
39             in_degree[u] & 1))) {
40             return {};
41         }
42     }
43     while (!st.empty()) {
44         int u = st.top();
45         if (h[u].empty()) {
46             result.emplace_back(u);
47             st.pop();
48         } else {
49             int v = *h[u].begin();
50             auto it = h[u].find(v);
51             if (it != h[u].end()) h[u].erase(it);
52             --in_degree[v];
53             if (!directed) {
54                 auto it2 = h[v].find(u);
55                 if (it2 != h[v].end()) h[v].erase(it2);
56             }
57             --in_degree[u];
58             st.emplace(v);
59         }
60     }
61     for (int u = 0; u < n; ++u) {
62         if (in_degree[u] != 0) return {};
63     }
64     reverse(result.begin(), result.end());
65     return result;
66 }

```

## 6.4 Dinitz

```

1 // Complexidade: O(V^2E)
2
3 struct FlowEdge {
4     int from, to;
5     long long cap, flow = 0;
6     FlowEdge(int from, int to, long long cap) : from(
7         from), to(to), cap(cap) {}
8 }
9 struct Dinic {
10     const long long flow_inf = 1e18;
11     vector<FlowEdge> edges;
12     vector<vector<int>> adj;
13     int n, m = 0;
14     int s, t;
15     vector<int> level, ptr;
16     queue<int> q;
17
18     Dinic(int n, int s, int t) : n(n), s(s), t(t) {
19         adj.resize(n);
20         level.resize(n);
21         ptr.resize(n);
22     }
23
24     void add_edge(int from, int to, long long cap) {
25         edges.emplace_back(from, to, cap);
26         edges.emplace_back(to, from, 0);
27         adj[from].push_back(m);
28         adj[to].push_back(m + 1);
29         m += 2;
30     }
31
32     bool bfs() {
33         while (!q.empty()) {
34             int from = q.front();
35             q.pop();
36             for (int id : adj[from]) {
37                 if (edges[id].cap == edges[id].flow)
38                     continue;
39                 if (level[edges[id].to] != -1)
40                     continue;
41                 level[edges[id].to] = level[from] +
42                     1;
43                 q.push(edges[id].to);
44             }
45         }
46         return level[t] != -1;
47     }
48
49     long long dfs(int from, long long pushed) {
50         if (pushed == 0)
51             return 0;
52         if (from == t)
53             return pushed;
54         for (int& cid = ptr[from]; cid < (int)adj[from].size(); cid++) {
55             int id = adj[from][cid];
56             int to = edges[id].to;
57             if (level[from] + 1 != level[to])
58                 continue;
59             long long tr = dfs(to, min(pushed, edges[id].cap - edges[id].flow));
60             if (tr == 0)
61                 continue;
62             edges[id].flow += tr;
63             edges[id ^ 1].flow -= tr;
64             return tr;
65         }
66         return 0;
67     }
68
69     long long flow() {
70         long long f = 0;
71         while (true) {
72             fill(level.begin(), level.end(), -1);
73             level[s] = 0;
74             q.push(s);
75             if (!bfs())
76                 break;
77             fill(ptr.begin(), ptr.end(), 0);
78             while (long long pushed = dfs(s, flow_inf))
79                 f += pushed;
80         }
81         return f;
82     }
83 }

```

## 6.5 Khan

```

1 // topo-sort DAG
2 // lexicograficamente menor.
3 // N: numero de vértices (1-indexado)
4 // adj: lista de adjacencia do grafo
5
6 const int MAXN = 5 * 1e5 + 2;
7 vector<int> adj[MAXN];
8 int N;
9
10 vector<int> kahn() {
11     vector<int> indegree(N + 1, 0);
12     for (int u = 1; u <= N; u++) {
13         for (int v : adj[u]) {
14             indegree[v]++;
15         }
16     }
17     priority_queue<int, vector<int>, greater<int>> pq;
18     for (int i = 1; i <= N; i++) {
19         if (indegree[i] == 0) {
20             pq.push(i);
21         }
22     }
23     vector<int> result;
24     while (!pq.empty()) {
25         int u = pq.top();
26         pq.pop();
27         result.push_back(u);
28         for (int v : adj[u]) {
29             indegree[v]--;
30             if (indegree[v] == 0) {
31                 pq.push(v);
32             }
33         }
34     }
35     if (result.size() != N) {
36         return {};
37     }
38     return result;
39 }
```

## 6.6 Topological Sort

```

1 vector<int> adj[MAXN];
2 vector<int> estado(MAXN); // 0: nao visitado 1:
   processamento 2: processado
3 vector<int> ordem;
4 bool temCiclo = false;
5
6 void dfs(int v) {
7     if(estado[v] == 1) {
8         temCiclo = true;
9         return;
10    }
11    if(estado[v] == 2) return;
12    estado[v] = 1;
13    for(auto &nei : adj[v]) {
14        if(estado[v] != 2) dfs(nei);
15    }
16    estado[v] = 2;
17    ordem.push_back(v);
18    return;
19 }
```

## 6.7 Acha Pontes

```

1 vector<int> d, low, pai; // d[v] Tempo de
   descoberta (discovery time)
2 vector<bool> vis;
3 vector<int> pontos_articulacao;
```

```

4 vector<pair<int, int>> pontes;
5 int tempo;
6
7 vector<vector<int>> adj;
8
9 void dfs(int u) {
10     vis[u] = true;
11     tempo++;
12     d[u] = low[u] = tempo;
13     int filhos_dfs = 0;
14     for (int v : adj[u]) {
15         if (v == pai[u]) continue;
16         if (vis[v]) { // back edge
17             low[u] = min(low[u], d[v]);
18         } else {
19             pai[v] = u;
20             filhos_dfs++;
21             dfs(v);
22             low[u] = min(low[u], low[v]);
23             if (pai[u] == -1 && filhos_dfs > 1) {
24                 pontos_articulacao.push_back(u);
25             }
26             if (pai[u] != -1 && low[v] >= d[u]) {
27                 pontos_articulacao.push_back(u);
28             }
29             if (low[v] > d[u]) {
30                 pontes.push_back({min(u, v), max(u, v)});
31             }
32         }
33     }
34 }
```

## 6.8 Edmonds-karp

```

1 // Edmonds-Karp com scaling O(E log(F))
2
3 int n, m;
4 const int MAXN = 510;
5 vector<vector<int>> capacity(MAXN, vector<int>(MAXN,
   0));
6 vector<vector<int>> adj(MAXN);
7
8 int bfs(int s, int t, int scale, vector<int>& parent)
{
9     fill(parent.begin(), parent.end(), -1);
10    parent[s] = -2;
11    queue<pair<int, int>> q;
12    q.push({s, LLONG_MAX});
13
14    while (!q.empty()) {
15        int cur = q.front().first;
16        int flow = q.front().second;
17        q.pop();
18
19        for (int next : adj[cur]) {
20            if (parent[next] == -1 && capacity[cur][
21                next] >= scale) {
22                parent[next] = cur;
23                int new_flow = min(flow, capacity[cur]
24                [next]);
25                if (next == t)
26                    return new_flow;
27                q.push({next, new_flow});
28            }
29        }
30    }
31    return 0;
32}
33
34 int maxflow(int s, int t) {
35     int flow = 0;
```

```

35     vector<int> parent(MAXN);
36     int new_flow;
37     int scalling = 111 << 62;
38
39     while (scalling > 0) {
40         while (new_flow = bfs(s, t, scalling, parent)) {
41             if (new_flow == 0) continue;
42             flow += new_flow;
43             int cur = t;
44             while (cur != s) {
45                 int prev = parent[cur];
46                 capacity[prev][cur] -= new_flow;
47                 capacity[cur][prev] += new_flow;
48                 cur = prev;
49             }
50         }
51         scalling /= 2;
52     }
53
54     return flow;
55 }
```

## 6.9 Kruskal

```

1 // Ordena as arestas por peso, insere se ja nao
2 // estiver no mesmo componente
3 // O(E log E)
4
5 struct Edge {
6     int u, v, w;
7     bool operator <(Edge const & other) {
8         return weight < other.weight;
9     }
10
11 vector<Edge> kruskal(int n, vector<Edge> edges) {
12     vector<Edge> mst;
13     DSU dsu = DSU(n + 1);
14     sort(edges.begin(), edges.end());
15     for (Edge e : edges) {
16         if (dsu.find(e.u) != dsu.find(e.v)) {
17             mst.push_back(e);
18             dsu.join(e.u, e.v);
19         }
20     }
21     return mst;
22 }
```

## 6.10 Bellman Ford

```

1 struct Edge {
2     int u, v, w;
3 };
4
5 // se x = -1, nao tem ciclo
6 // se x != -1, pegar pais de x pra formar o ciclo
7
8 int n, m;
9 vector<Edge> edges;
10 vector<int> dist(n);
11 vector<int> pai(n, -1);
12
13 for (int i = 0; i < n; i++) {
14     x = -1;
15     for (Edge &e : edges) {
16         if (dist[e.u] + e.w < dist[e.v]) {
17             dist[e.v] = max(-INF, dist[e.u] + e.w);
18         };
19         pai[e.v] = e.u;
20         x = e.v;
21     }
22 }
```

```

21         }
22     }
23
24 // achando caminho (se precisar)
25 for (int i = 0; i < n; i++) x = pai[x];
26
27 vector<int> ciclo;
28 for (int v = x;; v = pai[v]) {
29     cycle.push_back(v);
30     if (v == x && ciclo.size() > 1) break;
31 }
32 reverse(ciclo.begin(), ciclo.end());
```

## 6.11 Lca Jc

```

1 const int MAXN = 200005;
2 int N;
3 int LOG;
4
5 vector<vector<int>> adj;
6 vector<int> profundidade;
7 vector<vector<int>> cima; // cima[v][j] eh o 2^j-
8 // esimo ancestral de v
9
10 void dfs(int v, int p, int d) {
11     profundidade[v] = d;
12     cima[v][0] = p; // o pai direto eh o 2^0-Ãºltimo
13     ancestral
14     for (int j = 1; j < LOG; j++) {
15         // se o ancestral 2^(j-1) existir, calculamos
16         // o 2^j
17         if (cima[v][j - 1] != -1) {
18             cima[v][j] = cima[cima[v][j - 1]][j - 1];
19         } else {
20             cima[v][j] = -1; // nao tem ancestral
21             superior
22         }
23     }
24     for (int nei : adj[v]) {
25         if (nei != p) {
26             dfs(nei, v, d + 1);
27         }
28     }
29 }
30
31 void build(int root) {
32     LOG = ceil(log2(N));
33     profundidade.assign(N + 1, 0);
34     cima.assign(N + 1, vector<int>(LOG, -1));
35     dfs(root, -1, 0);
36 }
37
38 int get_lca(int a, int b) {
39     if (profundidade[a] < profundidade[b]) {
40         swap(a, b);
41     }
42     // sobe 'a' ate a mesma profundidade de 'b'
43     for (int j = LOG - 1; j >= 0; j--) {
44         if (profundidade[a] - (1 << j) >=
45             profundidade[b]) {
46             a = cima[a][j];
47         }
48     }
49     // se 'b' era um ancestral de 'a', entÃ£o 'a'
50     // agora Ã© igual a 'b'
51     if (a == b) {
52         return a;
53     }
54     // sobe os dois juntos ate encontrar os filhos do
55     // LCA
56     for (int j = LOG - 1; j >= 0; j--) {
57         if (cima[a][j] != -1 && cima[a][j] != cima[b]
58             [j]) {
```

```

51         a = cima[a][j];
52         b = cima[b][j];
53     }
54     return cima[a][0];
55 }

```

## 6.12 Lca

```

1 // LCA - CP algorithm
2 // preprocessing O(NlogN)
3 // lca O(logN)
4 // Uso: criar LCA com a quantidade de vertices (n) e
5 // lista de adjacencias (adj)
6 // chamar a funcao preprocess com a raiz da arvore
7
8 struct LCA {
9     int n, l, timer;
10    vector<vector<int>> adj;
11    vector<int> tin, tout;
12    vector<vector<int>> up;
13
14    LCA(int n, const vector<vector<int>>& adj) : n(n)
15        , adj(adj) {}
16
17    void dfs(int v, int p) {
18        tin[v] = ++timer;
19        up[v][0] = p;
20        for (int i = 1; i <= l; ++i)
21            up[v][i] = up[up[v][i-1]][i-1];
22
23        for (int u : adj[v]) {
24            if (u != p)
25                dfs(u, v);
26        }
27
28        tout[v] = ++timer;
29    }
30
31    bool is_ancestor(int u, int v) {
32        return tin[u] <= tin[v] && tout[u] >= tout[v]
33    ];
34
35    int lca(int u, int v) {
36        if (is_ancestor(u, v))
37            return u;
38        if (is_ancestor(v, u))
39            return v;
40        for (int i = l; i >= 0; --i) {
41            if (!is_ancestor(up[u][i], v))
42                u = up[u][i];
43        }
44        return up[u][0];
45    }
46
47    void preprocess(int root) {
48        tin.resize(n);
49        tout.resize(n);
50        timer = 0;
51        l = ceil(log2(n));
52        up.assign(n, vector<int>(l + 1));
53        dfs(root, root);
54    };

```

## 6.13 Kosaraju

```

1 bool vis[MAXN];
2 vector<int> order;
3 int component[MAXN];
4 int N, m;

```

```

5     vector<int> adj[MAXN], adj_rev[MAXN];
6
7     // dfs no grafo original para obter a ordem (pos-
8     // order)
9     void dfs1(int u) {
10        vis[u] = true;
11        for (int v : adj[u]) {
12            if (!vis[v])
13                dfs1(v);
14        }
15        order.push_back(u);
16    }
17
18     // dfs o grafo reverso para encontrar os SCCs
19     void dfs2(int u, int c) {
20        component[u] = c;
21        for (int v : adj_rev[u]) {
22            if (component[v] == -1) {
23                dfs2(v, c);
24            }
25        }
26    }
27
28    int kosaraju() {
29        order.clear();
30        fill(vis + 1, vis + N + 1, false);
31        for (int i = 1; i <= N; i++) {
32            if (!vis[i])
33                dfs1(i);
34        }
35
36        fill(component + 1, component + N + 1, -1);
37        int c = 0;
38        reverse(order.begin(), order.end());
39        for (int u : order) {
40            if (component[u] == -1) {
41                dfs2(u, c++);
42            }
43        }
44        return c;
45    }

```

## 6.14 Pega Ciclo

```

1 // encontra um ciclo em g
2 // g[u] = vector<pair<id_aresta, vizinho>>
3 // rec_arestas: true -> retorna ids das arestas do
4 // ciclo; false -> retorna vertices do ciclo
5 // directed: grafo direcionado?
6
7 const int MAXN = 5 * 1e5 + 2;
8 vector<pair<int, int>> g[MAXN];
9 int N;
10 bool DIRECTED = false;
11 vector<int> color(MAXN), parent(MAXN, -1), edgein(
12     MAXN, -1); // color: 0,1,2 ; edgein[v] = id da
13 // aresta que entra em v
14 int ini_ciclo = -1, fim_ciclo = -1, back_edge_id =
15 -1;
16
17 bool dfs(int u, int pai_edge){
18    color[u] = 1; // cinza
19    for (auto [id, v] : g[u]) {
20        if (!DIRECTED && id == pai_edge) continue; // /
21        ignorar aresta de volta ao pai em n-dir
22        if (color[v] == 0) {
23            parent[v] = u;
24            edgein[v] = id;
25            if (dfs(v, id)) return true;
26        } else if (color[v] == 1) {
27            // back-edge u -> v detectado
28        }
29    }
30
31    if (color[u] == 2) {
32        ini_ciclo = u;
33        fim_ciclo = u;
34        back_edge_id = -1;
35        return true;
36    }
37
38    color[u] = 2;
39    return false;
40}

```

```

24         ini_ciclo = u;
25         fim_ciclo = v;
26         back_edge_id = id;
27         return true;
28     }
29     // se color[v] == 2, ignora
30 }
31 color[u] = 2; // preto
32 return false;
33 }

35 // retorna ids das arestas do ciclo
36 vector<int> pega_ciclo(bool rec_arestas) {
37     for (int u = 1; u <= N; u++) {
38         if (color[u] != 0) continue;
39         if (dfs(u, -1)) {
40             // caminho u -> ... -> v via parent
41             vector<int> path;
42             int cur = ini_ciclo;
43             path.push_back(cur);
44             while (cur != fim_ciclo) {
45                 cur = parent[cur];
46                 path.push_back(cur);
47             }
48             // path = [u, ..., v] -> inverter para [v
49             , ..., u]
50             reverse(path.begin(), path.end());
51             if (!rec_arestas) return path;
52             // converte para ids das arestas: edgein[50
53             node] eh a aresta que entra em node
54             vector<int> edges;
55             for (int i = 1; i < path.size(); i++)
56                 edges.push_back(edgein[path[i]]);
57             // adiciona a aresta de retorno u -> v
58             edges.push_back(back_edge_id);
59             return edges;
60         }
61     }
62     return {};
63 }

64 void add_edge(int from, int to, int capacity, int
65 cost) {
66     edges.push_back({from, to, capacity, cost, (int)
67 edges.size()});
68     edges.push_back({to, from, 0, -cost, (int)edges.
69 size()}); // reversa
70 }

71 int min_cost_flow(int N, int K, int s, int t) {
72     adj.assign(N, vector<array<int, 2>>());
73     for (Edge e : edges) {
74         adj[e.from].push_back({e.to, e.id});
75     }
76     int flow = 0;
77     int cost = 0;
78     vector<int> dist, edge_to;
79     while (flow < K) {
80         shortest_paths(N, s, dist, edge_to);
81         if (dist[t] == INF)
82             break;
83         // find max flow on that path
84         int f = K - flow;
85         int cur = t;
86         while (cur != s) {
87             int edge = edge_to[cur];
88             int rev_edge = edge ^ 1;
89             edges[edge].capacity -= f;
90             edges[rev_edge].capacity += f;
91             cur = edges[edge].from;
92         }
93         if (flow <= K)
94             return -1;
95         else
96             return cost;
97     }
98 }

99 
```

## 6.15 Min Cost Max Flow

```

1 // Encontra o menor custo para passar K de fluxo em
2 // um grafo com N vertices
3 // Funciona com multiplas arestas para o mesmo par de
4 // vertices
5 // Para encontrar o min cost max flow eh so fazer K = infinito
6
7 struct Edge {
8     int from, to, capacity, cost, id;
9 };
10
11 vector<vector<array<int, 2>>> adj;
12 vector<Edge> edges; // arestas pares sao as normais e
13 suas reversas sao as impares
14
15 const int INF = LLONG_MAX;
16
17 void shortest_paths(int n, int v0, vector<int>& dist,
18 vector<int>& edge_to) {
19     dist.assign(n, INF);
20     dist[v0] = 0;
21     vector<bool> in_queue(n, false);
22     queue<int> q;
23     q.push(v0);
24     edge_to.assign(n, -1);
25
26     while (!q.empty()) {
27         int u = q.front();
28         q.pop();
29         in_queue[u] = false;
30
31         for (auto [v, id] : adj[u]) {
32             if (edges[id].capacity > 0 && dist[v] >
33                 dist[u] + edges[id].cost) {
34                 dist[v] = dist[u] + edges[id].cost;
35                 edge_to[v] = id;
36                 if (!in_queue[v]) {
37                     in_queue[v] = true;
38                     q.push(v);
39                 }
40             }
41         }
42     }
43 }
44
45 int min_cost_flow(int N, int K, int s, int t) {
46     adj.assign(N, vector<array<int, 2>>());
47     for (Edge e : edges) {
48         adj[e.from].push_back({e.to, e.id});
49     }
50
51     int flow = 0;
52     int cost = 0;
53     vector<int> dist, edge_to;
54     while (flow < K) {
55         shortest_paths(N, s, dist, edge_to);
56         if (dist[t] == INF)
57             break;
58
59         // find max flow on that path
60         int f = K - flow;
61         int cur = t;
62         while (cur != s) {
63             int edge = edge_to[cur];
64             int rev_edge = edge ^ 1;
65             edges[edge].capacity -= f;
66             edges[rev_edge].capacity += f;
67             cur = edges[edge].from;
68         }
69
70         if (flow <= K)
71             return -1;
72         else
73             return cost;
74     }
75 }
```

## 7 Primitives

## 8 DP

### 8.1 Lis

```

1 int lis_nlogn(vector<int> &v) {
2     vector<int> lis;
3     lis.push_back(v[0]);
4     for (int i = 1; i < v.size(); i++) {
5         if (v[i] > lis.back()) {
6             // estende a lis
7             lis.push_back(v[i]);
8         } else {
9             // encontra o primeiro elemento em lis
10            que >= v[i];
11            auto it = lower_bound(lis.begin(), lis.
12            end(), v[i]);
13            *it = v[i];
14        }
15    }
16    return lis.size();
17 }
18 // lis na tree do problema da sub
19 const int MAXN_TREE = 100001;
20 vector<int> adj[MAXN_TREE];
21 int values[MAXN_TREE];
22 int ans = 0;
23 void dfs(int u, int p, vector<int>& tails) {
24     auto it = lower_bound(tails.begin(), tails.end(), values[u]);
25     int prev = -1;
26     bool coloquei = false;
27     if (it == tails.end()) {
28         tails.push_back(values[u]);
29         coloquei = true;
30     } else {
31         prev = *it;
32         *it = values[u];
33     }
34     ans = max(ans, (int)tails.size());
35     for (int v : adj[u]) {
36         if (v != p) {
37             dfs(v, u, tails);
38         }
39     }
40     if (coloquei) {
41         tails.pop_back();
42     } else {
43         *it = prev;
44     }
45 }

```

## 8.2 Edit Distance

```

1 vector<vector<int>> dp(n+1, vector<int>(m+1,
LLONG_MIN));
2 for(int j = 0; j <= m; j++) dp[0][j] = j;
3 for(int i = 0; i <= n; i++) dp[i][0] = i;
4 for(int i = 1; i <= n; i++) {
5     for(int j = 1; j <= m; j++) {
6         if(a[i-1] == b[j-1]) {
7             dp[i][j] = dp[i-1][j-1];
8         } else {
9             dp[i][j] = min({dp[i-1][j] + 1, dp[i].
10 [j-1] + 1, dp[i-1][j-1] + 1});
11         }
12     }
13     cout << dp[n][m];

```

## 8.3 Bitmask

```

1 // dp de intervalos com bitmask
2 int prox(int idx) {
3     return lower_bound(S.begin(), S.end(), array<int,
4 >{S[idx][1], 011, 011, 011}) - S.begin();

```

```

4 }
5
6 int dp[1002][(int)(111 << 10)];
7
8 int rec(int i, int vis) {
9     if (i == (int)S.size()) {
10         if (_builtin_popcountll(vis) == N) return 0;
11         return LLONG_MIN;
12     }
13     if (dp[i][vis] != -1) return dp[i][vis];
14     int ans = rec(i + 1, vis);
15     ans = max(ans, rec(prox(i), vis | (111 << S[i]
16 ] [3])) + S[i][2]);
17     return dp[i][vis] = ans;
18 }

```

## 8.4 Lcs

```

1 string s1, s2;
2 int dp[1001][1001];
3 int lcs(int i, int j) {
4     if (i < 0 || j < 0) return 0;
5     if (dp[i][j] != -1) return dp[i][j];
6     if (s1[i] == s2[j]) return dp[i][j] = 1 + lcs(i -
7     1, j - 1);
8     else return dp[i][j] = max(lcs(i - 1, j), lcs(i,
j - 1));
}

```

## 8.5 Digit

```

1 vector<int> digits;
2
3 int dp[20][10][2][2];
4
5 int rec(int i, int last, int flag, int started) {
6     if (i == (int)digits.size()) return 1;
7     if (dp[i][last][flag][started] != -1) return dp[i]
7 [last][flag][started];
8     int lim;
9     if (flag) lim = 9;
10    else lim = digits[i];
11    int ans = 0;
12    for (int d = 0; d <= lim; d++) {
13        if (started && d == last) continue;
14        int new_flag = flag;
15        int new_started = started;
16        if (d > 0) new_started = 1;
17        if (!flag && d < lim) new_flag = 1;
18        ans += rec(i + 1, d, new_flag, new_started);
19    }
20    return dp[i][last][flag][started] = ans;
21 }

```

## 8.6 Knapsack

```

1 // dp[i][j] => i-esimo item com j-carga sobrando na
2 // mochila
3 // O(N * W)
4 vector<vector<int>> dp(N + 1, vector<int>(W + 1, 0));
5 for (int i = 1; i <= N; i++) dp[i][0] = 0;
6 for (int j = 0; j <= W; j++) dp[0][j] = 0;
7 for (int i = 1; i <= N; i++) {
8     for (int j = 0; j <= W; j++) {
9         dp[i][j] = dp[i - 1][j];
10        if (j >= items[i-1].first) {
11            dp[i][j] = max(dp[i][j], dp[i - 1][j -
12           items[i-1].first] + items[i-1].second);
13        }
14    }
15 }
16
17 cout << dp[N][W] << '\n';

```

## 8.7 Lis Seg

```

1 // comprime coordenadas pra quando ai <= 1e9
2 vector<int> vals(a.begin(), a.end());
3 sort(vals.begin(), vals.end());
4 vals.erase(unique(vals.begin(), vals.end()), vals.end());
5 auto id = [&](int x) -> int {
6     return lower_bound(vals.begin(), vals.end(), x) -
7         vals.begin();
8 };
9 for (int i = 0; i < n; i++) a[i] = id(a[i]);
10 // fim da parte de compr
11 SegTree seg(n);
12 // dp[i]: lis que termina em i
13 vector<int> dp(n, 1); // dp[i] = 1 base case
14 for (int i = 0; i < n; i++) {
15     if (a[i] > 0) dp[i] = seg.query(0, max(0, a[i] - 1)) + 1;
16     seg.update(a[i], dp[i]);
17 cout << *max_element(dp.begin(), dp.end()) << '\n';

```

## 8.8 Disjoint Blocks

```

1 // num max de subarrays disjuntos com soma x usando
2 // apenas
3 // prefixo i (ou seja, considerando prefixo a[1..i]).
4 int disjointSumX(vector<int> &a, int x) {
5     map<int, int> best; // best[pref] = melhor dp
6     visto para esse pref
7     best[0] = 0;
8     int pref = 0;
9     vector<int> dp(n + 1, 0); // dp[0] = 0
10    for (int i = 1; i <= n; i++) {
11        pref += a[i - 1];
12        dp[i] = dp[i - 1];
13        auto it = best.find(pref - x);
14        if (it != best.end()) {
15            dp[i] = max(dp[i], it->second + 1);
16        }
17        best[pref] = max(best[pref], dp[i]);
18    }
19    return dp[n];
}

```

## 9 General

### 9.1 Brute Choose

```

1 vector<int> elements;
2 int N, K;
3 vector<int> comb;
4
5 void brute_choose(int i) {
6     if (comb.size() == K) {
7         for (int j = 0; j < comb.size(); j++) {
8             cout << comb[j] << ',';
9         }
10        cout << '\n';
11        return;
12    }
13    if (i == N) return;
14    int r = N - i;
15    int preciso = K - comb.size();
16    if (r < preciso) return;
17    comb.push_back(elements[i]);
18    brute_choose(i + 1);
19    comb.pop_back();
20    brute_choose(i + 1);
}

```

21 }

## 9.2 Struct

```

1 struct Pessoa{
2     // Atributos
3     string nome;
4     int idade;
5
6     // Comparador
7     bool operator<(const Pessoa& other) const{
8         if(idade != other.idade) return idade > other
9             .idade;
10        else return nome > other.nome;
11    }

```

## 9.3 Mex

```

1 struct MEX {
2     map<int, int> f;
3     set<int> falta;
4     int tam;
5     MEX(int n) : tam(n) {
6         for (int i = 0; i <= n; i++) falta.insert(i);
7     }
8     void add(int x) {
9         f[x]++;
10        if (f[x] == 1 && x >= 0 && x <= tam) {
11            falta.erase(x);
12        }
13    }
14    void rem(int x) {
15        if (f.count(x) && f[x] > 0) {
16            f[x]--;
17            if (f[x] == 0 && x >= 0 && x <= tam) {
18                falta.insert(x);
19            }
20        }
21    }
22    int get() {
23        if (falta.empty()) return tam + 1;
24        return *falta.begin();
25    }
26};

```

## 9.4 Count Permutations

```

1 // Returns the number of distinct permutations
2 // that are lexicographically less than the string t
3 // using the provided frequency (freq) of the
4 // characters
5 // O(n*freq.size())
6 int countPermLess(vector<int> freq, const string &t)
7 {
8     int n = t.size();
9     int ans = 0;
10
11    vector<int> fact(n + 1, 1), invfact(n + 1, 1);
12    for (int i = 1; i <= n; i++)
13        fact[i] = (fact[i - 1] * i) % MOD;
14    invfact[n] = fexp(fact[n], MOD - 2, MOD);
15    for (int i = n - 1; i >= 0; i--)
16        invfact[i] = (invfact[i + 1] * (i + 1)) % MOD;
17
18    // For each position in t, try placing a letter
19    // smaller than t[i] that is in freq
20    for (int i = 0; i < n; i++) {
21        for (char c = 'a'; c < t[i]; c++) {
22            if (freq[c - 'a'] > 0) {
23                freq[c - 'a']--;
24            }
25        }
26    }
}

```

```

21             int ways = fact[n - i - 1];
22             for (int f : freq)
23                 ways = (ways * invfact[f]) % MOD;
24             ans = (ans + ways) % MOD;
25             freq[c - 'a']++;
26         }
27     }
28     if (freq[t[i] - 'a'] == 0) break;
29     freq[t[i] - 'a']--;
30 }
31 return ans;
32 }
```

## 9.5 Bitwise

```

1 int check_kth_bit(int x, int k) {
2     return (x >> k) & 1;
3 }
4
5 void print_on_bits(int x) {
6     for (int k = 0; k < 32; k++) {
7         if (check_kth_bit(x, k)) {
8             cout << k << ' ';
9         }
10    }
11    cout << '\n';
12 }
13
14 int count_on_bits(int x) {
15     int ans = 0;
16     for (int k = 0; k < 32; k++) {
17         if (check_kth_bit(x, k)) {
18             ans++;
19         }
20     }
21     return ans;
22 }
23
24 bool is_even(int x) {
25     return ((x & 1) == 0);
26 }
27
28 int set_kth_bit(int x, int k) {
29     return x | (1 << k);
30 }
31
32 int unset_kth_bit(int x, int k) {
33     return x & (~(1 << k));
34 }
35
36 int toggle_kth_bit(int x, int k) {
37     return x ^ (1 << k);
38 }
39
40 bool check_power_of_2(int x) {
41     return count_on_bits(x) == 1;
42 }
```

## 10 Geometry

### 10.1 Convex Hull

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4 #define int long long
5 typedef int cod;
6
7 struct point
8 {
9     cod x,y;
```

```

10         point(cod x = 0, cod y = 0): x(x), y(y)
11     {}
12
13     double modulo()
14     {
15         return sqrt(x*x + y*y);
16     }
17
18     point operator+(point o)
19     {
20         return point(x+o.x, y+o.y);
21     }
22     point operator-(point o)
23     {
24         return point(x - o.x, y - o.y);
25     }
26     point operator*(cod t)
27     {
28         return point(x*t, y*t);
29     }
30     point operator/(cod t)
31     {
32         return point(x/t, y/t);
33     }
34
35     cod operator*(point o)
36     {
37         return x*o.x + y*o.y;
38     }
39     cod operator^(point o)
40     {
41         return x*o.y - y * o.x;
42     }
43     bool operator<(point o)
44     {
45         if( x != o.x) return x < o.x;
46         return y < o.y;
47     }
48 }
49
50
51 int ccw(point p1, point p2, point p3)
52 {
53     cod cross = (p2-p1) ^ (p3-p1);
54     if(cross == 0) return 0;
55     else if(cross < 0) return -1;
56     else return 1;
57 }
58
59 vector<point> convex_hull(vector<point> p)
60 {
61     sort(p.begin(), p.end());
62     vector<point> L,U;
63
64     //Lower
65     for(auto pp : p)
66     {
67         while(L.size() >= 2 and ccw(L[L.size() - 2],
68 L.back(), pp) == -1)
69         {
70             // Último pq eu não quero excluir os
71             colineares
72             L.pop_back();
73         }
74         L.push_back(pp);
75     }
76
77     reverse(p.begin(), p.end());
78
79     //Upper
80     for(auto pp : p)
81     {
82         while(U.size() >= 2 and ccw(U[U.size() - 2], U
```

```

1  .back(), pp) == -1)
2  {
3      U.pop_back();
4  }
5  U.push_back(pp);
6 }
7 L.pop_back();
8 L.insert(L.end(), U.begin(), U.end()-1);
9 return L;
10 }
11
12 cod area(vector<point> v)
13 {
14     int ans = 0;
15     int aux = (int)v.size();
16     for(int i = 2; i < aux; i++)
17     {
18         ans += ((v[i] - v[0])*(v[i-1] - v[0]))/2;
19     }
20     ans = abs(ans);
21     return ans;
22 }
23
24 int bound(point p1, point p2)
25 {
26     return __gcd(abs(p1.x-p2.x), abs(p1.y-p2.y));
27 }
28
29 // teorema de pick [pontos = A - (bound+points)/2 + 1]
30
31 int32_t main()
32 {
33     int n;
34     cin >> n;
35
36     vector<point> v(n);
37     for(int i = 0; i < n; i++)
38     {
39         cin >> v[i].x >> v[i].y;
40     }
41
42     vector<point> ch = convex_hull(v);
43
44     cout << ch.size() << '\n';
45     for(auto p : ch) cout << p.x << " " << p.y << "\n";
46     cout << "\n";
47
48     return 0;
49 }

```

## 10.2 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{
18             r=mid;
19         }
20     }
21 }

```

```

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 }

```

## 10.3 Point Location

```

1
2 int32_t main(){
3     sws;
4
5     int t; cin >> t;
6
7     while(t--){
8
9         int x1, y1, x2, y2, x3, y3; cin >> x1 >> y1
10        >> x2 >> y2 >> x3 >> y3;
11
12         int deltax1 = (x1-x2), deltay1 = (y1-y2);
13
14         int compx = (x1-x3), compy = (y1-y3);
15
16         int ans = (deltax1*compy) - (compx*deltay1);
17
18         if(ans == 0){cout << "TOUCH\n"; continue;}
19         if(ans < 0){cout << "RIGHT\n"; continue;}
20         if(ans > 0){cout << "LEFT\n"; continue;}
21     }
22     return 0;
23 }

```

## 10.4 Lattice Points

```

1 ll gcd(ll a, ll b) {
2     return b == 0 ? a : gcd(b, a % b);
3 }
4 ll area_triangulo(ll x1, ll y1, ll x2, ll y2, ll x3,
5                   ll y3) {
6     return abs(x1 * (y2 - y3) + x2 * (y3 - y1) + x3 *
7                (y1 - y2));
8 }
9 ll pontos_borda(ll x1, ll y1, ll x2, ll y2) {
10 }

```

```
8     return gcd(abs(x2 - x1), abs(y2 - y1));           17    ll tot_borda = pontos_borda(x1, y1, x2, y2) +  
9 }                                         18    pontos_borda(x2, y2, x3, y3) + pontos_borda(x3,  
10                                          19    y3, x1, y1);  
11 int32_t main() {                           20    ll ans = (area - tot_borda) / 2 + 1;  
12     ll x1, y1, x2, y2, x3, y3;                   21    cout << ans << endl;  
13     cin >> x1 >> y1;                         22    return 0;  
14     cin >> x2 >> y2;  
15     cin >> x3 >> y3;  
16     ll area = area_triangulo(x1, y1, x2, y2, x3, y3); 23 }
```