

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] from
4 // left to right - O(1)
5 // query_inv(l, r) from right to left - O(1)
6 // patrocinado por tiagodfs
7 mt19937 rng(time(nullptr));
8
9 struct Hash {
10     const int X = rng();
11     const int MOD = 1e9+7;
12     int n; string s;
13     vector<int> h, hi, p;
14     Hash() {}
15     Hash(string s): s(s), n(s.size()), h(n), hi(n), p(n) {
16         for (int i=0;i<n;i++) p[i] = (i ? X*p[i-1]:1) % MOD;
17         for (int i=0;i<n;i++)
18             h[i] = (s[i] + (i ? h[i-1]:0) * X) % MOD;
19         for (int i=n-1;i>=0;i--)
20             hi[i] = (s[i] + (i+1<n ? hi[i+1]:0) * X) % MOD;
21     }
22     int query(int l, int r) {
23         int hash = (h[r] - (l ? h[l-1]*p[r-l+1]:0)) % MOD;
24         return hash < 0 ? hash + MOD : hash;
25     }
26     int query_inv(int l, int r) {
27         int hash = (hi[r] - (r+1 < n ? hi[r+1]*p[r-l+1] % MOD
28 : 0));
29         return hash < 0 ? hash + MOD : hash;
30     }
31 };

```

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 - l]);
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 Segtree2d

```

1 // 0 index
2 struct SegTree2d {
3     int n;
4     vector<vector<int>> tree;
5     SegTree2d(int n) : n(n) {
6         tree.assign(4 * n, vector<int>(4 * n, 0));
7     }
8     void update_x(int no_y, int no_x, int lx, int rx, int x,
9 int val, bool folha_y) {
10         if (lx == rx) {
11             if (folha_y) tree[no_y][no_x] = val;
12             else tree[no_y][no_x] = tree[2 * no_y][no_x] + tree[2 *
13 no_y + 1][no_x];
14             return;
15         }
16         int mid = (lx + rx) / 2;
17         if (x <= mid) update_x(no_y, 2 * no_x, lx, mid, x, val,
18 folha_y);
19         else update_x(no_y, 2 * no_x + 1, mid + 1, rx, x, val,
20 folha_y);
21         tree[no_y][no_x] = tree[no_y][2 * no_x] + tree[no_y][2 *
22 no_x + 1];
23     }
24     void update_y(int no_y, int ly, int ry, int y, int x, int
25 val) {
26         if (ly == ry) {
27             update_x(no_y, 1, 0, n - 1, x, val, true);
28             return;
29         }
30         int mid = (ly + ry) / 2;
31         if (y <= mid) update_y(2 * no_y, ly, mid, y, x, val);
32         else update_y(2 * no_y + 1, mid + 1, ry, y, x, val);
33         update_x(no_y, 1, 0, n - 1, x, val, false);
34     }
35     int query_x(int no_y, int no_x, int lx, int rx, int x1, int
36 x2) {
37         if (rx < x1 || lx > x2) return 0;
38         if (lx >= x1 && rx <= x2) return tree[no_y][no_x];
39         int mid = (lx + rx) / 2;
40         return query_x(no_y, 2 * no_x, lx, mid, x1, x2) + query_x
41 (no_y, 2 * no_x + 1, mid + 1, rx, x1, x2);
42     }
43     int query_y(int no_y, int ly, int ry, int y1, int y2, int
44 x1, int x2) {
45         if (ry < y1 || ly > y2) return 0;
46         if (ly >= y1 && ry <= y2) return query_x(no_y, 1, 0, n -
47 1, x1, x2);
48         int mid = (ly + ry) / 2;

```

```

39     return query_y(2 * no_y, ly, mid, y1, y2, x1, x2) +
        query_y(2 * no_y + 1, mid + 1, ry, y1, y2, x1, x2);
40 }
41 void update(int y, int x, int val) {
42     update_y(1, 0, n - 1, y, x, val);
43 }
44 int query(int y1, int x1, int y2, int x2) {
45     return query_y(1, 0, n - 1, y1, y2, x1, x2);
46 }
47 };

```

2.2 Seg Lazy Pa

```

1  /* Notas
2   PA eh da forma a0 (a) e razão (d)
3   na hora de propagar o lazy
4   aplica no no S = (a0 + (a0 + (n - 1) * d)) * n / 2 (
5   variante da soma total do no)
6   pros filhos, o da esquerda eh normal
7   lazy_a[esq] += lazy_a[x]
8   lazy_d[esq] += lazy_d[x]
9   pro da direita tem que mudar o a (que eh o elemento inicial
10  naquele no da direita)
11  lazy_a[dir] += a + len_esq * (d)
12  lazy_d[dir] += lazy_d[x]
13  */
14  int gauss(int n, int a, int d) {
15      // (a0 + an) * n / 2
16      if (n <= 0)
17          return 0;
18      return (a + (a + (n - 1) * d)) * n / 2;
19  }
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 + 1, mid
47              + 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 * lazy_d[x]
62                      );
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, int a, int
69          d) {
70          push(x, lx, rx);

```

```

68     if (lx >= l && rx <= r) {
69         lazy_a[x] += a + (lx - l) * d;
70         lazy_d[x] += d;
71         push(x, lx, rx);
72         return;
73     }
74     if (lx > r || rx < l)
75         return;
76     int mid = (lx + rx) / 2;
77     update(2 * x, lx, mid, l, r, a, d);
78     update(2 * x + 1, mid + 1, rx, l, r, a, d);
79     tree[x] = tree[2 * x] + tree[2 * x + 1];
80 }
81 void update(int l, int r, int a, int d) {
82     update(1, 0, n - 1, l, r, a, d);
83 }
84 };

```

2.3 Segtree Iterativa

```

1  // Exemplo de uso:
2  // SegTree<int> st(vetor);
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 +
37                 1]);
38     }
39 };

```

2.4 Maximum Subarray Sum Range

```

1  struct SegTree {
2      int n;
3      vector<array<int, 4>> tree;
4      vector<int> v;
5      SegTree(vector<int> &a) : v(a), n(a.size()) {
6          tree.resize(4 * n);
7          build(1, 0, n - 1);
8      }
9      void build(int x, int lx, int rx) {
10         if (lx == rx) {
11             tree[x] = { v[lx], v[lx], v[lx], v[lx] };
12             return;
13         }
14         int mid = lx + (rx - lx) / 2;
15         build(2 * x, lx, mid);
16         build(2 * x + 1, mid + 1, rx);
17         tree[x] = combine(tree[2 * x], tree[2 * x + 1]);
18     }
19     array<int, 4> query(int x, int lx, int rx, int l, int r) {
20         if (lx >= l && rx <= r)
21             return tree[x];
22         if (lx > r || rx < l)

```

```

23     return { 0, LINF, LINF, LINF };
24     int mid = lx + (rx - lx) / 2;
25     return combine(query(2 * x, lx, mid, l, r), query(2 * x +
26         1, mid + 1, rx, l, r));
27 };
28 int query(int l, int r) {
29     return max(0ll, query(1, 0, n - 1, l, r)[3]);
30 }
31 void update(int x, int lx, int rx, int pos, int val) {
32     if (lx == rx) {
33         tree[x] = { val, val, val, val };
34         return;
35     }
36     int mid = lx + (rx - lx) / 2;
37     if (pos <= mid)
38         update(2 * x, lx, mid, pos, val);
39     else
40         update(2 * x + 1, mid + 1, rx, pos, val);
41     tree[x] = combine(tree[2 * x], tree[2 * x + 1]);
42 }
43 void update(int pos, int val) {
44     update(1, 0, n - 1, pos, val);
45 }
46 array<int, 4> combine(array<int, 4> x, array<int, 4> y) {
47     return {
48         x[0] + y[0],
49         max(x[1], x[0] + y[1]),
50         max(y[2], y[0] + x[2]),
51         max({x[3], y[3], x[2] + y[1]})
52     };
53 }

```

2.5 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        return query(2 * x, lx, mid, l, r, val) + query(2 * x +
31            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, l) retorna quantos caras distintos no
39     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 */

```

2.6 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, less<T>,
11     rb_tree_tag, tree_order_statistics_node_update>;
12 template<typename T, typename R> using o_map = tree<T, R,
13     less<T>, rb_tree_tag, tree_order_statistics_node_update>;
14
15 int main() {
16     int i, j, k, n, m;
17     o_set<int> st;
18     st.insert(1);
19     st.insert(2);
20     cout << *st.find_by_order(0) << endl; // k-esimo elemento
21     cout << st.order_of_key(2) << endl; // numero de elementos
22     // menores que k
23     o_map<int, int> mp;
24     mp.insert({1, 10});
25     mp.insert({2, 20});
26     cout << mp.find_by_order(0) ->second << endl; // k-esimo
27     // elemento
28     cout << mp.order_of_key(2) << endl; // numero de elementos
29     // (chave) menores que k
30     return 0;
31 }

```

2.7 Sparse Table

```

1 // 0-index, 0(1)
2 struct SparseTable {
3     vector<vector<int>>> st;
4     int max_log;
5     SparseTable(vector<int> &arr) {
6         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 + (1 << j)
15                     - 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     }
24 };

```

2.8 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[i-1][j
6             - 1];
7     }
8 }
9 // retorna a psum2d do intervalo inclusivo [(a, b), (c, d)]
10 int retangulo(int a, int b, int c, int d){
11     c = min(c, h), d = min(d, w);
12     a = max(0LL, a-1), b = max(0LL, b-1);
13     return psum[c][d] - psum[a][d] - psum[c][b] + psum[a][b];
14 }

```

2.9 Seglasy Iterativa

```

1  template <typename T, typename L>
2  struct SegLazy {
3      int n, h;
4      vector<T> tree;
5      vector<L> lazy;
6      vector<bool> has_lazy;
7      vector<int> sz; // se len = pow2, remove e sz[p] = 1 << h
8      [p]
9
10     // --- Mudar aqui ---
11     const T T_neutral = LLONG_MAX;
12
13     inline T combine(T a, T b) {
14         return min(a, b);
15     }
16
17     inline T apply_lazy_to_node(T node, L delta, int len) {
18         return node + (T)delta;
19     }
20
21     inline L combine_lazy(L old_delta, L new_delta) {
22         return old_delta + new_delta;
23     }
24     // -----
25     SegLazy(const vector<T>& data) {
26         n = data.size();
27         h = 32 - __builtin_clz(n);
28         tree.assign(2 * n, T_neutral);
29         lazy.assign(n, L());
30         has_lazy.assign(n, false);
31         sz.assign(2 * n, 1);
32
33         for (int i = 0; i < n; i++) tree[n + i] = data[i];
34         for (int i = n - 1; i > 0; --i) {
35             tree[i] = combine(tree[i << 1], tree[i << 1 | 1]);
36
37             sz[i] = sz[i << 1] + sz[i << 1 | 1];
38         }
39
40         inline void apply(int p, L v) {
41             tree[p] = apply_lazy_to_node(tree[p], v, sz[p]);
42             if (p < n) {
43                 if (has_lazy[p]) lazy[p] = combine_lazy(lazy[p],
44 v);
45                 else lazy[p] = v;
46                 has_lazy[p] = true;
47             }
48
49             inline void build(int p) {
50                 p += n;
51                 while (p > 1) {
52                     p >>= 1;
53                     T res = combine(tree[p << 1], tree[p << 1 | 1]);
54                     if (has_lazy[p]) tree[p] = apply_lazy_to_node(res
, lazy[p], sz[p]);
55                     else tree[p] = res;
56                 }
57             }
58
59             inline void push(int p) {
60                 p += n;
61                 for (int s = h; s > 0; --s) {
62                     int i = p >> s;
63                     if (has_lazy[i]) {
64                         apply(i << 1, lazy[i]);
65                         apply(i << 1 | 1, lazy[i]);
66                         has_lazy[i] = false;
67                     }
68                 }
69             }
70
71             void update(int l, int r, L v) {
72                 int l0 = l, r0 = r;
73                 push(l); push(r);
74                 for (l += n, r += n + 1; l < r; l >>= 1, r >>= 1) {
75                     if (l & 1) apply(l++, v);
76                     if (r & 1) apply(--r, v);
77                 }
78                 build(l0); build(r0);
79             }
80
81             T query(int l, int r) {
82                 push(l); push(r);

```

```

83         T res_l = T_neutral, res_r = T_neutral;
84         for (l += n, r += n + 1; l < r; l >>= 1, r >>= 1) {
85             if (l & 1) res_l = combine(res_l, tree[l++]);
86             if (r & 1) res_r = combine(tree[--r], res_r);
87         }
88         return combine(res_l, res_r);
89     }
90 };

```

2.10 Segtree Lazy

```

1  /*
2  Seg com double Lazy de soma e de set
3  tipo 1 - soma em range
4  tipo 2 - set em range
5  */
6  struct SegTree {
7      int n;
8      vector<int> v, tree;
9      vector<int> lazy_soma, lazy_set;
10     SegTree(vector<int> &a) : v(a), n(a.size()) {
11         tree.resize(4 * n);
12         lazy_soma.resize(4 * n, 0);
13         lazy_set.resize(4 * n, -1);
14         build(1, 0, n - 1);
15     };
16     void build(int x, int lx, int rx) {
17         if (lx == rx) {
18             tree[x] = v[lx];
19             return;
20         }
21         int mid = (lx + rx) / 2;
22         build(2 * x, lx, mid);
23         build(2 * x + 1, mid + 1, rx);
24         tree[x] = tree[2 * x] + tree[2 * x + 1];
25     }
26     void seta(int x, int lx, int rx, int val) {
27         tree[x] = val * (rx - lx + 1);
28         lazy_set[x] = val;
29         lazy_soma[x] = 0;
30     }
31     void soma(int x, int lx, int rx, int val) {
32         tree[x] += val * (rx - lx + 1);
33         if (lazy_set[x] != -1) {
34             lazy_set[x] += val;
35         } else {
36             lazy_soma[x] += val;
37         }
38     }
39     void push(int x, int lx, int rx) {
40         int mid = (lx + rx) / 2;
41         if (lazy_set[x] != -1) {
42             if (lx != rx) {
43                 seta(2 * x, lx, mid, lazy_set[x]);
44                 seta(2 * x + 1, mid + 1, rx, lazy_set[x]);
45             }
46             lazy_set[x] = -1;
47         }
48         if (lazy_soma[x] != 0) {
49             if (lx != rx) {
50                 soma(2 * x, lx, mid, lazy_soma[x]);
51                 soma(2 * x + 1, mid + 1, rx, lazy_soma[x]);
52             }
53             lazy_soma[x] = 0;
54         }
55     }
56     void update(int x, int lx, int rx, int l, int r, int val,
int type) {
57         push(x, lx, rx);
58         if (lx >= l && rx <= r) {
59             if (type == 1) soma(x, lx, rx, val);
60             else seta(x, lx, rx, val);
61             push(x, lx, rx);
62             return;
63         }
64         if (lx > r || rx < l) return;
65         int mid = (lx + rx) / 2;
66         update(2 * x, lx, mid, l, r, val, type);
67         update(2 * x + 1, mid + 1, rx, l, r, val, type);
68         tree[x] = tree[2 * x] + tree[2 * x + 1];
69     }
70     void update(int l, int r, int val, int type) {
71         update(1, 0, n - 1, l, r, val, type);
72     }
73     int query(int x, int lx, int rx, int l, int r) {
74         push(x, lx, rx);

```

```

75     if (lx >= l && rx <= r) return tree[x];
76     if (lx > r || rx < l) return 0;
77     int mid = (lx + rx) / 2;
78     return query(2 * x, lx, mid, l, r) + query(2 * x + 1, mid
79         + 1, rx, l, r);
80 }
81 int query(int l, int r) {
82     return query(1, 0, n - 1, l, r);
83 };

```

2.11 Bit2d

```

1 // 1-index
2 struct BIT2d {
3     int n, m;
4     vector<vector<int>> tree;
5     BIT2d(int n, int m) : n(n), m(m) {
6         tree.assign(n + 1, vector<int>(m + 1, 0));
7     }
8     void add(int y, int x, int delta) {
9         for (int i = y; i <= n; i += i & -i) {
10             for (int j = x; j <= m; j += j & -j) {
11                 tree[i][j] += delta;
12             }
13         }
14     }
15     int pref(int y, int x) {
16         int res = 0;
17         for (int i = y; i > 0; i -= i & -i) {
18             for (int j = x; j > 0; j -= j & -j) {
19                 res += tree[i][j];
20             }
21         }
22         return res;
23     }
24     int query(int y1, int x1, int y2, int x2) {
25         return pref(y2, x2) - pref(y1 - 1, x2) - pref(y2, x1 - 1)
26             + pref(y1 - 1, x1 - 1);
27     }
28 };

```

2.12 Min Queue

```

1 struct MinQueue {
2     deque<pair<int, int>> dq;
3     void push(int val, int idx) {
4         while (!dq.empty() && dq.back().first >= val) dq.
5             pop_back();
6         dq.emplace_back(val, idx);
7     }
8     void pop(int idx) {
9         if (!dq.empty() && dq.front().second == idx) {
10             dq.pop_front();
11         }
12     }
13     int get() {
14         return dq.front().first;
15     }
16     bool empty() {
17         return dq.empty();
18     }
19 };
20 /*
21 considerando janela de tamanho K
22 mq.push(v[i], i);
23 if (i >= k) {
24     mq.pop(i - k);
25 }
26 if (i >= k - 1) {
27     result.push_back(mq.get());
28 }
29 */

```

2.13 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 + 1, 1), c(
5         n) {
6         for (int i = 1; i <= n; ++i) par[i] = i;
7     }

```

```

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

```

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

```

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[i] : v[
8           s.top()] >= v[i])) {
9           s.pop();
10      }
11      if (s.empty()) {
12          result[i] = -1;
13      } else {
14          result[i] = v[s.top()];
15      }
16      s.push(i);
17  }
18  return result;
19 }
20 vector<int> find_dir(vector<int> &v, bool maior) {
21     int n = v.size();
22     vector<int> result(n);
23     stack<int> s;
24     for (int i = n - 1; i >= 0; i--) {
25         while (!s.empty() && (maior ? v[s.top()] <= v[i] : v[
26             s.top()] >= v[i])) {
27             s.pop();
28         }
29         if (s.empty()) {
30             result[i] = -1;
31         } else {
32             result[i] = v[s.top()];
33         }
34         s.push(i);
35     }
36     return result;

```

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 invés de <>
4 // compilar stress com: g++ -pipe -O3 -flto -march=native -
5 // mtune=native gen.cpp
6 // faz bastante diferença no runtime
7
8 #include <bits/stdc++.h>
9 #include <cstdlib>
10 #include <ctime>
11 using namespace std;
12
13 int randi(int L, int R) { return L + rand() % (R - L + 1); }
14 char randc(char L, char R) { return char(L + rand() % (R - L
15     + 1)); }
16
17 int main(int argc, char** argv) {
18     if (argc > 1) srand(atoi(argv[1]));
19     else srand(time(0));
20
21     int n = randi(1, 100);
22     cout << n << '\n';
23     for (int i = 0; i < n; i++) {
24         cout << randi(-10, 20) << ' ';
25     }
26     cout << '\n';
27 }

```

5 Math

5.1 Combinatorics

```

1 const int N = 200005;
2 const int MOD = 1e9 + 7;
3 // DEFINE INT LONG LONG PLMDS
4 int fat[N], fati[N];
5
6 // (a^b) % m em O(log b)
7 // coloque o fexp

```

```

8
9 int inv(int n) { return fexp(n, MOD - 2); }
10
11 void precalc() {
12     fat[0] = 1;
13     fati[0] = 1;
14     for (int i = 1; i < N; i++) fat[i] = (fat[i - 1] * i) %
15         MOD;
16     fati[N - 1] = inv(fat[N - 1]);
17     for (int i = N - 2; i >= 0; i--) fati[i] = (fati[i + 1] *
18         (i + 1)) % MOD;
19 }
20
21 int choose(int n, int k) {
22     if (k < 0 || k > n) return 0;
23     return ((fat[n] * fati[k]) % MOD) * fati[n - k] % MOD;
24 }
25
26 // n! / (n-k)!
27 int perm(int n, int k) {
28     if (k < 0 || k > n) return 0;
29     return (fat[n] * fati[n - k]) % MOD;
30 }
31
32 // C_n = (1 / (n+1)) * C(2n, n)
33 int catalan(int n) {
34     if (n < 0 || 2 * n >= N) return 0;
35     int c2n_n = choose(2 * n, n);
36     return (c2n_n * inv(n + 1)) % MOD;

```

5.2 Equacao 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, resultando em
2 // uma matrix N*M
3 vector<vector<int>> mm(vector<vector<int>> A, vector<vector<
4     int>> B) {
5     int N = A.size(), M = B[0].size(), K = B.size();
6     vector<vector<int>> C(N, vector<int>(M));
7
8     for (int i = 0; i < N; ++i)
9         for (int j = 0; j < M; ++j)
10             for (int k = 0; k < K; ++k)
11                 C[i][j] = (C[i][j] + A[i][k] * B[k][j] % mod) %
12                     mod;
13     return C;
14 }

```

5.4 Discrete Log

```

1 // returns minimum x for which a^x = b (mod m), a and m are
2 // coprime.
3 // if the answer dont need to be greater than some value, the
4 // vector<int> can be removed

```

```

3 int discrete_log(int a, int b, int m) {
4     a %= m, b %= m;
5     int n = sqrt(m) + 1;
6
7     int an = 1;
8     for (int i = 0; i < n; ++i)
9         an = (an * 111 * a) % m;
10
11     unordered_map<int, vector<int>>> vals;
12     for (int q = 0, cur = b; q <= n; ++q) {
13         vals[cur].push_back(q);
14         cur = (cur * 111 * a) % m;
15     }
16
17     int res = LLONG_MAX;
18
19     for (int p = 1, cur = 1; p <= n; ++p) {
20         cur = (cur * 111 * an) % m;
21         if (vals.count(cur)) {
22             for (int q: vals[cur]) {
23                 int ans = n * p - q;
24                 res = min(res, ans);
25             }
26         }
27     }
28     return res;
29 }

```

5.5 Segment Sieve

```

1 // Retorna quantos primos tem entre [l, r] (inclusivo)
2 // precisa de um vetor com os primos ate sqrt(r)
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 - l] = 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) phiv[j] -=
24                 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 = fatora(n);
35     int nod = 1;
36     for (auto &[primo, expoente] : fatores) nod *= (expoente
37         + 1);
38     return nod;
39 }
40
41 // DEFINE INT LONG LONG
42 int soma_dos_divisores(int n) {
43     if (n == 1) return 1;
44     map<int, int> fatores = fatora(n);
45     int sod = 1;
46     for (auto &[primo, expoente] : fatores) {
47         int termo_soma = 1;
48         int potencia_primo = 1;
49         for (int i = 0; i < expoente; i++) {
50             potencia_primo *= primo;
51             termo_soma += potencia_primo;
52         }
53         sod *= termo_soma;
54     }
55     return sod;
56 }

```

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 // 0(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 // 0(divisores)
4
5 vector<int> divs(int x){
6     vector<int> ans = {1};
7     vector<array<int, 2>> primos; // {primo, expoente}
8
9     while (x > 1) {
10         int p = crivo[x], cnt = 0;
11         while (x % p == 0) cnt++, x /= p;
12         primos.push_back({p, cnt});
13     }
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 // 0(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     int n_base_10 = to_base_10(num, bfrom);
35     return from_base_10(n_base_10, bto);
36 }

```

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
33     if (invert) {
34         for (auto &x : A)
35             x /= N;
36     }
37 }
38
39 vector<int> multiply(vector<int> const& A, vector<int> const&
40     B) {
41     vector<cd> fa(begin(A), end(A)), fb(begin(B), end(B));
42     int N = 1;
43     while (N < size(A) + size(B))
44         N <= 1;
45     fa.resize(N);
46     fb.resize(N);
47
48     fft(fa, false);
49     fft(fb, false);
50     for (int i = 0; i < N; i++)
51         fa[i] *= fb[i];
52     fft(fa, true);
53
54     vector<int> result(N);
55     for (int i = 0; i < N; i++)
56         result[i] = round(fa[i].real());
57     return result;
58 }

```

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     pq.push({0, S});
10    while(pq.size()) {

```

```

11         ll v = pq.top().second;
12         pq.pop();
13         if(vis[v]) continue;
14         vis[v] = 1;
15         for(auto &[peso, vizinho] : adj[v]) {
16             if(dist[vizinho] > dist[v] + peso) {
17                 dist[vizinho] = dist[v] + peso;
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] +
12                                 dist[k][j]);
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     }
29     for(int i = 0; i < m; i++) {
30         int u, v, w;
31         cin >> u >> v >> w; u--; v--;
32         dist[u][v] = min(dist[u][v], w);
33         dist[v][u] = min(dist[v][u], w);
34     }
35     floydWarshall();
36     while(q--) {
37         int u, v;
38         cin >> u >> v; 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 existir).
5  * - g: lista de adjacencia (vector<vector<int>>).
6  * - directed: true se o grafo for dirigido.
7  * - s: vertice inicial.
8  * - e: vertice final (opcional). Se informado, tenta caminho
9  *   de s ate e.
10  * - O(Nlog(N))
11  * Retorna vetor com a sequencia de vertices, ou vazio se
12  *   impossivel.
13  */
14 vector<int> eulerian_path(const vector<vector<int>>& g, bool
15     directed, int s, int e = -1) {
16     int n = (int)g.size();
17     // copia das adjacencias em multiset para permitir
18     // remoção especifica
19     vector<multiset<int>> h(n);
20     vector<int> in_degree(n, 0);
21     vector<int> result;
22     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 {}; // impossivel
33 }
34 for (int u = 0; u < n; ++u) {
35     if (e != -1 && (u == s || u == e)) continue;
36     int out_u = (int)h[u].size();
37     if (in_degree[u] != out_u || (!directed && (in_degree
38         [u] & 1))) {
39         return {};
40     }
41 }
42 while (!st.empty()) {
43     int u = st.top();
44     if (h[u].empty()) {
45         result.emplace_back(u);
46         st.pop();
47     } else {
48         int v = *h[u].begin();
49         auto it = h[u].find(v);
50         if (it != h[u].end()) h[u].erase(it);
51         --in_degree[v];
52         if (!directed) {
53             auto it2 = h[v].find(u);
54             if (it2 != h[v].end()) h[v].erase(it2);
55             --in_degree[u];
56         }
57         st.emplace(v);
58     }
59 }
60 for (int u = 0; u < n; ++u) {
61     if (in_degree[u] != 0) return {};
62 }
63 reverse(result.begin(), result.end());
64 return result;
65 }

```

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

```

6.5 Khan

```

1 // topo-sort DAG
2 // lexicograficamente menor.
3 // N: numero de v rtices (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
3 // 2: processado
4 vector<int> ordem;
5 bool temCiclo = false;
6
7 void dfs(int v) {
8     if (estado[v] == 1) {
9         temCiclo = true;
10        return;
11    }
12    if (estado[v] == 2) return;
13    estado[v] = 1;
14    for (auto &nei : adj[v]) {
15        if (estado[nei] != 2) dfs(nei);
16    }
17    estado[v] = 2;
18    ordem.push_back(v);
19    return;
20 }

```

6.7 Acha Pontes

```

1 vector<int> d, low, pai; // d[v] Tempo de descoberta (
2 // discovery time)
3 vector<bool> vis;
4 vector<int> pontos_articulacao;
5 vector<pair<int, int>> pontes;
6 int tempo;
7
8 vector<vector<int>> adj;
9
10 void dfs(int u) {
11     vis[u] = true;
12     tempo++;
13     d[u] = low[u] = tempo;
14     int filhos_dfs = 0;
15     for (int v : adj[u]) {
16         if (v == pai[u]) continue;
17         if (vis[v]) { // back edge
18             low[u] = min(low[u], d[v]);
19         } else {
20             pai[v] = u;
21             filhos_dfs++;
22             dfs(v);
23             low[u] = min(low[u], low[v]);
24             if (pai[u] == -1 && filhos_dfs > 1) {
25                 pontos_articulacao.push_back(u);
26             }
27             if (pai[u] != -1 && low[v] >= d[u]) {
28                 pontos_articulacao.push_back(u);
29             }
30             if (low[v] > d[u]) {
31                 pontes.push_back({min(u, v), max(u, v)});
32             }
33         }
34     }
35 }

```

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][next] >=
scale) {
21             parent[next] = cur;
22             int new_flow = min(flow, capacity[cur][next]);
23
24             if (next == t)
25                 return new_flow;
26             q.push({next, new_flow});
27         }
28     }
29 }
30 return 0;
31 }
32
33 int maxflow(int s, int t) {
34     int flow = 0;
35     vector<int> parent(MAXN);
36     int new_flow;
37     int scaling = 1ll << 62;
38
39     while (scaling > 0) {
40         while (new_flow = bfs(s, t, scaling, 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             scaling /= 2;
51         }
52     }
53     return flow;
54 }
55 }

```

6.9 Kruskal

```

1 // Ordena as arestas por peso, insere se ja nao estiver no
  mesmo componente
2 // O(E log E)
3
4 struct Edge {
5     int u, v, w;
6     bool operator <(Edge const & other) {
7         return weight < other.weight;
8     }
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             pai[e.v] = e.u;
19             x = e.v;
20         }
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-esimo
  ancestral de v
8
9 void dfs(int v, int p, int d) {
10     profundidade[v] = d;
11     cima[v][0] = p; // o pai direto eh o 2^0-ésimo ancestral
12     for (int j = 1; j < LOG; j++) {
13         // se o ancestral 2^(j-1) existir, calculamos o 2^j
14         if (cima[v][j-1] != -1) {
15             cima[v][j] = cima[cima[v][j-1]][j-1];
16         } else {
17             cima[v][j] = -1; // nao tem ancestral superior
18         }
19     }
20     for (int nei : adj[v]) {
21         if (nei != p) {
22             dfs(nei, v, d + 1);
23         }
24     }
25 }
26
27 void build(int root) {
28     LOG = ceil(log2(N));
29     profundidade.assign(N + 1, 0);
30     cima.assign(N + 1, vector<int>(LOG, -1));
31     dfs(root, -1, 0);
32 }
33
34 int get_lca(int a, int b) {
35     if (profundidade[a] < profundidade[b]) {
36         swap(a, b);
37     }
38     // sobe 'a' ate a mesma profundidade de 'b'
39     for (int j = LOG - 1; j >= 0; j--) {
40         if (profundidade[a] - (1 << j) >= profundidade[b]) {
41             a = cima[a][j];
42         }
43     }
44     // se 'b' era um ancestral de 'a', entãõ 'a' agora ã
45     igual a 'b'
46     if (a == b) {
47         return a;
48     }
49     // sobe os dois juntos ate encontrar os filhos do LCA
50     for (int j = LOG - 1; j >= 0; j--) {
51         if (cima[a][j] != -1 && cima[a][j] != cima[b][j]) {
52             a = cima[a][j];
53             b = cima[b][j];
54         }
55     }
56     return cima[a][0];
57 }

```

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

```

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-order)
8 void dfs1(int u) {
9     vis[u] = true;
10    for (int v : adj[u]) {
11        if (!vis[v]) {
12            dfs1(v);
13        }
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 }

```

```

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 Min Cost Max Flow

```

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

```

```

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             f = min(f, edges[edge_to[cur]].capacity);
64             cur = edges[edge_to[cur]].from;
65         }
66
67         // apply flow
68         flow += f;
69         cost += f * dist[t];
70         cur = t;
71         while (cur != s) {
72             int edge = edge_to[cur];
73             int rev_edge = edge^1;
74
75             edges[edge].capacity -= f;
76             edges[rev_edge].capacity += f;
77             cur = edges[edge].from;
78         }
79     }
80
81     if (flow < K)
82         return -1;
83     else
84         return cost;
85 }

```

6.15 Diametro

```

1  /*
2  0(N + M), retorna cara mais distante, len
3  do caminho em arestas e os caras do caminho em um vetor
4  Para pegar o diametro da arvore, chamar duas vezes
5  auto [a, DA, PA] = calc(1);
6  auto [b, len_diametro, caminho_diametro] = calc(a);
7  */
8  auto calc = [&](int S) -> tuple<int, int, vector<int>> {
9      queue<pair<int, int>> q;
10     q.push({S, 0});
11     vector<int> dp(n + 1, -1), pai(n + 1, 0);
12     dp[S] = 0;
13     pai[S] = -1;
14     int longe = S;
15     int dist = 0;
16     while (!q.empty()){
17         auto [u, d] = q.front();
18         q.pop();
19         if (d > dist){
20             dist = d;
21             longe = u;
22         }
23         for (int v : adj[u]){
24             if (dp[v] == -1){
25                 dp[v] = d + 1;
26                 pai[v] = u;
27                 q.push({v, d + 1});
28             }
29         }
30     }
31     int cur = longe;
32     vector<int> caminho;
33     while (cur != -1){
34         caminho.push_back(cur);
35         cur = pai[cur];
36     }
37     return { longe, dist, caminho };
38 };

```

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 que >= v[i]
10             auto it = lower_bound(lis.begin(), lis.end(), v[i]);
11             *it = v[i];
12         }
13     }
14     return lis.size();
15 }
16
17 // lis na tree do problema da sub
18 const int MAXN_TREE = 100001;
19 vector<int> adj[MAXN_TREE];
20 int values[MAXN_TREE];
21 int ans = 0;
22
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][j-1] + 1, dp[i-1][j-1] + 1});
10             }
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][3])) + S[i][2]);
16     return dp[i][vis] = ans;
17 }

```

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 - 1, j - 1);
7     else return dp[i][j] = max(lcs(i - 1, j), lcs(i, j - 1));
8 }
```

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][last][
8         flag][started];
9     int lim;
10    if (flag) lim = 9;
11    else lim = digits[i];
12    int ans = 0;
13    for (int d = 0; d <= lim; d++) {
14        if (started && d == last) continue;
15        int new_flag = flag;
16        int new_started = started;
17        if (d > 0) new_started = 1;
18        if (!flag && d < lim) new_flag = 1;
19        ans += rec(i + 1, d, new_flag, new_started);
20    }
21    return dp[i][last][flag][started] = ans;
22 }
```

8.6 Knapsack

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

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) - vals.
7     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(0ll, a[i] - 1)) + 1;
16     seg.update(a[i], dp[i]);
17 }
18 cout << *max_element(dp.begin(), dp.end()) << '\n';
19 }
```

8.8 Disjoint Blocks

```
1 // num max de subarrays disjuntos com soma x usando apenas
2 // prefixo i (ou seja, considerando prefixo a[1..i]).
3 int disjointSumX(vector<int> &a, int x) {
```

```
4     int n = a.size();
5     map<int, int> best; // best[pref] = melhor dp visto para
6     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];
20 }
```

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.idade;
9         else return nome > other.nome;
10    }
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 characters
4 // 0(n*freq.size())
5 int countPermLess(vector<int> freq, const string &t) {
6     int n = t.size();
7     int ans = 0;
8
9     vector<int> fact(n + 1, 1), invfact(n + 1, 1);
10    for (int i = 1; i <= n; i++)
11        fact[i] = (fact[i - 1] * i) % MOD;
12    invfact[n] = fexp(fact[n], MOD - 2, MOD);
13    for (int i = n - 1; i >= 0; i--)
14        invfact[i] = (invfact[i + 1] * (i + 1)) % MOD;
15
16    // For each position in t, try placing a letter smaller
17    // than t[i] that is in freq
18    for (int i = 0; i < n; i++) {
19        for (char c = 'a'; c < t[i]; c++) {
20            if (freq[c - 'a'] > 0) {
21                freq[c - 'a']--;
22                int ways = fact[n - i - 1];
23                for (int f : freq)
24                    ways = (ways * invfact[f]) % MOD;
25                ans = (ans + ways) % MOD;
26                freq[c - 'a']++;
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], L.back(),
68             , pp) == -1)
69         {
70             // ÃŁ -1 pq eu nÃŁo quero excluir os colineares
71             L.pop_back();
72         }
73         L.push_back(pp);
74     }
75     reverse(p.begin(), p.end());
76
77     //Upper
78     for(auto pp : p)
79     {
80         while(U.size() >= 2 and ccw(U[U.size()-2], U.back(),

```



```

    pp) == -1)
    {
        U.pop_back();
    }
    U.push_back(pp);
}

L.pop_back();
L.insert(L.end(), U.begin(), U.end()-1);
return L;
}

cod area(vector<point> v)
{
    int ans = 0;
    int aux = (int)v.size();
    for(int i = 2; i < aux; i++)
    {
        ans += ((v[i].x - v[0].x)*(v[i-1].y - v[0].y))/2;
    }
    ans = abs(ans);
    return ans;
}

int bound(point p1, point p2)
{
    return __gcd(abs(p1.x-p2.x), abs(p1.y-p2.y));
}

//teorema de pick [pontos = A - (bound+points)/2 + 1]

int32_t main()
{
    int n;
    cin >> n;

    vector<point> v(n);
    for(int i = 0; i < n; i++)
    {
        cin >> v[i].x >> v[i].y;
    }

    vector<point> ch = convex_hull(v);

    cout << ch.size() << '\n';
    for(auto p : ch) cout << p.x << " " << p.y << "\n";

    return 0;
}

```

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 || y==1 || z==1) and (x==-1 || y==-1 || z==-1));
8 }
9
10 bool inside(vp &p, point e){ // ccw
11     int l=2, r=(int)p.size()-1;
12     while(l<r){
13         int mid = (l+r)/2;
14         if(ccw(p[0], p[mid], e) == 1)
15             l=mid+1;
16         else{
17             r=mid;
18         }
19     }
20     // bordo
21     // if(r==(int)p.size()-1 and ccw(p[0], p[r], e)==0)
22     // return false;
23     // if(r==2 and ccw(p[0], p[1], e)==0) return false;
24     // if(ccw(p[r], p[r-1], e)==0) return false;
25     return insideT(p[0], p[r-1], p[r], e);
26 }
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[i], p[j], pp)==1)
42             inter++; // up
43         else if(p[j].x <= pp.x and pp.x < p[i].x and ccw(p[i], p[j], pp)==-1)
44             inter++; // down
45     }
46
47     if(inter%2==0) return -1; // outside
48     else return 1; // inside
49 }

```

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 >> x2 >> y2 >> x3 >> y3;
10
11         int deltax1 = (x1-x2), deltax2 = (x1-x3);
12         int compx = (x1-x3), compy = (y1-y3);
13
14         int ans = (deltax1*compy) - (compx*deltax2);
15
16         if(ans == 0){cout << "TOUCH\n"; continue;}
17         if(ans < 0){cout << "RIGHT\n"; continue;}
18         if(ans > 0){cout << "LEFT\n"; continue;}
19
20     }
21     return 0;
22 }

```

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, ll y3) {
5     return abs(x1 * (y2 - y3) + x2 * (y3 - y1) + x3 * (y1 - y2));
6 }
7 ll pontos_borda(ll x1, ll y1, ll x2, ll y2) {
8     return gcd(abs(x2 - x1), abs(y2 - y1));
9 }
10
11 int32_t main() {
12     ll x1, y1, x2, y2, x3, y3;
13     cin >> x1 >> y1;
14     cin >> x2 >> y2;
15     cin >> x3 >> y3;
16     ll area = area_triangulo(x1, y1, x2, y2, x3, y3);
17     ll tot_borda = pontos_borda(x1, y1, x2, y2) +
18         pontos_borda(x2, y2, x3, y3) + pontos_borda(x3, y3, x1, y1);
19
20     ll ans = (area - tot_borda) / 2 + 1;
21     cout << ans << endl;
22
23     return 0;
24 }

```