Competitive Programming Notebook

Programadores Roblox

Contents

1   String

1.1   Trie

```cpp
// Trie por array
int trie[MAXN][26];
int tot_nos = 0;
vector<bool> acaba(MAXN, false);
vector<int> contador(MAXN, 0);

void insere(string s) {
    int no = 0;
    for(auto &c : s) {
        if(trie[no][c - 'a'] == 0) {
            trie[no][c - 'a'] = ++tot_nos;
        }
        no = trie[no][c - 'a'];
        contador[no]++;
    }
    acaba[no] = true;
}

bool busca(string s) {
    int no = 0;
    for(auto &c : s) {
        if(trie[no][c - 'a'] == 0) {
            return false;
        }
        no = trie[no][c - 'a'];
    }
    return acaba[no];
}

int isPref(string s) {
    int no = 0;
    for(auto &c : s) {
        if(trie[no][c - 'a'] == 0){
            return -1;
        }
        no = trie[no][c - 'a'];
    }
    return contador[no];
}
```

1.2   Hashing

```cpp
// String Hash template
// constructor(s) - O(|s|)
// query(l, r) - returns the hash of the range [l,r] from
    left to right - O(1)
// query_inv(l, r) from right to left - O(1)
// patrocinado por tiagodfs

mt19937 rng(time(nullptr));

struct Hash {
    const int X = rng();
    const int MOD = 1e9+7;
    int n; string s;
    vector<int> h, hi, p;
    Hash() {}
    Hash(string s): s(s), n(s.size()), h(n), hi(n), p(n) {
        for (int i=0;i<n;i++) p[i] = (i ? X*p[i-1]:1) % MOD;
        for (int i=0;i<n;i++)
            h[i] = (s[i] + (i ? h[i-1]:0) * X) % MOD;
        for (int i=n-1;i>=0;i--)
            hi[i] = (s[i] + (i+1<n ? hi[i+1]:0) * X) % MOD;
    }
    int query(int l, int r) {
        int hash = (h[r] - (l ? h[l-1]*p[r-l+1]%MOD : 0));
        return hash < 0 ? hash + MOD : hash;
    }
    int query_inv(int l, int r) {
        int hash = (hi[l] - (r+1 < n ? hi[r+1]*p[r-l+1] % MOD
    : 0));
        return hash < 0 ? hash + MOD : hash;
    }
};
```

1.3   Z Function

```cpp
vector<int> z_function(string s) {
    int n = s.size();
    vector<int> z(n);
    int l = 0, r = 0;
    for(int i = 1; i < n; i++) {
        if(i < r) {
            z[i] = min(r - i, z[i - l]);
        }
        while(i + z[i] < n && s[z[i]] == s[i + z[i]]) {
            z[i]++;
        }
        if(i + z[i] > r) {
            l = i;
            r = i + z[i];
        }
    }
    return z;
}
```

1.4   Kmp

```cpp
vector<int> kmp(string &s) {
    int m = s.size();
    vector<int> lsp(m, 0);
    for (int i = 1, j = 0; i < m; i++) {
        while (j > 0 && s[j] != s[i]) j = lsp[j - 1];
        if (s[i] == s[j]) j++;
        lsp[i] = j;
    }
    return lsp;
}
```

2   DS

2.1   Seg Lazy Pa

```cpp
/* Notas
   PA eh da forma a0 (a) e razÃčo (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;
}

struct SegTree {
    int n;
    vector<int> v, lazy_a, lazy_d, tree;
    SegTree(vector<int> &a) : v(a), n(a.size()) {
        tree.resize(4 * n);
        lazy_a.resize(4 * n, 0ll);
        lazy_d.resize(4 * n, 0ll);
        build(1, 0, n - 1);
    }
    void build(int x, int lx, int rx) {
        if (lx == rx) {
            tree[x] = v[lx];
            return;
        }
        int mid = (lx + rx) / 2;
        build(2 * x, lx, mid);
        build(2 * x + 1, mid + 1, rx);
        tree[x] = tree[2 * x] + tree[2 * x + 1];
    }
    int query(int x, int lx, int rx, int l, int r) {
        push(x, lx, rx);
        if (lx >= l && rx <= r)
            return tree[x];
        if (lx > r || rx < l)
            return 0;
        int mid = (lx + rx) / 2;
        return query(2 * x, lx, mid, l, r) + query(2 * x + 1, mid
    + 1, rx, l, r);
```

```
47    }
48    int query(int l, int r) {
49      return query(1, 0, n - 1, l, r);
50    }
51    void push(int x, int lx, int rx) {
52      if (lazy_a[x] && lazy_d[x]) {
53        int tam = rx - lx + 1;
54        tree[x] += gauss(tam, lazy_a[x], lazy_d[x]);
55        if (lx != rx) {
56          int mid = (lx + rx) / 2;
57          int tam_esq = mid - lx + 1;
58          lazy_a[2 * x] += lazy_a[x];
59          lazy_d[2 * x] += lazy_d[x];
60          lazy_a[2 * x + 1] += (lazy_a[x] + tam_esq * lazy_d[x
      ]);
61          lazy_d[2 * x + 1] += lazy_d[x];
62        }
63        lazy_a[x] = lazy_d[x] = 0;
64      }
65    }
66    void update(int x, int lx, int rx, int l, int r, int a, int
       d) {
67      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  };
```

2.2 Segtree Iterativa

```cpp
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 +
    1]);
37     }
38 };
```

2.3 Merge Sort Tree

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

2.4 Ordered Set E Map

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

```
24 }
```

2.5 Sparse Table

```cpp
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 + (1 << (j
   - 1))][j - 1]);
15             }
16         }
17     }
18     int query(int L, int R) {
19         int tamanho = R - L + 1;
20         int k = floor(log2(tamanho));
21         return max(st[L][k], st[R - (1 << k) + 1][k]);
22     }
23 };
```

2.6 Psum 2d

```cpp
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
   -1];
6      }
7  }
8  // retorna a psum2d do intervalo inclusivo [(a, b), (c, d)]
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 Lazy

```cpp
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
    + 1, rx, l, r);
79   }
80   int query(int l, int r) {
81     return query(1, 0, n - 1, l, r);
82   }
83 };
```

2.8 Bit2d

```cpp
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)
    + pref(y1 - 1, x1 - 1);
26   }
27 };
```

2.9 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.
    pop_back();
5          dq.emplace_back(val, idx);
6      }
7      void pop(int idx) {
8          if (!dq.empty() && dq.front().second == idx) {
9              dq.pop_front();
10         }
11     }
12     int get() {
13         return dq.front().first;
14     }
15     bool empty() {
16         return dq.empty();
17     }
18 };
19 /*
20 considerando janela de tamanho K
21 mq.push(v[i], i);
22 if (i >= k) {
23   mq.pop(i - k);
24 }
25 if (i >= k - 1) {
26   result.push_back(mq.get());
27 }
28 */
```

2.10   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(
    n) {
5          for (int i = 1; i <= n; ++i) par[i] = i;
6      }
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 };
```

2.11   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[
    s.top()] >= v[i])) {
8              s.pop();
9          }
10         if (s.empty()) {
11             result[i] = -1;
12         } else {
13             result[i] = v[s.top()];
14         }
15         s.push(i);
16     }
17     return result;
18 }
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[
    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

```cpp
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

```cpp
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
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 < MAXN_FATORIAL; i++) fat[i] = (fat[i -
        1] * i) % MOD;
15     fati[MAXN_FATORIAL - 1] = inv(fat[MAXN_FATORIAL - 1]);
16     for (int i = MAXN_FATORIAL - 2; i >= 0; i--) fati[i] = (
        fati[i + 1] * (i + 1)) % MOD;
17 }
18
19 int choose(int n, int k) {
20     if (k < 0 || k > n) return 0;
21     return (((fat[n] * fati[k]) % MOD) * fati[n - k]) % MOD;
22 }
23
24 // n! / (n-k)!
25 int perm(int n, int k) {
26     if (k < 0 || k > n) return 0;
27     return (fat[n] * fati[n - k]) % MOD;
28 }
29
30 // C_n = (1 / (n+1)) * C(2n, n)
31 int catalan(int n) {
32     if (n < 0 || 2 * n >= MAXN_FATORIAL) return 0;
33     int c2n_n = choose(2 * n, n);
34     return (c2n_n * inv(n + 1)) % MOD;
35 }
```

5.2   Equacao Diofantina

```cpp
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;
```

```cpp
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

```cpp
1  // multiplica matrizes de tamanhos variados, resultando 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));
5
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] % mod)%
       mod;
10
11     return C;
12 }
```

5.4   Discrete Log

```cpp
1  // returns minimum x for which a^x = b (mod m), a and m are
       coprime
2  // if the answer dont need to be greater than some value, the
        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 * 1ll * 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 * 1ll * a) % m;
15     }
16
17     int res = LLONG_MAX;
18
19     for (int p = 1, cur = 1; p <= n; ++p) {
20         cur = (cur * 1ll * 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

```cpp
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      return accumulate(all(is_prime), 0ll);;
18  }
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] -=
    phiv[j] / i;
24          }
25      }
26  }
```

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
56  }
```

5.8 Exgcd

```
1   // O 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       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   // 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);
```

```cpp
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

```cpp
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

```cpp
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;
```

```cpp
36   }
37 }
38
39 vector<int> multiply(vector<int> const& A, vector<int> 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

```cpp
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

```cpp
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 void solve() {
17     int m, q;
18     cin >> n >> m >> q;
19     for(int i = 0; i < n; i++) {
20         for(int j = i; j < n; j++) {
21             if(i == j) {
22                 dist[i][j] = dist[j][i] = 0;
23             } else {
24                 dist[i][j] = dist[j][i] = linf;
25             }
26         }
27     }
28     for(int i = 0; i < m; i++) {
```

```
29        int u, v, w;
30        cin >> u >> v >> w; u--; v--;
31        dist[u][v] = min(dist[u][v], w);
32        dist[v][u] = min(dist[v][u], w);
33    }
34    floydWarshall();
35    while(q--) {
36        int u, v;
37        cin >> u >> v; u--; v--;
38        if(dist[u][v] == linf) cout << -1 << '\n';
39        else cout << dist[u][v] << '\n';
40    }
41 }
```

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
        de s ate e.
9   * - O(Nlog(N))
10  * Retorna vetor com a sequencia de vertices, ou vazio se
       impossivel.
11  */
12 vector<int> eulerian_path(const vector<vector<int>>& g, bool
      directed, int s, int e = -1) {
13     int n = (int)g.size();
14     // copia das adjacencias em multiset para permitir
        remoÃ§Ã£o 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 {}; // 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
      [u] & 1))) {
38             return {};
39         }
40     }
41     while (!st.empty()) {
42         int u = st.top();
43         if (h[u].empty()) {
44             result.emplace_back(u);
45             st.pop();
46         } else {
47             int v = *h[u].begin();
48             auto it = h[u].find(v);
49             if (it != h[u].end()) h[u].erase(it);
50             --in_degree[v];
51             if (!directed) {
52                 auto it2 = h[v].find(u);
53                 if (it2 != h[v].end()) h[v].erase(it2);
54                 --in_degree[u];
55             }
56             st.emplace(v);
57         }
58     }
59     for (int u = 0; u < n; ++u) {
60         if (in_degree[u] != 0) return {};
61     }
62     reverse(result.begin(), result.end());
63     return result;
```

```
64 }
```

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),
       to(to), cap(cap) {}
7  };
8
9  struct Dinic {
10     const long long flow_inf = 1e18;
11     vector<FlowEdge> edges;
12     vector<vector<int>> adj;
13     int qntV, qntE = 0;
14     int source, sink;
15     vector<int> level, ptr;
16     queue<int> q;
17
18     Dinic(int qntV, int source, int sink) : qntV(qntV),
       source(source), sink(sink) {
19         adj.resize(qntV);
20         level.resize(qntV);
21         ptr.resize(qntV);
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(qntE);
28         adj[to].push_back(qntE + 1);
29         qntE += 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] + 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
       (); cid++) {
54             int id = adj[from][cid];
55             int to = edges[id].to;
56             if (level[from] + 1 != level[to])
57                 continue;
58             long long tr = dfs(to, min(pushed, edges[id].cap
       - edges[id].flow));
59             if (tr == 0)
60                 continue;
61             edges[id].flow += tr;
62             edges[id ^ 1].flow -= tr;
63             return tr;
64         }
65         return 0;
66     }
67
68     long long max_flow() {
69         long long f = 0;
70         while (true) {
71             fill(level.begin(), level.end(), -1);
72             level[source] = 0;
73             q.push(source);
74             if (!bfs())
75                 break;
76             fill(ptr.begin(), ptr.end(), 0);
77             while (long long pushed = dfs(source, flow_inf))
       {
```

```
78                f += pushed;
79            }
80        }
81        return f;
82    }
83 };
```

6.5   Khan

```
1  // topo-sort DAG
2  // lexicograficamente menor.
3  // N: numero de vÃrtices (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 scalling O(EÂšlog(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                 if (next == t)
24                     return new_flow;
25                 q.push({next, new_flow});
26             }
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 scalling = 1ll << 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

```cpp
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

```cpp
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

```cpp
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
```

```cpp
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', então 'a' agora é
         igual a 'b'
45     if (a == b) {
46         return a;
47     }
48     // sobe os dois juntos ate encontrar os filhos do LCA
49     for (int j = LOG - 1; j >= 0; j--) {
50         if (cima[a][j] != -1 && cima[a][j] != cima[b][j]) {
51             a = cima[a][j];
52             b = cima[b][j];
53         }
54     }
55     return cima[a][0];
56 }
```

6.12   Lca

```cpp
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 }
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()});
       // reversa
42 }
43
44 int min_cost_flow(int N, int K, int s, int t) {
45     adj.assign(N, vector<array<int, 2>>());
46
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             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  O(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], 0ll, 0ll, 0ll}) - S.begin();
4  }
5
6  int dp[1002][(int)(1ll << 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 | (1ll << 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][
   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 mochila
2  // O(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;
```

```cpp
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
      -1].first] + items[i-1].second);
11          }
12      }
13  }
14  cout << dp[N][W] << '\n';
```

8.7   Lis Seg

```cpp
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.
      begin();
7   };
8   for (int i = 0; i < n; i++) a[i] = id(a[i]);
9   // fim da parte de compr
10  SegTree seg(n);
11  // dp[i]: lis que termina em i
12  vector<int> dp(n, 1); // dp[i] = 1 base case
13  for (int i = 0; i < n; i++) {
14      if (a[i] > 0) dp[i] = seg.query(0, max(0ll, a[i] - 1)) +
      1;
15      seg.update(a[i], dp[i]);
16  }
17  cout << *max_element(dp.begin(), dp.end()) << '\n';
```

8.8   Disjoint Blocks

```cpp
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
       esse pref
6       best[0] = 0;
7       int pref = 0;
8       vector<int> dp(n + 1, 0); // dp[0] = 0
9       for (int i = 1; i <= n; i++) {
10          pref += a[i - 1];
11          dp[i] = dp[i-1];
12          auto it = best.find(pref - x);
13          if (it != best.end()) {
14              dp[i] = max(dp[i], it->second + 1);
15          }
16          best[pref] = max(best[pref], dp[i]);
17      }
18      return dp[n];
19  }
```

9   General

9.1   Brute Choose

```cpp
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

```cpp
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

```cpp
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

```cpp
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   // O(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
       than t[i] that is in freq
17      for (int i = 0; i < n; i++) {
18          for (char c = 'a'; c < t[i]; c++) {
19              if (freq[c - 'a'] > 0) {
20                  freq[c - 'a']--;
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

```cpp
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

```cpp
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(), pp) == -1)
68         {
69             // Ãľ -1 pq eu nÃčo quero excluir os colineares
70             L.pop_back();
71         }
72         L.push_back(pp);
73     }
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)
81         {
82             U.pop_back();
83         }
84         U.push_back(pp);
85     }
86
87     L.pop_back();
88     L.insert(L.end(), U.begin(), U.end()-1);
89     return L;
90 }
91
92 cod area(vector<point> v)
93 {
94     int ans = 0;
95     int aux = (int)v.size();
96     for(int i = 2; i < aux; i++)
97     {
98         ans += ((v[i] - v[0])^(v[i-1] - v[0]))/2;
99     }
100    ans = abs(ans);
101    return ans;
102 }
103
104 int bound(point p1 , point p2)
105 {
106     return __gcd(abs(p1.x-p2.x), abs(p1.y-p2.y));
107 }
108 //teorema de pick [pontos = A - (bound+points)/2 + 1]
109
110 int32_t main()
111 {
112
113     int n;
114     cin >> n;
115
116     vector<point> v(n);
117     for(int i = 0; i < n; i++)
118     {
119         cin >> v[i].x >> v[i].y;
120     }
121
```

```
122        vector <point> ch = convex_hull(v);
123
124        cout << ch.size() << '\n';
125        for(auto p : ch) cout << p.x << " " << p.y << "\n";
126
127        return 0;
128    }
```

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==-1 or 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)
        return false;
22      // if(r==2 and ccw(p[0], p[1], e)==0) return false;
23      // if(ccw(p[r], p[r-1], e)==0) return false;
24      return insideT(p[0], p[r-1], p[r], e);
25  }
26
27  // Any O(n)
28
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), deltay1 = (y1-y2);
12
13          int compx = (x1-x3), compy = (y1-y3);
14
15          int ans = (deltax1*compy) - (compx*deltay1);
16
17          if(ans == 0){cout << "TOUCH\n"; continue;}
18          if(ans < 0){cout << "RIGHT\n"; continue;}
19          if(ans > 0){cout << "LEFT\n"; continue;}
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) +
        pontos_borda(x2, y2, x3, y3) + pontos_borda(x3, y3, x1,
        y1);
18
19      ll ans = (area - tot_borda) / 2 + 1;
20      cout << ans << endl;
21
22      return 0;
23  }
```