

C++ Competitive Programming Library

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1. Template

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4
5 #define INF (1ll << 62)
6 #define pb push_back
7 #define ii pair<int,int>
8 #define OK cerr <<"OK"<< endl
9 #define debug(x) cerr << #x " = " << (x) << endl
10 #define ff first
11 #define ss second
12 #define int long long
13 #define tt tuple<int, int, int>
14 #define endl '\n'
15
16 signed main () {
17
18     ios_base::sync_with_stdio(false);
19     cin.tie(NULL);
20
21 }
```

2. Data Structures

2.1. Bit2D

```

1 // INDEX BY ONE ALWAYS!!!
2 class BIT_2D {
3 private:
4     // row, column
5     int n, m;
6     vector<vector<int>>> tree;
7
8 private:
9     // Returns an integer which constains only the least significant bit.
10    int low(int i) {
11        return i & (-i);
12    }
13
14    void bit_update(const int x, const int y, const int delta) {
15        for(int i = x; i < n; i += low(i))
16            for(int j = y; j < m; j += low(j))
17                this->tree[i][j] += delta;
18    }
19
20    int bit_query(const int x, const int y) {
21        int ans = 0;
22        for(int i = x; i > 0; i -= low(i))
23            for(int j = y; j > 0; j -= low(j))
24                ans += this->tree[i][j];
25
26        return ans;
27    }
28
29 public:
30     // put the size of the array without 1 indexing.
31     /// Time Complexity: O(n * m)
32     BIT_2D(int n, int m) {
33         this->n = n + 1;
34         this->m = m + 1;
35
36         this->tree.resize(n, vector<int>(m, 0));
```

```

37 }
38
39 /// Time Complexity: O(n * m * (log(n) + log(m)))
40 BIT_2D(const vector<vector<int>> &mat) {
41     // Check if it is 1 index.
42     assert(mat[0][0] == 0);
43     this->n = mat.size();
44     this->m = mat.front().size();
45
46     this->tree.resize(n, vector<int>(m, 0));
47     for(int i = 1; i < n; i++)
48         for(int j = 1; j < m; j++)
49             update(i, j, mat[i][j]);
50 }
51
52 /// Query from (1, 1) to (x, y).
53 ///
54 /// Time Complexity: O(log(n) + log(m))
55 int prefix_query(const int x, const int y) {
56     assert(0 < x); assert(x < this->n);
57     assert(0 < y); assert(y < this->m);
58
59     return bit_query(x, y);
60 }
61
62 /// Query from (x1, y1) to (x2, y2).
63 ///
64 /// Time Complexity: O(log(n) + log(m))
65 int query(const int x1, const int y1, const int x2, const int y2) {
66     assert(0 < x1); assert(x1 <= x2); assert(x2 < this->n);
67     assert(0 < y1); assert(y1 <= y2); assert(y2 < this->m);
68
69     return bit_query(x2, y2) - bit_query(x1 - 1, y2) - bit_query(x2, y1 - 1)
70     + bit_query(x1 - 1, y1 - 1);
71 }
72
73 /// Updates point (x, y).
74 ///
75 /// Time Complexity: O(log(n) + log(m))
76 void update(const int x, const int y, const int delta) {
77     assert(0 < x); assert(x < this->n);
78     assert(0 < y); assert(y < this->m);
79
80     bit_update(x, y, delta);
81 };

```

2.2. Merge Sort Tree (K-Esimo Maior Elemento Num Intervalo, Valores Maiores Que K Num Intervalo,

```

1 // retornar a qtd de números maiores q um numero k numa array de i...j
2 struct Tree {
3     vector<int> vet;
4 };
5 Tree tree[4*(int)3e4];
6 int arr[(int)5e4];
7
8 int query(int l, int r, int i, int j, int k, int pos) {
9     if(l > j || r < i)
10         return 0;
11
12     if(i <= l && r <= j) {
13         auto it = upper_bound(tree[pos].vet.begin(), tree[pos].vet.end(), k);
14         return tree[pos].vet.end() - it;

```

```

15     }
16
17     int mid = (l+r)>>1;
18     return query(l, mid, i, j, k, 2*pos+1) + query(mid+1, r, i, j, k, 2*pos+2);
19 }
20
21 void build(int l, int r, int pos) {
22
23     if(l == r) {
24         tree[pos].vet.pb(arr[l]);
25         return;
26     }
27
28     int mid = (l+r)>>1;
29     build(l, mid, 2*pos+1);
30     build(mid + 1, r, 2*pos+2);
31
32     merge(tree[2*pos+1].vet.begin(), tree[2*pos+1].vet.end(),
33           tree[2*pos+2].vet.begin(), tree[2*pos+2].vet.end(),
34           back_inserter(tree[pos].vet));
35 }

```

2.3. Mos Algorithm

```

1 struct Tree {
2     int l, r, ind;
3 };
4 Tree query[311111];
5 int arr[311111];
6 int freq[111111];
7 int ans[311111];
8 int block = sqrt(n), cont = 0;
9
10 bool cmp(Tree a, Tree b) {
11     if(a.l/block == b.l/block)
12         return a.r < b.r;
13     return a.l/block < b.l/block;
14 }
15
16 void add(int pos) {
17     freq[arr[pos]]++;
18     if(freq[arr[pos]] == 1) {
19         cont++;
20     }
21 }
22
23 void del(int pos) {
24     freq[arr[pos]]--;
25     if(freq[arr[pos]] == 0)
26         cont--;
27 }
28
29 int main () {
30     int n; cin >> n;
31     block = sqrt(n);
32
33     for(int i = 0; i < n; i++) {
34         cin >> arr[i];
35         freq[arr[i]] = 0;
36     }
37
38     int m; cin >> m;
39
40     for(int i = 0; i < m; i++) {
41         cin >> query[i].l >> query[i].r;
42         query[i].l--, query[i].r--;

```

```

41     query[i].ind = i;
42 }
43 sort(query, query + m, cmp);
44
45 int s,e;
46 s = e = query[0].l;
47 add(s);
48 for(int i = 0; i < m; i++) {
49     while(s > query[i].l)
50         add(--s);
51     while(s < query[i].l)
52         del(s++);
53     while(e < query[i].r)
54         add(++e);
55     while(e > query[i].r)
56         del(e--);
57     ans[query[i].ind] = cont;
58 }
59
60 for(int i = 0; i < m; i++)
61     cout << ans[i] << endl;
62 }

```

2.4. Ordenacao De Estruturas (Pq, Etc)

```

1 struct cmp {
2     bool operator(ii a, ii b) {
3         //ordena primeiro pelo first(decrecente), dps pelo second(crescente)
4         if(a.first == b.first)
5             return a.second < b.second;
6         return a.first > b.first;
7     }
8 }
9 Ex: pq<ii,vector<ii>,cmp> fila;

```

2.5. Sqrt Decomposition

```

1 // Problem: Sum from l to r
2 // Ver MO'S ALGORITHM
3 // -----
4 int getId(int indx,int blockSZ) {
5     return indx/blockSZ;
6 }
7 void init(int sz) {
8     for(int i=0; i<=sz; i++)
9         BLOCK[i]=inf;
10 }
11 int query(int left, int right) {
12     int startBlockIndex=left/sqrt;
13     int endIBlockIndex = right / sqrt;
14     int sum = 0;
15     for (int i = startBlockIndex + 1; i < endIBlockIndex; i++) {
16         sum += blockSums[i];
17     }
18     for(i=left...(startBlockIndex*BLOCK_SIZE-1))
19         sum += a[i];
20     for(j = endIBlockIndex*BLOCK_SIZE ... right)
21         sum += a[i];
22 }

```

2.6. Bit

```

1 /// INDEX THE ARRAY BY 1!!!
2 class BIT {
3 private:
4     vector<int> bit;
5     int n;
6
7 private:
8     int low(const int i) { return (i & (-i)); }
9
10    // point update
11    void bit_update(int i, const int delta) {
12        while (i <= this->n) {
13            this->bit[i] += delta;
14            i += this->low(i);
15        }
16    }
17
18    // point query
19    int bit_query(int i) {
20        int sum = 0;
21        while (i > 0) {
22            sum += bit[i];
23            i -= this->low(i);
24        }
25        return sum;
26    }
27
28 public:
29     BIT(const vector<int> &arr) { this->build(arr); }
30
31     BIT(const int n) {
32         // OBS: BIT IS INDEXED FROM 1
33         // THE USE OF 1-BASED ARRAY IS RECOMMENDED
34         this->n = n;
35         this->bit.resize(n + 1, 0);
36     }
37
38    // build the bit
39    void build(const vector<int> &arr) {
40        // OBS: BIT IS INDEXED FROM 1
41        // THE USE OF 1-BASED ARRAY IS RECOMMENDED
42        assert(arr.front() == 0);
43        this->n = (int)arr.size() - 1;
44        this->bit.resize(arr.size(), 0);
45
46        for (int i = 1; i <= this->n; i++)
47            this->bit_update(i, arr[i]);
48    }
49
50    // point update
51    void update(const int i, const int delta) {
52        assert(1 <= i), assert(i <= this->n);
53        this->bit_update(i, delta);
54    }
55
56    // point query
57    int query(const int i) {
58        assert(1 <= i), assert(i <= this->n);
59        return this->bit_query(i);
60    }
61
62    // range query
63    int query(const int l, const int r) {
64        assert(1 <= l), assert(l <= r), assert(r <= this->n);

```

```

65     return this->bit_query(r) - this->bit_query(l - 1);
66 }
67 };

```

2.7. Bit (Range Update)

```

1  /// INDEX THE ARRAY BY 1!!!
2  class BIT {
3  private:
4      vector<int> bit1;
5      vector<int> bit2;
6      int n;
7
8  private:
9      int low(int i) { return (i & (-i)); }
10
11     // point update
12     void update(int i, const int delta, vector<int> &bit) {
13         while (i <= this->n) {
14             bit[i] += delta;
15             i += this->low(i);
16         }
17     }
18
19     // point query
20     int query(int i, const vector<int> &bit) {
21         int sum = 0;
22         while (i > 0) {
23             sum += bit[i];
24             i -= this->low(i);
25         }
26         return sum;
27     }
28
29     // build the bit
30     void build(const vector<int> &arr) {
31         // OBS: BIT IS INDEXED FROM 1
32         // THE USE OF 1-BASED ARRAY IS MANDATORY
33         assert(arr.front() == 0);
34         this->n = (int)arr.size() - 1;
35         this->bit1.resize(arr.size(), 0);
36         this->bit2.resize(arr.size(), 0);
37
38         for (int i = 1; i <= this->n; i++)
39             this->update(i, arr[i]);
40     }
41
42 public:
43     BIT(const vector<int> &arr) { this->build(arr); }
44
45     BIT(const int n) {
46         // OBS: BIT IS INDEXED FROM 1
47         // THE USAGE OF 1-INDEXED ARRAY IS MANDATORY
48         this->n = n;
49         this->bit1.resize(n + 1, 0);
50         this->bit2.resize(n + 1, 0);
51     }
52
53     // range update
54     void update(const int l, const int r, const int delta) {
55         assert(l <= 1), assert(l <= r), assert(r <= this->n);
56         this->update(l, delta, this->bit1);
57         this->update(r + 1, -delta, this->bit1);
58         this->update(l, delta * (l - 1), this->bit2);

```

```

59         this->update(r + 1, -delta * r, this->bit2);
60     }
61
62     // point update
63     void update(const int i, const int delta) {
64         assert(1 <= i), assert(i <= this->n);
65         this->update(i, i, delta);
66     }
67
68     // range query
69     int query(const int l, const int r) {
70         assert(1 <= l), assert(l <= r), assert(r <= this->n);
71         return this->query(r) - this->query(l - 1);
72     }
73
74     // point prefix query
75     int query(const int i) {
76         assert(i <= this->n);
77         return (this->query(i, this->bit1) * i) - this->query(i, this->bit2);
78     }
79 };
80
81 // TESTS
82 // signed main()
83 // {
84
85 //     vector<int> input = {0,1,2,3,4,5,6,7};
86
87 //     BIT ft(input);
88
89 //     assert (1 == ft.query(1));
90 //     assert (3 == ft.query(2));
91 //     assert (6 == ft.query(3));
92 //     assert (10 == ft.query(4));
93 //     assert (15 == ft.query(5));
94 //     assert (21 == ft.query(6));
95 //     assert (28 == ft.query(7));
96 //     assert (12 == ft.query(3,5));
97 //     assert (21 == ft.query(1,6));
98 //     assert (28 == ft.query(1,7));
99 // }

```

2.8. Counting Inversions (Minimum Number Of Adjacent Swaps To Sort Array)

```

1  // REQUIRES bit.cpp!!
2  // REQUIRES point_compression.cpp!!
3  int count_inversions(vector<int> &arr) {
4      arr = compress(arr);
5      int ans = 0;
6      BIT bit(arr.size());
7      for (int i = arr.size() - 1; i > 0; --i) {
8          ans += bit.query(arr[i] - 1);
9          bit.update(arr[i], 1);
10     }
11     return ans;
12 }

```

2.9. Ordered Set

```

1 #include <bits/stdc++.h>
2 #include <ext/pb_ds/assoc_container.hpp>
3 #include <ext/pb_ds/trie_policy.hpp>

```

```

4
5 using namespace std;
6 using namespace __gnu_pbds;
7
8 template <typename T>
9 using ordered_set =
10     tree<T, null_type, less<T>, rb_tree_tag,
11         tree_order_statistics_node_update>;
12
13 ordered_set<int> X;
14 X.insert(1);
15 X.insert(2);
16 X.insert(4);
17 X.insert(8);
18 X.insert(16);
19
20 // 1, 2, 4, 8, 16
21 // returns the k-th greatest element from 0
22 cout << *X.find_by_order(1) << endl; // 2
23 cout << *X.find_by_order(2) << endl; // 4
24 cout << *X.find_by_order(4) << endl; // 16
25 cout << (end(X) == X.find_by_order(6)) << endl; // true
26
27 // returns the number of items strictly less than a number
28 cout << X.order_of_key(-5) << endl; // 0
29 cout << X.order_of_key(1) << endl; // 0
30 cout << X.order_of_key(3) << endl; // 2
31 cout << X.order_of_key(4) << endl; // 2
32 cout << X.order_of_key(400) << endl; // 5

```

2.10. Persistent Segment Tree

```

1 class Persistent_Seg_Tree {
2     struct Node {
3         int val;
4         Node *left, *right;
5         Node() {}
6         Node(int v, Node *l, Node *r) : val(v), left(l), right(r) {}
7     };
8     #define NEUTRAL_NODE Node(0, nullptr, nullptr);
9     Node _NEUTRAL_NODE = Node(0, nullptr, nullptr);
10
11 public:
12     int merge_nodes(const int x, const int y) { return x + y; }
13
14 private:
15     int n;
16     vector<Node *> version;
17
18 public:
19     Persistent_Seg_Tree() { this->n = -1; }
20     /// Builds version[0] with the values in the array.
21     ///
22     /// Time complexity: O(n)
23     Node *pst_build(Node *node, const int l, const int r,
24                     const vector<int> &arr) {
25         node = new NEUTRAL_NODE;
26         if (l == r) {
27             node->val = arr[l];
28             return node;
29         }
30
31         int mid = (l + r) / 2;
32         node->left = pst_build(node->left, l, mid, arr);

```

```

33         node->right = pst_build(node->right, mid + 1, r, arr);
34         node->val = merge_nodes(node->left->val, node->right->val);
35         return node;
36     }
37
38     /// Builds version[0] with 0.
39     ///
40     /// Time complexity: O(n)
41     Node *pst_build_empty(Node *node, const int l, const int r) {
42         node = new NEUTRAL_NODE;
43         if (l == r)
44             return node;
45
46         int mid = (l + r) / 2;
47         node->left = pst_build_empty(node->left, l, mid);
48         node->right = pst_build_empty(node->right, mid + 1, r);
49         node->val = merge_nodes(node->left->val, node->right->val);
50         return node;
51     }
52
53     Node *pst_update(Node *cur_tree, Node *prev_tree, const int l, const int r,
54                     const int idx, const int delta) {
55         if (l > idx || r < idx) {
56             if (cur_tree != nullptr)
57                 return cur_tree;
58             return prev_tree;
59         }
60
61         if (cur_tree == nullptr)
62             cur_tree = new Node(prev_tree->val, prev_tree->left, prev_tree->right);
63         else
64             cur_tree = new Node(cur_tree->val, cur_tree->left, cur_tree->right);
65
66         if (l == r) {
67             cur_tree->val += delta;
68             return cur_tree;
69         }
70
71         int mid = (l + r) / 2;
72         cur_tree->left =
73             pst_update(cur_tree->left, prev_tree->left, l, mid, idx, delta);
74         cur_tree->right =
75             pst_update(cur_tree->right, prev_tree->right, mid + 1, r, idx,
76                       delta);
77         cur_tree->val = merge_nodes(cur_tree->left->val, cur_tree->right->val);
78         return cur_tree;
79     }
80
81     int pst_query(Node *node, const int l, const int r, const int i,
82                  const int j) {
83         if (l > j || r < i)
84             return _NEUTRAL_NODE.val;
85
86         if (i <= l && r <= j)
87             return node->val;
88
89         int mid = (l + r) / 2;
90         return merge_nodes(pst_query(node->left, l, mid, i, j),
91                             pst_query(node->right, mid + 1, r, i, j));
92     }
93
94 public:
95     Persistent_Seg_Tree(const int n, const int number_of_versions) {
96         this->n = n;
97         version.resize(number_of_versions);

```

```

97     this->version[0] = this->pst_build_empty(this->version[0], 0, this->n -
98     1);
99 }
100 /// Constructor that allows to pass initial values to the leafs.
101 Persistent_Seg_Tree(const vector<int> &arr, const int number_of_versions) {
102     this->n = arr.size();
103     version.resize(number_of_versions);
104     this->version[0] = this->pst_build(this->version[0], 0, this->n - 1,
105     arr);
106 }
107 /// Links the root of a version to a previous version.
108 ///
109 /// Time Complexity: O(1)
110 void link(const int version, const int prev_version) {
111     assert(this->n > -1);
112     assert(0 <= prev_version);
113     assert(prev_version <= version);
114     assert(version < this->version.size());
115     this->version[version] = this->version[prev_version];
116 }
117
118 /// Updates an index in cur_tree based on prev_tree with a delta.
119 ///
120 /// Time Complexity: O(log(n))
121 void update(const int cur_version, const int prev_version, const int idx,
122     const int delta) {
123     assert(this->n > -1);
124     assert(0 <= prev_version);
125     assert(prev_version <= cur_version);
126     assert(cur_version < this->version.size());
127     this->version[cur_version] = this->pst_update(this->version[cur_version],
128     this->version[prev_version],
129     0, this->n - 1, idx,
130     delta);
131 }
132
133 /// Query from l to r.
134 ///
135 /// Time Complexity: O(log(n))
136 int query(const int version, const int l, const int r) {
137     assert(this->n > -1);
138     assert(this->version[version] != nullptr);
139     assert(0 <= l);
140     assert(l <= r);
141     assert(r < this->n);
142     return this->pst_query(this->version[version], 0, this->n - 1, l, r);
143 };

```

2.11. Segment Tree

```

1 class Seg_Tree {
2 public:
3     struct Node {
4         int val, lazy;
5
6         Node() {}
7         Node(const int val, const int lazy) : val(val), lazy(lazy) {}
8     };
9 private:

```

```

11 // // range sum
12 // Node NEUTRAL_NODE = Node(0, 0);
13 // Node merge_nodes(const Node &x, const Node &y) {
14 //     return Node(x.val + y.val, 0);
15 // }
16 // void apply_lazy(const int l, const int r, const int pos) {
17 //     tree[pos].val += (r - l + 1) * tree[pos].lazy;
18 // }
19
20 // // RMQ max
21 // Node NEUTRAL_NODE = Node(-INF, 0);
22 // Node merge_nodes(const Node &x, const Node &y) {
23 //     return Node(max(x.val, y.val), 0);
24 // }
25 // void apply_lazy(const int l, const int r, const int pos) {
26 //     tree[pos].val += tree[pos].lazy;
27 // }
28
29 // // RMQ min
30 // Node NEUTRAL_NODE = Node(INF, 0);
31 // Node merge_nodes(const Node &x, const Node &y) {
32 //     return Node(min(x.val, y.val), 0);
33 // }
34 // void apply_lazy(const int l, const int r, const int pos) {
35 //     tree[pos].val += tree[pos].lazy;
36 // }
37
38 // XOR
39 // Only works with point updates
40 // Node NEUTRAL_NODE = Node(0, 0);
41 // Node merge_nodes(const Node &x, const Node &y) {
42 //     return Node(x.val ^ y.val, 0);
43 // }
44 // void apply_lazy(const int l, const int r, const int pos) {}
45
46 private:
47     int n;
48
49 public:
50     vector<Node> tree;
51
52 private:
53     void st_propagate(const int l, const int r, const int pos) {
54         if (tree[pos].lazy != 0) {
55             apply_lazy(l, r, pos);
56             if (l != r) {
57                 tree[2 * pos + 1].lazy += tree[pos].lazy;
58                 tree[2 * pos + 2].lazy += tree[pos].lazy;
59             }
60             tree[pos].lazy = 0;
61         }
62     }
63
64     Node st_build(const int l, const int r, const vector<int> &arr,
65         const int pos) {
66         if (l == r)
67             return tree[pos] = Node(arr[l], 0);
68
69         int mid = (l + r) / 2;
70         return tree[pos] = merge_nodes(st_build(l, mid, arr, 2 * pos + 1),
71             st_build(mid + 1, r, arr, 2 * pos + 2));
72     }
73
74     int st_get_first(const int l, const int r, const int v, const int pos) {
75         st_propagate(l, r, pos);

```



```

76 // Needs RMQ MAX
77 // Replace to <= for greater or equal or (with RMQ MIN) > for smaller or
78 // equal or >= for smaller
79 if (tree[pos].val < v)
80     return -1;
81
82
83 if (l == r)
84     return l;
85
86 int mid = (l + r) / 2;
87 int aux = st_get_first(l, mid, v, 2 * pos + 1);
88 if (aux != -1)
89     return aux;
90 return st_get_first(mid + 1, r, v, 2 * pos + 2);
91 }
92
93 Node st_query(const int l, const int r, const int i, const int j,
94             const int pos) {
95     st_propagate(l, r, pos);
96
97     if (l > r || l > j || r < i)
98         return NEUTRAL_NODE;
99
100     if (i <= l && r <= j)
101         return tree[pos];
102
103     int mid = (l + r) / 2;
104     return merge_nodes(st_query(l, mid, i, j, 2 * pos + 1),
105                       st_query(mid + 1, r, i, j, 2 * pos + 2));
106 }
107
108 // it adds a number delta to the range from i to j
109 Node st_update(const int l, const int r, const int i, const int j,
110              const int delta, const int pos) {
111     st_propagate(l, r, pos);
112
113     if (l > r || l > j || r < i)
114         return tree[pos];
115
116     if (i <= l && r <= j) {
117         tree[pos].lazy = delta;
118         st_propagate(l, r, pos);
119         return tree[pos];
120     }
121
122     int mid = (l + r) / 2;
123     return tree[pos] =
124         merge_nodes(st_update(l, mid, i, j, delta, 2 * pos + 1),
125                   st_update(mid + 1, r, i, j, delta, 2 * pos + 2));
126 }
127
128 void build(const vector<int> &arr) {
129     this->n = arr.size();
130     this->tree.resize(4 * this->n);
131     this->st_build(0, this->n - 1, arr, 0);
132 }
133
134 public:
135     /// N equals to -1 means the Segment Tree hasn't been created yet.
136     Seg_Tree() : n(-1) {}
137
138     /// Constructor responsible initialize a tree with 0.
139     ///
140     /// Time Complexity O(n)

```

```

141 Seg_Tree(const int n) : n(n) { this->tree.resize(4 * this->n, Node(0, 0));
142 }
143
144 /// Constructor responsible for building the initial tree based on a
145 vector.
146 ///
147 /// Time Complexity O(n)
148 Seg_Tree(const vector<int> &arr) { this->build(arr); }
149
150 /// Returns the first index from left to right.
151 /// Uncomment the line in the original funtion to get the proper element
152 that
153 /// may be: GREATER OR EQUAL, GREATER, SMALLER OR EQUAL, SMALLER.
154 ///
155 int get_first(const int v) {
156     assert(this->n >= 0);
157     return this->st_get_first(0, this->n - 1, v, 0);
158 }
159
160 /// Update at a single index.
161 ///
162 /// Time Complexity O(log n)
163 void update(const int idx, const int delta) {
164     assert(this->n >= 0);
165     assert(0 <= idx), assert(idx < this->n);
166     this->st_update(0, this->n - 1, idx, idx, delta, 0);
167 }
168
169 /// Range update from l to r.
170 ///
171 /// Time Complexity O(log n)
172 void update(const int l, const int r, const int delta) {
173     assert(this->n >= 0);
174     assert(0 <= l), assert(l <= r), assert(r < this->n);
175     this->st_update(0, this->n - 1, l, r, delta, 0);
176 }
177
178 /// Query at a single index.
179 ///
180 /// Time Complexity O(log n)
181 int query(const int idx) {
182     assert(this->n >= 0);
183     assert(0 <= idx), assert(idx < this->n);
184     return this->st_query(0, this->n - 1, idx, idx, 0).val;
185 }
186
187 /// Range query from l to r.
188 ///
189 /// Time Complexity O(log n)
190 int query(const int l, const int r) {
191     assert(this->n >= 0);
192     assert(0 <= l), assert(l <= r), assert(r < this->n);
193     return this->st_query(0, this->n - 1, l, r, 0).val;
194 }
195 };

```

2.12. Segment Tree 2D

```

1 // REQUIRES segment_tree.cpp!!
2 class Seg_Tree_2d {
3 private:
4     // // range sum
5     // int NEUTRAL_VALUE = 0;

```

```

6 // int merge_nodes(const int &x, const int &y) {
7 //     return x + y;
8 // }
9
10 // // RMQ max
11 // int NEUTRAL_VALUE = -INF;
12 // int merge_nodes(const int &x, const int &y) {
13 //     return max(x, y);
14 // }
15
16 // // RMQ min
17 // int NEUTRAL_VALUE = INF;
18 // int merge_nodes(const int &x, const int &y) {
19 //     return min(x, y);
20 // }
21
22 private:
23     int n, m;
24
25 public:
26     vector<Seg_Tree> tree;
27
28 private:
29     void st_build(const int l, const int r, const int pos, const
        vector<vector<int>> &mat) {
30         if(l == r)
31             tree[pos] = Seg_Tree(mat[l]);
32         else {
33             int mid = (l + r) / 2;
34             st_build(l, mid, 2*pos + 1, mat);
35             st_build(mid + 1, r, 2*pos + 2, mat);
36             for(int i = 0; i < tree[2*pos + 1].tree.size(); i++)
37                 tree[pos].tree[i].val = merge_nodes(tree[2*pos + 1].tree[i].val,
38                                                         tree[2*pos + 2].tree[i].val);
39         }
40     }
41
42     int st_query(const int l, const int r, const int x1, const int y1, const
        int x2, const int y2, const int pos) {
43         if(l > x2 || r < x1)
44             return NEUTRAL_VALUE;
45
46         if(x1 <= l && r <= x2)
47             return tree[pos].query(y1, y2);
48
49         int mid = (l + r) / 2;
50         return merge_nodes(st_query(l, mid, x1, y1, x2, y2, 2*pos + 1),
51                             st_query(mid + 1, r, x1, y1, x2, y2, 2*pos + 2));
52     }
53
54     void st_update(const int l, const int r, const int x, const int y, const
        int delta, const int pos) {
55         if(l > x || r < x)
56             return;
57
58         // Only supports point updates.
59         if(l == r) {
60             tree[pos].update(y, delta);
61             return;
62         }
63
64         int mid = (l + r) / 2;
65         st_update(l, mid, x, y, delta, 2*pos + 1);
66         st_update(mid + 1, r, x, y, delta, 2*pos + 2);
67         tree[pos].update(y, delta);

```

```

68     }
69
70 public:
71     Seg_Tree_2d() {
72         this->n = -1;
73         this->m = -1;
74     }
75
76     Seg_Tree_2d(const int n, const int m) {
77         this->n = n;
78         this->m = m;
79         // MAY TLE IN BUILD, TEST IT OR UPDATE EACH NODE MANUALLY!
80         assert(m < 10000);
81         tree.resize(4 * n, Seg_Tree(m));
82     }
83
84     Seg_Tree_2d(const int n, const int m, const vector<vector<int>> &mat) {
85         this->n = n;
86         this->m = m;
87         // MAY TLE IN BUILD, TEST IT OR UPDATE EACH NODE MANUALLY!
88         assert(m < 10000);
89         tree.resize(4 * n, Seg_Tree(m));
90         st_build(0, n - 1, 0, mat);
91     }
92
93     // Query from (x1, y1) to (x2, y2).
94     //
95     // Time complexity: O((log n) * (log m))
96     int query(const int x1, const int y1, const int x2, const int y2) {
97         assert(this->n > -1);
98         assert(0 <= x1); assert(x1 <= x2); assert(x2 < this->n);
99         assert(0 <= y1); assert(y1 <= y2); assert(y2 < this->n);
100         return st_query(0, this->n - 1, x1, y1, x2, y2, 0);
101     }
102
103     // Point updates on position (x, y).
104     //
105     // Time complexity: O((log n) * (log m))
106     void update(const int x, const int y, const int delta) {
107         assert(0 <= x); assert(x < this->n);
108         assert(0 <= y); assert(y < this->n);
109         st_update(0, this->n - 1, x, y, delta, 0);
110     }
111 };

```

2.13. Segment Tree Polynomial

```

1 // Works for the polynomial f(x) = z1*x + z0
2 class Seg_Tree {
3 public:
4     struct Node {
5         int val, z1, z0;
6
7         Node() {}
8         Node(const int val, const int z1, const int z0)
9             : val(val), z1(z1), z0(z0) {}
10    };
11
12 private:
13     // range sum
14     Node NEUTRAL_NODE = Node(0, 0, 0);
15     Node merge_nodes(const Node &x, const Node &y) {
16         return Node(x.val + y.val, 0, 0);
17    }

```

```

18 void apply_lazy(const int l, const int r, const int pos) {
19     tree[pos].val += (r - l + 1) * tree[pos].z0;
20     tree[pos].val += (r - l) * (r - l + 1) / 2 * tree[pos].z1;
21 }
22
23 private:
24     int n;
25
26 public:
27     vector<Node> tree;
28
29 private:
30     void st_propagate(const int l, const int r, const int pos) {
31         if (tree[pos].z0 != 0 || tree[pos].z1 != 0) {
32             apply_lazy(l, r, pos);
33             int mid = (l + r) / 2;
34             int sz_left = mid - l + 1;
35             if (l != r) {
36                 tree[2 * pos + 1].z0 += tree[pos].z0;
37                 tree[2 * pos + 1].z1 += tree[pos].z1;
38
39                 tree[2 * pos + 2].z0 += tree[pos].z0 + sz_left * tree[pos].z1;
40                 tree[2 * pos + 2].z1 += tree[pos].z1;
41             }
42             tree[pos].z0 = 0;
43             tree[pos].z1 = 0;
44         }
45     }
46
47     Node st_build(const int l, const int r, const vector<int> &arr,
48                 const int pos) {
49         if (l == r)
50             return tree[pos] = Node(arr[l], 0, 0);
51
52         int mid = (l + r) / 2;
53         return tree[pos] = merge_nodes(st_build(l, mid, arr, 2 * pos + 1),
54                                       st_build(mid + 1, r, arr, 2 * pos + 2));
55     }
56
57     Node st_query(const int l, const int r, const int i, const int j,
58                 const int pos) {
59         st_propagate(l, r, pos);
60
61         if (l > r || l > j || r < i)
62             return NEUTRAL_NODE;
63
64         if (i <= l && r <= j)
65             return tree[pos];
66
67         int mid = (l + r) / 2;
68         return merge_nodes(st_query(l, mid, i, j, 2 * pos + 1),
69                           st_query(mid + 1, r, i, j, 2 * pos + 2));
70     }
71
72     // it adds a number delta to the range from i to j
73     Node st_update(const int l, const int r, const int i, const int j,
74                  const int z1, const int z0, const int pos) {
75         st_propagate(l, r, pos);
76
77         if (l > r || l > j || r < i)
78             return tree[pos];
79
80         if (i <= l && r <= j) {
81             tree[pos].z0 = (l - i + 1) * z0;
82             tree[pos].z1 = z1;

```

```

83         st_propagate(l, r, pos);
84         return tree[pos];
85     }
86
87     int mid = (l + r) / 2;
88     return tree[pos] =
89         merge_nodes(st_update(l, mid, i, j, z1, z0, 2 * pos + 1),
90                   st_update(mid + 1, r, i, j, z1, z0, 2 * pos + 2));
91 }
92
93 public:
94     Seg_Tree() : n(-1) {}
95
96     Seg_Tree(const int n) : n(n) { this->tree.resize(4 * this->n, Node(0, 0)); }
97
98     Seg_Tree(const vector<int> &arr) { this->build(arr); }
99
100     void build(const vector<int> &arr) {
101         this->n = arr.size();
102         this->tree.resize(4 * this->n);
103         this->st_build(0, this->n - 1, arr, 0);
104     }
105
106     /// Index update of a polynomial  $f(x) = z1*x + z0$ 
107     ///
108     /// Time Complexity  $O(\log n)$ 
109     void update(const int i, const int z1, const int z0) {
110         assert(this->n >= 0);
111         assert(0 <= i), assert(i < this->n);
112         this->st_update(0, this->n - 1, i, i, z1, z0, 0);
113     }
114
115     /// Range update of a polynomial  $f(x) = z1*x + z0$  from l to r
116     ///
117     /// Time Complexity  $O(\log n)$ 
118     void update(const int l, const int r, const int z1, const int z0) {
119         assert(this->n >= 0);
120         assert(0 <= l), assert(l <= r), assert(r < this->n);
121         this->st_update(0, this->n - 1, l, r, z1, z0, 0);
122     }
123
124     /// Range sum query from l to r
125     ///
126     /// Time Complexity  $O(\log n)$ 
127     int query(const int l, const int r) {
128         assert(this->n >= 0);
129         assert(0 <= l), assert(l <= r), assert(r < this->n);
130         return this->st_query(0, this->n - 1, l, r, 0).val;
131     }
132 };

```

2.14. Sparse Table

```

1 // RMQ min implementation
2 class Sparse_Table {
3 private:
4     int n;
5     vector<vector<int>> > table;
6     vector<int> lg;
7
8     /// lg[i] represents the log2(i)
9     void build_log_array() {
10         lg.resize(this->n + 1);

```

```

11     for(int i = 2; i <= this->n; i++)
12         lg[i] = lg[i/2] + 1;
13 }
14
15 /// Time Complexity: O(n*log(n))
16 /// Space Complexity: O(n*log(n))
17 void build_sparse_table(const vector<int> &arr) {
18     table.resize(lg[this->n] + 1, vector<int>(this->n));
19
20     table[0] = arr;
21     int pow2 = 1;
22
23     for(int i = 1; i < table.size(); i++) {
24         int lastsz = this->n - pow2 + 1;
25         for(int j = 0; j + pow2 < lastsz; j++) {
26             table[i][j] = merge(table[i-1][j], table[i-1][j+pow2]);
27         }
28         pow2 <= 1;
29     }
30 }
31
32 int merge(const int &l, const int &r) {
33     return min(l, r);
34 }
35
36 public:
37 Sparse_Table(const vector<int> &arr) {
38     this->n = arr.size();
39
40     this->build_log_array();
41     this->build_sparse_table(arr);
42 }
43
44 void print() {
45     int pow2 = 1;
46     for(int i = 0; i < table.size(); i++) {
47         int sz = (int)(table.front().size()) - pow2 + 1;
48         for(int j = 0; j < sz; j++) {
49             cout << table[i][j] << " \n"[(j+1) == sz];
50         }
51         pow2 <= 1;
52     }
53 }
54
55 /// Query of a range from l to r.
56 ///
57 /// Time Complexity: O(1)
58 /// Space Complexity: O(1)
59 int query(int l, int r) {
60     assert(l <= r);
61     assert(0 <= l && r <= this->n - 1);
62
63     int lgg = lg[(r - l + 1)];
64     return merge(table[lgg][l], table[lgg][r - (1 << lgg) + 1]);
65 }
66 };

```

3. Dp

3.1. Achar Maior Palindromo

1 Fazer LCS da string com o reverso

3.2. Digit Dp

```

1 /// How many numbers x are there in the range a to b, where the digit d
2   occurs exactly k times in x?
3 vector<int> num;
4 int a, b, d, k;
5 int DP[12][12][2];
6 /// DP[p][c][f] = Number of valid numbers <= b from this state
7 /// p = current position from left side (zero based)
8 /// c = number of times we have placed the digit d so far
9 /// f = the number we are building has already become smaller than b? [0 =
10    no, 1 = yes]
11
12 int call(int pos, int cnt, int f){
13     if(cnt > k) return 0;
14
15     if(pos == num.size()){
16         if(cnt == k) return 1;
17         return 0;
18     }
19
20     if(DP[pos][cnt][f] != -1) return DP[pos][cnt][f];
21     int res = 0;
22     int lim = (f ? 9 : num[pos]);
23
24     /// Try to place all the valid digits such that the number doesn't exceed b
25     for(int dgt = 0; dgt <= LMT; dgt++){
26         int nf = f;
27         int ncnt = cnt;
28         if(f == 0 && dgt < LMT) nf = 1; /// The number is getting smaller at
29         this position
30         if(dgt == d) ncnt++;
31         if(ncnt <= k) res += call(pos+1, ncnt, nf);
32     }
33
34     return DP[pos][cnt][f] = res;
35 }
36
37 int solve(int b){
38     num.clear();
39     while(b>0){
40         num.push_back(b%10);
41         b/=10;
42     }
43     reverse(num.begin(), num.end());
44     /// Stored all the digits of b in num for simplicity
45
46     memset(DP, -1, sizeof(DP));
47     int res = call(0, 0, 0);
48     return res;
49 }
50
51 int main () {
52     cin >> a >> b >> d >> k;
53     int res = solve(b) - solve(a-1);
54     cout << res << endl;
55
56     return 0;
57 }

```

3.3. Longest Common Subsequence

```

1 string lcs(string &s, string &t) {
2
3     int n = s.size(), m = t.size();
4
5     s.insert(s.begin(), '#');
6     t.insert(t.begin(), '$');
7
8     vector<vector<int>>> mat(n + 1, vector<int>(m + 1, 0));
9
10    for(int i = 1; i <= n; i++) {
11        for(int j = 1; j <= m; j++) {
12            if(s[i] == t[j])
13                mat[i][j] = mat[i - 1][j - 1] + 1;
14            else
15                mat[i][j] = max(mat[i - 1][j], mat[i][j - 1]);
16        }
17    }
18
19    string ans;
20    int i = n, j = m;
21    while(i > 0 && j > 0) {
22        if(s[i] == t[j])
23            ans += s[i], i--, j--;
24        else if(mat[i][j - 1] > mat[i - 1][j])
25            j--;
26        else
27            i--;
28    }
29
30    reverse(ans.begin(), ans.end());
31    return ans;
32 }

```

3.4. Longest Common Substring

```

1 int LCSuff(char *X, char *Y, int m, int n) {
2     // Create a table to store lengths of longest common suffixes of
3     // substrings. Notethat LCSuff[i][j] contains length of longest
4     // common suffix of X[0..i-1] and Y[0..j-1]. The first row and
5     // first column entries have no logical meaning, they are used only
6     // for simplicity of program
7     int LCSuff[m+1][n+1];
8     int result = 0; // To store length of the longest common substring
9
10    /* Following steps build LCSuff[m+1][n+1] in bottom up fashion. */
11    for (int i=0; i<=m; i++) {
12        for (int j=0; j<=n; j++) {
13            if (i == 0 || j == 0)
14                LCSuff[i][j] = 0;
15
16            else if (X[i-1] == Y[j-1]) {
17                LCSuff[i][j] = LCSuff[i-1][j-1] + 1;
18                result = max(result, LCSuff[i][j]);
19            }
20            else LCSuff[i][j] = 0;
21        }
22    }
23    return result;
24 }

```

3.5. Longest Increasing Subsequence 2D (Not Sorted)

```

1 set<ii> s[(int)2e6];
2 bool check(ii par, int ind) {
3
4     auto it = s[ind].lower_bound(ii(par.ff, -INF));
5     if(it == s[ind].begin())
6         return false;
7
8     it--;
9
10    if(it->ss < par.ss)
11        return true;
12    return false;
13 }
14
15 int lis2d(vector<ii> &arr) {
16
17     int n = arr.size();
18     s[1].insert(arr[0]);
19
20     int maior = 1;
21     for(int i = 1; i < n; i++) {
22
23         ii x = arr[i];
24
25         int l = 1, r = maior;
26         int ansbb = 0;
27         while(l <= r) {
28             int mid = (l+r)/2;
29             if(check(x, mid)) {
30                 l = mid + 1;
31                 ansbb = mid;
32             } else {
33                 r = mid - 1;
34             }
35         }
36
37         // inserting in list
38         auto it = s[ansbb+1].lower_bound(ii(x.ff, -INF));
39         while(it != s[ansbb+1].end() && it->ss >= x.ss)
40             it = s[ansbb+1].erase(it);
41
42         it = s[ansbb+1].lower_bound(ii(x.ff, -INF));
43         if(s[ansbb+1].size() > 0 && it != s[ansbb+1].end() && it->ff == x.ff &&
44            it->ss <= x.ss)
45             continue;
46         s[ansbb+1].insert(arr[i]);
47
48         maior = max(maior, ansbb + 1);
49     }
50
51     return maior;
52 }

```

3.6. Longest Increasing Subsequence 2D (Sorted)

```

1 set<ii> s[(int)2e6];
2 bool check(ii par, int ind) {
3
4     auto it = s[ind].lower_bound(ii(par.ff, -INF));
5     if(it == s[ind].begin())
6         return false;

```

```

7   it--;
8
9   if(it->ss < par.ss)
10      return true;
11   return false;
12 }
13
14 int lis2d(vector<ii> &arr) {
15
16   int n = arr.size();
17   s[1].insert(arr[0]);
18
19   int maior = 1;
20   for(int i = 1; i < n; i++) {
21
22     ii x = arr[i];
23
24     int l = 1, r = maior;
25     int ansbb = 0;
26     while(l <= r) {
27       int mid = (l+r)/2;
28       if(check(x, mid)) {
29         l = mid + 1;
30         ansbb = mid;
31       } else {
32         r = mid - 1;
33       }
34     }
35
36     // inserting in list
37     auto it = s[ansbb+1].lower_bound(ii(x.ff, -INF));
38     while(it != s[ansbb+1].end() && it->ss >= x.ss)
39       it = s[ansbb+1].erase(it);
40
41     it = s[ansbb+1].lower_bound(ii(x.ff, -INF));
42     if(s[ansbb+1].size() > 0 && it != s[ansbb+1].end() && it->ff == x.ff &&
43        it->ss <= x.ss)
44       continue;
45     s[ansbb+1].insert(arr[i]);
46
47     maior = max(maior, ansbb + 1);
48   }
49
50   return maior;
51 }
52

```

3.7. Longest Increasing Subsequence

```

1  int lis(vector<int> &arr){
2    int n = arr.size();
3    vector<int> lis;
4    for(int i = 0; i < n; i++){
5      int l = 0, r = (int)lis.size() - 1;
6      int ansj = -1;
7      while(l <= r){
8        int mid = (l+r)/2;
9        // OBS: PARA >= TROCAR SINAL EMBAIXO POR <=
10       if(arr[i] < lis[mid]){
11         r = mid - 1;
12         ansj = mid;
13       }
14       else l = mid + 1;

```

```

15   }
16   if(ansj == -1){
17     // se arr[i] e maior que todos
18     lis.push_back(arr[i]);
19   }
20   else {
21     lis[ansj] = arr[i];
22   }
23 }
24
25 return lis.size();
26 }

```

3.8. Subset Sum Com Bitset

```

1  bitset<312345> bit;
2  int arr[112345];
3  void subsetSum(int n) {
4    bit.reset();
5    bit.set(0);
6    for(int i = 0; i < n; i++) {
7      bit |= (bit << arr[i]);
8    }
9  }

```

3.9. Catalan

$$C_n = \frac{1}{n+1} \binom{2n}{n} = \frac{(2n)!}{(n+1)!n!} = \prod_{k=2}^n \frac{n+k}{k} \quad \text{para } n \geq 0.$$

3.10. Catalan

```

1  // The first few Catalan numbers for n = 0, 1, 2, 3, ...
2  // are 1, 1, 2, 5, 14, 42, 132, 429, 1430, 4862, ...
3  // Formula Recursiva:
4  // cat(0) = 0
5  // cat(n+1) = somatorio(i from 0 to n) (cat(i)*cat(n-i))
6  //
7  // Using Binomial Coefficient
8  // We can also use the below formula to find nth catalan number in O(n) time.
9  // Formula acima
10
11 // Returns value of Binomial Coefficient C(n, k)
12
13 int binomialCoeff(int n, int k) {
14   int res = 1;
15
16   // Since C(n, k) = C(n, n-k)
17   if (k > n - k)
18     k = n - k;
19
20   // Calculate value of [n*(n-1)*---*(n-k+1)] / [k*(k-1)*---*1]
21   for (int i = 0; i < k; ++i) {
22     res *= (n - i);
23     res /= (i + 1);
24   }
25 }

```

```

26     return res;
27 }
28 // A Binomial coefficient based function to find nth catalan
29 // number in O(n) time
30 int catalan(int n) {
31     // Calculate value of 2nCn
32     int c = binomialCoeff(2*n, n);
33
34     // return 2nCn/(n+1)
35     return c/(n+1);
36 }

```

3.11. Coin Change Problem

```

1 // função que recebe o valor de troco N, o número de moedas disponíveis M,
2 // e um vetor com as moedas disponíveis arr
3 // essa função deve retornar o número mínimo de moedas,
4 // de acordo com a solução com Programação Dinâmica.
5 int num_moedas(int N, int M, int arr[]) {
6     int dp[N+1];
7     // caso base
8     dp[0] = 0;
9     // sub-problemas
10    for(int i=1; i<=N; i++) {
11        // é comum atribuir um valor alto, que concerteza
12        // é maior que qualquer uma das próximas possibilidades,
13        // sendo assim substituído
14        dp[i] = 1000000;
15        for(int j=0; j<M; j++) {
16            if(i-arr[j] >= 0) {
17                dp[i] = min(dp[i], dp[i-arr[j]]+1);
18            }
19        }
20    }
21    // solução
22    return dp[N];
23 }

```

3.12. Knapsack

```

1 int dp[2001][2001];
2 int moc(int q,int p,vector<ii> vec) {
3     for(int i = 1; i <= q; i++)
4     {
5         for(int j = 1; j <= p; j++) {
6             if(j >= vec[i-1].ff)
7                 dp[i][j] = max(dp[i-1][j],vec[i-1].ss + dp[i-1][j-vec[i-1].ff]);
8             else
9                 dp[i][j] = dp[i-1][j];
10        }
11    }
12    return dp[q][p];
13 }
14 int main(int argc, char *argv[])
15 {
16     int p,q;
17     vector<ii> vec;
18     cin >> p >> q;
19     int x,y;
20     for(int i = 0; i < q; i++) {
21         cin >> x >> y;
22         vec.push_back(make_pair(x,y));
23     }

```

```

24     for(int i = 0; i <= p; i++)
25         dp[0][i] = 0;
26     for(int i = 1; i <= q; i++)
27         dp[i][0] = 0;
28     sort(vec.begin(),vec.end());
29     cout << moc(q,p,vec) << endl;
30 }

```

4. Geometry

4.1. Centro De Massa De Um Poligono

```

1 double area = 0;
2 pto c;
3
4 c.x = c.y = 0;
5 for(int i = 0; i < n ; i++) {
6     double aux = (arr[i].x * arr[i+1].y) - (arr[i].y * arr[i+1].x); // shoelace
7     area += aux;
8     c.x += aux*(arr[i].x + arr[i+1].x);
9     c.y += aux*(arr[i].y + arr[i+1].y);
10 }
11
12 c.x /= (3.0*area);
13 c.y /= (3.0*area);
14
15 cout << c.x << ' ' << c.y << endl;

```

4.2. Closest Pair Of Points

```

1 struct Point {
2     int x, y;
3 };
4 int compareX(const void *a,const void *b){
5     Point *p1 = (Point *)a, *p2 = (Point *)b;
6     return (p1->x - p2->x);
7 }
8 int compareY(const void *a,const void *b) {
9     Point *p1 = (Point *)a,*p2 = (Point *)b;
10    return (p1->y - p2->y);
11 }
12 float dist(Point p1, Point p2) {
13     return sqrt((p1.x- p2.x)*(p1.x- p2.x) +(p1.y - p2.y)*(p1.y - p2.y));
14 }
15 float bruteForce(Point P[], int n){
16     float min = FLT_MAX;
17     for (int i = 0; i < n; ++i)
18         for (int j = i+1; j < n; ++j)
19             if (dist(P[i], P[j]) < min)
20                 min = dist(P[i], P[j]);
21     return min;
22 }
23 float min(float x, float y) {
24     return (x < y)? x : y;
25 }
26 float stripClosest(Point strip[], int size, float d) {
27     float min = d;
28     for (int i = 0; i < size; ++i)
29         for (int j = i+1; j < size && (strip[j].y - strip[i].y) < min; ++j)
30             if (dist(strip[i],strip[j]) < min)
31                 min = dist(strip[i], strip[j]);
32     return min;
33 }

```

```

34 float closestUtil(Point Px[], Point Py[], int n){
35     if (n <= 3)
36         return bruteForce(Px, n);
37     int mid = n/2;
38     Point midPoint = Px[mid];
39     Point Pyl[mid+1];
40     Point Pyr[n-mid-1];
41     int li = 0, ri = 0;
42     for (int i = 0; i < n; i++)
43         if (Py[i].x <= midPoint.x)
44             Pyl[li++] = Py[i];
45         else
46             Pyr[ri++] = Py[i];
47
48     float dl = closestUtil(Px, Pyl, mid);
49     float dr = closestUtil(Px + mid, Pyr, n-mid);
50     float d = min(dl, dr);
51     Point strip[n];
52     int j = 0;
53     for (int i = 0; i < n; i++)
54         if (abs(Py[i].x - midPoint.x) < d)
55             strip[j] = Py[i], j++;
56     return min(d, stripClosest(strip, j, d));
57 }
58
59 float closest(Point P[], int n) {
60     Point Px[n];
61     Point Py[n];
62     for (int i = 0; i < n; i++) {
63         Px[i] = P[i];
64         Py[i] = P[i];
65     }
66     qsort(Px, n, sizeof(Point), compareX);
67     qsort(Py, n, sizeof(Point), compareY);
68     return closestUtil(Px, Py, n);
69 }

```

4.3. Condicao De Existencia De Um Triangulo

```

1
2     | b - c | < a < b + c
3     | a - c | < b < a + c
4     | a - b | < c < a + b
5
6 Para a < b < c, basta checar
7     a + b > c
8
9 OBS: Para um conjunto n >= 100 sempre existe um triângulo válido, pois a
    sequência de triângulos não válidos seguem a sequência de Fibonacci e
    Fib(100) > 2^64

```

4.4. Convex Hull

```

1 // Asymptotic complexity: O(n log n).
2 struct pto {
3     double x, y;
4     bool operator <(const pto &p) const {
5         return x < p.x || (x == p.x && y < p.y);
6         /* a impressao será em prioridade por mais a esquerda, mais
7            abaixo, e antihorário pelo cross abaixo */
8     }
9 };
10

```

```

11 double cross(const pto &O, const pto &A, const pto &B) {
12     return (A.x - O.x) * (B.y - O.y) - (A.y - O.y) * (B.x - O.x);
13 }
14
15 vector<pto> convex_hull(vector<pto> P) {
16     int n = P.size(), k = 0;
17     vector<pto> H(2 * n);
18     // Sort points lexicographically
19     sort(P.begin(), P.end());
20     // Build lower hull
21     for (int i = 0; i < n; ++i) {
22         // esse <= 0 representa sentido anti-horario, caso deseje mudar
23         // trocar por >= 0
24         while (k >= 2 && cross(H[k - 2], H[k - 1], P[i]) <= 0)
25             k--;
26         H[k++] = P[i];
27     }
28     // Build upper hull
29     for (int i = n - 2, t = k + 1; i >= 0; i--) {
30         // esse <= 0 representa sentido anti-horario, caso deseje mudar
31         // trocar por >= 0
32         while (k >= t && cross(H[k - 2], H[k - 1], P[i]) <= 0)
33             k--;
34         H[k++] = P[i];
35     }
36     H.resize(k);
37     /* o último ponto do vetor é igual ao primeiro, atente para isso
38        as vezes é necessário mudar */
39     return H;
40 }

```

4.5. Cross Product

```

1 // Outra forma de produto vetorial
2 // reta ab,ac se for zero e colinear
3 // se for < 0 entao antiHorario, > 0 horario
4 bool ehcol(pto a,pto b,pto c) {
5     return ((b.y-a.y)*(c.x-a.x) - (b.x-a.x)*(c.y-a.y));
6 }
7 -----
8 //Produto vetorial AB x AC, se for zero e colinear
9 int cross(pto A, pto B, pto C){
10     pto AB, AC;
11     AB.x = B.x-A.x;
12     AB.y = B.y-A.y;
13     AC.x = C.x-A.x;
14     AC.y = C.y-A.y;
15     int cross = AB.x*AC.y-AB.y * AC.x;
16     return cross;
17 }
18
19 // OBS: DEFINE ÁREA DE QUADRILÁTERO FORMADO PELAS RETAS, A ÁREA DO TRIÂNGULO
    É A METADE

```

4.6. Distance Point Segment

```

1 // use struct point and line
2 double dist_point_segment(const Point p, const Point s, const Point t) {
3     if (sgn(dot(p-s, t-s)) < 0)
4         return (p-s).norm();
5     if (sgn(dot(p-t, s-t)) < 0)
6         return (p-t).norm();
7     return abs(det(s-p, t-p) / dist(s, t));

```


8 }

41 }

4.7. Line-Line Intersection

```

1 // Intersecção de retas Ax + By = C   dados pontos (x1,y1) e (x2,y2)
2 A = y2-y1
3 B = x1-x2
4 C = A*x1+B*y1
5 //Retas definidas pelas equações:
6 A1x + B1y = C1
7 A2x + B2y = C2
8 //Encontrar x e y resolvendo o sistema
9 double det = A1*B2 - A2*B1;
10 if(det == 0){
11     //Lines are parallel
12 }else{
13     double x = (B2*C1 - B1*C2)/det;
14     double y = (A1*C2 - A2*C1)/det;
15 }

```

4.8. Line-Point Distance

```

1 double ptoReta(double x1, double y1, double x2, double y2, double pointX,
2     double pointY, double *ptox, double *ptoy){
3     double diffX = x2 - x1;
4     double diffY = y2 - y1;
5     if ((diffX == 0) && (diffY == 0)) {
6         diffX = pointX - x1;
7         diffY = pointY - y1;
8         //se os dois sao pontos
9         return hypot(pointX - x1, pointY - y1);
10    }
11    double t = ((pointX - x1) * diffX + (pointY - y1) * diffY) /
12              (diffX * diffX + diffY * diffY);
13    if (t < 0) {
14        //point is nearest to the first point i.e x1 and y1
15        // Ex:
16        // cord do pto na reta = pto inicial(x1,y1);
17        *ptox = x1, *ptoy = y1;
18        diffX = pointX - x1;
19        diffY = pointY - y1;
20    } else if (t > 1) {
21        //point is nearest to the end point i.e x2 and y2
22        // Ex :
23        // cord do pto na reta = pto final(x2,y2);
24        *ptox = x2, *ptoy = y2;
25        diffX = pointX - x2;
26        diffY = pointY - y2;
27    } else {
28        //if perpendicular line intersect the line segment.
29        // pto nao esta mais proximo de uma das bordas do segmento
30        // Ex:
31        // |
32        // | (Ângulo Reto)
33        // |
34        // cord x do pto na reta = (x1 + t * diffX)
35        // cord y do pto na reta = (y1 + t * diffY)
36        *ptox = (x1 + t * diffX), *ptoy = (y1 + t * diffY);
37        diffX = pointX - (x1 + t * diffX);
38        diffY = pointY - (y1 + t * diffY);
39    }
40    //returning shortest distance
41    return sqrt(diffX * diffX + diffY * diffY);

```

4.9. Point Inside Convex Polygon - Log(N)

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4
5 #define INF 1e18
6 #define pb push_back
7 #define ii pair<int,int>
8 #define OK cout<<"OK"<<endl
9 #define debug(x) cout << #x " = " << (x) << endl
10 #define ff first
11 #define ss second
12 #define int long long
13
14 struct pto {
15     double x, y;
16     bool operator <(const pto &p) const {
17         return x < p.x || (x == p.x && y < p.y);
18         /* a impressao será em prioridade por mais a esquerda, mais
19         abaixo, e antihorário pelo cross abaixo */
20     }
21 };
22 double cross(const pto &O, const pto &A, const pto &B) {
23     return (A.x - O.x) * (B.y - O.y) - (A.y - O.y) * (B.x - O.x);
24 }
25
26 vector<pto> lower, upper;
27
28 vector<pto> convex_hull(vector<pto> &P) {
29     int n = P.size(), k = 0;
30     vector<pto> H(2 * n);
31     // Sort points lexicographically
32     sort(P.begin(), P.end());
33     // Build lower hull
34     for (int i = 0; i < n; ++i) {
35         // esse <= 0 representa sentido anti-horario, caso deseje mudar
36         // trocar por >= 0
37         while (k >= 2 && cross(H[k - 2], H[k - 1], P[i]) <= 0)
38             k--;
39         H[k++] = P[i];
40     }
41     // Build upper hull
42     for (int i = n - 2, t = k + 1; i >= 0; i--) {
43         // esse <= 0 representa sentido anti-horario, caso deseje mudar
44         // trocar por >= 0
45         while (k >= t && cross(H[k - 2], H[k - 1], P[i]) <= 0)
46             k--;
47         H[k++] = P[i];
48     }
49     H.resize(k);
50     /* o último ponto do vetor é igual ao primeiro, atente para isso
51     as vezes é necessário mudar */
52
53     int j = 1;
54     lower.pb(H.front());
55     while(H[j].x >= H[j-1].x) {
56         lower.pb(H[j++]);
57     }
58
59     int l = H.size()-1;
60     while(l >= j) {

```

```

61     upper.pb(H[l--]);
62 }
63 upper.pb(H[l--]);
64
65 return H;
66 }
67
68 bool insidePolygon(pto p, vector<pto> &arr) {
69
70     if(pair<double,double>(p.x, p.y) == pair<double,double>(lower[0].x,
71         lower[0].y))
72         return true;
73
74     pto lo = {p.x, -(double)INF};
75     pto hi = {p.x, (double)INF};
76     auto itl = lower_bound(lower.begin(), lower.end(), lo);
77     auto itu = lower_bound(upper.begin(), upper.end(), lo);
78
79     if(itl == lower.begin() || itu == upper.end()) {
80         auto it = lower_bound(arr.begin(), arr.end(), lo);
81         auto it2 = lower_bound(arr.begin(), arr.end(), hi);
82         it2--;
83         if(it2 >= it && p.x == it->x && it->x == it2->x && it->y <= p.y && p.y
84             <= it2->y)
85             return true;
86         return false;
87     }
88
89     if(itl == lower.end() || itu == upper.end()) {
90         return false;
91     }
92
93     auto ol = itl, ou = itu;
94     ol--, ou--;
95     if(cross(*ol, *itl, p) >= 0 && cross(*ou, *itu, p) <= 0)
96         return true;
97
98     auto it = lower_bound(arr.begin(), arr.end(), lo);
99     auto it2 = lower_bound(arr.begin(), arr.end(), hi);
100     it2--;
101     if(it2 >= it && p.x == it->x && it->x == it2->x && it->y <= p.y && p.y <=
102         it2->y)
103         return true;
104     return false;
105 }
106
107 signed main () {
108
109     ios_base::sync_with_stdio(false);
110     cin.tie(NULL);
111
112     double n, m, k;
113
114     cin >> n >> m >> k;
115
116     vector<pto> arr(n);
117
118     for(pto &x: arr) {
119         cin >> x.x >> x.y;
120     }
121
122     convex_hull(arr);
123
124     pto p;

```

```

123
124     int c = 0;
125     while(m--) {
126         cin >> p.x >> p.y;
127         cout << (insidePolygon(p, arr) ? "dentro" : "fora") << endl;
128     }
129
130 }

```

4.10. Point Inside Polygon

```

1
2  /* Traça-se uma reta do ponto até um outro ponto qualquer fora do triangulo
3     e checa o número de interseção com a borda do polígono se este for ímpar
4     então está dentro se não está fora */
5
6  // Define Infinite (Using INT_MAX caused overflow problems)
7  #define INF 10000
8
9  struct pto {
10     int x, y;
11     pto() {}
12     pto(int x, int y) : x(x), y(y) {}
13 };
14
15 // Given three colinear ptos p, q, r, the function checks if
16 // pto q lies on line segment 'pr'
17 bool onSegment(pto p, pto q, pto r) {
18     if (q.x <= max(p.x, r.x) && q.x >= min(p.x, r.x) &&
19         q.y <= max(p.y, r.y) && q.y >= min(p.y, r.y))
20         return true;
21     return false;
22 }
23
24 // To find orientation of ordered triplet (p, q, r).
25 // The function returns following values
26 // 0 --> p, q and r are colinear
27 // 1 --> Clockwise
28 // 2 --> Counterclockwise
29 int orientation(pto p, pto q, pto r) {
30     int val = (q.y - p.y) * (r.x - q.x) -
31         (q.x - p.x) * (r.y - q.y);
32
33     if (val == 0) return 0; // colinear
34     return (val > 0) ? 1 : 2; // clock or counterclock wise
35 }
36
37 // The function that returns true if line segment 'p1q1'
38 // and 'p2q2' intersect.
39 bool doIntersect(pto p1, pto q1, pto p2, pto q2) {
40     // Find the four orientations needed for general and
41     // special cases
42     int o1 = orientation(p1, q1, p2);
43     int o2 = orientation(p1, q1, q2);
44     int o3 = orientation(p2, q2, p1);
45     int o4 = orientation(p2, q2, q1);
46
47     // General case
48     if (o1 != o2 && o3 != o4)
49         return true;
50
51     // Special Cases
52     // p1, q1 and p2 are colinear and p2 lies on segment p1q1
53     if (o1 == 0 && onSegment(p1, p2, q1)) return true;

```

```

52 // p1, q1 and p2 are colinear and q2 lies on segment plq1
53 if (o2 == 0 && onSegment(p1, q2, q1)) return true;
54
55 // p2, q2 and p1 are colinear and p1 lies on segment p2q2
56 if (o3 == 0 && onSegment(p2, p1, q2)) return true;
57
58 // p2, q2 and q1 are colinear and q1 lies on segment p2q2
59 if (o4 == 0 && onSegment(p2, q1, q2)) return true;
60
61 return false; // Doesn't fall in any of the above cases
62 }
63
64 // Returns true if the pto p lies inside the polygon[] with n vertices
65 bool isInside(pto polygon[], int n, pto p) {
66     // There must be at least 3 vertices in polygon[]
67     if (n < 3) return false;
68
69     // Create a pto for line segment from p to infinite
70     pto extreme = pto(INF, p.y);
71
72     // Count intersections of the above line with sides of polygon
73     int count = 0, i = 0;
74     do {
75         int next = (i+1)%n;
76
77         // Check if the line segment from 'p' to 'extreme' intersects
78         // with the line segment from 'polygon[i]' to 'polygon[next]'
79         if (doIntersect(polygon[i], polygon[next], p, extreme)) {
80             // If the pto 'p' is colinear with line segment 'i-next',
81             // then check if it lies on segment. If it lies, return true,
82             // otherwise false
83             if (orientation(polygon[i], p, polygon[next]) == 0)
84                 return onSegment(polygon[i], p, polygon[next]);
85
86             count++;
87         }
88         i = next;
89     } while (i != 0);
90
91     // Return true if count is odd, false otherwise
92     return count%2 == 1; // Same as (count%2 == 1)
93 }
94

```

4.11. Points Inside And In Boundary Polygon

```

1 int cross(pto a, pto b) {
2     return a.x * b.y - b.x * a.y;
3 }
4
5 int boundaryCount(pto a, pto b) {
6     if(a.x == b.x)
7         return abs(a.y-b.y)-1;
8     if(a.y == b.y)
9         return abs(a.x-b.x)-1;
10    return _gcd(abs(a.x-b.x), abs(a.y-b.y))-1;
11 }
12
13 int totalBoundaryPolygon(vector<pto> &arr, int n) {
14
15     int boundPoint = n;
16     for(int i = 0; i < n; i++) {
17         boundPoint += boundaryCount(arr[i], arr[(i+1)%n]);
18     }
19

```

```

19     return boundPoint;
20 }
21
22 int polygonArea2(vector<pto> &arr, int n) {
23     int area = 0;
24     // N = quantidade de pontos no polígono e armazenados em p;
25     // OBS: VALE PARA CONVEXO E NÃO CONVEXO
26     for(int i = 0; i < n; i++){
27         area += cross(arr[i], arr[(i+1)%n]);
28     }
29     return abs(area);
30 }
31
32 int internalCount(vector<pto> &arr, int n) {
33
34     int area_2 = polygonArea2(arr, n);
35     int boundPoints = totalBoundaryPolygon(arr,n);
36     return (area_2 - boundPoints + 2)/2;
37 }

```

4.12. Polygon Area (3D)

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4
5 struct point{
6     double x,y,z;
7     void operator=(const point & b){
8         x = b.x;
9         y = b.y;
10        z = b.z;
11    }
12 };
13
14 point cross(point a, point b){
15     point ret;
16     ret.x = a.y*b.z - b.y*a.z;
17     ret.y = a.z*b.x - a.x*b.z;
18     ret.z = a.x*b.y - a.y*b.x;
19     return ret;
20 }
21
22 int main(){
23     int num;
24     cin >> num;
25     point v[num];
26     for(int i=0; i<num; i++) cin >> v[i].x >> v[i].y >> v[i].z;
27
28     point cur;
29     cur.x = 0, cur.y = 0, cur.z = 0;
30
31     for(int i=0; i<num; i++){
32         point res = cross(v[i], v[(i+1)%num]);
33         cur.x += res.x;
34         cur.y += res.y;
35         cur.z += res.z;
36     }
37
38     double ans = sqrt(cur.x*cur.x + cur.y*cur.y + cur.z*cur.z);
39
40     double area = abs(ans);
41
42     cout << fixed << setprecision(9) << area/2. << endl;

```

43

4.13. Polygon Area

```

1 double polygonArea(vector<pto> &arr, int n) {
2     int area = 0;
3     // N = quantidade de pontos no polígono e armazenados em p;
4     // OBS: VALE PARA CONVEXO E NÃO CONVEXO
5     for(int i = 0; i < n; i++){
6         area += cross(arr[i], arr[(i+1)%n]);
7     }
8     return (double)abs(area/2.0);
9 }
10

```

4.14. Segment-Segment Intersection

```

1 // Given three colinear points p, q, r, the function checks if
2 // point q lies on line segment 'pr'
3 int onSegment(Point p, Point q, Point r) {
4     if (q.x <= max(p.x, r.x) && q.x >= min(p.x, r.x) && q.y <= max(p.y, r.y)
5         && q.y >= min(p.y, r.y))
6         return true;
7     return false;
8 }
9 /* PODE SER RETIRADO
10 int onSegmentNotBorda(Point p, Point q, Point r) {
11     if (q.x < max(p.x, r.x) && q.x > min(p.x, r.x) && q.y <= max(p.y, r.y)
12         && q.y > min(p.y, r.y))
13         return true;
14     if (q.x <= max(p.x, r.x) && q.x >= min(p.x, r.x) && q.y < max(p.y, r.y)
15         && q.y > min(p.y, r.y))
16         return true;
17     return false;
18 }
19 */
20 // To find orientation of ordered triplet (p, q, r).
21 // The function returns following values
22 // 0 --> p, q and r are colinear
23 // 1 --> Clockwise
24 // 2 --> Counterclockwise
25 int orientation(Point p, Point q, Point r) {
26     int val = (q.y - p.y) * (r.x - q.x) -
27             (q.x - p.x) * (r.y - q.y);
28     if (val == 0) return 0; // colinear
29     return (val > 0) ? 1 : 2; // clock or counterclock wise
30 }
31 // The main function that returns true if line segment 'p1p2'
32 // and 'q1q2' intersect.
33 int doIntersect(Point p1, Point p2, Point q1, Point q2) {
34     // Find the four orientations needed for general and
35     // special cases
36     int o1 = orientation(p1, p2, q1);
37     int o2 = orientation(p1, p2, q2);
38     int o3 = orientation(q1, q2, p1);
39     int o4 = orientation(q1, q2, p2);
40
41     // General case
42     if (o1 != o2 && o3 != o4) return 2;
43
44     /* PODE SER RETIRADO
45     if(o1 == o2 && o2 == o3 && o3 == o4 && o4 == 0) {
46         //INTERCEPTAM EM RETA

```

```

44     if(onSegmentNotBorda(p1,q1,p2) || onSegmentNotBorda(p1,q2,p2)) return 1;
45     if(onSegmentNotBorda(q1,p1,q2) || onSegmentNotBorda(q1,p2,q2)) return 1;
46 }
47 */
48 // Special Cases (INTERCEPTAM EM PONTO)
49 // p1, p2 and q1 are colinear and q1 lies on segment p1p2
50 if (o1 == 0 && onSegment(p1, q1, p2)) return 2;
51 // p1, p2 and q1 are colinear and q2 lies on segment p1p2
52 if (o2 == 0 && onSegment(p1, q2, p2)) return 2;
53 // q1, q2 and p1 are colinear and p1 lies on segment q1q2
54 if (o3 == 0 && onSegment(q1, p1, q2)) return 2;
55 // q1, q2 and p2 are colinear and p2 lies on segment q1q2
56 if (o4 == 0 && onSegment(q1, p2, q2)) return 2;
57 return false; // Doesn't fall in any of the above cases
58 }
59 // OBS: SE (C2/A2 == C1/A1) SÃO COLINEARES

```

4.15. Upper And Lower Hull

```

1 struct pto {
2     double x, y;
3     bool operator <(const pto &p) const {
4         return x < p.x || (x == p.x && y < p.y);
5         /* a impressao será em prioridade por mais a esquerda, mais
6            abaixo, e anti-horário pelo cross abaixo */
7     }
8 };
9 double cross(const pto &O, const pto &A, const pto &B) {
10     return (A.x - O.x) * (B.y - O.y) - (A.y - O.y) * (B.x - O.x);
11 }
12
13 vector<pto> lower, upper;
14
15 vector<pto> convex_hull(vector<pto> &P) {
16     int n = P.size(), k = 0;
17     vector<pto> H(2 * n);
18     // Sort points lexicographically
19     sort(P.begin(), P.end());
20     // Build lower hull
21     for (int i = 0; i < n; ++i) {
22         // esse <= 0 representa sentido anti-horario, caso deseje mudar
23         // trocar por >= 0
24         while (k >= 2 && cross(H[k - 2], H[k - 1], P[i]) <= 0)
25             k--;
26         H[k++] = P[i];
27     }
28     // Build upper hull
29     for (int i = n - 2; i >= 0; i--) {
30         // esse <= 0 representa sentido anti-horario, caso deseje mudar
31         // trocar por >= 0
32         while (k >= t && cross(H[k - 2], H[k - 1], P[i]) <= 0)
33             k--;
34         H[k++] = P[i];
35     }
36     H.resize(k);
37     /* o último ponto do vetor é igual ao primeiro, atente para isso
38        as vezes é necessário mudar */
39
40     int j = 1;
41     lower.pb(H.front());
42     while(H[j].x >= H[j-1].x) {
43         lower.pb(H[j++]);
44     }
45

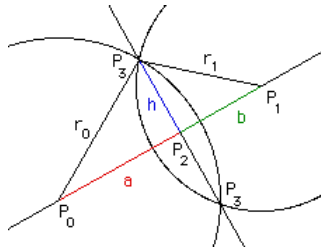
```

```

46 int l = H.size()-1;
47 while(l >= j) {
48     upper.pb(H[l--]);
49 }
50 upper.pb(H[l--]);
51
52 return H;
53 }

```

4.16. Circle Circle Intersection



4.17. Circle Circle Intersection

```

1  /* circle_circle_intersection() *
2  * Determine the points where 2 circles in a common plane intersect.
3  *
4  * int circle_circle_intersection(
5  *     // center and radius of 1st circle
6  *     double x0, double y0, double r0,
7  *     // center and radius of 2nd circle
8  *     double x1, double y1, double r1,
9  *     // 1st intersection point
10 *     double *xi, double *yi,
11 *     // 2nd intersection point
12 *     double *xi_prime, double *yi_prime)
13 *
14 * This is a public domain work. 3/26/2005 Tim Voght
15 *
16 */
17
18 int circle_circle_intersection(double x0, double y0, double r0, double x1,
19                             double y1, double r1, double *xi, double *yi,
20                             double *xi_prime, double *yi_prime) {
21     double a, dx, dy, d, h, rx, ry;
22     double x2, y2;
23
24     /* dx and dy are the vertical and horizontal distances between
25      * the circle centers.
26      */
27     dx = x1 - x0;
28     dy = y1 - y0;
29
30     /* Determine the straight-line distance between the centers. */
31     // d = sqrt((dy*dy) + (dx*dx));
32     d = hypot(dx, dy); // Suggested by Keith Briggs
33
34     /* Check for solvability. */
35     if (d > (r0 + r1)) {
36         /* no solution. circles do not intersect. */
37         return 0;

```

```

38     }
39     if (d < fabs(r0 - r1)) {
40         /* no solution. one circle is contained in the other */
41         return 0;
42     }
43
44     /* 'point 2' is the point where the line through the circle
45      * intersection points crosses the line between the circle
46      * centers.
47      */
48
49     /* Determine the distance from point 0 to point 2. */
50     a = ((r0 * r0) - (r1 * r1) + (d * d)) / (2.0 * d);
51
52     /* Determine the coordinates of point 2. */
53     x2 = x0 + (dx * a / d);
54     y2 = y0 + (dy * a / d);
55
56     /* Determine the distance from point 2 to either of the
57      * intersection points.
58      */
59     h = sqrt((r0 * r0) - (a * a));
60
61     /* Now determine the offsets of the intersection points from
62      * point 2.
63      */
64     rx = -dy * (h / d);
65     ry = dx * (h / d);
66
67     /* Determine the absolute intersection points. */
68     *xi = x2 + rx;
69     *xi_prime = x2 - rx;
70     *yi = y2 + ry;
71     *yi_prime = y2 - ry;
72
73     return 1;
74 }

```

4.18. Struct Point And Line

```

1  int sgn(double x) {
2      if (abs(x) < 1e-8) return 0;
3      return x > 0 ? 1 : -1;
4  }
5  inline double sqr(double x) { return x * x; }
6
7  struct Point {
8      double x, y, z;
9      Point() {}
10     Point(double a, double b): x(a), y(b) {}
11     Point(double x, double y, double z): x(x), y(y), z(z) {}
12
13     void input() { scanf("%lf %lf", &x, &y); }
14     friend Point operator+(const Point &a, const Point &b) {
15         return Point(a.x + b.x, a.y + b.y);
16     }
17     friend Point operator-(const Point &a, const Point &b) {
18         return Point(a.x - b.x, a.y - b.y);
19     }
20
21     bool operator!=(const Point& a) const {
22         return (x != a.x || y != a.y);
23     }
24 }

```

```

25 bool operator <(const Point &a) const{
26     if(x == a.x)
27         return y < a.y;
28     return x < a.x;
29 }
30
31 double norm() {
32     return sqrt(sqr(x) + sqr(y));
33 }
34 };
35 double det(const Point &a, const Point &b) {
36     return a.x * b.y - a.y * b.x;
37 }
38 double dot(const Point &a, const Point &b) {
39     return a.x * b.x + a.y * b.y;
40 }
41 double dist(const Point &a, const Point &b) {
42     return (a-b).norm();
43 }
44
45 struct Line {
46     Point a, b;
47     Line() {}
48     Line(Point x, Point y): a(x), b(y) {};
49 };
50
51 double dis_point_segment(const Point p, const Point s, const Point t) {
52     if(sgn(dot(p-s, t-s)) < 0)
53         return (p-s).norm();
54     if(sgn(dot(p-t, s-t)) < 0)
55         return (p-t).norm();
56     return abs(det(s-p, t-p) / dist(s, t));
57 }
58

```

5. Graphs

5.1. Checa Grafo Bipartido

```

1 bool isBipartite(int src, int V){
2
3     int colorArr[V + 1];
4     memset(colorArr, -1, sizeof(colorArr));
5     colorArr[src] = 1;
6
7     queue <int> q; q.push(src);
8
9     while (!q.empty()) {
10         int u = q.front(); q.pop();
11
12         // Find all non-colored adjacent vertices
13         for (auto it = adj[u].begin(); it != adj[u].end(); it++) {
14             //Return false if there is a self-loop
15             if (u == *it)
16                 return false;
17             // An edge from u to v exists and destination v is not colored
18
19             if (colorArr[*it] == -1) {
20                 // Assign alternate color to this adjacent v of u
21                 colorArr[*it] = 1 - colorArr[u];
22                 q.push(*it);
23             }
24             // An edge from u to v exists and destination v is colored with same
25             color as u

```

```

25         else if (colorArr[*it] == colorArr[u])
26             return false;
27     }
28 }
29 // If we reach here, then all adjacent vertices can be colored with
30 // alternate color
31 return true;
32 }

```

5.2. Ciclo Grafo

```

1 int n;
2 vector<vector<int>> adj;
3 vector<char> color;
4 vector<int> parent;
5 int cycle_start, cycle_end;
6
7 bool dfs(int v) {
8     color[v] = 1;
9     for (int u : adj[v]) {
10         if (color[u] == 0) {
11             parent[u] = v;
12             if (dfs(u))
13                 return true;
14         } else if (color[u] == 1) {
15             cycle_end = v;
16             cycle_start = u;
17             return true;
18         }
19     }
20     color[v] = 2;
21     return false;
22 }
23
24 void find_cycle() {
25     color.assign(n, 0);
26     parent.assign(n, -1);
27     cycle_start = -1;
28
29     for (int v = 0; v < n; v++) {
30         if (dfs(v))
31             break;
32     }
33
34     if (cycle_start == -1) {
35         cout << "Acyclic" << endl;
36     } else {
37         vector<int> cycle;
38         cycle.push_back(cycle_start);
39         for (int v = cycle_end; v != cycle_start; v = parent[v])
40             cycle.push_back(v);
41         cycle.push_back(cycle_start);
42         reverse(cycle.begin(), cycle.end());
43
44         cout << "Cycle found: ";
45         for (int v : cycle)
46             cout << v << " ";
47         cout << endl;
48     }
49 }

```

5.3. Diametro Em Arvore

```
1 Calcula qual o vértice a mais distante de um qualquer vértice X e do vértice
  A calcula-se o vértice B mais distante dele.
```

5.4. Ford Fulkersson (Maximum Flow)

```
1 int rGraph[2000][2000];
2 int graph[2000][2000];
3
4 int V;
5 bool bfs(int s, int t, int parent[]) {
6     bool visited[V];
7     memset(visited, 0, sizeof(visited));
8
9     // Create a queue, enqueue source vertex and mark source vertex
10    // as visited
11    queue<int> q;
12    q.push(s);
13    visited[s] = true;
14    parent[s] = -1;
15
16    // Standard BFS Loop
17    while (!q.empty()) {
18        int u = q.front();
19        q.pop();
20
21        for (int v=0; v<V; v++) {
22            if (visited[v]==false && rGraph[u][v] > 0) {
23                q.push(v);
24                parent[v] = u;
25                visited[v] = true;
26            }
27        }
28    }
29    // If we reached sink in BFS starting from source, then return true, else
30    // false
31    return (visited[t] == true);
32 }
33
34 // Returns the maximum flow from s to t in the given graph
35 int fordFulkerson(int s, int t) {
36     int u, v;
37     // Create a residual graph and fill the residual graph with given
38     // capacities in the original graph as residual capacities in residual
39     // graph residual capacity of edge from i to j (if there is an edge. If
40     // rGraph[i][j] is 0, then there is not)
41     for (u = 0; u < V; u++)
42         for (v = 0; v < V; v++)
43             rGraph[u][v] = graph[u][v];
44
45     int parent[V]; // This array is filled by BFS and to store path
46
47     int max_flow = 0; // There is no flow initially
48
49     // Augment the flow while there is path from source to sink
50     while (bfs(s, t, parent)) {
51         // Find minimum residual capacity of the edges along the path filled by
52         // BFS. Or we can say find the maximum flow through the path found.
53         int path_flow = INT_MAX;
54         for (v=t; v!=s; v=parent[v]) {
55             u = parent[v];
56             path_flow = min(path_flow, rGraph[u][v]);
57         }
58         for (v=t; v!=s; v=parent[v]) {
59             u = parent[v];
60             rGraph[u][v] -= path_flow;
61             rGraph[v][u] += path_flow;
62         }
63         max_flow += path_flow;
64     }
65
66     // PRINT THE FLOW AFTER RUNNING THE ALGORITHM
67     void print(int n) {
68         for(int i = 1; i <= m; i++) {
69             for(int j = m+1; j <= m*2; j++) {
70                 cout << "flow from i(left) to j(right) is " << graph[i][j] -
71                     rGraph[i][j] << endl;
72             }
73         }
74     }
75
76     void addEdge(int l, int r, int n, int x) {
77         graph[l][r+n] = x;
78     }
79
80     void addEdgeSource(int l, int x) {
81         graph[0][l] = x;
82     }
83
84     void addEdgeSink(int r, int n, int x) {
85         graph[r+n][V-1] = x;
86     }
87 }
```

```
54 // update residual capacities of the edges and reverse edges
55 // along the path
56 for (v=t; v != s; v=parent[v]) {
57     u = parent[v];
58     rGraph[u][v] -= path_flow;
59     rGraph[v][u] += path_flow;
60 }
61
62 // Add path flow to overall flow
63 max_flow += path_flow;
64 }
65
66 // Return the overall flow
67 return max_flow;
68 }
69
70 // PRINT THE FLOW AFTER RUNNING THE ALGORITHM
71 void print(int n) {
72     for(int i = 1; i <= m; i++) {
73         for(int j = m+1; j <= m*2; j++) {
74             cout << "flow from i(left) to j(right) is " << graph[i][j] -
75                 rGraph[i][j] << endl;
76         }
77     }
78 }
79
80 void addEdge(int l, int r, int n, int x) {
81     graph[l][r+n] = x;
82 }
83
84 void addEdgeSource(int l, int x) {
85     graph[0][l] = x;
86 }
87
88 void addEdgeSink(int r, int n, int x) {
89     graph[r+n][V-1] = x;
90 }
```

5.5. Pontes Num Grafo

```
1 //SE TIRA-LAS O GRAFO FICA DESCONEXO
2 // OBS: PRESTAR ATENCAO EM SELF-LOOPS, é MELHOR Não ADICIONA-LOS
3 // SO FUNCIONA EM GRAFO Não DIRECIONADO
4 int t=1;
5 vector<int> T((int)2e6,0); //Tempo necessário para chegar naquele vértice na
6     dfs
7 vector<int> adj[(int)2e6];
8 vector<int> Low((int)2e6); // Tempo "mínimo" para chegar naquele vértice na
9     dfs
10 vector<int> ciclo((int)2e6, false);
11 vector<ii> bridges;
12 void dfs(int u, int p){
13     Low[u] = T[u] = t;
14     t++;
15     for(auto v : adj[u]){
16         if(v==p){
17             //checa arestas paralelas
18             p=-1;
19             continue;
20         }
21         //se ele ainda não foi visited
22         else if(T[v]==0){
23             dfs(v,u);
24             Low[u]=min(Low[u], Low[v]);
25         }
26         else{
27             Low[u]=min(Low[u], Low[v]);
28         }
29     }
30     for(int i=0; i<adj[u].size(); i++){
31         int v=adj[u][i];
32         if(Low[v]>T[u]){
33             bridges.push_back({u,v});
34         }
35     }
36 }
```

```

23     if(Low[v]>T[u]) {
24         bridges.pb(ii(min(u,v), (max(u,v))));
25         // ponte de u para v
26     }
27 }
28 else
29     Low[u]=min(Low[u], T[v]);
30     ciclo[u] |= (T[u]>=Low[v]);
31     //checa se o vértice u faz parte de um ciclo
32 }
33 }
34
35 void clear() {
36
37     for(int i = 0; i <= n; i++) {
38         T[i] = 0, Low[i] = 0, adj[i].clear(), ciclo[i] = false;
39     }
40     bridges.clear();
41 }
42
43 signed main () {
44
45     for(int i = 0; i < n; i++)
46         if(T[i] == 0)
47             dfs(i, -1);
48
49     sort(bridges.begin(), bridges.end());
50
51     cout << (int)bridges.size() << endl;
52     for(int i = 0; i < bridges.size(); i++) {
53         cout << bridges[i].ff << " - " << bridges[i].ss << endl;
54     }
55     cout << endl;
56
57     clear();
58
59 }
60

```

5.6. Pontos De Articulação

```

1 // SE TIRAR TAIS VERTICES O GRAFO FICA DESCONEXO
2
3 vector<bool> ap(100000,false);
4 vector<int> low(100000,0), T(100000,0);
5 int tempo = 1;
6 list<int> adj[100000];
7
8 void artPoint(int u, int p) {
9
10     low[u] = T[u] = tempo++;
11     int children = 0;
12
13     for(int v: adj[u]) {
14
15         // cuidado com arestas paralelas
16         // se tiver nao podemos fazer assim
17
18         if(T[v] == 0) {
19
20             children++;
21             artPoint(v,u);
22             low[u] = min(low[v],low[u]);
23

```

```

24         if(p == -1 && children > 1) {
25             ap[u] = true;
26         }
27
28         if(p != -1 && low[v] > T[u])
29             ap[u] = true;
30     } else if(v != p)
31         low[u] = min(low[u], T[v]);
32 }
33 }
34 }
35
36 int main() {
37
38     for(int i = 0; i < n; i++)
39         if(T[i] == 0)
40             artPoint(i,-1);
41 }

```

5.7. Scc (Kosaraju)

```

1 class SCC {
2     private:
3         // number of vertices
4         int n;
5         // indicates whether it is indexed from 0 or 1
6         int indexed_from;
7         // reversed graph
8         vector<vector<int>> trans;
9
10    private:
11    void dfs_trans(int u, int id) {
12        comp[u] = id;
13        scc[id].push_back(u);
14
15        for (int v: trans[u])
16            if (comp[v] == -1)
17                dfs_trans(v, id);
18    }
19
20    void get_transpose(vector<vector<int>>& adj) {
21        for (int u = indexed_from; u < this->n + indexed_from; u++)
22            for(int v: adj[u])
23                trans[v].push_back(u);
24    }
25
26    void dfs_fill_order(int u, stack<int> &s, vector<vector<int>>& adj) {
27        comp[u] = true;
28
29        for(int v: adj[u])
30            if(!comp[v])
31                dfs_fill_order(v, s, adj);
32
33        s.push(u);
34    }
35
36    // The main function that finds all SCCs
37    void compute_SCC(vector<vector<int>>& adj) {
38
39        stack<int> s;
40        // Fill vertices in stack according to their finishing times
41        for(int i = indexed_from; i < this->n + indexed_from; i++)
42            if(!comp[i])
43                dfs_fill_order(i, s, adj);

```



```

44 // Create a reversed graph
45 get_transpose(adj);
46
47 fill(comp.begin(), comp.end(), -1);
48
49 // Now process all vertices in order defined by stack
50 while(s.empty() == false) {
51     int v = s.top();
52     s.pop();
53
54     if(comp[v] == -1)
55         dfs_trans(v, this->number_of_comp++);
56 }
57
58 public:
59 // number of the component of the i-th vertex
60 // it's always indexed from 0
61 vector<int> comp;
62 // the i-th vector contains the vertices that belong to the i-th scc
63 // it's always indexed from 0
64 vector<vector<int>> scc;
65 int number_of_comp = 0;
66
67 SCC(int n, int indexed_from, vector<vector<int>>& adj) {
68     this->n = n;
69     this->indexed_from = indexed_from;
70     comp.resize(n + 1);
71     trans.resize(n + 1);
72     scc.resize(n + 1);
73
74     this->compute_SCC(adj);
75 }
76 };
77
78

```

5.8. All Eulerian Path Or Tour

```

1 struct edge {
2     int v, id;
3     edge() {}
4     edge(int v, int id) : v(v), id(id) {}
5 };
6
7 // The undirected + path and directed + tour wasn't tested in a problem.
8 // TEST AGAIN BEFORE SUBMITTING IT!
9 namespace graph {
10     // Namespace which auxiliary functions are defined.
11     namespace detail {
12         pair<bool, pair<int, int>> check_both_directed(const
13             vector<vector<edge>> &adj, const vector<int> &in_degree) {
14             // source and destination
15             int src = -1, dest = -1;
16             // adj[i].size() represents the out degree of an vertex
17             for(int i = 0; i < adj.size(); i++) {
18                 if((int)adj[i].size() - in_degree[i] == 1) {
19                     if(src != -1)
20                         return make_pair(false, pair<int, int>());
21                     src = i;
22                 } else if((int)adj[i].size() - in_degree[i] == -1) {
23                     if(dest != -1)
24                         return make_pair(false, pair<int, int>());
25                     dest = i;
26                 } else if(abs((int)adj[i].size() - in_degree[i]) > 1)

```

```

26         return make_pair(false, pair<int, int>());
27     }
28
29     if(src == -1 && dest == -1)
30         return make_pair(true, pair<int, int>(src, dest));
31     else if(src != -1 && dest != -1)
32         return make_pair(true, pair<int, int>(src, dest));
33
34     return make_pair(false, pair<int, int>());
35 }
36
37 /// Builds the path/tour for directed graphs.
38 void build(const int u, vector<int> &tour, vector<vector<edge>> &adj,
39     vector<bool> &used) {
40     while(!adj[u].empty()) {
41         const edge e = adj[u].back();
42         if(!used[e.id]) {
43             used[e.id] = true;
44             adj[u].pop_back();
45             build(e.v, tour, adj, used);
46         } else
47             adj[u].pop_back();
48     }
49     tour.push_back(u);
50 }
51
52 /// Auxiliary function to build the eulerian tour/path.
53 vector<int> set_build(vector<vector<edge>> &adj, const int E, const int
54     first) {
55     vector<int> path;
56     vector<bool> used(E + 3);
57
58     build(first, path, adj, used);
59
60     for(int i = 0; i < adj.size(); i++)
61         // if there are some remaining edges, it's not possible to build the
62         // tour.
63         if(adj[i].size())
64             return vector<int>();
65
66     reverse(path.begin(), path.end());
67     return path;
68 }
69
70 /// All vertices v should have in_degree[v] == out_degree[v]. It must not
71 contain a specific
72 start and end vertices.
73 ///
74 /// Time complexity: O(V * (log V) + E)
75 bool has_euler_tour_directed(const vector<vector<edge>> &adj, const
76     vector<int> &in_degree) {
77     const pair<bool, pair<int, int>> aux = detail::check_both_directed(adj,
78         in_degree);
79     const bool valid = aux.first;
80     const int src = aux.second.first;
81     const int dest = aux.second.second;
82     return (valid && src == -1 && dest == -1);
83 }
84
85 /// A directed graph has an eulerian path/tour if has:
86 /// - One vertex v such that out_degree[v] - in_degree[v] == 1
87 /// - One vertex v such that in_degree[v] - out_degree[v] == 1
88 /// - The remaining vertices v such that in_degree[v] == out_degree[v]

```

```

85  /// or
86  /// - All vertices v such that in_degree[v] - out_degree[v] == 0 -> TOUR
87  ///
88  /// Returns a boolean value that indicates whether there's a path or not.
89  /// If there's a valid path it also returns two numbers: the source and
    the destination.
90  /// If the source and destination can be an arbitrary vertex it will
    return the pair (-1, -1)
91  /// for the source and destination (it means the contains an eulerian
    tour).
92  ///
93  /// Time complexity: O(V + E)
94  pair<bool, pair<int, int>> has_euler_path_directed(const
    vector<vector<edge>> &adj, const vector<int> &in_degree) {
95      return detail::check_both_directed(adj, in_degree);
96  }
97
98  /// Returns the euler path. If the graph doesn't have an euler path it
    returns an empty vector.
99  ///
100  /// Time Complexity: O(V + E) for directed, O(V * log(V) + E) for
    undirected.
101  /// Time Complexity: O(adj.size() + sum(adj[i].size()))
102  vector<int> get_euler_path_directed(const int E, vector<vector<edge>>
    &adj, const vector<int> &in_degree) {
103      const pair<bool, pair<int, int>> aux = has_euler_path_directed(adj,
        in_degree);
104      const bool valid = aux.first;
105      const int src = aux.second.first;
106      const int dest = aux.second.second;
107
108      if(!valid)
109          return vector<int>();
110
111      int first;
112      if(src != -1)
113          first = src;
114      else {
115          first = 0;
116          while(adj[first].empty())
117              first++;
118      }
119
120      return detail::set_build(adj, E, first);
121  }
122
123  /// Returns the euler tour. If the graph doesn't have an euler tour it
    returns an empty vector.
124  ///
125  /// Time Complexity: O(V + E)
126  /// Time Complexity: O(adj.size() + sum(adj[i].size()))
127  vector<int> get_euler_tour_directed(const int E, vector<vector<edge>>
    &adj, const vector<int> &in_degree) {
128      const bool valid = has_euler_tour_directed(adj, in_degree);
129
130      if(!valid)
131          return vector<int>();
132
133      int first = 0;
134      while(adj[first].empty())
135          first++;
136
137      return detail::set_build(adj, E, first);
138  }
139

```

```

140  /// The graph has a tour that passes to every edge exactly once and gets
141  /// back to the first edge on the tour.
142  ///
143  /// A graph with an euler path has zero odd degree vertex.
144  ///
145  /// Time Complexity: O(V)
146  bool has_euler_tour_undirected(const vector<int> &degree) {
147      for(int i = 0; i < degree.size(); i++)
148          if(degree[i] & 1)
149              return false;
150      return true;
151  }
152
153  /// The graph has a path that passes to every edge exactly once.
154  /// It doesn't necessarily gets back to the beginning.
155  ///
156  /// A graph with an euler path has two or zero (tour) odd degree vertices.
157  ///
158  /// Returns a pair with the startpoint/endpoint of the path.
159  ///
160  /// Time Complexity: O(V)
161  pair<bool, pair<int, int>> has_euler_path_undirected(const vector<int>
    &degree) {
162      vector<int> odd_degree;
163      for(int i = 0; i < degree.size(); i++)
164          if(degree[i] & 1)
165              odd_degree.pb(i);
166
167      if(odd_degree.size() == 0)
168          return make_pair(true, make_pair(-1, -1));
169      else if (odd_degree.size() == 2)
170          return make_pair(true, make_pair(odd_degree.front(),
            odd_degree.back()));
171      else
172          return make_pair(false, pair<int, int>());
173  }
174
175  vector<int> get_euler_tour_undirected(const int E, const vector<int>
    &degree, vector<vector<edge>> &adj) {
176      if(!has_euler_tour_undirected(degree))
177          return vector<int>();
178
179      int first = 0;
180      while(adj[first].empty())
181          first++;
182
183      return detail::set_build(adj, E, first);
184  }
185
186  /// Returns the euler tour. If the graph doesn't have an euler tour it
    returns an empty vector.
187  ///
188  /// Time Complexity: O(V + E)
189  /// Time Complexity: O(adj.size() + sum(adj[i].size()))
190  vector<int> get_euler_path_undirected(const int E, const vector<int>
    &degree, vector<vector<edge>> &adj) {
191      auto aux = has_euler_path_undirected(degree);
192      const bool valid = aux.first;
193      const int x = aux.second.first;
194      const int y = aux.second.second;
195
196      if(!valid)
197          return vector<int>();
198
199      int first;

```

```

200     if(x != -1) {
201         first = x;
202         adj[x].emplace_back(y, E + 1);
203         adj[y].emplace_back(x, E + 1);
204     } else {
205         first = 0;
206         while(adj[first].empty())
207             first++;
208     }
209
210     vector<int> ans = detail::set_build(adj, E, first);
211     reverse(ans.begin(), ans.end());
212     if(x != -1)
213         ans.pop_back();
214     return ans;
215 }
216 };

```

5.9. Bellman Ford

```

1 struct edge {
2     int src, dest, weight;
3     edge() {}
4     edge(int src, int dest, int weight) : src(src), dest(dest), weight(weight)
5     {}
6
7     bool operator<(const edge &a) const {
8         return weight < a.weight;
9     }
10 };
11
12 /// Works to find the shortest path with negative edges.
13 /// Also detects cycles.
14 ///
15 /// Time Complexity: O(n * e)
16 /// Space Complexity: O(n)
17 bool bellman_ford(vector<edge> &edges, int src, int n) {
18     // n = qtd of vertices, E = qtd de arestas
19
20     // To calculate the shortest path uncomment the line below
21     // vector<int> dist(n, INF);
22
23     // To check cycles uncomment the line below
24     // vector<int> dist(n, 0);
25
26     vector<int> pai(n, -1);
27     int E = edges.size();
28
29     dist[src] = 0;
30     // Relax all edges n - 1 times.
31     // A simple shortest path from src to any other vertex can have at-most n
32     // - 1 edges.
33     for (int i = 1; i <= n - 1; i++) {
34         for (int j = 0; j < E; j++) {
35             int u = edges[j].src;
36             int v = edges[j].dest;
37             int weight = edges[j].weight;
38             if (dist[u] != INF && dist[u] + weight < dist[v]) {
39                 dist[v] = dist[u] + weight;
40                 pai[v] = u;
41             }
42         }
43     }
44 }

```

```

43 // Check for NEGATIVE-WEIGHT CYCLES.
44 // The above step guarantees shortest distances if graph doesn't contain
45 // negative weight cycle.
46 // If we get a shorter path, then there is a cycle.
47 bool is_cycle = false;
48 int vert_in_cycle;
49 for (int i = 0; i < E; i++) {
50     int u = edges[i].src;
51     int v = edges[i].dest;
52     int weight = edges[i].weight;
53     if (dist[u] != INF && dist[u] + weight < dist[v]) {
54         is_cycle = true;
55         pai[v] = u;
56         vert_in_cycle = v;
57     }
58 }
59
60 if(is_cycle) {
61     for(int i = 0; i < n; i++)
62         vert_in_cycle = pai[vert_in_cycle];
63
64     vector<int> cycle;
65     for(int v = vert_in_cycle; (v != vert_in_cycle || cycle.size() <= 1) ; v
66         = pai[v])
67         cycle.pb(v);
68
69     reverse(cycle.begin(), cycle.end());
70
71     for(int x: cycle) {
72         cout << x + 1 << ' ';
73     }
74     cout << cycle.front() + 1 << endl;
75     return true;
76 } else
77     return false;
78 }

```

5.10. De Bruijn Sequence

```

1 // We can solve this problem by constructing a directed graph with
2 // k^(n-1) nodes with each node having k outgoing edges_order. Each node
3 // corresponds to a string of size n-1. Every edge corresponds to one of the
4 // characters in A and adds that character to the starting string. For
5 // example,
6 // if n=3 and k=2, then we construct the following graph:
7
8 //           - 1 -> (01)  - 1 ->
9 //           /      ^      |      \
10 // 0 -> (00)      1  0          (11) <- 1
11 //           \      |      v      /
12 //           <- 0 - (10)  <- 0 -
13
14 // The node '01' is connected to node '11' through edge '1', as adding '1' to
15 // '01' (and removing the first character) gives us '11'.
16
17 // We can observe that every node in this graph has equal in-degree and
18 // out-degree, which means that a Eulerian circuit exists in this graph.
19
20 namespace graph {
21 namespace detail {
22 // Finding an valid eulerian path
23 void dfs(const string &node, const string &alphabet, set<string> &vis,
24         string &edges_order) {

```

```

24   for (char c : alphabet) {
25       string nxt = node + c;
26       if (vis.count(nxt))
27           continue;
28
29       vis.insert(nxt);
30       nxt.erase(nxt.begin());
31       dfs(nxt, alphabet, vis, edges_order);
32       edges_order += c;
33   }
34 }
35 }; // namespace detail
36
37 // Returns a string in which every string of the alphabet of size n appears
38 // in the resulting string exactly once.
39 //
40 // Time Complexity: O(alphabet.size() ^ n * log2(alphabet.size() ^ n))
41 string de_bruijn(const int n, const string &alphabet) {
42     set<string> vis;
43     string edges_order;
44
45     string starting_node = string(n - 1, alphabet.front());
46     detail::dfs(starting_node, alphabet, vis, edges_order);
47
48     return edges_order + starting_node;
49 }
50 }; // namespace graph

```

5.11. Dijkstra + Dij Graph

```

1  /// Works with 1-indexed graphs.
2  class Dijkstra {
3  private:
4      static constexpr int INF = 2e18;
5      bool CREATE_GRAPH = false;
6      int src;
7      int n;
8      vector<int> _dist;
9      vector<vector<int>> parent;
10
11 private:
12     void _compute(const int src, const vector<vector<pair<int, int>>> &adj) {
13         _dist.resize(this->n, INF);
14         vector<bool> vis(this->n, false);
15
16         if (CREATE_GRAPH) {
17             parent.resize(this->n);
18
19             for (int i = 0; i < this->n; i++)
20                 parent[i].emplace_back(i);
21         }
22
23         priority_queue<pair<int, int>, vector<pair<int, int>>,
24             greater<pair<int, int>>>
25             pq;
26         pq.emplace(0, src);
27         _dist[src] = 0;
28
29         while (!pq.empty()) {
30             int u = pq.top().second;
31             pq.pop();
32             if (vis[u])
33                 continue;

```

```

34         vis[u] = true;
35
36         for (const pair<int, int> &x : adj[u]) {
37             int v = x.first;
38             int w = x.second;
39
40             if (_dist[u] + w < _dist[v]) {
41                 _dist[v] = _dist[u] + w;
42                 pq.emplace(_dist[v], v);
43                 if (CREATE_GRAPH) {
44                     parent[v].clear();
45                     parent[v].emplace_back(u);
46                 }
47             } else if (CREATE_GRAPH && _dist[u] + w == _dist[v]) {
48                 parent[v].emplace_back(u);
49             }
50         }
51     }
52 }
53
54 vector<vector<int>> gen_dij_graph(const int dest) {
55     vector<vector<int>> dijkstra_graph(this->n);
56     vector<bool> vis(this->n, false);
57     queue<int> q;
58
59     q.emplace(dest);
60     while (!q.empty()) {
61         int v = q.front();
62         q.pop();
63
64         for (const int u : parent[v]) {
65             if (u == v)
66                 continue;
67             dijkstra_graph[u].emplace_back(v);
68             if (!vis[u]) {
69                 q.emplace(u);
70                 vis[u] = true;
71             }
72         }
73     }
74     return dijkstra_graph;
75 }
76
77 vector<int> gen_min_path(const int dest) {
78     vector<int> path;
79     vector<int> prev(this->n, -1);
80     vector<int> d(this->n, INF);
81     queue<int> q;
82
83     q.emplace(dest);
84     d[dest] = 0;
85
86     while (!q.empty()) {
87         int v = q.front();
88         q.pop();
89
90         for (const int u : parent[v]) {
91             if (u == v)
92                 continue;
93             if (d[v] + 1 < d[u]) {
94                 d[u] = d[v] + 1;
95                 prev[u] = v;
96                 q.emplace(u);
97             }
98         }

```

```

99     }
100
101     int cur = this->src;
102     while (cur != -1) {
103         path.emplace_back(cur);
104         cur = prev[cur];
105     }
106
107     return path;
108 }
109
110 public:
111     /// Allows creation of dijkstra graph and getting the minimum path.
112     Dijkstra(const int src, const bool create_graph,
113             const vector<vector<pair<int, int>>> &adj)
114         : n(adj.size()), src(src), CREATE_GRAPH(create_graph) {
115         this->_compute(src, adj);
116     }
117
118     /// Constructor that computes only the Dijkstra minimum path from src.
119     ///
120     /// Time Complexity: O(E log V)
121     Dijkstra(const int src, const vector<vector<pair<int, int>>> &adj)
122         : n(adj.size()), src(src) {
123         this->_compute(src, adj);
124     }
125
126     /// Returns the Dijkstra graph of the graph.
127     ///
128     /// Time Complexity: O(V)
129     vector<vector<int>>> dij_graph(const int dest) {
130         assert(CREATE_GRAPH);
131         return gen_dij_graph(dest);
132     }
133
134     /// Returns the vertices present in a path from src to dest with
135     /// minimum cost and a minimum length.
136     ///
137     /// Time Complexity: O(V)
138     vector<int> min_path(const int dest) {
139         assert(CREATE_GRAPH);
140         return gen_min_path(dest);
141     }
142
143     /// Returns the distance from src to dest.
144     int dist(const int dest) {
145         assert(0 <= dest), assert(dest < n);
146         return _dist[dest];
147     }
148 };

```

5.12. Dinic (Max Flow)

```

1  // Created by Ubiratan Neto
2
3  struct Dinic {
4
5      struct FlowEdge {
6          int v, rev, c, cap;
7          bool is_rev;
8          FlowEdge() {}
9          FlowEdge(int v, int c, int cap, int rev, bool is_rev) : v(v), c(c),
10 cap(cap), rev(rev), is_rev(is_rev) {}

```

```

11     vector<vector<FlowEdge>>> adj;
12     vector<int> level, used;
13     int src, snk, V;
14     int sz;
15     int max_flow;
16     bool calculated;
17     Dinic() {}
18     Dinic(int n) {
19         calculated = false;
20         src = 0;
21         snk = n+1;
22         adj.resize(n+2, vector<FlowEdge>());
23         level.resize(n+2);
24         used.resize(n+2);
25         sz = n+2;
26         V = n+2;
27         max_flow = 0;
28     }
29
30     void add_edge(int u, int v, int c) {
31         int id1 = adj[u].size();
32         int id2 = adj[v].size();
33         adj[u].pb(FlowEdge(v, c, c, id2, false));
34         adj[v].pb(FlowEdge(u, 0, 0, id1, true));
35     }
36
37     void add_to_src(int v, int c) {
38         adj[src].pb(FlowEdge(v, c, c, -1, false));
39     }
40
41     void add_to_snk(int u, int c) {
42         adj[u].pb(FlowEdge(snk, c, c, -1, false));
43     }
44
45     bool bfs() {
46         for(int i=0; i<sz; i++){
47             level[i] = -1;
48         }
49
50         level[src] = 0;
51         queue<int> q; q.push(src);
52
53         while(!q.empty()) {
54             int cur = q.front();
55             q.pop();
56             for(FlowEdge e : adj[cur]) {
57                 if(level[e.v] == -1 && e.c > 0) {
58                     level[e.v] = level[cur]+1;
59                     q.push(e.v);
60                 }
61             }
62         }
63     }
64
65     return (level[snk] == -1 ? false : true);
66 }
67
68 int send_flow(int u, int flow) {
69     if(u == snk) return flow;
70
71     for(int &i = used[u]; i<adj[u].size(); i++){
72         FlowEdge &e = adj[u][i];
73
74         if(level[u]+1 != level[e.v] || e.c <= 0) continue;
75

```

```

76     int new_flow = min(flow, e.c);
77     int adjusted_flow = send_flow(e.v, new_flow);
78
79     if(adjusted_flow > 0){
80         e.c -= adjusted_flow;
81         if(e.rev != -1) adj[e.v][e.rev].c += adjusted_flow;
82         return adjusted_flow;
83     }
84 }
85
86 return 0;
87 }
88
89 int calculate() {
90     if(src == snk){max_flow = -1; return -1;} //not sure if needed
91
92     max_flow = 0;
93
94     while(bfs()){
95         for(int i=0; i<sz; i++) used[i] = 0;
96         while(int inc = send_flow(src, INF)) max_flow += inc;
97     }
98     calculated = true;
99
100    return max_flow;
101 }
102
103 vector<ii> mincut(vector<vector<int>>> &mat_adj) {
104     assert(calculated);
105     int mat[sz][sz];
106     memset(mat, 0, sizeof mat);
107     for(int i = 0; i < V; i++)
108         for(FlowEdge x: adj[i])
109             mat[i][x.v] += x.c;
110
111     vector<bool> vis(sz);
112     queue<int> q;
113     q.push(src);
114     vis[src] = true;
115     while(!q.empty()){
116         int u = q.front();
117         q.pop();
118         for(int v = 0; v < sz; v++) {
119             if(mat[u][v] > 0 && !vis[v]) {
120                 q.push(v);
121                 vis[v] = true;
122             }
123         }
124     }
125
126     vector<ii> cut;
127     for(int i = 0; i < sz; i++)
128         for(int j = 0; j < sz; j++)
129             if(vis[i] && !vis[j])
130                 // if there's an edge from i to j.
131                 if(mat_adj[i][j] > 0)
132                     cut.emplace_back(i, j);
133
134     return cut;
135 }
136
137 vector<ii> min_edge_cover(){
138     bool covered[sz];
139     for(int i=0; i<sz; i++) covered[i] = false;
140

```

```

141     vector< ii > edge_cover;
142     for(int i=1; i<sz-1; i++){
143         for(FlowEdge e : adj[i]){
144             if(e.cap == 0 || e.v > sz-2) continue;
145             if(e.c == 0){
146                 edge_cover.pb(ii(i, e.v));
147                 covered[i] = true;
148                 covered[e.v] = true;
149                 break;
150             }
151         }
152     }
153     for(int i=1; i<sz-1; i++){
154         for(FlowEdge e : adj[i]){
155             if(e.cap == 0 || e.v > sz-2) continue;
156             if(e.c == 0) continue;
157             if(!covered[i] || !covered[e.v]){
158                 edge_cover.pb(ii(i, e.v));
159                 covered[i] = true;
160                 covered[e.v] = true;
161             }
162         }
163     }
164     return edge_cover;
165 }
166
167 vector<vector<int>>> allFlow() {
168     assert(calculated);
169     vector<vector<int>>> ret(V, vector<int>(V, 0));
170
171     for(int i = 0; i < V; i++) {
172         for(FlowEdge x: adj[i]) {
173             if(x.is_rev)
174                 continue;
175             // flow from vertex i to x.v
176             ret[i][x.v] += x.cap - x.c;
177         }
178     }
179
180     // for(int i = 0; i < V; i++) {
181     //     for(int j = 0; j < V; j++) {
182     //         cout << ret[i][j] << ' ';
183     //     }
184     //     cout << endl;
185     // }
186
187     return ret;
188 }
189
190 void dfs_build_path(int u, vector<int> &path, vector<vector<int>>>
191     &mat_flow, vector<vector<int>>> &ans, vector<vector<int>>> &adj) {
192     path.pb(u);
193     if(u == this->snk) {
194         ans.pb(path);
195         return;
196     }
197
198     for(int v: adj[u]) {
199         if(mat_flow[u][v]) {
200             mat_flow[u][v]--;
201             dfs_build_path(v, path, mat_flow, ans, adj);
202             return;
203         }
204     }

```

```

205 }
206
207 vector<vector<int>> get_all_paths(vector<vector<int>> &adj) {
208     assert(calculated);
209
210     vector<vector<int>> mat_flow = allFlow();
211     vector<vector<int>> ans;
212     ans.reserve(max_flow);
213
214     for(int i = 0; i < max_flow; i++) {
215         vector<int> path;
216         path.reserve(V);
217         dfs_build_path(this->src, path, mat_flow, ans, adj);
218     }
219
220     return ans;
221 }
222 };

```

5.13. Floyd Warshall

```

1  /// Put n = n + 1 for 1 based.
2  void floyd_warshall(const int n) {
3      // OBS: Always assign adj[i][i] = 0.
4      for (int i = 0; i < n; i++)
5          adj[i][i] = 0;
6
7      for (int k = 0; k < n; k++)
8          for (int i = 0; i < n; i++)
9              for (int j = 0; j < n; j++)
10                 adj[i][j] = min(adj[i][j], adj[i][k] + adj[k][j]);
11 }

```

5.14. Functional Graph

```

1  // Based on:
2  // http://maratona.ic.unicamp.br/MaratonaVerao2020/lecture-b/20200122.pdf
3
4  class Functional_Graph {
5      // FOR DIRECTED GRAPH
6      private:
7          void compute_cycle(int u, vector<int> &nxt, vector<bool> &vis) {
8              int id_cycle = cycle_cnt++;
9              int cur_id = 0;
10              this->first[id_cycle] = u;
11
12              while(!vis[u]) {
13                  vis[u] = true;
14
15                  this->cycle[id_cycle].push_back(u);
16
17                  this->in_cycle[u] = true;
18                  this->cycle_id[u] = id_cycle;
19                  this->id_in_cycle[u] = cur_id;
20                  this->near_in_cycle[u] = u;
21                  this->id_near_cycle[u] = id_cycle;
22                  this->cycle_dist[u] = 0;
23
24                  u = nxt[u];
25                  cur_id++;
26              }
27 }

```

```

28 // Time Complexity: O(V)
29 void build(int n, int indexed_from, vector<int> &nxt, vector<int>
30     &in_degree) {
31     queue<int> q;
32     vector<bool> vis(n + indexed_from);
33     for(int i = indexed_from; i < n + indexed_from; i++) {
34         if(in_degree[i] == 0) {
35             q.push(i);
36             vis[i] = true;
37         }
38     }
39
40     vector<int> process_order;
41     process_order.reserve(n + indexed_from);
42     while(!q.empty()) {
43         int u = q.front();
44         q.pop();
45
46         process_order.push_back(u);
47
48         if(--in_degree[nxt[u]] == 0) {
49             q.push(nxt[u]);
50             vis[nxt[u]] = true;
51         }
52     }
53
54     int cycle_cnt = 0;
55     for(int i = indexed_from; i < n + indexed_from; i++)
56         if(!vis[i])
57             compute_cycle(i, nxt, vis);
58
59     for(int i = (int)process_order.size() - 1; i >= 0; i--) {
60         int u = process_order[i];
61
62         this->near_in_cycle[u] = this->near_in_cycle[nxt[u]];
63         this->id_near_cycle[u] = this->id_near_cycle[nxt[u]];
64         this->cycle_dist[u] = this->cycle_dist[nxt[u]] + 1;
65     }
66
67     void allocate(int n, int indexed_from) {
68         this->cycle.resize(n + indexed_from);
69         this->first.resize(n + indexed_from);
70
71         this->in_cycle.resize(n + indexed_from, false);
72         this->cycle_id.resize(n + indexed_from, -1);
73         this->id_in_cycle.resize(n + indexed_from, -1);
74         this->near_in_cycle.resize(n + indexed_from);
75         this->id_near_cycle.resize(n + indexed_from);
76         this->cycle_dist.resize(n + indexed_from);
77     }
78
79     public:
80     Functional_Graph(int n, int indexed_from, vector<int> &nxt, vector<int>
81         &in_degree) {
82         this->allocate(n, indexed_from);
83         this->build(n, indexed_from, nxt, in_degree);
84     }
85
86     // THE CYCLES ARE ALWAYS INDEXED BY ZERO!
87
88     // number of cycles
89     int cycle_cnt = 0;
90     // Vertices present in the i-th cycle.
91     vector<vector<int>> cycle;

```

```

91 // first vertex of the i-th cycle
92 vector<int> first;
93
94 // The i-th vertex is present in any cycle?
95 vector<bool> in_cycle;
96 // id of the cycle that the vertex belongs. -1 if it doesn't belong to any
   cycle.
97 vector<int> cycle_id;
98 // Represents the id of the cycle of the i-th vertex. -1 if it doesn't
   belong to any cycle.
99 vector<int> id_in_cycle;
100 // Represents the id of the nearest vertex present in a cycle.
101 vector<int> near_in_cycle;
102 // Represents the id of the nearest cycle.
103 vector<int> id_near_cycle;
104 // Distance to the nearest cycle.
105 vector<int> cycle_dist;
106 // Represent the id of the component of the vertex.
107 // Equal to id_near_cycle
108 vector<int> &comp = id_near_cycle;
109 };
110
111 class Functional_Graph {
112 // FOR UNDIRECTED GRAPH
113 private:
114 void compute_cycle(int u, vector<int> &nxt, vector<bool> &vis,
   vector<vector<int>> &adj) {
115     int id_cycle = cycle_cnt++;
116     int cur_id = 0;
117     this->first[id_cycle] = u;
118
119     while(!vis[u]) {
120         vis[u] = true;
121
122         this->cycle[id_cycle].push_back(u);
123         nxt[u] = find_nxt(u, vis, adj);
124         if(nxt[u] == -1)
125             nxt[u] = this->first[id_cycle];
126
127         this->in_cycle[u] = true;
128         this->cycle_id[u] = id_cycle;
129         this->id_in_cycle[u] = cur_id;
130         this->near_in_cycle[u] = u;
131         this->id_near_cycle[u] = id_cycle;
132         this->cycle_dist[u] = 0;
133
134         u = nxt[u];
135         cur_id++;
136     }
137 }
138
139 int find_nxt(int u, vector<bool> &vis, vector<vector<int>> &adj) {
140     for(int v: adj[u])
141         if(!vis[v])
142             return v;
143     return -1;
144 }
145
146 // Time Complexity: O(V + E)
147 void build(int n, int indexed_from, vector<int> &degree,
   vector<vector<int>> &adj) {
148     queue<int> q;
149     vector<bool> vis(n + indexed_from, false);
150     vector<int> nxt(n + indexed_from);
151     for(int i = indexed_from; i < n + indexed_from; i++) {

```

```

152         if(adj[i].size() == 1) {
153             q.push(i);
154             vis[i] = true;
155         }
156     }
157
158     vector<int> process_order;
159     process_order.reserve(n + indexed_from);
160     while(!q.empty()) {
161         int u = q.front();
162         q.pop();
163
164         process_order.push_back(u);
165
166         nxt[u] = find_nxt(u, vis, adj);
167         if(--degree[nxt[u]] == 1) {
168             q.push(nxt[u]);
169             vis[nxt[u]] = true;
170         }
171     }
172
173     int cycle_cnt = 0;
174     for(int i = indexed_from; i < n + indexed_from; i++)
175         if(!vis[i])
176             compute_cycle(i, nxt, vis, adj);
177
178     for(int i = (int)process_order.size() - 1; i >= 0; i--) {
179         int u = process_order[i];
180
181         this->near_in_cycle[u] = this->near_in_cycle[nxt[u]];
182         this->id_near_cycle[u] = this->id_near_cycle[nxt[u]];
183         this->cycle_dist[u] = this->cycle_dist[nxt[u]] + 1;
184     }
185 }
186
187 void allocate(int n, int indexed_from) {
188     this->cycle.resize(n + indexed_from);
189     this->first.resize(n + indexed_from);
190
191     this->in_cycle.resize(n + indexed_from, false);
192     this->cycle_id.resize(n + indexed_from, -1);
193     this->id_in_cycle.resize(n + indexed_from, -1);
194     this->near_in_cycle.resize(n + indexed_from);
195     this->id_near_cycle.resize(n + indexed_from);
196     this->cycle_dist.resize(n + indexed_from);
197 }
198
199 public:
200 Functional_Graph(int n, int indexed_from, vector<int> degree,
   vector<vector<int>> &adj) {
201     this->allocate(n, indexed_from);
202     this->build(n, indexed_from, degree, adj);
203 }
204
205 // THE CYCLES ARE ALWAYS INDEXED BY ZERO!
206
207 // number of cycles
208 int cycle_cnt = 0;
209 // Vertices present in the i-th cycle.
210 vector<vector<int>> cycle;
211 // first vertex of the i-th cycle
212 vector<int> first;
213
214 // The i-th vertex is present in any cycle?
215 vector<bool> in_cycle;

```



```

216 // id of the cycle that the vertex belongs. -1 if it doesn't belong to any
    cycle.
217 vector<int> cycle_id;
218 // Represents the id of the cycle of the i-th vertex. -1 if it doesn't
    belong to any cycle.
219 vector<int> id_in_cycle;
220 // Represents the id of the nearest vertex present in a cycle.
221 vector<int> near_in_cycle;
222 // Represents the id of the nearest cycle.
223 vector<int> id_near_cycle;
224 // Distance to the nearest cycle.
225 vector<int> cycle_dist;
226 // Represent the id of the component of the vertex.
227 // Equal to id_near_cycle
228 vector<int> &comp = id_near_cycle;
229 };

```

5.15. Hld

```

1 class HLD {
2 private:
3     int n;
4     // number of nodes below the i-th node
5     vector<int> sz;
6
7 private:
8     int get_sz(const int u, const int p, const vector<vector<int>> &adj) {
9         this->sz[u] = 1;
10        for (const int v : adj[u]) {
11            if (v == p)
12                continue;
13            this->sz[u] += this->get_sz(v, u, adj);
14        }
15        return this->sz[u];
16    }
17
18 void dfs(const int u, const int id, const int p,
19         const vector<vector<int>> &adj) {
20     this->chain_id[u] = id;
21     this->id_in_chain[u] = chain_size[id];
22     this->parent[u] = p;
23
24     if (this->chain_head[id] == -1)
25         this->chain_head[id] = u;
26     this->chain_size[id]++;
27
28     int maxx = -1, idx = -1;
29     for (const int v : adj[u]) {
30         if (v == p)
31             continue;
32         if (sz[v] > maxx) {
33             maxx = sz[v];
34             idx = v;
35         }
36     }
37
38     if (idx != -1)
39         this->dfs(idx, id, u, adj);
40
41     for (const int v : adj[u]) {
42         if (v == idx || v == p)
43             continue;
44         this->dfs(v, this->number_of_chains++, u, adj);
45     }

```

```

46 }
47
48 public:
49     /// Builds the chains.
50     ///
51     /// Time Complexity: O(n)
52     HLD(const int root_idx, const vector<vector<int>> &adj) {
53         this->n = adj.size();
54         this->chain_head.resize(this->n + 1, -1);
55         this->id_in_chain.resize(this->n + 1, -1);
56         this->chain_id.resize(this->n + 1, -1);
57         this->sz.resize(this->n + 1);
58         this->chain_size.resize(this->n + 1);
59         this->parent.resize(this->n + 1, -1);
60         this->get_sz(root_idx, -1, adj);
61         this->dfs(root_idx, 0, -1, adj);
62     }
63
64     // the chains are indexed from 0
65     int number_of_chains = 1;
66     // topmost node of the chain
67     vector<int> chain_head;
68     // id of the i-th node in his chain
69     vector<int> id_in_chain;
70     // id of the chain that the i-th node belongs
71     vector<int> chain_id;
72     // size of the i-th chain
73     vector<int> chain_size;
74     // parent of the i-th node, -1 for root
75     vector<int> parent;
76 };

```

5.16. Kruskal + Dsu

```

1 class DSU {
2
3 public:
4
5     vector<int> root;
6     vector<int> sz;
7
8     DSU(int n) {
9         this->root.resize(n + 1);
10        iota(this->root.begin(), this->root.begin() + n + 1, 0);
11        this->sz.resize(n + 1, 1);
12    }
13
14     int Find(int x) {
15         if(this->root[x] == x)
16             return x;
17         return this->root[x] = this->Find(this->root[x]);
18     }
19
20     bool Union(int p, int q) {
21
22         p = this->Find(p), q = this->Find(q);
23
24         if(p == q)
25             return false;
26
27         if(this->sz[p] > this->sz[q]) {
28             this->root[q] = p;
29             this->sz[p] += this->sz[q];
30         } else {

```

```

31     this->root[p] = q;
32     this->sz[q] += this->sz[p];
33 }
34
35     return true;
36 }
37
38 };
39
40 struct edge {
41     int u, v, w;
42     edge() {}
43     edge(int u, int v, int w) : u(u), v(v), w(w) {}
44
45     bool operator<(const edge &a) const {
46         return w < a.w;
47     }
48 };
49
50 int kruskal(int n, vector<edge>& edges) {
51     DSU dsu(n);
52
53     sort(edges.begin(), edges.end());
54
55     int weight = 0;
56     for(int i = 0; i < (int)edges.size(); i++) {
57         if(dsu.Union(edges[i].u, edges[i].v)) {
58             weight += edges[i].w;
59         }
60     }
61
62     // returns weight of mst
63     return weight;
64 }
65 }

```

5.17. Lca

```

1 // #define DIST
2 // #define COST
3 /// UNCOMMENT ALSO THE LINE BELOW FOR COST!
4
5 class LCA {
6     private:
7         int n;
8         // INDEXED from 0 or 1??
9         int indexed_from;
10        /// Store all log2 from 1 to n
11        vector<int> lg;
12        // level of the i-th node (height)
13        vector<int> level;
14        // matrix to store the ancestors of each node in power of 2 levels
15        vector<vector<int>>> anc;
16
17        #ifdef DIST
18            vector<int> dist;
19        #endif
20        #ifdef COST
21            // int NEUTRAL_VALUE = -INF; // MAX COST
22            // int combine(const int a, const int b) {return max(a, b);}
23            // int NEUTRAL_VALUE = INF; // MIN COST
24            // int combine(const int a, const int b) {return min(a, b);}
25            vector<vector<int>>> cost;
26        #endif

```

```

27
28     private:
29     void allocate() {
30         // initializes a matrix [n][lg n] with -1
31         this->build_log_array();
32         this->anc.resize(n + 1, vector<int>(lg[n] + 1, -1));
33         this->level.resize(n + 1, -1);
34
35         #ifdef DIST
36             this->dist.resize(n + 1, 0);
37         #endif
38         #ifdef COST
39             this->cost.resize(n + 1, vector<int>(lg[n] + 1, NEUTRAL_VALUE));
40         #endif
41     }
42
43     void build_log_array() {
44         this->lg.resize(this->n + 1);
45
46         for(int i = 2; i <= this->n; i++)
47             this->lg[i] = this->lg[i/2] + 1;
48     }
49
50     void build_anc() {
51         for(int j = 1; j < anc.front().size(); j++)
52             for(int i = 0; i < anc.size(); i++)
53                 if(this->anc[i][j - 1] != -1) {
54                     this->anc[i][j] = this->anc[this->anc[i][j - 1]][j - 1];
55                     #ifdef COST
56                         this->cost[i][j] = combine(this->cost[i][j - 1],
57 this->cost[anc[i][j - 1]][j - 1]);
58                     #endif
59                 }
60
61     void build_weighted(const vector<vector<pair<int, int>>> &adj) {
62         this->dfs_LCA_weighted(this->indexed_from, -1, 1, 0, adj);
63
64         this->build_anc();
65     }
66
67     void dfs_LCA_weighted(const int u, const int p, const int l, const int d,
68 const vector<vector<pair<int, int>>> &adj) {
69         this->level[u] = l;
70         this->anc[u][0] = p;
71         #ifdef DIST
72             this->dist[u] = d;
73         #endif
74
75         for(const pair<int, int> &x: adj[u]) {
76             int v = x.first, w = x.second;
77             if(v == p)
78                 continue;
79             #ifdef COST
80                 this->cost[v][0] = w;
81             #endif
82             this->dfs_LCA_weighted(v, u, l + 1, d + w, adj);
83         }
84
85     void build_unweighted(const vector<vector<int>>> &adj) {
86         this->dfs_LCA_unweighted(this->indexed_from, -1, 1, 0, adj);
87
88         this->build_anc();
89     }

```

```

90
91 void dfs_LCA_unweighted(const int u, const int p, const int l, const int
92     d, const vector<vector<int>> &adj) {
93     this->level[u] = l;
94     this->anc[u][0] = p;
95     #ifdef DIST
96         this->dist[u] = d;
97     #endif
98
99     for(const int v: adj[u]) {
100         if(v == p)
101             continue;
102         this->dfs_LCA_unweighted(v, u, l + 1, d + 1, adj);
103     }
104
105     // go up k levels from x
106     int lca_go_up(int x, int k) {
107         for(int i = 0; k > 0; i++, k >>= 1)
108             if(k & 1) {
109                 x = this->anc[x][i];
110                 if(x == -1)
111                     return -1;
112             }
113
114         return x;
115     }
116
117     #ifdef COST
118     /// Query between the an ancestor of v (p) and v. It returns the
119     /// max/min edge between them.
120     int lca_query_cost_in_line(int v, int p) {
121         assert(this->level[v] >= this->level[p]);
122
123         int k = this->level[v] - this->level[p];
124         int ans = NEUTRAL_VALUE;
125
126         for(int i = 0; k > 0; i++, k >>= 1)
127             if(k & 1) {
128                 ans = combine(ans, this->cost[v][i]);
129                 v = this->anc[v][i];
130             }
131
132         return ans;
133     }
134     #endif
135
136     int get_lca(int a, int b) {
137         // a is below b
138         if(this->level[b] > this->level[a])
139             swap(a, b);
140
141         const int logg = lg[this->level[a]];
142
143         // putting a and b in the same level
144         for(int i = logg; i >= 0; i--)
145             if(this->level[a] - (1 << i) >= this->level[b])
146                 a = this->anc[a][i];
147
148         if(a == b)
149             return a;
150
151         for(int i = logg; i >= 0; i--)
152             if(this->anc[a][i] != -1 && this->anc[a][i] != this->anc[b][i]) {
153                 a = this->anc[a][i];

```

```

154         b = this->anc[b][i];
155     }
156
157     return anc[a][0];
158 }
159
160 public:
161     /// Builds an weighted graph.
162     ///
163     /// Time Complexity: O(n*log(n))
164     explicit LCA(const vector<vector<pair<int, int>>> &adj, const int
165         indexed_from) {
166         this->n = adj.size();
167         this->indexed_from = indexed_from;
168         this->allocate();
169
170         this->build_weighted(adj);
171     }
172
173     /// Builds an unweighted graph.
174     ///
175     /// Time Complexity: O(n*log(n))
176     explicit LCA(const vector<vector<int>> &adj, const int indexed_from) {
177         this->n = adj.size();
178         this->indexed_from = indexed_from;
179         this->allocate();
180
181         this->build_unweighted(adj);
182     }
183
184     /// Goes up k levels from v. If it passes the root, returns -1.
185     ///
186     /// Time Complexity: O(log(k))
187     int go_up(const int v, const int k) {
188         assert(indexed_from <= v); assert(v < this->n + indexed_from);
189
190         return this->lca_go_up(v, k);
191     }
192
193     /// Returns the parent of v in the LCA dfs from 1.
194     ///
195     /// Time Complexity: O(1)
196     int parent(int v) {
197         assert(indexed_from <= v); assert(v < this->n + indexed_from);
198
199         return this->anc[v][0];
200     }
201
202     /// Returns the LCA of a and b.
203     ///
204     /// Time Complexity: O(log(n))
205     int query_lca(const int a, const int b) {
206         assert(indexed_from <= min(a, b)); assert(max(a, b) < this->n +
207             indexed_from);
208
209         return this->get_lca(a, b);
210     }
211
212     #ifdef DIST
213     /// Returns the distance from a to b. When the graph is unweighted, it is
214     /// considered
215     /// 1 as the weight of the edges.
216     ///
217     /// Time Complexity: O(log(n))
218     int query_dist(const int a, const int b) {

```

```

216     assert(indexed_from <= min(a, b)); assert(max(a, b) < this->n +
        indexed_from);
217
218     return this->dist[a] + this->dist[b] - 2*this->dist[this->get_lca(a, b)];
219 }
220 #endif
221
222 #ifdef COST
223 /// Returns the max/min weight edge from a to b.
224 ///
225 /// Time Complexity: O(log(n))
226 int query_cost(const int a, const int b) {
227     assert(indexed_from <= min(a, b)); assert(max(a, b) < this->n +
        indexed_from);
228
229     const int l = this->query_lca(a, b);
230     return combine(this->lca_query_cost_in_line(a, l),
        this->lca_query_cost_in_line(b, l));
231 }
232 #endif
233 };

```

5.18. Maximum Path Unweighted Graph

```

1  /// Returns the maximum path between the vertices 0 and n - 1 in a
    unweighted graph.
2  ///
3  /// Time Complexity: O(V + E)
4  int maximum_path(int n) {
5      vector<int> top_order = topological_sort(n);
6      vector<int> pai(n, -1);
7      if(top_order.empty())
8          return -1;
9
10     vector<int> dp(n);
11     dp[0] = 1;
12     for(int u: top_order)
13         for(int v: adj[u])
14             if(dp[u] && dp[u] + 1 > dp[v]) {
15                 dp[v] = dp[u] + 1;
16                 pai[v] = u;
17             }
18
19     if(dp[n - 1] == 0)
20         return -1;
21
22     vector<int> path;
23     int cur = n - 1;
24     while(cur != -1) {
25         path.pb(cur);
26         cur = pai[cur];
27     }
28     reverse(path.begin(), path.end());
29
30     // cout << path.size() << endl;
31     // for(int x: path) {
32     //     cout << x + 1 << ' ';
33     // }
34     // cout << endl;
35
36     return dp[n - 1];
37 }

```

5.19. Number Of Different Spanning Trees In A Complete Graph

```

1  Cayley's formula
2
3   $n^{n-2}$ 

```

5.20. Number Of Ways To Make A Graph Connected

```

1   $s_{\{1\}} * s_{\{2\}} * s_{\{3\}} * (...) * s_{\{k\}} * (n^{n-k})$ 
2  n = number of vertices
3  s_{i} = size of the i-th connected component
4  k = number of connected components

```

5.21. Pruffer Decode

```

1  // IT MUST BE INDEXED BY 0.
2  /// Returns the adjacency matrix of the decoded tree.
3  ///
4  /// Time Complexity: O(V)
5  vector<vector<int>> pruefer_decode(const vector<int> &code) {
6
7      int n = code.size() + 2;
8      vector<vector<int>> adj = vector<vector<int>>(n, vector<int>());
9
10     vector<int> degree(n, 1);
11     for (int x : code)
12         degree[x]++;
13
14     int ptr = 0;
15     while (degree[ptr] > 1)
16         ++ptr;
17
18     int nxt = ptr;
19     for (int u : code) {
20         adj[u].push_back(nxt);
21         adj[nxt].push_back(u);
22
23         if (--degree[u] == 1 && u < ptr)
24             nxt = u;
25         else {
26             while (degree[++ptr] > 1)
27                 ;
28             nxt = ptr;
29         }
30     }
31     adj[n - 1].push_back(nxt);
32     adj[nxt].push_back(n - 1);
33
34     return adj;
35 }

```

5.22. Pruffer Encode

```

1  void dfs(int v, const vector<vector<int>> &adj, vector<int> &parent) {
2      for (int u : adj[v]) {
3          if (u != parent[v]) {
4              parent[u] = v;
5              dfs(u, adj, parent);
6          }
7      }
8  }
9
10 // IT MUST BE INDEXED BY 0.

```

```

11 /// Returns prueffer code of the tree.
12 ///
13 /// Time Complexity: O(V)
14 vector<int> prueffer_code(const vector<vector<int>> &adj) {
15     int n = adj.size();
16     vector<int> parent(n);
17     parent[n - 1] = -1;
18     dfs(n - 1, adj, parent);
19
20     int ptr = -1;
21     vector<int> degree(n);
22     for (int i = 0; i < n; i++) {
23         degree[i] = adj[i].size();
24         if (degree[i] == 1 && ptr == -1)
25             ptr = i;
26     }
27
28     vector<int> code(n - 2);
29     int leaf = ptr;
30     for (int i = 0; i < n - 2; i++) {
31         int next = parent[leaf];
32         code[i] = next;
33         if (--degree[next] == 1 && next < ptr)
34             leaf = next;
35         else {
36             ptr++;
37             while (degree[ptr] != 1)
38                 ptr++;
39             leaf = ptr;
40         }
41     }
42
43     return code;
44 }

```

5.23. Prüfer Properties

- 1 * After constructing the Prüfer code two vertices will remain. One of them is the highest vertex $n-1$, but nothing **else** can be said about the other one.
- 2 * Each vertex appears in the Prüfer code exactly a fixed number of times - its degree minus one. This can be easily checked, since the degree will get smaller every time we record its label in the code, **and** we remove it once the degree is 1. For the two remaining vertices **this** fact is also **true**.

5.24. Remove All Bridges From Graph

- 1 1. Start a DFS **and** store the leafs in an array.
- 2 2. Connect the first leaf vertex in the array with the one in the middle,
- 3 the second one **and** the middle + 1, **and** so on.

5.25. Shortest Cycle In A Graph

```

1 int bfs(int vt) {
2
3     vector<int> dist(MAXN, INF);
4     queue<pair<int, int>> q;
5
6     q.emplace(vt, -1);
7     dist[vt] = 0;
8

```

```

9     int ans = INF;
10    while (!q.empty()) {
11        pair<int, int> aux = q.front();
12        int u = aux.first, p = aux.second;
13        q.pop();
14
15        for (int v : adj[u]) {
16            if (v == p)
17                continue;
18            if (dist[v] < INF)
19                ans = min(ans, dist[u] + dist[v] + 1);
20            else {
21                dist[v] = dist[u] + 1;
22                q.emplace(v, u);
23            }
24        }
25    }
26
27    return ans;
28 }
29
30 /// Returns the shortest cycle in the graph
31 ///
32 /// Time Complexity: O(V^2)
33 int get_girth(int n) {
34     int ans = INF;
35     for (int u = 1; u <= n; u++)
36         ans = min(ans, bfs(u));
37     return ans;
38 }

```

5.26. Topological Sort

```

1 /// INDEXED BY ZERO
2 ///
3 /// Time Complexity: O(n)
4 vector<int> topological_sort(int n) {
5     vector<int> in_degree(n, 0);
6
7     for(int u = 0; u < n; u++)
8         for(int v: adj[u])
9             in_degree[v]++;
10
11     queue<int> q;
12     for(int i = 0; i < n; i++)
13         if(in_degree[i] == 0)
14             q.push(i);
15
16     int cnt = 0;
17     vector<int> top_order;
18     while(!q.empty()) {
19         int u = q.front();
20         q.pop();
21
22         top_order.push_back(u);
23         cnt++;
24
25         for(int v: adj[u])
26             if(--in_degree[v] == 0)
27                 q.push(v);
28     }
29
30     if(cnt != n) {
31         cerr << "There exists a cycle in the graph" << endl;

```

```

32     return vector<int>();
33 }
34
35 return top_order;
36 }

```

5.27. Tree Distance

```

1 vector<pair<int, int>> sub(MAXN, pair<int, int>(0, 0));
2
3 void subu(int u, int p) {
4     for (const pair<int, int> x : adj[u]) {
5         int v = x.first, w = x.second;
6         if (v == p)
7             continue;
8         subu(v, u);
9         if (sub[v].first + w > sub[u].first) {
10             swap(sub[u].first, sub[u].second);
11             sub[u].first = sub[v].first + w;
12         } else if (sub[v].first + w > sub[u].second) {
13             sub[u].second = sub[v].first + w;
14         }
15     }
16 }
17
18 // Contains the maximum distance to the node i
19 vector<int> ans(MAXN);
20
21 void dfs(int u, int d, int p) {
22     ans[u] = max(d, sub[u].first);
23     for (const pair<int, int> x : adj[u]) {
24         int v = x.first, w = x.second;
25         if (v == p)
26             continue;
27         if (sub[v].first + w == ans[u]) {
28             dfs(v, max(d, sub[u].second) + w, u);
29         } else {
30             dfs(v, ans[u] + w, u);
31         }
32     }
33 }
34
35 // Returns the maximum tree distance
36 int solve() {
37     subu(0, -1);
38     dfs(0, 0, -1);
39     return *max_element(ans.begin(), ans.end());
40 }

```

6. Language Stuff

6.1. Binary String To Int

```

1 int y = bitset<qtdDeBits>(stringVar).to_ulong();
2 Ex: x = 1010, qtdDeBits = 32;
3 y = bitset<32>(x).to_ulong(); // y = 10

```

6.2. Climits

```

1 LONG_MIN -> (-2^31+1) :: LONG_MAX -> (2^31-1)
2 ULONG_MAX -> (2^32-1) -> UNSIGNED
3 LLONG_MIN, LLONG_MAX, ULLONG_MAX

```

6.3. Checagem Brute Force Com Solucao

```

1 $ g++ -std=c++11 gen.cpp && ./a.out > gen.out && g++ -std=c++11 brute.cpp &&
   (./a.out < gen.in) > brute.out && g++ -std=c++11 sol.cpp && (./a.out <
   gen.in) > sol.out && diff brute.out sol.out

```

6.4. Checagem De Bits

```

1 // OBS: SO FUNCIONA PARA INT (NAO FUNCIONA COM LONG LONG)
2 __builtin_popcount(int) -> Número de bits ativos;
3 __builtin_ctz(int) -> Número de zeros à direita
4 __builtin_clz(int) -> Número de zeros à esquerda
5 __builtin_parity(int) -> Retorna se a quantidade de uns é ímpar(1) ou par(0)

```

6.5. Checagem E Transformacao De Caractere

```

1 #include <cctype>
2 isdigit(str[i]); //checa se str[i] é número
3 isalpha(str[i]); //checa se é uma letra
4 islower(str[i]); //checa minúsculo
5 isupper(str[i]); //checa maiúsculo
6 isalnum(str[i]); //checa letra ou número
7 tolower(str[i]); //converte para minusculo
8 toupper(str[i]); //converte para maiusculo

```

6.6. Conta Digitos 1 Ate N

```

1 int solve(int n) {
2
3     int maxx = 9, minn = 1, dig = 1, ret = 0;
4
5     for(int i = 1; i <= 17; i++) {
6         int q = min(maxx, n);
7         ret += max(0ll, (q - minn + 1) * dig);
8         maxx = (maxx * 10 + 9), minn *= 10, dig++;
9     }
10
11     return ret;
12 }

```

6.7. Escrita Em Arquivo

```

1 ofstream cout("output.txt");

```

6.8. Gcd

```

1 int __gcd(int a, int b){
2     if(a == 0 || b == 0) return 0;
3     else return abs(__gcd(a,b));
4 }

```

6.9. Hipotenusa

```

1 cout << hypot(3,4); // output: 5

```

6.10. Int To Binary String

```
1 string s = bitset<qtdDeBits>(intVar).to_string();
2 Ex: x = 10, qtdDeBits = 32;
3 s = bitset<32>(x).to_string(); // s = 00...0001010
```

6.11. Int To String

```
1 int a; string b;
2 b = to_string(a);
```

6.12. Leitura De Arquivo

```
1 ifstream cin("input.txt");
```

6.13. Max E Min Element Num Vektor

```
1 int maior = *max_element(arr.begin(), arr.end());
2 int menor = *min_element(arr.begin(), arr.end());
3 // OBS: Retorna iterator
```

6.14. Permutacao

```
1 int v[] = {1,2,3};
2 sort(v, v+3);
3 do {
4     cout << v[0] << ' ' << v[1] << ' ' << v[2];
5 } while(next_permutation(v, v+3));
```

6.15. Printf De Uma String

```
1 char buffer [50];
2 int n, a=5, b=3;
3 n=sprintf (buffer, "%d plus %d is %d", a, b, a+b);
4 printf ("%s] is a string %d chars long\n",buffer,n);
5 // Output:
6 // [5 plus 3 is 8] is a string 13 chars long
```

6.16. Remove Repeticoes Continuas Num Vektor

```
1 // arr = {10,20,20,20,30,20,20,10}
2 it = unique(arr.begin(), arr.end());
3 // arr = {10,20,30,20,10, iterator aponta pra aqui, ...}
4 arr.resize(distance(arr.begin(), it));
5 // arr = {10,20,30,20,10}
```

6.17. Rotate (Left)

```
1 Passado o inicio o meio e o fim ele rotaciona de forma que o meio seja o
  novo inicio.
2 vector<int> arr(n); // 1 2 3 4 5 6 7 8 9
3 rotate(arr.begin(),arr.begin()+3,arr.end()); //4 5 6 7 8 9 1 2 3
```

6.18. Rotate (Right)

```
1 vector<int> arr(n); // 1 2 3 4 5 6 7 8 9
2 rotate(arr.begin(),arr.rbegin()+3,arr.rend()); //7 8 9 1 2 3 4 5 6
```

6.19. Scanf De Uma String

```
1 char sentence[]="Rudolph is 12 years old";
2 char str [20]; int i;
3 sscanf (sentence,"%s %s %d",str,&i);
4 printf ("%s -> %d\n",str,i);
5 // Output: Rudolph -> 12
```

6.20. Split Function

```
1 // SEPARA STRING POR UM DELIMITADOR
2 // EX: str=A-B-C split -> x = {A,B,C}
3 vector<string> split(const string &s, char delim) {
4     stringstream ss(s);
5     string item;
6     vector<string> tokens;
7     while (getline(ss, item, delim)) {
8         tokens.push_back(item);
9     }
10    return tokens;
11 }
12 int main () {
13     vector<string> x = split("cap-one-best-opinion-language", '-');
14     // x = {cap,one,best,opinion,language};
15 }
```

6.21. String To Long Long

```
1 string s = "0xFFFF"; int base = 16;
2 string::size_type sz = 0;
3 int ll = stoll(s,&sz,base); // ll = 65535, sz = 6;
4 OBS: Não precisa colocar o sz, pode colocar 0; // stoll(s,0,base);
```

6.22. Substring

```
1 string s = "abcdef";
2 s.substr(posição inicial, qtd de char(opcional));
3 string s2 = s.substr(3,2); // s2 = "de"
4 string s3 = s.substr(2); // s3 = "cdef"
```

6.23. Width

```
1 cout << width(13);
2 cout << 100 << endl; // "      100      "
3 cout.fill('x');
4 cout.width(13);
5 cout << 100 << endl; // "xxxxx100xxxxx"
6 cout << right << 100 << endl; "xxxxxxx100"
```

6.24. Check Overflow

```
1 bool __builtin_add_overflow (type1 a, type2 b, type3 *res)
2 bool __builtin_sadd_overflow (int a, int b, int *res)
3 bool __builtin_saddl_overflow (long int a, long int b, long int *res)
4 bool __builtin_saddll_overflow (long long int a, long long int b, long long
  int *res)
5 bool __builtin_uadd_overflow (unsigned int a, unsigned int b, unsigned int
  *res)
6 bool __builtin_uaddl_overflow (unsigned long int a, unsigned long int b,
  unsigned long int *res)
```

```

7 bool __builtin_uaddll_overflow (unsigned long long int a, unsigned long long
  int b, unsigned long long int *res)
8
9 bool __builtin_sub_overflow (type1 a, type2 b, type3 *res)
10 bool __builtin_ssub_overflow (int a, int b, int *res)
11 bool __builtin_ssubl_overflow (long int a, long int b, long int *res)
12 bool __builtin_ssubll_overflow (long long int a, long long int b, long long
  int *res)
13 bool __builtin_usub_overflow (unsigned int a, unsigned int b, unsigned int
  *res)
14 bool __builtin_usubl_overflow (unsigned long int a, unsigned long int b,
  unsigned long int *res)
15 bool __builtin_usubll_overflow (unsigned long long int a, unsigned long long
  int b, unsigned long long int *res)
16
17 bool __builtin_mul_overflow (type1 a, type2 b, type3 *res)
18 bool __builtin_smul_overflow (int a, int b, int *res)
19 bool __builtin_smull_overflow (long int a, long int b, long int *res)
20 bool __builtin_smulll_overflow (long long int a, long long int b, long long
  int *res)
21 bool __builtin_umul_overflow (unsigned int a, unsigned int b, unsigned int
  *res)
22 bool __builtin_umull_overflow (unsigned long int a, unsigned long int b,
  unsigned long int *res)
23 bool __builtin_umulll_overflow (unsigned long long int a, unsigned long long
  int b, unsigned long long int *res)

```

6.25. Readint

```

1 int readInt(){
2     int a = 0;
3     char c;
4     while( !(c >= '0' && c <= '9') ) c = getchar();
5     while( c>= '0' && c <= '9') a = 10*a + (c - '0') , c = getchar();
6     return a;
7 }

```

7. Math

7.1. Bell Numbers

```

1 int bellNumber(int n) {
2     int bell[n+1][n+1];
3     bell[0][0] = 1;
4     for (int i=1; i<=n; i++) {
5         // Explicitly fill for j = 0
6         bell[i][0] = bell[i-1][i-1];
7
8         // Fill for remaining values of j
9         for (int j=1; j<=i; j++)
10             bell[i][j] = bell[i-1][j-1] + bell[i][j-1];
11     }
12     return bell[n][0];
13 }

```

7.2. Checagem De Primalidade

```

1 bool isPrime(int n) {
2     if (n <= 1) return false;
3     if (n <= 3) return true;
4     // This is checked so that we can skip
5     // middle five numbers in below loop

```

```

6     if (n%2 == 0 || n%3 == 0)
7         return false;
8     for (int i=5; i*i<=n; i += 6)
9         if (n%i == 0 || n%(i+2) == 0)
10            return false;
11     return true;
12 }

```

7.3. Combinacao Ncr Mod Primo

```

1 inv[1] = 1;
2 for(int i = 2; i < m; ++i)
3     inv[i] = (m - (m/i) * inv[m%i] % m) % m;
4
5 factorial[0] = 1;
6 for (int i = 1; i <= MAXN; i++) {
7     factorial[i] = factorial[i - 1] * i % m;
8 }
9
10 int binomial_coefficient(int n, int k) {
11     return factorial[n] * inverse(factorial[k]) % m * inverse(factorial[n -
  k]) % m;
12 }

```

7.4. Combinacao Ncr

```

1 // Returns value of Binomial Coefficient C(n, k)
2 int binomialCoeff(int n, int k) {
3     int res = 1;
4     // Since C(n, k) = C(n, n-k)
5     if (k > n - k)
6         k = n - k;
7     // Calculate value of [n*(n-1)*---*(n-k+1)] / [k*(k-1)*---*1]
8     for (int i = 0; i < k; ++i) {
9         res *= (n - i);
10        res /= (i + 1);
11    }
12    return res;
13 }

```

7.5. Compressao De Pontos

```

1 map<int, int> rev;
2 for(int x : arr) {
3     sl.insert(x);
4 }
5 vector<int> aux;
6 for(int x : sl) aux.pb(x);
7 for(int i=0; i<n; i++){
8     int id = lower_bound(aux.begin(), aux.end(), arr[i]) - aux.begin();
9     rev[id] = arr[i];
10    arr[i] = id;
11 }

```

7.6. Equacao Diofantina

```

1 int gcd(int a, int b, int &x, int &y) {
2     if (a == 0) {
3         x = 0; y = 1;
4         return b;
5     }

```



```

6  int x1, y1;
7  int d = gcd(b%a, a, x1, y1);
8  x = y1 - (b / a) * x1;
9  y = x1;
10 return d;
11 }
12
13 bool find_any_solution(int a, int b, int c, int &x0, int &y0, int &g) {
14     g = gcd(abs(a), abs(b), x0, y0);
15     if (c % g)
16         return false;
17
18     x0 *= c / g;
19     y0 *= c / g;
20     if (a < 0) x0 = -x0;
21     if (b < 0) y0 = -y0;
22     return true;
23 }

```

7.7. Euclides Estendido

```

1  int gcd(x,y;
2
3  //Ax + By = gcd(A,B)
4
5  void extendedEuclidian(int a,int b){
6
7      if(b==0){
8          gcd=a;
9          x=1;
10         y=0;
11     } else{
12         extendedEuclidian(b, a%b);
13
14         int temp = x;
15         x=y;
16         y = temp - (a/b)*y;
17     }
18 }

```

7.8. Euler Totient

```

1  int phi(int n) {
2      int result = n;
3      for (int i = 2; i * i <= n; i++) {
4          if(n % i == 0) {
5              while(n % i == 0)
6                  n /= i;
7              result -= result / i;
8          }
9      }
10
11     if(n > 1)
12         result -= result / n;
13     return result;
14 }

```

7.9. Fatoracao Multiplas Queries

```

1  //stor smallest prime factor for every num
2  int spf[MAXN];
3  // Calculating SPF (Smallest Prime Factor) for every number till MAXN.

```

```

4  // Time Complexity : O(nloglogn)
5  void sieve() {
6      spf[1] = 1;
7      for (int i=2; i<MAXN; i++)
8          // marking smallest prime factor for every number to be itself.
9          spf[i] = i;
10
11     // separatelyMarking spf for every even
12     // number as 2
13     for (int i=4; i<MAXN; i+=2)
14         spf[i] = 2;
15
16     for (int i=3; i<MAXN; i++) {
17         // checking if i is prime
18         if (spf[i] == i){
19             // marking SPF for all numbers divisible by i
20             for (int j=i*i; j<MAXN; j+=i)
21                 // marking spf[j] if it is not previously marked
22                 if (spf[j]==0)
23                     spf[j] = i;
24         }
25     }
26 }
27 // A O(log n) function returning primefactorization
28 // by dividing by smallest prime factor at every step
29 vector<int> getFactorization(int x) {
30     vector<int> ret;
31     while (x != 1) {
32         ret.push_back(spf[x]);
33         x = x / spf[x];
34     }
35     return ret;
36 }

```

7.10. Fatoracao Simples

```

1  map<int, int> primeFactors(int n) {
2      set<int> ret;
3      while (n%2 == 0) {
4          m[2]++;
5          n = n/2;
6      }
7
8      int sq = sqrt(n);
9      for (int i = 3; i <= sq; i = i+2) {
10         while (n%i == 0) {
11             m[i]++;
12             n = n/i;
13         }
14         /* OBS1
15         IF(N < 1E7)
16             FATORE COM SPF
17         */
18     }
19
20     if (n > 2)
21         m[n]++;
22
23     return ret;
24 }

```

7.11. Numero De Fatores

```

1 int calcFat(vector<int> fatores) {
2     int x = fatores[1];
3     auto lo = lower_bound(fatores.begin(), fatores.end(), x);
4     auto up = upper_bound(fatores.begin(), fatores.end(), x);
5     int fat = 1;
6     while(up != fatores.end()) {
7         fat *= (up-lo+1);
8         lo = lower_bound(fatores.begin(), fatores.end(), *up);
9         up = upper_bound(fatores.begin(), fatores.end(), *up);
10    }
11    fat *= (up-lo+1);
12    return fat;
13 }

```

7.12. Pollard Rho (Find A Divisor)

```

1 /* Function to calculate (base^exponent)%modulus */
2 int modular_pow(int base, int exponent,
3                 int modulus) {
4     /* initialize result */
5     int result = 1;
6     while (exponent > 0) {
7         /* if y is odd, multiply base with result */
8         if (exponent & 1)
9             result = (result * base) % modulus;
10        /* exponent = exponent/2 */
11        exponent = exponent >> 1;
12        /* base = base * base */
13        base = (base * base) % modulus;
14    }
15    return result;
16 }
17
18 /* method to return prime divisor for n */
19 int PollardRho(int n) {
20     /* initialize random seed */
21     srand (time(NULL));
22
23     /* no prime divisor for 1 */
24     if (n==1) return n;
25
26     /* even number means one of the divisors is 2 */
27     if (n % 2 == 0) return 2;
28
29     /* we will pick from the range [2, N) */
30     int x = (rand()%(n-2))+2;
31     int y = x;
32
33     /* the constant in f(x).
34     * Algorithm can be re-run with a different c
35     * if it throws failure for a composite. */
36     int c = (rand()%(n-1))+1;
37
38     /* Initialize candidate divisor (or result) */
39     int d = 1;
40
41     /* until the prime factor isn't obtained.
42     If n is prime, return n */
43     while (d==1) {
44         /* Tortoise Move: x(i+1) = f(x(i)) */
45         x = (modular_pow(x, 2, n) + c + n)%n;
46
47         /* Hare Move: y(i+1) = f(f(y(i))) */

```

```

48         y = (modular_pow(y, 2, n) + c + n)%n;
49         y = (modular_pow(y, 2, n) + c + n)%n;
50
51         /* check gcd of |x-y| and n */
52         d = __gcd(abs(x-y), n);
53
54         /* retry if the algorithm fails to find prime factor
55         * with chosen x and c */
56         if (d==n) return PollardRho(n);
57     }
58
59     return d;
60 }
61
62 /* driver function */
63 signed main() {
64     int n = 12;
65     printf("One of the divisors for %lld is %lld.",
66           n, PollardRho(n));
67     return 0;
68 }

```

7.13. Precomputar Combinacao Ncr

```

1 int C[1123][1123];
2
3 int mod(int n) {return n%((int)1e9+7);}
4
5 int nCr(int n, int k) {
6     for(int i = 0; i <= n; i++) {
7         for(int j = 0; j <= min(i,k); j++) {
8             if(j == 0 || j == i) {
9                 C[i][j] = 1;
10            } else {
11                C[i][j] = mod(C[i-1][j-1] + C[i-1][j]);
12            }
13        }
14    }
15 }

```

7.14. Teorema Chines Do Resto

```

1 int inv(int a, int m) {
2     int m0 = m, t, q;
3     int x0 = 0, x1 = 1;
4
5     if (m == 1)
6         return 0;
7
8     // Apply extended Euclid Algorithm
9     while (a > 1) {
10        // q is quotient
11        if (m == 0)
12            return INF;
13        q = a / m;
14        t = m;
15        // m is remainder now, process same as euclid's algo
16        m = a % m, a = t;
17        t = x0;
18        x0 = x1 - q * x0;
19        x1 = t;
20    }
21 }

```

```

22 // Make x1 positive
23 if (x1 < 0)
24     x1 += m0;
25 // debug(x1);
26
27 return x1;
28 }
29 // k is size of num[] and rem[]. Returns the smallest
30 // number x such that:
31 // x % num[0] = rem[0],
32 // x % num[1] = rem[1],
33 // .....
34 // x % num[k-2] = rem[k-1]
35 // Assumption: Numbers in num[] are pairwise coprimes
36 // (gcd for every pair is 1)
37 int findMinX(int num[], int rem[], int k){
38     // Compute product of all numbers
39     int prod = 1;
40     for (int i = 0; i < k; i++)
41         prod *= num[i];
42
43     // Initialize result
44     int result = 0;
45
46     // Apply above formula
47     for (int i = 0; i < k; i++){
48         int pp = prod / num[i];
49         // debug(pp);
50         int iv = inv(pp, num[i]);
51         if(iv == INF)
52             return INF;
53         result += rem[i] * inv(pp, num[i]) * pp;
54     }
55
56     // IF IS NOT VALID RETURN INF
57     return (result % prod == 0 ? INF : result % prod);
58 }

```

7.15. Binary Exponentiation

```

1 int power(const int x, const int p, const int MOD = ((int)1e9 + 7)) {
2     if(p == 0)
3         return 1%MOD;
4     if(p == 1)
5         return x%MOD;
6     int res = power(x, p/2, MOD);
7     res = (long long)res*res%MOD;
8     if(p&1)
9         res = (long long)res*x%MOD;
10    return res;
11 }

```

7.16. Combinatorics

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4
5 #define eb emplace_back
6 #define ii pair<int, int>
7 #define OK (cerr << "OK" << endl)
8 #define debug(x) cerr << #x " = " << (x) << endl
9 #define ff first

```

```

10 #define ss second
11 #define int long long
12 #define tt tuple<int, int, int>
13 #define all(x) x.begin(), x.end()
14 #define Matrix vector<vector<int>>
15 #define Mat(n, m, v) vector<vector<int>>(n, vector<int>(m, v))
16 #define endl '\n'
17
18 constexpr int INF = 2e18;
19 constexpr int MOD = 1e9 + 7;
20 constexpr int MAXN = 2e5 + 3;
21
22 class Combinatorics {
23     constexpr int MOD = 1e9 + 7;
24     const int max_val;
25     vector<int> inv, fat;
26
27     int mod(int x) {
28         x %= MOD;
29         if (x < 0)
30             x += MOD;
31         return MOD;
32     }
33
34     vector<int> build_inverse(const int max_val) {
35         vector<int> inv(max_val + 1);
36         inv[1] = 1;
37         for (int i = 2; i <= max_val; ++i)
38             inv[i] = mod(-MOD / i * inv[MOD % i]);
39         return inv;
40     }
41
42     vector<int> build_fat(const int max_val) {
43         vector<int> fat(max_val + 1);
44         fat[0] = 1;
45         for (int i = 1; i <= max_val; ++i)
46             fat[i] = mod(i * fat[i - 1]);
47         return fat;
48     }
49
50 public:
51     Combinatorics(const int max_val) : max_val(max_val) {
52         assert(1 <= max_val), assert(max_val <= MOD);
53         this->inv = this->build_inverse(max_val);
54         this->fat = this->build_fat(max_val);
55     }
56
57     int choose(const int n, const int k) {
58         assert(0 <= k), assert(k <= n), assert(n <= this->max_val);
59         return mod(this->fat[n] * mod(this->fat[k] * this->fat[n - k]));
60     }
61 };
62
63 void solve() {
64     Combinatorics c(6);
65     int n, k;
66     cin >> n >> k;
67
68     cout << c.choose(n, k) << endl;
69 }
70
71 signed main() {
72
73     ios_base::sync_with_stdio(false);
74     cin.tie(NULL);

```

```

75
76 int t;
77
78 // cin >> t;
79 t = 1;
80 while (t--)
81     solve();
82 }

```

7.17. Divisors

```

1 // OBS: EACH NUMBER HAS AT MOST  $\sqrt[3]{N}$  DIVISORS
2 vector<int> divisors(int n) {
3     vector<int> ans;
4     for (int i=1; i * i <= n; i++) {
5         if (n%i==0) {
6             // If divisors are equal, print only one
7             if (n/i == i)
8                 ans.pb(i);
9             else // Otherwise print both
10                ans.pb(i), ans.pb(n/i);
11         }
12     }
13     return ans;
14 }

```

7.18. Inclusion Exclusion

$$\left| \bigcup_{i=1}^n A_i \right| = \sum_{k=1}^n (-1)^{k+1} \left(\sum_{1 \leq i_1 < \dots < i_k \leq n} |A_{i_1} \cap \dots \cap A_{i_k}| \right)$$

7.19. Inclusion Exclusion

```

1 // |A ∪ B ∪ C| = |A| + |B| + |C| - |A ∩ B| - |A ∩ C| - |B ∩ C| + |A ∩ B ∩ C|
2
3 // EXEMPLO: Quantos números de 1 a 10^9 são múltiplos de 42, 54, 137 ou 201?
4
5 int f(vector<int> arr, int LIMIT) {
6
7     int n = arr.size();
8     int c = 0;
9
10    for(int mask = 1; mask < (1<<n); mask++) {
11        int lcm = 1;
12        for(int i = 0; i < n; i++)
13            if(mask & (1<<i))
14                lcm = lcm * arr[i] / __gcd(lcm, arr[i]);
15        // se o numero de conjutos a unir for impar entao soma
16        if(__builtin_popcount(mask) % 2 == 1)
17            c += LIMIT/lcm;
18        else // se nao subtrai
19            c -= LIMIT/lcm;
20    }
21
22    return LIMIT-c;

```

```

23
24 }

```

7.20. Matrix Exponentiation

```

1 namespace matrix {
2 #define Matrix vector<vector<int>>
3 const int MOD = 1e9 + 7;
4
5 /// Creates an n x n identity matrix.
6 ///
7 /// Time Complexity: O(n*n)
8 Matrix identity(const int n) {
9     assert(n > 0);
10
11     Matrix mat_identity(n, vector<int>(n, 0));
12
13     for (int i = 0; i < n; i++)
14         mat_identity[i][i] = 1;
15
16     return mat_identity;
17 }
18
19 /// Multiplies matrices a and b.
20 ///
21 /// Time Complexity: O(mat.size() ^ 3)
22 Matrix mult(const Matrix &a, const Matrix &b) {
23     assert(a.front().size() == b.size());
24
25     Matrix ans(a.size(), vector<int>(b.front().size(), 0));
26     for (int i = 0; i < ans.size(); i++)
27         for (int j = 0; j < ans.front().size(); j++)
28             for (int k = 0; k < a.front().size(); k++)
29                 ans[i][j] = (ans[i][j] + a[i][k] * b[k][j]) % MOD;
30
31     return ans;
32 }
33
34 /// Exponentiates the matrix mat to the power of p.
35 ///
36 /// Time Complexity: O((mat.size() ^ 3) * log2(p))
37 Matrix expo(Matrix &mat, int p) {
38     assert(p >= 0);
39
40     Matrix ans = identity(mat.size());
41     Matrix cur_power;
42     cur_power.swap(mat);
43
44     while (p) {
45         if (p & 1)
46             ans = mult(ans, cur_power);
47
48         cur_power = mult(cur_power, cur_power);
49         p >>= 1;
50     }
51
52     return ans;
53 }
54 }; // namespace matrix

```

7.21. Modular Inverse

```

1 int gcd(int a, int b) {

```

```

2   if (a == 0)
3       return b;
4   return gcd(b%a, a);
5 }
6
7 int power(int x, int p, int MOD) {
8     if(p == 0)
9         return 1%MOD;
10    if(p == 1)
11        return x%MOD;
12    int res = power(x, p/2, MOD);
13    res = (long long)res*res%MOD;
14    if(p&1)
15        res = (long long)res*x%MOD;
16    return res;
17 }
18
19 // A*B = x (mod m)
20 // B = x * A^(-1)
21 // Function to find modular inverse of a under modulo m
22 // Assumption: m is prime
23 int modInverse(int a, int mod) {
24     int g = gcd(a, mod);
25     if (g != 1)
26         return -1;
27     else
28         // If a and m are relatively prime, then modulo inverse
29         // is a^(m-2) mod m
30         return power(a, mod-2, mod);
31 }

```

7.22. Sieve + Segmented Sieve

```

1  const int MAXN = 1e6;
2
3  /// Contains all the primes in the segments
4  vector<int> segPrimes;
5  bitset<MAXN+5> primesInSeg;
6
7  /// smallest prime factor
8  int spf[MAXN+5];
9
10 vector<int> primes;
11 bitset<MAXN+5> isPrime;
12
13 void sieve(int n = MAXN + 2) {
14
15     for(int i = 0; i <= n; i++)
16         spf[i] = i;
17
18     isPrime.set();
19     for(int i = 2; i <= n; i++) {
20         if(!isPrime[i])
21             continue;
22
23         for(int j = i*i; j <= n; j+=i) {
24             isPrime[j] = false;
25             spf[j] = min(i, spf[j]);
26         }
27         primes.pb(i);
28     }
29 }
30
31 vector<int> getFactorization(int x) {

```

```

32 vector<int> ret;
33 while (x != 1) {
34     ret.push_back(spf[x]);
35     x = x / spf[x];
36 }
37 return ret;
38 }
39
40 /// Gets all primes from 1 to r
41 void segSieve(int l, int r) {
42     // primes from 1 to r
43     // transferred to 0..(l-r)
44     segPrimes.clear();
45     primesInSeg.set();
46     int sq = sqrt(r) + 5;
47
48     for(int p: primes) {
49         if(p > sq)
50             break;
51
52         for(int i = l - l%p; i <= r; i += p) {
53             if(i - l < 0)
54                 continue;
55
56             // if i is less than 1e6, it could be checked in the
57             // array of the sieve
58             if(i >= (int)1e6 || !isPrime[i])
59                 primesInSeg[i-l] = false;
60         }
61     }
62
63     for(int i = 0; i < r-l+1; i++) {
64         if(primesInSeg[i])
65             segPrimes.pb(i+l);
66     }
67 }

```

8. Miscellaneous

8.1. 2-Sat

```

1  /// REQUIRES SCC code
2
3  /// OBS: INDEXED FROM 0
4  class SAT {
5
6  private:
7      vector<vector<int>>> adj;
8      int n;
9
10 public:
11     vector<bool> ans;
12
13     SAT(int n) {
14         this->n = n;
15         adj.resize(2 * n);
16         ans.resize(n);
17     }
18
19     // (X v Y) = (X -> ~Y) & (~X -> Y)
20     void add_or(int x, bool pos_x, int y, bool pos_y) {
21         assert(0 <= x), assert(x < n);
22         assert(0 <= y), assert(y < n);
23         adj[(x << 1) ^ pos_x].pb((y << 1) ^ (pos_y ^ 1));

```

```

24     adj[(y << 1) ^ pos_y].pb((x << 1) ^ (pos_x ^ 1));
25 }
26
27 // (X xor Y) = (X v Y) & (~X v ~Y)
28 // for this function the result is always 0 1 or 1 0
29 void add_xor(int x, bool pos_x, int y, bool pos_y) {
30     assert(0 <= x), assert(x < n);
31     assert(0 <= y), assert(y < n);
32     add_or(x, y, pos_x, pos_y);
33     add_or(x, y, pos_x ^ 1, pos_y ^ 1);
34 }
35
36 bool check() {
37     SCC scc(2 * n, 0, adj);
38
39     for (int i = 0; i < n; i++) {
40         if (scc.comp[(i << 1) | 1] == scc.comp[(i << 1) | 0])
41             return false;
42         ans[i] = (scc.comp[(i << 1) | 1] < scc.comp[(i << 1) | 0]);
43     }
44
45     return true;
46 }
47 };

```

8.2. 3Sum Problem

```

1 // vetor arr e valor x, a soma de três valores desse vetor deve ser igual a x
2
3 bool sum3(int arr[], int x, int n) {
4     sort(arr, arr + n);
5     for(int i = 0; i < n-2; i++) {
6         int l = i+1, r = n-1;
7         /* 2SUM problem -> ponteiro que aponta para o primeiro e ultimo da
8            sequencia e caso a soma for menor do que x adianta em uma casa o
9            ponteiro da esquerda caso seja maior diminui em uma casa o ponteiro da
10            direita */
11         while(l < r) {
12             if(arr[i] + arr[l] + arr[r] == x) {
13                 return true;
14             } else if(arr[i] + arr[l] + arr[r] < x)
15                 l++;
16             else
17                 r--;
18         }
19     }
20     return false;
21 }

```

8.3. Fibonacci Matrix Exponentiation

```

1 int fib(int n) {
2     long long fib[2][2] = {{1,1},{1,0}};
3     int ret[2][2] = {{1,0},{0,1}};
4     int tmp[2][2] = {{0,0},{0,0}};
5     int i,j,k;
6     while(n) {
7         if(n&1) {
8             memset(tmp,0,sizeof tmp);
9             for(i=0; i<2; i++)
10                 for(j=0; j<2; j++)
11                     for(k=0; k<2; k++)
12                         tmp[i][j] = (tmp[i][j] + ret[i][k]*fib[k][j]);

```

```

13         for(i=0; i<2; i++)
14             for(j=0; j<2; j++)
15                 ret[i][j] = tmp[i][j];
16         }
17         memset(tmp,0,sizeof tmp);
18         for(i=0; i<2; i++)
19             for(j=0; j<2; j++)
20                 for(k=0; k<2; k++)
21                     tmp[i][j] = (tmp[i][j] + fib[i][k]*fib[k][j]);
22         for(i=0; i<2; i++)
23             for(j=0; j<2; j++)
24                 fib[i][j] = tmp[i][j];
25         n/=2;
26     }
27     return (ret[0][1]);
28 }

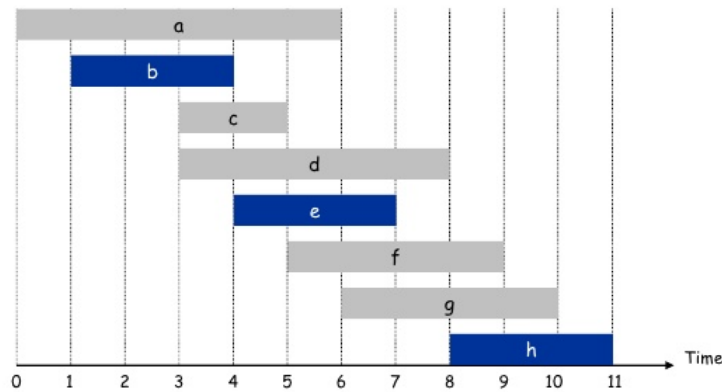
```

8.4. Infix To Prefix

```

1 int main() {
2     map<char,int> prec;
3     stack<char> op;
4
5     string postfix;
6     string infix;
7     cin >> infix;
8
9     prec['+'] = prec['-'] = 1;
10    prec['*'] = prec['/'] = 2;
11    prec['^'] = 3;
12    for(int i = 0; i < infix.length(); i++) {
13        char x = infix[i];
14        if('0' <= x && x <= '9') {
15            for(i; i < infix.length() && ('0' <= infix[i] && infix[i] <= '9'); i++)
16                postfix += infix[i];
17            i--;
18        } else if(('a' <= x && x <= 'z') || ('A' <= x && x <= 'Z')) {
19            postfix += x;
20        } else if (x == '(')
21            op.push('(');
22        else if (x == ')') {
23            while(!op.empty() && op.top() != '(') {
24                postfix += op.top();
25                op.pop();
26            }
27            op.pop();
28        } else {
29            while(!op.empty() && prec[op.top()] >= prec[x]) {
30                postfix += op.top();
31                op.pop();
32            }
33            op.push(x);
34        }
35    }
36    while(!op.empty()) {
37        postfix += op.top();
38        op.pop();
39    }
40    cout << postfix << endl;
41 }

```



8.5. Interval Scheduling

8.6. Interval Scheduling

- 1 1 -> Ordena pelo final **do** evento, depois pelo inicio.
- 2 2 -> Vai iterando pelos eventos, se eles não tiverem horário em comum então adiciona o evento à lista.

8.7. Kadane (Maior Soma Num Vetor)

```

1 int kadane(int arr[], int l) {
2
3     int soma, total;
4     soma = total = arr[0];
5
6     for(int i = 1; i < l; i++) {
7         soma = max(arr[i], arr[i] + soma);
8         if(soma > total)
9             total = soma;
10    }
11    return total;
12
13 }
```

8.8. Kadane 2D

```

1 // Program to find maximum sum subarray in a given 2D array
2 #include <stdio.h>
3 #include <string.h>
4 #include <limits.h>
5 int mat[1001][1001]
6 int ROW = 1000, COL = 1000;
7
8 // Implementation of Kadane's algorithm for 1D array. The function
9 // returns the maximum sum and stores starting and ending indexes of the
10 // maximum sum subarray at addresses pointed by start and finish pointers
11 // respectively.
12 int kadane(int* arr, int* start, int* finish, int n) {
13     // initialize sum, maxSum and
```

```

15 int sum = 0, maxSum = INT_MIN, i;
16
17 // Just some initial value to check for all negative values case
18 *finish = -1;
19
20 // local variable
21 int local_start = 0;
22
23 for (i = 0; i < n; ++i) {
24     sum += arr[i];
25     if (sum < 0) {
26         sum = 0;
27         local_start = i+1;
28     }
29     else if (sum > maxSum){
30         maxSum = sum;
31         *start = local_start;
32         *finish = i;
33     }
34 }
35
36 // There is at-least one non-negative number
37 if (*finish != -1)
38     return maxSum;
39
40 // Special Case: When all numbers in arr[] are negative
41 maxSum = arr[0];
42 *start = *finish = 0;
43
44 // Find the maximum element in array
45 for (i = 1; i < n; i++) {
46     if (arr[i] > maxSum) {
47         maxSum = arr[i];
48         *start = *finish = i;
49     }
50 }
51 return maxSum;
52 }
53
54 // The main function that finds maximum sum rectangle in mat[][]
55 int findMaxSum() {
56     // Variables to store the final output
57     int maxSum = INT_MIN, finalLeft, finalRight, finalTop, finalBottom;
58
59     int left, right, i;
60     int temp[ROW], sum, start, finish;
61
62     // Set the left column
63     for (left = 0; left < COL; ++left) {
64         // Initialize all elements of temp as 0
65         for(int i = 0; i < ROW; i++)
66             temp[i] = 0;
67
68         // Set the right column for the left column set by outer loop
69         for (right = left; right < COL; ++right) {
70             // Calculate sum between current left and right for every row 'i'
71             for (i = 0; i < ROW; ++i)
72                 temp[i] += mat[i][right];
73
74             // Find the maximum sum subarray in temp[]. The kadane()
75             // function also sets values of start and finish. So 'sum' is
76             // sum of rectangle between (start, left) and (finish, right)
77             // which is the maximum sum with boundary columns strictly as
78             // left and right.
79             sum = kadane(temp, &start, &finish, ROW);
```

```

80
81 // Compare sum with maximum sum so far. If sum is more, then
82 // update maxSum and other output values
83 if (sum > maxSum) {
84     maxSum = sum;
85     finalLeft = left;
86     finalRight = right;
87     finalTop = start;
88     finalBottom = finish;
89 }
90 }
91 }
92
93 return maxSum;
94 // Print final values
95 printf("Top, Left) (%d, %d)\n", finalTop, finalLeft);
96 printf("Bottom, Right) (%d, %d)\n", finalBottom, finalRight);
97 printf("Max sum is: %d\n", maxSum);
98 }

```

8.9. Oito Rainhas

```

1 #define N 4
2 bool isSafe(int mat[N][N], int row, int col) {
3     for(int i = row - 1; i >= 0; i--)
4         if(mat[i][col])
5             return false;
6     for(int i = row - 1, j = col - 1; i >= 0 && j >= 0; i--, j--)
7         if(mat[i][j])
8             return false;
9     for(int i = row - 1, j = col + 1; i >= 0 && j < N; i--, j++)
10        if(mat[i][j])
11            return false;
12    return true;
13 }
14 // inicialmente a matriz esta zerada
15 int queen(int mat[N][N], int row = 0) {
16     if(row >= N) {
17         for(int i = 0; i < N; i++) {
18             for(int j = 0; j < N; j++) {
19                 cout << mat[i][j] << ' ';
20             }
21             cout << endl;
22         }
23         cout << endl << endl;
24         return false;
25     }
26     for(int i = 0; i < N; i++) {
27         if(isSafe(mat, row, i)) {
28             mat[row][i] = 1;
29             if(queen(mat, row+1))
30                 return true;
31             mat[row][i] = 0;
32         }
33     }
34     return false;
35 }

```

8.10. Sliding Window Minimum

```

1 // mínimo num vetor arr de arr[0] ... arr[k-1], arr[l] ... arr[k], arr[2]
2 ... arr[k+1]

```

```

3 void swma(vector<int> arr, int k) {
4     deque<int> window;
5     for(int i = 0; i < arr.size(); i++) {
6         while(!window.empty() && window.back().ff > arr[i])
7             window.pop_back();
8         window.pb(arr[i]);
9         while(window.front().ss <= i - k)
10            window.pop_front();
11
12         if(i >= k)
13             cout << ' ';
14         if(i - k + 1 >= 0)
15             cout << window.front().ff;
16     }
17 }

```

8.11. Torre De Hanoi

```

1 #include <stdio.h>
2
3 // C recursive function to solve tower of hanoi puzzle
4 void towerOfHanoi(int n, char from_rod, char to_rod, char aux_rod) {
5     if (n == 1) {
6         printf("\n Move disk 1 from rod %c to rod %c", from_rod, to_rod);
7         return;
8     }
9     towerOfHanoi(n-1, from_rod, aux_rod, to_rod);
10    printf("\n Move disk %d from rod %c to rod %c", n, from_rod, to_rod);
11    towerOfHanoi(n-1, aux_rod, to_rod, from_rod);
12 }
13
14 int main() {
15     int n = 4; // Number of disks
16     towerOfHanoi(n, 'A', 'C', 'B'); // A, B and C are names of rods
17     return 0;
18 }

```

8.12. Kadane (Segment Tree)

```

1 struct Node {
2     int pref, suf, tot, best;
3     Node () {}
4     Node(int pref, int suf, int tot, int best) : pref(pref), suf(suf),
5         tot(tot), best(best) {}
6 };
7
8 const int MAXN = 2E5 + 10;
9 Node tree[5*MAXN];
10 int arr[MAXN];
11
12 Node query(const int l, const int r, const int i, const int j, const int
13 pos) {
14     if(l > r || l > j || r < i)
15         return Node(-INF, -INF, -INF, -INF);
16
17     if(i <= l && r <= j)
18         return Node(tree[pos].pref, tree[pos].suf, tree[pos].tot,
19 tree[pos].best);
20
21     int mid = (l + r) / 2;
22     Node left = query(l, mid, i, j, 2*pos+1), right = query(mid+1, r, i, j, 2*pos+2);
23     Node x;

```



```

22 x.pref = max({left.pref, left.tot, left.tot + right.pref});
23 x.suf = max({right.suf, right.tot, right.tot + left.suf});
24 x.tot = left.tot + right.tot;
25 x.best = max({left.best, right.best, left.suf + right.pref});
26 return x;
27 }
28
29 // Update arr[idx] to v
30 // ITS NOT DELTA!!!
31 void update(int l, int r, const int idx, const int v, const int pos) {
32     if(l > r || l > idx || r < idx)
33         return;
34
35     if(l == idx && r == idx) {
36         tree[pos] = Node(v, v, v, v);
37         return;
38     }
39
40     int mid = (l + r)/2;
41     update(l, mid, idx, v, 2*pos+1); update(mid+1, r, idx, v, 2*pos+2);
42     l = 2*pos+1, r = 2*pos+2;
43     tree[pos].pref = max({tree[l].pref, tree[l].tot, tree[l].tot +
44         tree[r].pref});
45     tree[pos].suf = max({tree[r].suf, tree[r].tot, tree[r].tot + tree[l].suf});
46     tree[pos].tot = tree[l].tot + tree[r].tot;
47     tree[pos].best = max({tree[l].best, tree[r].best, tree[l].suf +
48         tree[r].pref});
49 }
50
51 void build(int l, int r, const int pos) {
52     if(l == r) {
53         tree[pos] = Node(arr[l], arr[l], arr[l], arr[l]);
54         return;
55     }
56
57     int mid = (l + r)/2;
58     build(l, mid, 2*pos+1); build(mid+1, r, 2*pos+2);
59     l = 2*pos+1, r = 2*pos+2;
60     tree[pos].pref = max({tree[l].pref, tree[l].tot, tree[l].tot +
61         tree[r].pref});
62     tree[pos].suf = max({tree[r].suf, tree[r].tot, tree[r].tot + tree[l].suf});
63     tree[pos].tot = tree[l].tot + tree[r].tot;
64     tree[pos].best = max({tree[l].best, tree[r].best, tree[l].suf +
65         tree[r].pref});
66 }

```

8.13. Largest Area In Histogram

```

1 // Time Complexity: O(n)
2 int largest_area_in_histogram(vector<int> &arr) {
3     arr.pb(0);
4
5     stack<int> s;
6     int ans = 0;
7     for (int i = 0; i < arr.size(); ++i) {
8         while (!s.empty() && arr[s.top()] >= arr[i]) {
9             int height = arr[s.top()];
10            s.pop();
11            int l = (s.empty() ? 0 : s.top() + 1);
12            // creates a rectangle from l to i - 1
13            ans = max(ans, height * (i - l));
14        }
15        s.emplace(i);

```

```

16     }
17     return ans;
18 }

```

8.14. Point Compression

```

1 // map<int, int> rev;
2
3 /// Compress points in the array arr to the range [0..n-1].
4 ///
5 /// Time Complexity: O(n log n)
6 vector<int> compress(vector<int> &arr) {
7     vector<int> aux = arr;
8     sort(aux.begin(), aux.end());
9     aux.erase(unique(aux.begin(), aux.end()), aux.end());
10
11     for (size_t i = 0; i < arr.size(); i++) {
12         int id = lower_bound(aux.begin(), aux.end(), arr[i]) - aux.begin();
13         // rev[id] = arr[i];
14         arr[i] = id;
15     }
16     return arr;
17 }

```

9. Strings

9.1. Kmp

```

1 vector<int> pi(const string &s) {
2     int n = s.size();
3     vector<int> pi(n);
4
5     int l = 0, r = 1;
6     while (r < n) {
7         if (s[l] == s[r]) {
8             l++;
9             pi[r] = l;
10            r++;
11        } else {
12            if (l == 0) {
13                pi[r] = 0;
14                r++;
15            } else
16                l = pi[l - 1];
17        }
18    }
19    return pi;
20 }
21
22 // returns the index of first occurrence of a pat in a txt
23 int kmp(const string &txt, const string &pat) {
24     int n = txt.size(), m = pat.size();
25
26     int t = 0, p = 0;
27     vector<int> pi_pat = pi(pat);
28     // vector<int> occ;
29
30     while (t < n) {
31
32         if (txt[t] == pat[p]) {
33             t++, p++;
34             if (p == m) {
35                 return t - m;

```

```

36 // if you want to continue searching
37 // occ.pb(t - m);
38 // p = pi_pat[p - 1];
39 }
40 } else {
41     if (p == 0) {
42         t++;
43     } else {
44         p = pi_pat[p - 1];
45     }
46 }
47 }
48 return -1;
49 // return occ;
50 }

```

9.2. Trie - Maximum Xor Sum

```

1 // XOR(L,R) = XOR(L,L-1) ^ XOR(L,R)
2 ans= pre = 0
3 Trie.insert(0)
4 for i=1 to N:
5     pre = pre XOR a[i]
6     Trie.insert(pre)
7     ans=max(ans, Trie.query(pre))
8 print ans
9
10 // a funcao query é a mesma da maximum xor between two elements

```

9.3. Trie - Maximum Xor Two Elements

```

1 1. Dada uma trie de números binários e um numero X, tente achar o número
   máximo que resultante da operação XOR
2
3 Ex: Para o número 10(=1010)2), o número que resulta no xor máximo é (0101)2
   , tente acha-lo na trie.

```

9.4. Z-Function

```

1 // What is Z Array?
2 // For a string str[0..n-1], Z array is of same length as string.
3 // An element Z[i] of Z array stores length of the longest substring
4 // starting from str[i] which is also a prefix of str[0..n-1]. The
5 // first entry of Z array is meaning less as complete string is always
6 // prefix of itself.
7 // Example:
8 // Index
9 // 0 1 2 3 4 5 6 7 8 9 10 11
10 // Text
11 // a a b c a a b x a a a z
12 // Z values
13 // X 1 0 0 3 1 0 0 2 2 1 0
14 // More Examples:
15 // str = "aaaaaa"
16 // Z[] = {x, 5, 4, 3, 2, 1}
17
18 // str = "aabaacd"
19 // Z[] = {x, 1, 0, 2, 1, 0, 0}
20
21 // str = "abababab"
22 // Z[] = {x, 0, 6, 0, 4, 0, 2, 0}
23

```

```

24 vector<int> z_function(const string &s) {
25     vector<int> z(s.size());
26     int l = -1, r = -1;
27     for (int i = 1; i < s.size(); ++i) {
28         z[i] = i >= r ? 0 : min(r - i, z[i - l]);
29         while (i + z[i] < s.size() && s[i + z[i]] == s[z[i]])
30             z[i]++;
31         if (i + z[i] > r)
32             l = i, r = i + z[i];
33     }
34     return z;
35 }

```

9.5. Aho Corasick

```

1 /// REQUIRES trie.cpp
2
3 class Aho {
4 private:
5     // node of the output list
6     struct Out_Node {
7         vector<int> str_idx;
8         Out_Node *next = nullptr;
9     };
10
11     vector<Trie::Node *> fail;
12     Trie trie;
13     // list of nodes of output
14     vector<Out_Node *> out_node;
15     const vector<string> arr;
16
17     /// Time Complexity: O(number of characters in arr)
18     void build_trie() {
19         const int n = arr.size();
20         int node_cnt = 1;
21
22         for (int i = 0; i < n; ++i)
23             node_cnt += arr[i].size();
24
25         out_node.reserve(node_cnt);
26         for (int i = 0; i < node_cnt; ++i)
27             out_node.push_back(new Out_Node());
28
29         fail.resize(node_cnt);
30         for (int i = 0; i < n; ++i) {
31             const int id = trie.insert(arr[i]);
32             out_node[id]->str_idx.push_back(i);
33         }
34
35         this->build_failures();
36     }
37
38     /// Returns the fail node of cur.
39     Trie::Node *find_fail_node(Trie::Node *cur, char c) {
40         while (cur != this->trie.root() && !cur->next.count(c))
41             cur = fail[cur->id];
42         // if cur is pointing to the root node and c is not a child
43         if (!cur->next.count(c))
44             return trie.root();
45         return cur->next[c];
46     }
47
48     /// Time Complexity: O(number of characters in arr)
49     void build_failures() {

```

```

50 queue<const Trie::Node *> q;
51
52 fail[trie.root()->id] = trie.root();
53 for (const pair<char, Trie::Node *> v : trie.root()->next) {
54     q.emplace(v.second);
55     fail[v.second->id] = trie.root();
56     out_node[v.second->id]->next = out_node[trie.root()->id];
57 }
58
59 while (!q.empty()) {
60     const Trie::Node *u = q.front();
61     q.pop();
62
63     for (const pair<char, Trie::Node *> x : u->next) {
64         const char c = x.first;
65         const Trie::Node *v = x.second;
66         Trie::Node *fail_node = find_fail_node(fail[u->id], c);
67         fail[v->id] = fail_node;
68
69         if (!out_node[fail_node->id]->str_idx.empty())
70             out_node[v->id]->next = out_node[fail_node->id];
71         else
72             out_node[v->id]->next = out_node[fail_node->id]->next;
73
74         q.emplace(v);
75     }
76 }
77
78 vector<vector<pair<int, int>>> aho_find_occurrences(const string &text) {
79     vector<vector<pair<int, int>>> ans(arr.size());
80     Trie::Node *cur = trie.root();
81
82     for (int i = 0; i < text.size(); ++i) {
83         cur = find_fail_node(cur, text[i]);
84         for (Out_Node *node = out_node[cur->id]; node != nullptr;
85              node = node->next)
86             for (const int idx : node->str_idx)
87                 ans[idx].emplace_back(i - (int)arr[idx].size() + 1, i);
88     }
89     return ans;
90 }
91
92 public:
93     /// Constructor that builds the trie and the failures.
94     ///
95     /// Time Complexity: O(number of characters in arr)
96     Aho(const vector<string> &arr) : arr(arr) { this->build_trie(); }
97
98     /// Searches in text for all occurrences of all strings in array arr.
99     ///
100     /// Time Complexity: O(text.size() + number of characters in arr)
101     vector<vector<pair<int, int>>> find_occurrences(const string &text) {
102         return this->aho_find_occurrences(text);
103     }
104 }
105

```

9.6. Hashing

```

1 // OBS: CHOOSE THE OFFSET AND THE PRIMES BELOW!!
2 class Hash {
3     /// Prime numbers to be used in mod operations
4     /// OBS: if you change m's size, please change the return type of both
    query

```

```

5     /// and _query methods.
6     vector<int> m = {1000000007, 1000000009};
7
8     /// Case the alphabet goes from 'a' to 'z'.
9     static constexpr int OFFSET = 'a';
10    /// Choose primes greater than the size of the alphabet.
11    vector<int> prime = {31, 37};
12
13    /// Case the alphabet goes from 'A' to 'Z'.
14    /// constexpr int OFFSET = 'A';
15    /// Choose primes greater than the size of the alphabet.
16    /// vector<int> prime = {61, 67};
17
18    vector<vector<int>> hash_table;
19    vector<vector<int>> pot;
20    /// size of the string
21    int n;
22
23 private:
24     int mod(int n, int m) {
25         n %= m;
26         if (n < 0)
27             n += m;
28         return n;
29     }
30
31    /// Time Complexity: O(1)
32    pair<int, int> _query(const int l, const int r) {
33        vector<int> ans(m.size());
34
35        if (l == 0) {
36            for (int i = 0; i < m.size(); i++)
37                ans[i] = hash_table[i][r];
38        } else {
39            for (int i = 0; i < m.size(); i++)
40                ans[i] =
41                    mod((hash_table[i][r] - hash_table[i][l - 1] * pot[i][r - 1 +
42                        1])),
43                        m[i]);
44        }
45
46        return {ans.front(), ans.back()};
47    }
48
49    /// Builds the hash table and the pot table.
50    ///
51    /// Time Complexity: O(n)
52    void build(string &s) {
53        pot.resize(m.size(), vector<int>(this->n));
54        hash_table.resize(m.size(), vector<int>(this->n));
55        /// Remapping the string
56        for (char &c : s)
57            c -= OFFSET;
58
59        for (int i = 0; i < m.size(); i++) {
60            hash_table[i][0] = s[0];
61            pot[i][0] = 1;
62            for (int j = 1; j < this->n; j++) {
63                hash_table[i][j] = (s[j] + hash_table[i][j - 1] * prime[i]) % m[i];
64                pot[i][j] = (pot[i][j - 1] * prime[i]) % m[i];
65            }
66        }
67
68    public:

```

```

69  /// Constructor that is responsible for building the hash table and pot
    table.
70  ///
71  /// Time Complexity: O(n)
72  Hash(string s) {
73      assert(m.size() == prime.size());
74      this->n = s.size();
75
76      build(s);
77  }
78
79  /// Returns the hash from l to r.
80  ///
81  /// Time Complexity: O(1) -> Actually O(number_of_primes)
82  pair<int, int> query(const int l, const int r) {
83      assert(0 <= l), assert(l <= r), assert(r < this->n);
84      return _query(l, r);
85  }
86  };

```

9.7. Lcs K Strings

```

1  // Make the change below in SuffixArray code.
2  int MaximumNumberOfStrings;
3
4  void build_suffix_array() {
5      vector<pair<Rank, int>> ranks(this->n + 1);
6      vector<int> arr;
7
8      for (int i = 1, separators = 0; i <= n; i++)
9          if(this->s[i] > 0) {
10             ranks[i] = pair<Rank, int>(Rank((int)this->s[i] +
                MaximumNumberOfStrings, 0), i);
11             this->s[i] += MaximumNumberOfStrings;
12         } else {
13             ranks[i] = pair<Rank, int>(Rank(separators, 0), i);
14             this->s[i] = separators;
15             separators++;
16         }
17
18     RadixSort::sort_pairs(ranks, 256 + MaximumNumberOfStrings);
19     ...
20 }
21
22 /// Program to find the LCS between k different strings.
23 ///
24 /// Time Complexity: O(n*log(n))
25 /// Space Complexity: O(n*log(n))
26 int main() {
27     int n;
28
29     cin >> n;
30
31     MaximumNumberOfStrings = n;
32
33     vector<string> arr(n);
34
35     int sum = 0;
36     for(string &x: arr) {
37         cin >> x;
38         sum += x.size() + 1;
39     }
40
41     string concat;

```

```

42     vector<int> ind(sum + 1);
43     int cnt = 0;
44     for(string &x: arr) {
45         if(concat.size())
46             concat += (char)cnt;
47         concat += x;
48     }
49
50     cnt = 0;
51     for(int i = 0; i < concat.size(); i++) {
52         ind[i + 1] = cnt;
53         if(concat[i] < MaximumNumberOfStrings)
54             cnt++;
55     }
56
57     Suffix_Array say(concat);
58     vector<int> sa = say.get_suffix_array();
59     Sparse_Table spt(say.get_lcp());
60
61     vector<int> freq(n);
62     int cnt1 = 0;
63
64     /// Ignore separators
65     int i = n, j = n - 1;
66     int ans = 0;
67
68     while(true) {
69
70         if(cnt1 == n) {
71
72             ans = max(ans, spt.query(i, j - 1));
73
74             int idx = ind[sa[i]];
75             freq[idx]--;
76             if(freq[idx] == 0)
77                 cnt1--;
78             i++;
79         } else if(j == (int)sa.size() - 1)
80             break;
81         else {
82             j++;
83             int idx = ind[sa[j]];
84             freq[idx]++;
85             if(freq[idx] == 1)
86                 cnt1++;
87         }
88     }
89
90     cout << ans << endl;
91 }

```

9.8. Lexicographically Smallest Rotation

```

1  int booth(string &s) {
2      s += s;
3      int n = s.size();
4
5      vector<int> f(n, -1);
6      int k = 0;
7      for(int j = 1; j < n; j++) {
8          int sj = s[j];
9          int i = f[j - k - 1];
10         while(i != -1 && sj != s[k + i + 1]) {
11             if(sj < s[k + i + 1])

```

```

12     k = j - i - 1;
13     i = f[i];
14 }
15 if(s[j] != s[k + i + 1]) {
16     if(s[j] < s[k])
17         k = j;
18     f[j - k] = -1;
19 }
20 else
21     f[j - k] = i + 1;
22 }
23 return k;
24 }

```

9.9. Manacher (Longest Palindrome)

```

1 //
2 // https://medium.com/hackernoon/manachers-algorithm-explained-longest-palindrome-c-substring-228b27a3e98f
3 /// Create a string containing '#' characters between any two characters.
4 string get_modified_string(string &s){
5     string ret;
6     for(int i = 0; i < s.size(); i++){
7         ret.push_back('#');
8         ret.push_back(s[i]);
9     }
10    ret.push_back('#');
11    return ret;
12 }
13
14 /// Returns the first occurrence of the longest palindrome based on the lps
15 /// array.
16 /// Time Complexity: O(n)
17 string get_best(const int max_len, const string &str, const vector<int>
18 &lps) {
19     for(int i = 0; i < lps.size(); i++) {
20         if(lps[i] == max_len) {
21             string ans;
22             int cnt = max_len / 2;
23             int io = i - 1;
24             while(cnt) {
25                 if(str[io] != '#') {
26                     ans += str[io];
27                     cnt--;
28                 }
29                 io--;
30             }
31             reverse(ans.begin(), ans.end());
32             if(str[i] != '#')
33                 ans += str[i];
34             cnt = max_len / 2;
35             io = i + 1;
36             while(cnt) {
37                 if(str[io] != '#') {
38                     ans += str[io];
39                     cnt--;
40                 }
41                 io++;
42             }
43             return ans;
44         }
45     }
46 }

```

```

46
47 /// Returns a pair containing the size of the longest palindrome and the
48 /// first occurrence of it.
49 ///
50 /// Time Complexity: O(n)
51 pair<int, string> manacher(string &s) {
52     int n = s.size();
53     string str = get_modified_string(s);
54     int len = (2 * n) + 1;
55     //the i-th index contains the longest palindromic substring with the i-th
56     //char as the center
57     vector<int> lps(len);
58     int c = 0; //stores the center of the longest palindromic substring until
59     //now
60     int r = 0; //stores the right boundary of the longest palindromic
61     //substring until now
62     int max_len = 0;
63     for(int i = 0; i < len; i++) {
64         //get mirror index of i
65         int mirror = (2 * c) - i;
66
67         //see if the mirror of i is expanding beyond the left boundary of
68         //current longest palindrome at center c
69         //if it is, then take r - i as lps[i]
70         //else take lps[mirror] as lps[i]
71         if(i < r)
72             lps[i] = min(r - i, lps[mirror]);
73
74         //expand at i
75         int a = i + (1 + lps[i]);
76         int b = i - (1 + lps[i]);
77         while(a < len && b >= 0 && str[a] == str[b]) {
78             lps[i]++;
79             a++;
80             b--;
81         }
82
83         //check if the expanded palindrome at i is expanding beyond the right
84         //boundary of current longest palindrome at center c
85         //if it is, the new center is i
86         if(i + lps[i] > r) {
87             c = i;
88             r = i + lps[i];
89
90             if(lps[i] > max_len) //update max_len
91                 max_len = lps[i];
92         }
93     }
94     return make_pair(max_len, get_best(max_len, str, lps));
95 }

```

9.10. Suffix Array

```

1 namespace RadixSort {
2     /// Sorts the array arr stably in ascending order.
3     ///
4     /// Time Complexity: O(n + max_element)
5     /// Space Complexity: O(n + max_element)
6     template <typename T>
7     void sort(vector<T> &arr, const int max_element, int (*get_key)(T &),
8               int begin = 0) {
9         const int n = arr.size();
10        vector<T> new_order(n);

```

```

11 vector<int> count(max_element + 1, 0);
12
13 for (int i = begin; i < n; i++)
14     count[get_key(arr[i])]++;
15
16 for (int i = 1; i <= max_element; i++)
17     count[i] += count[i - 1];
18
19 for (int i = n - 1; i >= begin; i--) {
20     new_order[count[get_key(arr[i])] - (begin == 0)] = arr[i];
21     count[get_key(arr[i])]--;
22 }
23
24 arr.swap(new_order);
25 }
26
27 /// Sorts an array by their pair of ranks stably in ascending order.
28 template <typename T> void sort_pairs(vector<T> &arr, const int rank_size) {
29     // Sort by the second rank
30     RadixSort::sort<T>(
31         arr, rank_size, [(T &item) { return item.first.second; }, 0]);
32
33     // Sort by the first rank
34     RadixSort::sort<T>(
35         arr, rank_size, [(T &item) { return item.first.first; }, 0]);
36 }
37 } // namespace RadixSort
38
39 /// It is indexed by 0.
40 /// Let the given string be "banana".
41 ///
42 /// 0 banana          5 a
43 /// 1 anana          Sort the Suffixes 3 ana
44 /// 2 nana          -----> 1 anana
45 /// 3 ana            alphabetically 0 banana
46 /// 4 na              4 na
47 /// 5 a              2 nana
48 /// So the suffix array for "banana" is {5, 3, 1, 0, 4, 2}
49 ///
50 /// LCP
51 ///
52 /// 1 a
53 /// 3 ana
54 /// 0 anana
55 /// 0 banana
56 /// 2 na
57 /// 0 nana (The last position will always be zero)
58 ///
59 /// So the LCP for "banana" is {1, 3, 0, 0, 2, 0}
60 ///
61 class Suffix_Array {
62 private:
63     string s;
64     int n;
65
66     typedef pair<int, int> Rank;
67
68 public:
69     Suffix_Array(string &s) {
70         this->n = s.size();
71         this->s = s;
72         // little optimization, remove the line above
73         // this->s.swap(s);
74
75         this->sa = build_suffix_array();

```

```

76         this->lcp = build_lcp();
77     }
78
79 private:
80     /// The vector containing the ranks will be present at ret
81     void build_ranks(const vector<pair<Rank, int>> &ranks, vector<int> &ret) {
82         ret[ranks[0].second] = 1;
83         for (int i = 1; i < n; i++) {
84             // If their rank are equal, than its position should be the same.
85             if (ranks[i - 1].first == ranks[i].first)
86                 ret[ranks[i].second] = ret[ranks[i - 1].second];
87             else
88                 ret[ranks[i].second] = ret[ranks[i - 1].second] + 1;
89         }
90     }
91
92     /// Builds the Suffix Array for the string s.
93     ///
94     /// Time Complexity: O(n*log(n))
95     /// Space Complexity: O(n)
96     vector<int> build_suffix_array() {
97         // This tuple below represents the rank and the index associated with it.
98         vector<pair<Rank, int>> ranks(this->n);
99         vector<int> arr(this->n);
100
101         for (int i = 0; i < n; i++)
102             ranks[i] = pair<Rank, int>(Rank(s[i], 0), i);
103
104         RadixSort::sort_pairs(ranks, 256);
105         build_ranks(ranks, arr);
106
107         {
108             int jump = 1;
109             int max_rank = arr[ranks.back().second];
110             // It will be compared intervals a pair of intervals (i, jump-1), (i +
111             // jump, i + 2*jump - 1). The variable jump is always a power of 2.
112             while (max_rank != this->n) {
113                 for (int i = 0; i < this->n; i++) {
114                     ranks[i].first.first = arr[i];
115                     ranks[i].first.second = (i + jump < this->n ? arr[i + jump] : 0);
116                     ranks[i].second = i;
117                 }
118
119                 RadixSort::sort_pairs(ranks, n);
120                 build_ranks(ranks, arr);
121
122                 max_rank = arr[ranks.back().second];
123                 jump *= 2;
124             }
125         }
126
127         vector<int> sa(this->n);
128         for (int i = 0; i < this->n; i++)
129             sa[arr[i] - 1] = i;
130         return sa;
131     }
132
133     /// Builds the lcp (Longest Common Prefix) array for the string s.
134     /// A value lcp[i] indicates length of the longest common prefix of the
135     /// suffixes indexed by i and i + 1. Implementation of the Kasai's
136     /// Algorithm.
137     ///
138     /// Time Complexity: O(n)
139     /// Space Complexity: O(n)
140     vector<int> build_lcp() {

```

```

140     lcp.resize(n, 0);
141     vector<int> inverse_suffix(this->n);
142
143     for (int i = 0; i < this->n; i++)
144         inverse_suffix[sa[i]] = i;
145
146     int k = 0;
147
148     for (int i = 0; i < this->n; i++) {
149         if (inverse_suffix[i] == this->n - 1) {
150             k = 0;
151             continue;
152         }
153
154         int j = sa[inverse_suffix[i] + 1];
155
156         while (i + k < this->n && j + k < this->n && s[i + k] == s[j + k])
157             k++;
158
159         lcp[inverse_suffix[i]] = k;
160
161         if (k > 0)
162             k--;
163     }
164
165     return lcp;
166 }
167
168 public:
169     vector<int> sa;
170     vector<int> lcp;
171
172     /// LCS of two strings A and B.
173     ///
174     /// The string s must be initialized in the constructor as the string (A +
175     /// '$' + B).
176     ///
177     /// The string A starts at index 1 and ends at index (separator - 1).
178     /// The string B starts at index (separator + 1) and ends at the end of the
179     /// string.
180     ///
181     /// Time Complexity: O(n)
182     /// Space Complexity: O(1)
183     int lcs(int separator) {
184         assert(!isalpha(this->s[separator] && !isdigit(this->s[separator])));
185
186         int ans = 0;
187
188         for (int i = 0; i + 1 < this->sa.size(); i++) {
189             int left = this->sa[i];
190             int right = this->sa[i + 1];
191
192             if ((left < separator && right > separator) ||
193                 (left > separator && right < separator))
194                 ans = max(ans, lcp[i]);
195         }
196
197         return ans;
198     }
199 };

```

9.11. Suffix Array Pessoa

```

1  // OBS: Suffix Array build code imported from:
2  //
3  // https://github.com/gabrielpessoa1/Biblioteca-Maratona/blob/master/code/String/Suf
4  // Because it's faster.
5
6  /// It is indexed by 0.
7  /// Let the given string be "banana".
8  ///
9  /// 0 banana          5 a
10 /// 1 anana          Sort the Suffixes      3 ana
11 /// 2 nana           ----->              1 anana
12 /// 3 ana            alphabetically         0 banana
13 /// 4 na              4 na
14 /// 5 a              2 nana
15 /// So the suffix array for "banana" is {5, 3, 1, 0, 4, 2}
16
17 /// LCP
18 ///
19 /// 1 a
20 /// 3 ana
21 /// 0 anana
22 /// 0 banana
23 /// 2 na
24 /// 0 nana (The last position will always be zero)
25
26 /// So the LCP for "banana" is {1, 3, 0, 0, 2, 0}
27
28 class Suffix_Array {
29 private:
30     string s;
31     int n;
32
33     typedef pair<int, int> Rank;
34
35 public:
36     Suffix_Array(string &s) {
37         this->n = s.size();
38         this->s = s;
39         // little optimization, remove the line above
40         // this->s.swap(s);
41
42         this->sa = build_suffix_array();
43         this->lcp = build_lcp();
44     }
45
46 private:
47     /// Builds the Suffix Array for the string s.
48     ///
49     /// Time Complexity: O(n*log(n))
50     /// Space Complexity: O(n)
51     vector<int> build_suffix_array() {
52         int n = this->s.size(), c = 0;
53         vector<int> temp(n), posBucket(n), bucket(n), bpos(n), out(n);
54         for (int i = 0; i < n; i++)
55             out[i] = i;
56         sort(out.begin(), out.end(),
57             [&](int a, int b) { return this->s[a] < this->s[b]; });
58         for (int i = 0; i < n; i++) {
59             bucket[i] = c;
60             if (i + 1 == n || this->s[out[i]] != this->s[out[i + 1]])
61                 c++;
62         }
63         for (int h = 1; h < n && c < n; h <= 1) {
64             for (int i = 0; i < n; i++)
65                 posBucket[out[i]] = bucket[i];

```

```

65     for (int i = n - 1; i >= 0; i--)
66         bpos[bucket[i]] = i;
67     for (int i = 0; i < n; i++) {
68         if (out[i] >= n - h)
69             temp[bpos[bucket[i]]++] = out[i];
70     }
71     for (int i = 0; i < n; i++) {
72         if (out[i] >= h)
73             temp[bpos[posBucket[out[i] - h]]++] = out[i] - h;
74     }
75     c = 0;
76     for (int i = 0; i + 1 < n; i++) {
77         int a = (bucket[i] != bucket[i + 1]) || (temp[i] >= n - h) ||
78             (posBucket[temp[i + 1] + h] != posBucket[temp[i] + h]);
79         bucket[i] = c;
80         c += a;
81     }
82     bucket[n - 1] = c++;
83     temp.swap(out);
84 }
85 return out;
86 }
87
88 /// Builds the lcp (Longest Common Prefix) array for the string s.
89 /// A value lcp[i] indicates length of the longest common prefix of the
90 /// suffixes indexed by i and i + 1. Implementation of the Kasai's
91 /// Algorithm.
92 ///
93 /// Time Complexity: O(n)
94 /// Space Complexity: O(n)
95 vector<int> build_lcp() {
96     lcp.resize(n, 0);
97     vector<int> inverse_suffix(this->n);
98
99     for (int i = 0; i < this->n; i++)
100         inverse_suffix[sa[i]] = i;
101
102     int k = 0;
103
104     for (int i = 0; i < this->n; i++) {
105         if (inverse_suffix[i] == this->n - 1) {
106             k = 0;
107             continue;
108         }
109         int j = sa[inverse_suffix[i] + 1];
110
111         while (i + k < this->n && j + k < this->n && s[i + k] == s[j + k])
112             k++;
113
114         lcp[inverse_suffix[i]] = k;
115
116         if (k > 0)
117             k--;
118     }
119
120     return lcp;
121 }
122
123 public:
124     vector<int> sa;
125     vector<int> lcp;
126
127     /// LCS of two strings A and B.
128     ///

```

```

129     /// The string s must be initialized in the constructor as the string (A +
130     /// 's'
131     /// + B).
132     ///
133     /// The string A starts at index 1 and ends at index (separator - 1).
134     /// The string B starts at index (separator + 1) and ends at the end of the
135     /// string.
136     ///
137     /// Time Complexity: O(n)
138     /// Space Complexity: O(1)
139     int lcs(int separator) {
140         assert(!isalpha(this->s[separator] && !isdigit(this->s[separator]]));
141
142         int ans = 0;
143
144         for (int i = 0; i + 1 < this->sa.size(); i++) {
145             int left = this->sa[i];
146             int right = this->sa[i + 1];
147
148             if ((left < separator && right > separator) ||
149                 (left > separator && right < separator))
150                 ans = max(ans, lcp[i]);
151         }
152
153         return ans;
154     }
155 };

```

9.12. Suffix Array With Additional Memory

```

1 namespace RadixSort {
2     /// Sorts the array arr stably in ascending order.
3     ///
4     /// Time Complexity: O(n + max_element)
5     /// Space Complexity: O(n + max_element)
6     template <typename T>
7     void sort(vector<T> &arr, const int max_element, int (*get_key)(T &),
8               int begin = 0) {
9         const int n = arr.size();
10        vector<T> new_order(n);
11        vector<int> count(max_element + 1, 0);
12
13        for (int i = begin; i < n; i++)
14            count[get_key(arr[i])]++;
15
16        for (int i = 1; i <= max_element; i++)
17            count[i] += count[i - 1];
18
19        for (int i = n - 1; i >= begin; i--) {
20            new_order[count[get_key(arr[i])] - 1] = arr[i];
21            count[get_key(arr[i])]--;
22        }
23
24        arr = new_order;
25    }
26
27    /// Sorts an array by their pair of ranks stably in ascending order.
28    template <typename T> void sort_pairs(vector<T> &arr, const int rank_size) {
29        // Sort by the second rank
30        RadixSort::sort<T>(
31            arr, rank_size, [](T &item) { return item.first.second; }, 1ll);
32
33        // Sort by the first rank
34        RadixSort::sort<T>(

```



```

35     arr, rank_size, [(T &item) { return item.first.first; }, 111]);
36 }
37 } // namespace RadixSort
38
39 /// It is indexed by 1.
40 class Suffix_Array {
41 private:
42     string s;
43     int n;
44
45     typedef pair<int, int> Rank;
46     vector<int> suffix_array;
47     vector<int> lcp;
48
49     vector<vector<int>>> rank_table;
50     vector<int> log_array;
51
52 public:
53     Suffix_Array(const string &s) {
54         this->n = s.size();
55         this->s = "#" + s;
56
57         build_log_array();
58         build_suffix_array();
59         lcp = build_lcp();
60     }
61
62 private:
63     vector<int> build_ranks(const vector<pair<Rank, int>> &ranks) {
64         vector<int> arr(this->n + 1);
65
66         arr[ranks[1].second] = 1;
67         for (int i = 2; i <= n; i++) {
68             // If their rank are equal, than its position should be the same.
69             if (ranks[i - 1].first == ranks[i].first)
70                 arr[ranks[i].second] = arr[ranks[i - 1].second];
71             else
72                 arr[ranks[i].second] = arr[ranks[i - 1].second] + 1;
73         }
74
75         return arr;
76     }
77
78     /// Builds the Suffix Array for the string s.
79     ///
80     /// Time Complexity: O(n*log(n))
81     /// Space Complexity: O(n*log(n))
82     void build_suffix_array() {
83         // This tuple below represents the rank and the index associated with it.
84         vector<pair<Rank, int>> ranks(this->n + 1);
85         vector<int> arr;
86
87         int rank_table_size = 0;
88         this->rank_table.resize(log_array[this->n] + 2);
89
90         for (int i = 1; i <= this->n; i++)
91             ranks[i] = pair<Rank, int>(Rank(s[i], 0), i);
92
93         // Inserting only the ranks in the table.
94         transform(ranks.begin(), ranks.end(),
95                 back_inserter(rank_table[rank_table_size++]),
96                 [](pair<Rank, int> &pair) { return pair.first.first; });
97
98         RadixSort::sort_pairs(ranks, 256);
99         arr = build_ranks(ranks);

```

```

100
101 {
102     int jump = 1;
103     int max_rank = arr[ranks.back().second];
104
105     // It will be compared intervals a pair of intervals (i, jump-1), (i +
106     // jump, i + 2*jump - 1). The variable jump is always a power of 2.
107     while (jump < n) {
108         for (int i = 1; i <= this->n; i++) {
109             ranks[i].first.first = arr[i];
110             ranks[i].first.second = (i + jump <= this->n ? arr[i + jump] : 0);
111             ranks[i].second = i;
112         }
113
114         // Inserting only the ranks in the table.
115         transform(ranks.begin(), ranks.end(),
116                 back_inserter(rank_table[rank_table_size++]),
117                 [](pair<Rank, int> &pair) { return pair.first.first; });
118
119         RadixSort::sort_pairs(ranks, n);
120
121         arr = build_ranks(ranks);
122
123         max_rank = arr[ranks.back().second];
124         jump *= 2;
125     }
126
127     for (int i = 1; i <= n; i++) {
128         ranks[i].first.first = arr[i];
129         ranks[i].first.second = (i + jump <= this->n ? arr[i + jump] : 0);
130         ranks[i].second = i;
131     }
132
133     // Inserting only the ranks in the table.
134     transform(ranks.begin(), ranks.end(),
135             back_inserter(rank_table[rank_table_size++]),
136             [](pair<Rank, int> &pair) { return pair.first.first; });
137
138     this->suffix_array.resize(this->n + 1);
139     for (int i = 1; i <= this->n; i++)
140         this->suffix_array[arr[i]] = i;
141 }
142
143 /// Builds the lcp (Longest Common Prefix) array for the string s.
144 /// A value lcp[i] indicates length of the longest common prefix of the
145 /// suffixes indexed by i and i + 1. Implementation of the Kasai's
146 /// Algorithm.
147 ///
148 /// Time Complexity: O(n)
149 /// Space Complexity: O(n)
150 vector<int> build_lcp() {
151     vector<int> lcp(this->n + 1, 0);
152     vector<int> inverse_suffix(this->n + 1, 0);
153
154     for (int i = 1; i <= n; i++)
155         inverse_suffix[suffix_array[i]] = i;
156
157     int k = 0;
158
159     for (int i = 1; i <= n; i++) {
160         if (inverse_suffix[i] == n) {
161             k = 0;
162             continue;
163         }

```

```

164     int j = suffix_array[inverse_suffix[i] + 1];
165
166     while (i + k <= this->n && j + k <= this->n && s[i + k] == s[j + k])
167         k++;
168
169     lcp[inverse_suffix[i]] = k;
170
171     if (k > 0)
172         k--;
173 }
174
175 return lcp;
176 }
177
178 void build_log_array() {
179     log_array.resize(this->n + 1, 0);
180
181     for (int i = 2; i <= this->n; i++)
182         log_array[i] = log_array[i / 2] + 1;
183 }
184
185 public:
186     const vector<int> &get_suffix_array() { return suffix_array; }
187
188     const vector<int> &get_lcp() { return lcp; }
189
190     /// LCS of two strings A and B.
191     ///
192     /// The string s must be initialized in the constructor as the string (A +
193     /// 's'
194     /// + B).
195     ///
196     /// The string A starts at index 1 and ends at index (separator - 1).
197     /// The string B starts at index (separator + 1) and ends at the end of the
198     /// string.
199     ///
200     /// Time Complexity: O(n)
201     /// Space Complexity: O(1)
202     int lcs(int separator) {
203         separator++;
204         assert(!isalpha(this->s[separator] && !isdigit(this->s[separator]]));
205
206         int ans = 0;
207
208         for (int i = 1; i < this->n - 1; i++) {
209             int left = this->suffix_array[i];
210             int right = this->suffix_array[i + 1];
211
212             if ((left < separator && right > separator) ||
213                 (left > separator && right < separator))
214                 ans = max(ans, lcp[i]);
215         }
216
217         return ans;
218     }
219
220     /// Compares two substrings beginning at indexes i and j of a fixed length.
221     ///
222     /// OBS: Necessary build rank_table (uncomment build_suffix_array) and
223     /// build
224     /// log_array.
225     ///
226     /// Time Complexity: O(1)
227     /// Space Complexity: O(1)

```

```

227     int compare(const int i, const int j, const int length) {
228         assert(1 <= i && i <= this->n && 1 <= j && j <= this->n);
229         assert(!this->log_array.empty() && !this->rank_table.empty());
230         assert(i + length - 1 <= this->n && j + length - 1 <= this->n);
231
232         // Greatest k such that 2^k <= 1
233         const int k = this->log_array[length];
234
235         const int jump = length - (1 << k);
236
237         const pair<int, int> iRank = {
238             this->rank_table[k][i],
239             (i + jump <= this->n ? this->rank_table[k][i + jump] : -1)};
240         const pair<int, int> jRank = {
241             this->rank_table[k][j],
242             (j + jump <= this->n ? this->rank_table[k][j + jump] : -1)};
243
244         return iRank == jRank ? 0 : iRank < jRank ? -1 : 1;
245     }
246 };

```

9.13. Trie

```

1  class Trie {
2  private:
3      static const int INT_LEN = 31;
4      // static const int INT_LEN = 63;
5
6  public:
7      struct Node {
8          map<char, Node *> next;
9          int id;
10         // cnt counts the number of words which pass in that node
11         int cnt = 0;
12         // word counts the number of words ending at that node
13         int word_cnt = 0;
14
15         Node(const int x) : id(x) {}
16     };
17
18 private:
19     int trie_size = 0;
20     // contains the next id to be used in a node
21     int node_cnt = 0;
22     Node *trie_root = this->make_node();
23
24 private:
25     Node *make_node() { return new Node(node_cnt++); }
26
27     int trie_insert(const string &s) {
28         Node *aux = this->root();
29         for (const char c : s) {
30             if (!aux->next.count(c))
31                 aux->next[c] = this->make_node();
32             aux = aux->next[c];
33             ++aux->cnt;
34         }
35         ++aux->word_cnt;
36         ++this->trie_size;
37         return aux->id;
38     }
39
40     void trie_erase(const string &s) {
41         Node *aux = this->root();

```

```

42     for (const char c : s) {
43         Node *last = aux;
44         aux = aux->next[c];
45         --aux->cnt;
46         if (aux->cnt == 0) {
47             last->next.erase(c);
48             aux = nullptr;
49             break;
50         }
51     }
52     if (aux != nullptr)
53         --aux->word_cnt;
54     --this->trie_size;
55 }
56
57 int trie_count(const string &s) {
58     Node *aux = this->root();
59     for (const char c : s) {
60         if (aux->next.count(c))
61             aux = aux->next[c];
62         else
63             return 0;
64     }
65     return aux->word_cnt;
66 }
67
68 int trie_query_xor_max(const string &s) {
69     Node *aux = this->root();
70     int ans = 0;
71     for (const char c : s) {
72         const char inv = (c == '0' ? '1' : '0');
73         if (aux->next.count(inv)) {
74             ans = (ans << 111) | (inv - '0');
75             aux = aux->next[inv];
76         } else {
77             ans = (ans << 111) | (c - '0');
78             aux = aux->next[c];
79         }
80     }
81     return ans;
82 }
83
84 public:
85     Trie() {}
86
87     Node *root() { return this->trie_root; }
88
89     int size() { return this->trie_size; }
90
91     /// Returns the number of nodes present in the trie.
92     int node_count() { return this->node_cnt; }
93
94     /// Inserts s in the trie.
95     ///
96     /// Returns the id of the last character of the string in the trie.
97     ///
98     /// Time Complexity: O(s.size())
99     int insert(const string &s) { return this->trie_insert(s); }
100
101     /// Inserts the binary representation of x in the trie.
102     ///
103     /// Time Complexity: O(log x)
104     int insert(const int x) {
105         assert(x >= 0);
106         // converting x to binary representation

```

```

107         return this->trie_insert(bitset<INT_LEN>(x).to_string());
108     }
109
110     /// Removes the string s from the trie.
111     ///
112     /// Time Complexity: O(s.size())
113     void erase(const string &s) { this->trie_erase(s); }
114
115     /// Removes the binary representation of x from the trie.
116     ///
117     /// Time Complexity: O(log x)
118     void erase(const int x) {
119         assert(x >= 0);
120         // converting x to binary representation
121         this->trie_erase(bitset<INT_LEN>(x).to_string());
122     }
123
124     /// Returns the number of maximum xor sum with x present in the trie.
125     ///
126     /// Time Complexity: O(log x)
127     int query_xor_max(const int x) {
128         assert(x >= 0);
129         // converting x to binary representation
130         return this->trie_query_xor_max(bitset<INT_LEN>(x).to_string());
131     }
132
133     /// Returns the number of strings equal to s present in the trie.
134     ///
135     /// Time Complexity: O(s.size())
136     int count(const string &s) { return this->trie_count(s); }
137 };

```