

# Codesnatchers



## Contents

<b>1</b>	<b>Template</b>	<b>2</b>	<b>4</b>	<b>Math</b>	<b>6</b>
<b>2</b>	<b>Data structures</b>	<b>2</b>	4.1	Identities . . . . .	6
2.1	STL Algorithms . . . . .	2	4.2	Binary Exponentiation and Modular Arithmetic . . . . .	6
2.2	Binary Search . . . . .	3	4.3	Modular Inverse (dividir mod) . . . . .	7
2.3	Simplified DSU (Stolen from GGDem) . . . . .	4	4.4	Modular Binomial Coefficient and Permutations . . . . .	7
2.4	Disjoint Set Union . . . . .	4	4.5	Non-Mod Binomial Coefficient and Permutations . . . . .	7
2.5	Segment Tree . . . . .	4	4.6	Modular Catalan Numbers . . . . .	7
2.6	Segment Tree Lazy . . . . .	4	4.7	Ceil Fraccionario . . . . .	7
2.7	Trie . . . . .	4	4.8	Numeros de Fibonacci . . . . .	7
<b>3</b>	<b>Graphs</b>	<b>4</b>	4.9	Sieve Of Eratosthenes . . . . .	7
3.1	Graph Transversal . . . . .	4	4.10	Sieve-based Factorization . . . . .	8
3.1.1	BFS . . . . .	4	4.11	Cycle Finding . . . . .	8
3.1.2	DFS . . . . .	4	4.12	Berlekamp Massey . . . . .	8
3.2	Topological Sort . . . . .	5	4.13	Modular Berlekamp Massey . . . . .	8
3.3	APSP: Floyd Warshall . . . . .	5	4.14	Matrix exponentiation . . . . .	8
3.4	SSSP . . . . .	5	4.15	Ecuaciones Diofantinas . . . . .	8
3.4.1	Lazy Dijkstra . . . . .	5	4.16	Pollard-Rho, Stolen from GGDem . . . . .	8
3.4.2	Bellman-Ford . . . . .	6	4.17	FFT, Stolen from GGDem . . . . .	8
3.5	Strongly Connected Components: Kosaraju . . . . .	6	4.18	Euler Totient Function . . . . .	8
3.6	Articulation Points and Bridges: ModTarjan . . . . .	6	<b>5</b>	<b>Geometry</b>	<b>8</b>
			<b>6</b>	<b>Strings</b>	<b>8</b>
			6.1	Explode by token . . . . .	8
			6.2	Multiple Hashings DS . . . . .	9
			6.3	Permute chars of string . . . . .	9
			6.4	Longest common subsequence . . . . .	9
			6.5	KMP . . . . .	9
			6.6	Suffix Array . . . . .	9
			6.7	STL Suffix Array . . . . .	9
			<b>7</b>	<b>Classics</b>	<b>9</b>
			7.1	Job scheduling . . . . .	9
			7.1.1	One machine, linear penalty . . . . .	9
			7.1.2	One machine, deadlines . . . . .	9
			7.1.3	One machine, profit . . . . .	9
			7.1.4	Two machines, min time . . . . .	9
			<b>8</b>	<b>Flow</b>	<b>9</b>
			8.1	Dinic, thx GGDem . . . . .	9
			<b>9</b>	<b>Miscellaneous</b>	<b>9</b>
			9.1	pbds . . . . .	9

9.2 Bit Manipulation . . . . .	9
<b>10 Testing</b>	<b>9</b>
10.1 Gen and AutoRun testcases . . . . .	9
10.1.1 Gen.cpp . . . . .	9
10.1.2 Stress testing . . . . .	9
10.1.3 Autorun . . . . .	9
10.2 Highly Composite Numbers . . . . .	9

## 1 Template

```

1  #include <bits/stdc++.h>
2  #define endl '\n'
3  #define ll long long int
4  #define ull unsigned long long int
5  #define MOD7 1000000007
6  #define MOD9 1000000009
7  #define MAX 1000001
8
9  using namespace std;
10
11  /*-----SOLBEGIN-----*/
12
13  void solve() {
14      return;
15  }
16
17  int main() {
18      ios_base::sync_with_stdio(0);
19      cin.tie(0);
20
21      int t = 1; cin >> t;
22      while (t--) solve();
23
24      return 0;
25  }

```

## 2 Data structures

### 2.1 STL Algorithms

STL stands for Standard Template Library. It is a library that provides several generic classes and functions, allowing programmers to manipulate data structures in an easy and efficient way. The STL provides a range of algorithms which can be used to manipulate data stored in containers. The following list shows some of the algorithms provided by the STL and its functions:

#### Non-Manipulating Algorithms

- **sort(first\_iterator, last\_iterator)** - Sorts the elements in the range [first, last) in ascending order.
- **sort(first\_iterator, last\_iterator, greater<int>())** - Sorts elements inside the vector, in descending order.

- **reverse(first\_iterator, last\_iterator)** - Reverses elements inside a vector.
- **\*max\_element(first\_iterator, last\_iterator)** - Finds the maximum element of a vector.
- **\*min\_element(first\_iterator, last\_iterator)** - Finds the minimum element of a vector.
- **accumulate(first\_iterator, last\_iterator, initial value of sum)** - Summates all the vector elements.
- **count(first\_iterator, last\_iterator, x)** - Counts all occurrences 'x' inside a vector.
- **find(first\_iterator, last\_iterator, x)** - Returns an iterator to the first occurrence of 'x' in vector and points to last address if the element is not present.
- **binary\_search(first\_iterator, last\_iterator, x)** - Tests if 'x' exists in sorted vector or not.
- **lower\_bound(first\_iterator, last\_iterator, x)** - Returns an element pointing to the first element in range [first, last), which has a value less than 'x'.
- **upper\_bound(first\_iterator, last\_iterator, x)** - Returns an element pointing to the first element in range [first, last), which has a value greater than 'x'.

### Manipulating Algorithms

- **arr.erase(position to delete)** - Erases selected element in vector and shifts and resizes it accordingly.
- **arr.erase(unique(arr.begin(), arr.end()), arr.end())** - Erases the duplicate occurrences in sorted vector in a single line.
- **next\_permutation(first\_iterator, last\_iterator)** - Modifies the vector to its next permutation.
- **prev\_permutation(first\_iterator, last\_iterator)** - Modifies the vector to its previous permutation.
- **distance(first\_iterator, desired\_iterator)** - Returns the distance of the desired position from the first iterator to a desired one.

## 2.2 Binary Search

```

1  #include <bits/stdc++.h>
2  using namespace std;
3
4  vector<int> vec;
5
6  int binary_search_first_occurrence(const vector<int>& vec, int value) {
7      // Binary search algorithm finds the first occurrence of a value in
8      // a sorted vector
9      // Declare left and right pointers
10     int left = 0;
11     int right = vec.size() - 1;
12     int result = -1;
13     // While left and right pointers do not cross, keep searching
14     while (left <= right) {
15         // Calculate the middle element of the vector
16         int mid = left + (right - left) / 2;
17         // If the middle element is the value we are looking for, return
18         // its index
19         if (vec[mid] == value) {
20             result = mid;
21             // left = mid + 1; // Continue searching in the right half
22             // (for last occurrence)
23             right = mid - 1; // Continue searching in the left half
24             // If the middle element is smaller than the value we are
25             // looking for, search in the right half
26         } else if (vec[mid] < value) {
27             left = mid + 1;
28             // If the middle element is greater than the value we are
29             // looking for, search in the left half
30         } else {
31             right = mid - 1;
32         }
33     }
34     return result; // Returns -1 if value is not found
35 }
36
37 int main() {
38     // Assign the variable value to the value you want to search
39     int elements, value = 0;
40     cin >> elements;
41     // Read the elements of the vector

```

```

37     for (int i = 0; i < elements; i++) {
38         int x;
39         cin >> x;
40         vec.push_back(x);
41     }
42     cout << binary_search_first_occurrence(vec, value);
43
44     return 0;
45 }

```

## 2.3 Simplified DSU (Stolen from GGDem)

### 2.4 Disjoint Set Union

### 2.5 Segment Tree

### 2.6 Segment Tree Lazy

### 2.7 Trie

## 3 Graphs

### 3.1 Graph Transversal

#### 3.1.1 BFS

```

1  #include <bits/stdc++.h>
2  using namespace std;
3
4  vector<bool> visited;
5  vector<vector<int>> adj;
6
7  void breadth_first_search(int node) {
8      // BFS requires queue data structure, starting from a given initial
      // node
9      queue<int> q;
10     q.push(node);
11     visited[node] = true;
12     // While queue is not empty, pop the first element and push its
      // children
13     while (!q.empty()) {
14         int v = q.front();
15         cout << v << " ";
16         q.pop();
17         // Push all children of v

```

```

18         for (int u : adj[v]) {
19             // If not visited, push and mark as visited
20             if (!visited[u]) {
21                 q.push(u);
22                 visited[u] = true;
23             }
24         }
25     }
26 }
27
28 int main() {
29     int nodes, edges;
30     cin >> nodes >> edges;
31     // Initialize visited and adjacency list
32     visited.assign(nodes, false);
33     adj.assign(nodes, vector<int>());
34     int u, v;
35     // Values of nodes, given as pairs
36     for (int i = 0; i < edges; i++) {
37         cin >> u >> v;
38         adj[u].push_back(v);
39         adj[v].push_back(u); // <- Assuming undirected graph
40     }
41     breadth_first_search(0); // Start BFS from node x
42
43     return 0;
44 }

```

#### 3.1.2 DFS

```

1  #include <bits/stdc++.h>
2  using namespace std;
3
4  vector<bool> visited;
5  vector<vector<int>> adj;
6
7  void depth_first_search(int node) {
8      // DFS requires stack data structure, starting from a given initial
      // node
9      visited[node] = true;
10     cout << node << " ";
11     // For each child of node, if it hasn't been visited, call DFS
      // function

```

```

12     for(int i = 0; i < adj[node].size(); i++) {
13         int child = adj[node][i];
14         if(!visited[child]) {
15             depth_first_search(child);
16         }
17     }
18 }
19
20 int main() {
21     int nodes, edges;
22     cin >> nodes >> edges;
23     // Initialize visited and adjacency list
24     visited.assign(nodes, false);
25     adj.assign(nodes, vector<int>());
26     // Values of nodes, given as pairs
27     for(int i = 0; i < edges; i++) {
28         int u, v;
29         cin >> u >> v;
30         adj[u].push_back(v);
31         adj[v].push_back(u); // <- Assuming undirected graph
32     }
33     // For each node, if it hasn't been visited, call DFS function
34     for(int i = 0; i < nodes; i++) {
35         if(!visited[i]) {
36             depth_first_search(i);
37         }
38     }
39
40     return 0;
41 }

```

### 3.2 Topological Sort

### 3.3 APSP: Floyd Warshall

### 3.4 SSSP

#### 3.4.1 Lazy Dijkstra

```

1 // Lazy version of Dijkstra's algorithm usign priority queue
2 // Works with negative weights while there are no negative cycles
3 // If there are any negative cycles, the algorithm will not work
4 #include <bits/stdc++.h>
5 #define GS 1000

```

```

6 #define INF 100000000
7 using namespace std;
8
9 // Define the graph and the distance array
10 vector<pair<int, int>> graph[GS];
11 int distance[GS];
12
13 void dijkstra(int origin, int size) {
14     // Set all distances to INF
15     for (int i = 0; i <= size; i++) distance[i] = INF;
16     // Create the priority queue and the current pair
17     priority_queue<pair<int, int>, vector<pair<int, int>>, greater<pair<
18         int, int>>> pq;
19     pair<int, int> current;
20
21     // Set the distance to the origin to 0 and push it to the queue
22     pq.push(make_pair(0, origin));
23
24     // While the queue is not empty, get the top element and update the
25     // distances
26     while (!pq.empty()) {
27         // Get the top element and pop it
28         current = pq.top();
29         pq.pop();
30
31         // If the distance is already smaller, continue to next
32         // iteration
33         if (distance[current.second] < current.first) continue;
34         // Update the distance
35         distance[current.second] = current.first;
36
37         // Iterate over the neighbors and update the distances
38         for (pair<int, int> neighbor : graph[current.second]) {
39             // If the new distance is smaller, push it to the queue
40             if ((neighbor.second + current.first) < distance[neighbor.
41                 first]) {
42                 pq.push(make_pair(neighbor.second + current.first,
43                     neighbor.first));
44             }
45         }
46     }
47 }

```

### 3.4.2 Bellman-Ford

## 3.5 Strongly Connected Components: Kosaraju

## 3.6 Articulation Points and Bridges: ModTarjan

# 4 Math

## 4.1 Identities

**Coeficientes binomiales.**

$$(a+b)^n = \sum_{k=0}^n \binom{n}{k} a^{n-k} b^k$$

$$\binom{n}{k} = \binom{n}{n-k}$$

$$\binom{n}{k} = \binom{n-1}{k} + \binom{n-1}{k-1}$$

$$k \binom{n}{k} = n \binom{n-1}{k-1}$$

$$\sum_{k=0}^n n \binom{n}{k} = 2^n$$

$$\sum_{k=0}^n (-1)^k \binom{n}{k} = 0$$

$$\binom{n+m}{t} = \sum_{k=0}^t \binom{n}{k} \binom{m}{t-k}$$

$$\sum_{j=k}^n \binom{j}{k} = \binom{n+1}{k+1}$$

**Números Catalanés.**

$$C_n = \frac{2(2n-1)}{n+1} C_{n-1}$$

$$C_n = \frac{1}{n+1} \binom{2n}{n}$$

$$C_n \sim \frac{4^n}{n^{3/2} \sqrt{\pi}}$$

$$\Sigma(n) = O(\log(\log(n))) \text{ (number of divisors of } n)$$

$$F_{2n+1} = F_n^2 + F_{n+1}^2$$

$$F_{2n} = F_{n+1}^2 - F_{n-1}^2$$

$$\sum_{i=1}^n F_i = F_{n+2} - 1$$

$$F_{n+i} F_{n+j} - F_n F_{n+i+j} = (-1)^n F_i F_j$$

**(Möbius Function)**

0 if n is square-free

1 if n got even amount of distinct prime factors

0 if n got odd amount of distinct prime factors

**(Möbius Inv. Formula)**

$$\text{Let } g(n) = \sum_{d|n} f(d), \text{ then } f(n) = \sum_{d|n} g(d) \mu\left(\frac{n}{d}\right).$$

**Permutaciones objetos repetidos**

$$P(n, k) = \frac{P(n, k)}{n_1! n_2! \dots}$$

**Separadores, Ecuaciones lineales a variables = b**

$$\binom{a}{b} = \binom{a+b-1}{b} = \binom{a+b-1}{a-1}$$

**Teorema chino**

sean  $\{n_1, n_2, \dots, n_k\}$  primos relativos

$$P = n_1 \cdot n_2 \cdot \dots \cdot n_k$$

$$P_i = \frac{P}{n_i}$$

$$x \cong a_1(n_1)$$

$$x \cong a_2(n_2) \dots x \cong a_k(n_k)$$

$$P_1 S_1 \cong 1(n_1) \text{ Donde } S \text{ soluciones.}$$

$$x = P_1 S_1 a_1 + P_2 S_2 a_2 \dots P_k S_k a_k$$

## 4.2 Binary Exponentiation and Modular Arithmetic

Modular arithmetic is a system of arithmetic for integers, which considers the remainder. In modulus, numbers "wrap around" upon reaching a fixed value.

### Congruence

A number  $x \bmod N$  is the equivalent of the remainder of the division of  $x$  by  $N$ . Two numbers  $a$  and  $b$  are congruent modulo  $N$  if they have the same remainder upon division by  $N$ . We say that  $N$  if  $a \bmod N = b \bmod N$ .

- **For example:**  $54 \equiv 24 \pmod{7}$

Both numbers are congruent modulo 7, since  $54 \bmod 7 = 3$  and  $24 \bmod 7 = 3$ .

Another way of defining this is by saying that  $a$  and  $b$  are congruent modulo  $N$  if their difference  $(a - b)$  is an integer multiple of  $n$ , that is, if  $\frac{a-b}{n}$  has a remainder of 0.

- **For example:**  $36 \equiv 10 \pmod{13}$

36 and 10 are congruent modulo 13, since their difference  $36 - 10 = 26$  is a multiple of 13 ( $n = 13$ ).

### Addition

#### Properties of addition in Modular Arithmetic:

1. If  $a + b = c$  then  $a \pmod{N} + b \pmod{N} \equiv c \pmod{N}$ .
2. If  $a \equiv b \pmod{N}$ , then  $a + k \equiv b + k \pmod{N}$  for any integer  $k$ .
3. If  $a \equiv b \pmod{N}$  and  $c \equiv d \pmod{N}$ , then  $a + c \equiv b + d \pmod{N}$ .
4. If  $a \equiv b \pmod{N}$ , then  $-a \equiv -b \pmod{N}$ .

- **For example:** Find the sum of 31 and 148 in modulo 24.

31 in modulo 24 is 7 and 148 in modulo 24 is 4. Thus,  $31 + 148 \equiv 7 + 4 \equiv 11 \pmod{24}$ .

- **Another example:** Find the remainder when  $123 + 234 + 32 + 56 + 22 + 12 + 78$  is divided by 3.

We know that  $123 \bmod 3 = 0$ ,  $234 \bmod 3 = 0$ ,  $32 \bmod 3 = 2$ ,  $56 \bmod 3 = 2$ ,  $22 \bmod 3 = 1$ ,  $12 \bmod 3 = 0$ , and  $78 \bmod 3 = 0$ . Thus, the sum of all these numbers is  $0 + 0 + 2 + 2 + 1 + 0 + 0 = 5$ , and  $5 \bmod 3 = 2$ .

### Multiplication

#### Properties of multiplication in Modular Arithmetic:

1. If  $a \cdot b = c$ , then  $a \pmod{N} \cdot b \pmod{N} \equiv c \pmod{N}$ .
2. If  $a \equiv b \pmod{N}$ , then  $a \cdot k \equiv b \cdot k \pmod{N}$  for any integer  $k$ .
3. If  $a \equiv b$  and  $c \equiv d \pmod{N}$ , then  $a \cdot c \equiv b \cdot d \pmod{N}$ .

- **For example:** What is  $(8 \cdot 16) \pmod{7}$ .

Since  $8 \equiv 1 \pmod{7}$  and  $16 \equiv 2 \pmod{7}$ , then  $(8 \cdot 16) \equiv (1 \cdot 2) \equiv 2 \pmod{7}$ .

- **Another example:** What is the remainder when  $123 \cdot 234 \cdot 32 \cdot 56 \cdot 22 \cdot 12 \cdot 78$  is divided by 3.

We know that  $123 \equiv 1$ ,  $134 \equiv 2$ ,  $23 \equiv 2$ ,  $49 \equiv 1$ ,  $235 \equiv 1$  and  $13 \equiv 1$ , therefore:

$123 \cdot 234 \cdot 32 \cdot 56 \cdot 22 \cdot 12 \cdot 78 \equiv 1 \cdot 2 \cdot 2 \cdot 1 \cdot 1 \cdot 1 \equiv 4 \equiv 1 \pmod{3}$ . Leaving a remainder of 1.

```

1 void modArithmetic (int a, int b, int x) {
2     // If the result of adding a and b is greater than x, take the
3     // remainder of the division by x
4     (a + b) % x;
5     // If the result of subtracting a and b is less than 0, add x to the
6     // result and take the modulus again
7     (a - b %x + x) % x;
8     // If the result of multiplying a and b is greater than x, take the
9     // remainder of the division by x
10    (a * b) % x;
11 }

```

### 4.3 Modular Inverse (dividir mod)

The modular inverse of an integer  $a$  modulo  $m$  is an integer  $x$  such that  $ax \equiv 1 \pmod{m}$ .

- If  $a$  and  $N$  are integers such that  $\gcd(a, N) = 1$ , then there exists an integer  $x$  such that  $ax \equiv 1 \pmod{N}$ .  
 $x$  is called the modular inverse of  $a$  modulo  $N$ .

However,  $\frac{a}{b} \pmod{N}$  is not the same as  $(\frac{a \pmod{N}}{b \pmod{N}}) \pmod{N}$ .

- Lets take  $a = 10$ ,  $b = 2$ , and  $N = 3$ .

$\frac{10}{2} \pmod{3} = 5 \pmod{3} = 2$ ;  $(\frac{10 \pmod{3}}{2 \pmod{3}}) \pmod{3} = (\frac{1}{2}) \pmod{3} = 0.5$ .

This discrepancy is due to the fact that division is not always compatible with modular arithmetic.

On the other hand, using the extended Euclidean algorithm, we can find the modular inverse of  $a$  modulo  $N$ :

```

1 #include <bits/stdc++.h>
2 using namespace std;
3
4 int gcdExtended(int a, int b, int& x, int& y) {
5     // Base Case
6     if (b == 0) {
7         x = 1;
8         y = 0;
9         return a;
10    }
11
12    int x1, y1;
13    int gcd = gcdExtended(b%a, a, &x1, &y1);
14
15    x = y1;
16    y = x1 - y1 * (a / b);
17
18    return gcd;
19 }

```

### 4.4 Modular Binomial Coefficient and Permutations

### 4.5 Non-Mod Binomial Coefficient and Permutations

### 4.6 Modular Catalan Numbers

### 4.7 Ceil Fraccionario

```

1 long long int ceil(long long int numerator, long long int denominator) {
2     return (numerator + denominator - 1) / denominator;
3 }

```

### 4.8 Numeros de Fibonacci

```

1 #include <bits/stdc++.h>
2 using namespace std;
3
4 int fibonacci(int x) {
5     if (x == 0) return 0;
6     if (x == 1) return 1;
7     return fibonacci(x - 1) + fibonacci(x - 2);
8 }

```

### 4.9 Sieve Of Eratosthenes

```
1 #include <bits/stdc++.h>
2 #define MAX 1000001
3 using namespace std;
4
5 // Define both prime and pfix arrays
6 bool prime[MAX];
7 int pfix[MAX];
8
9 void sieve() {
10     // Set all numbers as prime
11     memset(prime, true, sizeof(prime));
12     // 0 and 1 are not prime
13     prime[0] = prime[1] = false;
14     // Iterate over all numbers
15     for (int p = 2; p * p < MAX; p++)
16         if (prime[p]) for (int i = p * p; i < MAX; i += p) prime[i] =
17             false;
18     // Calculate prefix sum of prime numbers
19     for (int i = 2; i < MAX; i++) {pfix[i] = pfix[i - 1] + prime[i];}
```

```
1 vector<string> explode_by_token(string const& s, char delimiter) {
2     vector<string> result;
3     // Create a string stream from the string, allowing to perform input
4     // output operations on strings.
5     stringstream iss(s);
6     // Read the string stream, tokenizing it by the delimiter
7     for(string token; getline(iss, token, delimiter);) {
8         // Split the string by the delimiter and push it to the result
9         // vector
10        result.push_back(move(token));
11    }
12    // Return the result vector
13    return result;
14 }
```

#### 4.10 Sieve-based Factorization

#### 4.11 Cycle Finding

#### 4.12 Berlekamp Massey

#### 4.13 Modular Berlekamp Massey

#### 4.14 Matrix exponentiation

#### 4.15 Ecuaciones Diofantinas

#### 4.16 Pollard-Rho, Stolen from GGDem

#### 4.17 FFT, Stolen from GGDem

#### 4.18 Euler Totient Function

### 5 Geometry

### 6 Strings

#### 6.1 Explode by token



## 6.2 Multiple Hashings DS

### 6.3 Permute chars of string

### 6.4 Longest common subsequence

### 6.5 KMP

### 6.6 Suffix Array

### 6.7 STL Suffix Array

## 7 Classics

### 7.1 Job scheduling

#### 7.1.1 One machine, linear penalty

#### 7.1.2 One machine, deadlines

#### 7.1.3 One machine, profit

#### 7.1.4 Two machines, min time

## 8 Flow

### 8.1 Dinic, thx GGDem

## 9 Miscellaneous

### 9.1 pbds

### 9.2 Bit Manipulation

## 10 Testing

### 10.1 Gen and AutoRun testcases

#### 10.1.1 Gen.cpp

#### 10.1.2 Stress testing

#### 10.1.3 Autorun

### 10.2 Highly Composite Numbers

Particularly useful when testing number theoretical solutions.