



Notebook - Maratona de Programação

Lenhadoras de Segtree

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1 Math

1.1 Ceil

```
1 long long division_ceil(long long a, long long b) {
2     return 1 + ((a - 1) / b); // if a != 0
3 }
```

1.2 Matrix Exponentiation

```
1 // Description:
2 // Calculate the nth term of a linear recursion
3
4 // Example Fibonacci:
5 // Given a linear recurrence, for example fibonacci
6 // F(n) = n, x <= 1
7 // F(n) = F(n - 1) + F(n - 2), x > 1
8
9 // The recurrence has two terms, so we can build a
10 // matrix 2 x 1 so that
11 // n + 1 = transition * n
12 // (2 x 1) = (2 x 2) * (2 x 1)
13 // F(n)      = a b * F(n - 1)
14 // F(n - 1)   c d   F(n - 2)
15
16 // Another Example:
17 // Given a grid 3 x n, you want to color it using 3
18 // distinct colors so that
19 // no adjacent place has the same color. In how many
20 // different ways can you do that?
21 // There are 6 ways for the first column to be
22 // colored using 3 distinct colors
23 // ans 6 ways using 2 equal colors and 1 distinct one
24
25 // Adding another column, there are:
26 // 3 ways to go from 2 equal to 2 equal
27 // 2 ways to go from 2 equal to 3 distinct
28 // 2 ways to go from 3 distinct to 2 equal
29 // 2 ways to go from 3 distinct to 3 distinct
30
31 // So we star with matrix 6 6 and multiply it by the
32 // transition 3 2 and get 18 12
33 //
34 //           2 2           12 12
35 // the we can exponentiate this matrix to find the
36 // nth column
37
38 // Problem:
39 // https://cses.fi/problemset/task/1722/
40
41 // Complexity:
42 // O(log n)
43
44 // How to use:
45 // vector<vector<ll>> v = {{1, 1}, {1, 0}};
46 // Matriz transition = Matriz(v);
47 // cout << fexp(transition, n)[0][1] << '\n';
48
49 using ll = long long;
50
51 const int MOD = 1e9+7;
52
53 struct Matriz{
54     vector<vector<ll>> mat;
55     int rows, columns;
56
57     vector<ll> operator[](int i){
58         return mat[i];
59     }
60
61     Matriz(vector<vector<ll>>& matriz){
```

```
56     mat = matriz;
57     rows = mat.size();
58     columns = mat[0].size();
59 }
60
61 Matriz(int row, int column, bool identity=false){
62     rows = row; columns = column;
63     mat.assign(rows, vector<ll>(columns, 0));
64     if(identity) {
65         for(int i = 0; i < min(rows, columns); i
66         ++){
67             mat[i][i] = 1;
68         }
69     }
70
71     Matriz operator * (Matriz a) {
72         assert(columns == a.rows);
73         vector<vector<ll>> resp(rows, vector<ll>(a.
74         columns, 0));
75
76         for(int i = 0; i < rows; i++){
77             for(int j = 0; j < a.columns; j++){
78                 for(int k = 0; k < a.rows; k++){
79                     resp[i][j] = (resp[i][j] + (mat[i
80                     ][k] * 1LL * a[k][j]) % MOD) % MOD;
81                 }
82             }
83         }
84         return Matriz(resp);
85     }
86
87     Matriz operator + (Matriz a) {
88         assert(rows == a.rows && columns == a.columns
89         );
90         vector<vector<ll>> resp(rows, vector<ll>(
91         columns, 0));
92         for(int i = 0; i < rows; i++){
93             for(int j = 0; j < columns; j++){
94                 resp[i][j] = (resp[i][j] + mat[i][j]
95                 + a[i][j]) % MOD;
96             }
97         }
98         return Matriz(resp);
99     }
100 };
101
102 Matriz fexp(Matriz base, ll exponent){
103     Matriz result = Matriz(base.rows, base.rows, 1);
104     while(exponent > 0){
105         if(exponent & 1LL) result = result * base;
106         base = base * base;
107         exponent = exponent >> 1;
108     }
109     return result;
110 }
```

1.3 Crt

```
1 ll crt(const vector<pair<ll, ll>> &vet){
2     ll ans = 0, lcm = 1;
3     ll a, b, g, x, y;
4     for(const auto &p : vet) {
5         tie(a, b) = p;
6         tie(g, x, y) = gcd(lcm, b);
7         if((a - ans) % g != 0) return -1; // no
8         solution
9         ans = ans + x * ((a - ans) / g) % (b / g) *
10         lcm;
11         lcm = lcm * (b / g);
12         ans = (ans % lcm + lcm) % lcm;
13     }
14     return ans;
15 }
```

```
13 }
```

1.4 Binary To Decimal

```
1 int binary_to_decimal(long long n) {
2     int dec = 0, i = 0, rem;
3
4     while (n!=0) {
5         rem = n % 10;
6         n /= 10;
7         dec += rem * pow(2, i);
8         ++i;
9     }
10
11     return dec;
12 }
13
14 long long decimal_to_binary(int n) {
15     long long bin = 0;
16     int rem, i = 1;
17
18     while (n!=0) {
19         rem = n % 2;
20         n /= 2;
21         bin += rem * i;
22         i *= 10;
23     }
24
25     return bin;
26 }
```

1.5 Fast Exponentiation

```
1 ll fexp(ll b, ll e, ll mod) {
2     ll res = 1;
3     b %= mod;
4     while(e){
5         if(e & 1LL)
6             res = (res * b) % mod;
7         e = e >> 1LL;
8         b = (b * b) % mod;
9     }
10     return res;
11 }
```

1.6 Linear Diophantine Equation

```
1 // int a, b, c, x1, x2, y1, y2; cin >> a >> b >> c >>
2     x1 >> x2 >> y1 >> y2;
3 // int ans = -1;
4 // if (a == 0 && b == 0) {
5 //     if (c != 0) ans = 0;
6 //     else ans = (x2 - x1 + 1) * (y2 - y1 + 1);
7 // }
8 // else if (a == 0) {
9 //     if (c % b == 0 && y1 <= c / b && y2 >= c / b)
10 //         ans = (x2 - x1 + 1);
11 //     else ans = 0;
12 // }
13 // else if (b == 0) {
14 //     if (c % a == 0 && x1 <= c / a && x2 >= c / a)
15 //         ans = (y2 - y1 + 1);
16 //     else ans = 0;
17 // }
18 // Careful when a or b are negative or zero
19 // if (ans == -1) ans = find_all_solutions(a, b, c,
20 //     x1, x2, y1, y2);
21 // cout << ans << '\n';
22 // Problems:
```

```
22 // https://www.spoj.com/problems/CEQU/
23 // http://codeforces.com/problemsets/acmsguru/problem
24 // 99999/106
```

```
24
25 // consider trivial case a or b is 0
26 int gcd(int a, int b, int& x, int& y) {
27     if (b == 0) {
28         x = 1;
29         y = 0;
30         return a;
31     }
32     int x1, y1;
33     int d = gcd(b, a % b, x1, y1);
34     x = y1;
35     y = x1 - y1 * (a / b);
36     return d;
37 }
38
39 // x and y are one solution and g is the gcd, all
40 // passed as reference
41 // minx <= x <= maxx miny <= y <= maxy
42 bool find_any_solution(int a, int b, int c, int &x0,
43     int &y0, int &g) {
44     g = gcd(abs(a), abs(b), x0, y0);
45     if (c % g) {
46         return false;
47     }
48     x0 *= c / g;
49     y0 *= c / g;
50     if (a < 0) x0 = -x0;
51     if (b < 0) y0 = -y0;
52     return true;
53 }
54 void shift_solution(int &x, int &y, int a, int b,
55     int cnt) {
56     x += cnt * b;
57     y -= cnt * a;
58 }
59 // return number of solutions in the interval
60 int find_all_solutions(int a, int b, int c, int minx,
61     int maxx, int miny, int maxy) {
62     int x, y, g;
63     if (!find_any_solution(a, b, c, x, y, g))
64         return 0;
65     a /= g;
66     b /= g;
67
68     int sign_a = a > 0 ? +1 : -1;
69     int sign_b = b > 0 ? +1 : -1;
70
71     shift_solution(x, y, a, b, (minx - x) / b);
72     if (x < minx)
73         shift_solution(x, y, a, b, sign_b);
74     if (x > maxx)
75         return 0;
76     int lx1 = x;
77
78     shift_solution(x, y, a, b, (maxx - x) / b);
79     if (x > maxx)
80         shift_solution(x, y, a, b, -sign_b);
81     int rx1 = x;
82
83     shift_solution(x, y, a, b, -(miny - y) / a);
84     if (y < miny)
85         shift_solution(x, y, a, b, -sign_a);
86     if (y > maxy)
87         return 0;
88     int lx2 = x;
89
90     shift_solution(x, y, a, b, -(maxy - y) / a);
```

```

90     if (y > maxy)
91         shift_solution(x, y, a, b, sign_a);
92     int rx2 = x;
93
94     if (lx2 > rx2)
95         swap(lx2, rx2);
96     int lx = max(lx1, lx2);
97     int rx = min(rx1, rx2);
98
99     if (lx > rx)
100         return 0;
101     return (rx - lx) / abs(b) + 1;
102 }

```

1.7 Sieve Of Eratosthenes

```

1  vector<bool> is_prime(MAX, true);
2  vector<int> primes;
3
4  void sieve() {
5      is_prime[0] = is_prime[1] = false;
6      for (int i = 2; i < MAX; i++) {
7          if (is_prime[i]) {
8              primes.push_back(i);
9
10             for (int j = i + i; j < MAX; j += i)
11                 is_prime[j] = false;
12         }
13     }
14 }

```

1.8 Multiplicative Inverse

```

1  ll extend_euclid(ll a, ll b, ll &x, ll &y) {
2      if (a == 0)
3      {
4          x = 0; y = 1;
5          return b;
6      }
7      ll x1, y1;
8      ll d = extend_euclid(b%a, a, x1, y1);
9      x = y1 - (b / a) * x1;
10     y = x1;
11     return d;
12 }
13
14 // gcd(a, m) = 1 para existir solucao
15 // ax + my = 1, ou a*x = 1 (mod m)
16 ll inv_gcd(ll a, ll m) { // com gcd
17     ll x, y;
18     extend_euclid(a, m, x, y);
19     return (((x % m) + m) % m);
20 }
21
22 ll inv(ll a, ll phim) { // com phi(m), se m for primo
23     entao phi(m) = p-1
24     ll e = phim-1;
25     return fexp(a, e, MOD);
26 }

```

1.9 Divisors

```

1  vector<long long> all_divisors(long long n) {
2      vector<long long> ans;
3      for(long long a = 1; a*a <= n; a++){
4          if(n % a == 0) {
5              long long b = n / a;
6              ans.push_back(a);
7              if(a != b) ans.push_back(b);
8          }
9      }
10     sort(ans.begin(), ans.end());

```

```

11     return ans;
12 }

```

1.10 Check If Bit Is On

```

1  // msb de 0 é undefined
2  #define msb(n) (32 - __builtin_clz(n))
3  // #define msb(n) (64 - __builtin_clzll(n) )
4  // popcount
5  // turn bit off
6
7  bool bit_on(int n, int bit) {
8      if(1 & (n >> bit)) return true;
9      else return false;
10 }

```

1.11 Prime Factors

```

1  vector<pair<long long, int>> fatora(long long n) {
2      vector<pair<long long, int>> ans;
3      for(long long p = 2; p*p <= n; p++) {
4          if(n % p == 0) {
5              int expoente = 0;
6              while(n % p == 0) {
7                  n /= p;
8                  expoente++;
9              }
10             ans.emplace_back(p, expoente);
11         }
12     }
13     if(n > 1) ans.emplace_back(n, 1);
14     return ans;
15 }

```

2 DP

2.1 Knapsack With Index

```

1  void knapsack(int W, int wt[], int val[], int n) {
2      int i, w;
3      int K[n + 1][W + 1];
4
5      for (i = 0; i <= n; i++) {
6          for (w = 0; w <= W; w++) {
7              if (i == 0 || w == 0)
8                  K[i][w] = 0;
9              else if (wt[i - 1] <= w)
10                 K[i][w] = max(val[i - 1] +
11                               K[i - 1][w - wt[i - 1]], K[i -
12                 1][w]);
13             else
14                 K[i][w] = K[i - 1][w];
15         }
16     }
17     int res = K[n][W];
18     cout<< res << endl;
19
20     w = W;
21     for (i = n; i > 0 && res > 0; i--) {
22         if (res == K[i - 1][w])
23             continue;
24         else {
25             cout<<" "<<wt[i - 1] ;
26             res = res - val[i - 1];
27             w = w - wt[i - 1];
28         }
29     }
30 }
31
32 int main()

```

```

33 {
34     int val[] = { 60, 100, 120 };
35     int wt[] = { 10, 20, 30 };
36     int W = 50;
37     int n = sizeof(val) / sizeof(val[0]);
38
39     knapsack(W, wt, val, n);
40
41     return 0;
42 }

```

2.2 Substr Palindrome

```

1 // êvoc deve informar se a substring de S formada
  pelos elementos entre os indices i e j
2 // é um palindromo ou ão.
3
4 char s[MAX];
5 int calculado[MAX][MAX]; // iniciado com false, ou 0
6 int tabela[MAX][MAX];
7
8 int is_palin(int i, int j){
9     if(calculado[i][j]){
10         return tabela[i][j];
11     }
12     if(i == j) return true;
13     if(i + 1 == j) return s[i] == s[j];
14
15     int ans = false;
16     if(s[i] == s[j]){
17         if(is_palin(i+1, j-1)){
18             ans = true;
19         }
20     }
21     calculado[i][j] = true;
22     tabela[i][j] = ans;
23     return ans;
24 }

```

2.3 Edit Distance

```

1 // Description:
2 // Minimum number of operations required to transform
  a string into another
3 // Operations allowed: add character, remove
  character, replace character
4
5 // Parameters:
6 // str1 - string to be transformed into str2
7 // str2 - string that str1 will be transformed into
8 // m - size of str1
9 // n - size of str2
10
11 // Problem:
12 // https://cses.fi/problemset/task/1639
13
14 // Complexity:
15 // O(m x n)
16
17 // How to use:
18 // memset(dp, -1, sizeof(dp));
19 // string a, b;
20 // edit_distance(a, b, (int)a.size(), (int)b.size());
21
22 // Notes:
23 // Size of dp matriz is m x n
24
25 int dp[MAX][MAX];
26
27 int edit_distance(string &str1, string &str2, int m,
  int n) {
28     if (m == 0) return n;

```

```

29     if (n == 0) return m;
30
31     if (dp[m][n] != -1) return dp[m][n];
32
33     if (str1[m - 1] == str2[n - 1]) return dp[m][n] =
  edit_distance(str1, str2, m - 1, n - 1);
34     return dp[m][n] = 1 + min({edit_distance(str1,
  str2, m, n - 1), edit_distance(str1, str2, m - 1,
  n), edit_distance(str1, str2, m - 1, n - 1)});
35 }

```

2.4 Knapsack

```

1 int val[MAXN], peso[MAXN], dp[MAXN][MAXN];
2
3 int knapsack(int n, int m){ // n Objetos | Peso max
4     for(int i=0;i<=n;i++){
5         for(int j=0;j<=m;j++){
6             if(i==0 or j==0)
7                 dp[i][j] = 0;
8             else if(peso[i-1]<=j)
9                 dp[i][j] = max(val[i-1]+dp[i-1][j-
  peso[i-1]], dp[i-1][j]);
10             else
11                 dp[i][j] = dp[i-1][j];
12         }
13     }
14     return dp[n][m];
15 }

```

2.5 Digits

```

1 // achar a quantidade de numeros menores que R que
  possuem no maximo 3 digitos nao nulos
2 // a ideia eh utilizar da ordem lexicografica para
  checar isso pois se temos por exemplo
3 // o numero 8500, a gente sabe que se pegarmos o
  numero 7... qualquer digito depois do 7
4 // sera necessariamente menor q 8500
5
6 string r;
7 int tab[20][2][5];
8
9 // i - digito de R
10 // menor - ja pegou um numero menor que um digito de
  R
11 // qt - quantidade de digitos nao nulos
12 int dp(int i, bool menor, int qt){
13     if(qt > 3) return 0;
14     if(i >= r.size()) return 1;
15     if(tab[i][menor][qt] != -1) return tab[i][menor][
  qt];
16
17     int dr = r[i]-'0';
18     int res = 0;
19
20     for(int d = 0; d <= 9; d++) {
21         int dnn = qt + (d > 0);
22         if(menor == true) {
23             res += dp(i+1, true, dnn);
24         }
25         else if(d < dr) {
26             res += dp(i+1, true, dnn);
27         }
28         else if(d == dr) {
29             res += dp(i+1, false, dnn);
30         }
31     }
32
33     return tab[i][menor][qt] = res;
34 }

```

2.6 Coins

```
1 int tb[1005];
2 int n;
3 vector<int> moedas;
4
5 int dp(int i){
6     if(i >= n)
7         return 0;
8     if(tb[i] != -1)
9         return tb[i];
10
11     tb[i] = max(dp(i+1), dp(i+2) + moedas[i]);
12     return tb[i];
13 }
14
15 int main(){
16     memset(tb, -1, sizeof(tb));
17 }
```

2.7 Minimum Coin Change

```
1 int n;
2 vector<int> valores;
3
4 int tabela[1005];
5
6 int dp(int k){
7     if(k == 0){
8         return 0;
9     }
10     if(tabela[k] != -1)
11         return tabela[k];
12     int melhor = 1e9;
13     for(int i = 0; i < n; i++){
14         if(valores[i] <= k)
15             melhor = min(melhor, 1 + dp(k - valores[i]));
16     }
17     return tabela[k] = melhor;
18 }
```

2.8 Kadane

```
1 // achar uma subsequencia continua no array que a
2 // soma seja a maior possivel
3 // nesse caso vc precisa multiplicar exatamente 1
4 // elemento da subsequencia
5 // e achar a maior soma com isso
6
7 int n, x, arr[MAX], tab[MAX][2]; // tab[maior
8 // resposta no intervalo][foi multiplicado ou ão]
9
10 int dp(int i, bool mult) {
11     if (i == n-1) {
12         if (!mult) return arr[n-1]*x;
13         return arr[n-1];
14     }
15     if (tab[i][mult] != -1) return tab[i][mult];
16
17     int res;
18
19     if (mult) {
20         res = max(arr[i], arr[i] + dp(i+1, 1));
21     }
22     else {
23         res = max({
24             arr[i]*x,
25             arr[i]*x + dp(i+1, 1),
26             arr[i] + dp(i+1, 0)
27         });
28     }
29 }
```

```
27     return tab[i][mult] = res;
28 }
29
30 int main() {
31
32     memset(tab, -1, sizeof(tab));
33
34     int ans = -oo;
35     for (int i = 0; i < n; i++) {
36         ans = max(ans, dp(i, 0));
37     }
38
39     return 0;
40 }
41
42
43
44 int ans = a[0], ans_l = 0, ans_r = 0;
45 int sum = 0, minus_pos = -1;
46
47 for (int r = 0; r < n; ++r) {
48     sum += a[r];
49     if (sum > ans) {
50         ans = sum;
51         ans_l = minus_pos + 1;
52         ans_r = r;
53     }
54     if (sum < 0) {
55         sum = 0;
56         minus_pos = r;
57     }
58 }
```

3 Template

3.1 Template

```
1 #include <bits/stdc++.h>
2 using namespace std;
3
4 #define int long long
5 #define optimize std::ios::sync_with_stdio(false);
6     cin.tie(NULL);
7
8 #define vi vector<int>
9 #define ll long long
10 #define pb push_back
11 #define mp make_pair
12 #define ff first
13 #define ss second
14 #define pii pair<int, int>
15 #define MOD 1000000007
16 #define sqr(x) ((x) * (x))
17 #define all(x) (x).begin(), (x).end()
18 #define FOR(i, j, n) for (int i = j; i < n; i++)
19 #define qle(i, n) (i == n ? "\n" : " ")
20 #define endl "\n"
21 const int oo = 1e9;
22 const int MAX = 1e6;
23
24 int32_t main(){ optimize;
25
26     return 0;
27 }
```

3.2 Template Clean

```
1 // Notes:
2 // Compile and execute
3 // g++ teste.cpp -o teste -std=c++17
4 // ./teste < teste.txt
5
```

```

6 // Print with precision
7 // cout << fixed << setprecision(12) << value << endl
8 ;
9 // File as input and output
10 // freopen("input.txt", "r", stdin);
11 // freopen("output.txt", "w", stdout);
12
13 #include <bits/stdc++.h>
14 using namespace std;
15
16 int main() {
17     ios::sync_with_stdio(false);
18     cin.tie(NULL);
19
20
21     return 0;
22 }
23 }

```

4 Strings

4.1 Kmp

```

1 vector<int> prefix_function(string s) {
2     int n = (int)s.length();
3     vector<int> pi(n);
4     for (int i = 1; i < n; i++) {
5         int j = pi[i-1];
6         while (j > 0 && s[i] != s[j])
7             j = pi[j-1];
8         if (s[i] == s[j])
9             j++;
10        pi[i] = j;
11    }
12    return pi;
13 }

```

4.2 Generate All Permutations

```

1 vector<string> generate_permutations(string s) {
2     int n = s.size();
3     vector<string> ans;
4
5     sort(s.begin(), s.end());
6
7     do {
8         ans.push_back(s);
9     } while (next_permutation(s.begin(), s.end()));
10
11     return ans;
12 }

```

4.3 Generate All Sequences Length K

```

1 // gera todas as possíveis sequências usando as letras
2 // em set (de comprimento n) e que tenham tamanho k
3 // sequence = ""
4 vector<string> generate_sequences(char set[], string
5     sequence, int n, int k) {
6     if (k == 0){
7         return { sequence };
8     }
9
10    vector<string> ans;
11    for (int i = 0; i < n; i++) {
12        auto aux = generate_sequences(set, sequence +
13            set[i], n, k - 1);
14        ans.insert(ans.end(), aux.begin(), aux.end());
15    }
16
17    // for (auto e : ans) ans.push_back(e);

```

```

13 }
14
15     return ans;
16 }

```

4.4 Lcs

```

1 // Description:
2 // Finds the longest common subsequence between two
3 // string
4
5 // Problem:
6 // https://codeforces.com/gym/103134/problem/B
7
8 // Complexity:
9 // O(mn) where m and n are the length of the strings
10
11 string lcsAlgo(string s1, string s2, int m, int n) {
12     int LCS_table[m + 1][n + 1];
13
14     for (int i = 0; i <= m; i++) {
15         for (int j = 0; j <= n; j++) {
16             if (i == 0 || j == 0)
17                 LCS_table[i][j] = 0;
18             else if (s1[i - 1] == s2[j - 1])
19                 LCS_table[i][j] = LCS_table[i - 1][j - 1] +
20                     1;
21             else
22                 LCS_table[i][j] = max(LCS_table[i - 1][j],
23                     LCS_table[i][j - 1]);
24         }
25     }
26
27     int index = LCS_table[m][n];
28     char lcsAlgo[index + 1];
29     lcsAlgo[index] = '\0';
30
31     int i = m, j = n;
32     while (i > 0 && j > 0) {
33         if (s1[i - 1] == s2[j - 1]) {
34             lcsAlgo[index - 1] = s1[i - 1];
35             i--;
36             j--;
37             index--;
38         }
39         else if (LCS_table[i - 1][j] > LCS_table[i][j - 1])
40             i--;
41         else
42             j--;
43     }
44
45     return lcsAlgo;
46 }

```

4.5 Trie

```

1 const int K = 26;
2
3 struct Vertex {
4     int next[K];
5     bool output = false;
6     int p = -1;
7     char pch;
8     int link = -1;
9     int go[K];
10
11     Vertex(int p=-1, char ch='$') : p(p), pch(ch) {
12         fill(begin(next), end(next), -1);
13         fill(begin(go), end(go), -1);
14     }

```



```

15 };
16
17 vector<Vertex> t(1);
18
19 void add_string(string const& s) {
20     int v = 0;
21     for (char ch : s) {
22         int c = ch - 'a';
23         if (t[v].next[c] == -1) {
24             t[v].next[c] = t.size();
25             t.emplace_back(v, ch);
26         }
27         v = t[v].next[c];
28     }
29     t[v].output = true;
30 }
31
32 int go(int v, char ch);
33
34 int get_link(int v) {
35     if (t[v].link == -1) {
36         if (v == 0 || t[v].p == 0)
37             t[v].link = 0;
38         else
39             t[v].link = go(get_link(t[v].p), t[v].pch);
40     }
41     return t[v].link;
42 }
43
44 int go(int v, char ch) {
45     int c = ch - 'a';
46     if (t[v].go[c] == -1) {
47         if (t[v].next[c] != -1)
48             t[v].go[c] = t[v].next[c];
49         else
50             t[v].go[c] = v == 0 ? 0 : go(get_link(v),
51                                         ch);
52     }
53     return t[v].go[c];
54 }

```

4.6 Z-function

```

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

```

5 Misc

5.1 Split

```

1 vector<string> split(string txt, char key = ' '){
2     vector<string> ans;
3
4     string palTemp = "";
5     for(int i = 0; i < txt.size(); i++){
6
7         if(txt[i] == key){
8             if(palTemp.size() > 0){

```

```

9                 ans.push_back(palTemp);
10                palTemp = "";
11            }
12        } else{
13            palTemp += txt[i];
14        }
15    }
16 }
17
18 if(palTemp.size() > 0)
19     ans.push_back(palTemp);
20
21 return ans;
22 }

```

5.2 Int128

```

1 __int128 read() {
2     __int128 x = 0, f = 1;
3     char ch = getchar();
4     while (ch < '0' || ch > '9') {
5         if (ch == '-') f = -1;
6         ch = getchar();
7     }
8     while (ch >= '0' && ch <= '9') {
9         x = x * 10 + ch - '0';
10        ch = getchar();
11    }
12    return x * f;
13 }
14 void print(__int128 x) {
15     if (x < 0) {
16         putchar('-');
17         x = -x;
18     }
19     if (x > 9) print(x / 10);
20     putchar(x % 10 + '0');
21 }

```

6 Graphs

6.1 Centroid Find

```

1 // Description:
2 // Indexed at zero
3 // Find a centroid, that is a node such that when it
4 // is appointed the root of the tree,
5 // each subtree has at most floor(n/2) nodes.
6
7 // Problem:
8 // https://cses.fi/problemset/task/2079/
9
10 // Complexity:
11 // O(n)
12
13 // How to use:
14 // get_subtree_size(0);
15 // cout << get_centroid(0) + 1 << endl;
16
17 int n;
18 vector<int> adj[MAX];
19 int subtree_size[MAX];
20
21 int get_subtree_size(int node, int par = -1) {
22     int &res = subtree_size[node];
23     res = 1;
24     for (int i : adj[node]) {
25         if (i == par) continue;
26         res += get_subtree_size(i, node);
27     }
28     return res;
29 }

```

```

28 }
29
30 int get_centroid(int node, int par = -1) {
31     for (int i : adj[node]) {
32         if (i == par) continue;
33
34         if (subtree_size[i] * 2 > n) { return
get_centroid(i, node); }
35     }
36     return node;
37 }
38
39 int main() {
40     cin >> n;
41     for (int i = 0; i < n - 1; i++) {
42         int u, v; cin >> u >> v;
43         u--; v--;
44         adj[u].push_back(v);
45         adj[v].push_back(u);
46     }
47
48     get_subtree_size(0);
49     cout << get_centroid(0) + 1 << endl;
50 }

```

6.2 Bipartite

```

1 const int NONE = 0, BLUE = 1, RED = 2;
2 vector<vector<int>> graph(100005);
3 vector<bool> visited(100005);
4 int color[100005];
5
6 bool bfs(int s = 1){
7
8     queue<int> q;
9     q.push(s);
10    color[s] = BLUE;
11
12    while (not q.empty()){
13        auto u = q.front(); q.pop();
14
15        for (auto v : graph[u]){
16            if (color[v] == NONE){
17                color[v] = 3 - color[u];
18                q.push(v);
19            }
20            else if (color[v] == color[u]){
21                return false;
22            }
23        }
24    }
25
26    return true;
27 }
28
29 bool is_bipartite(int n){
30
31     for (int i = 1; i<=n; i++)
32         if (color[i] == NONE and not bfs(i))
33             return false;
34
35     return true;
36 }

```

6.3 Prim

```

1 int n;
2 vector<vector<int>> adj; // adjacency matrix of graph
3 const int INF = 1000000000; // weight INF means there
   is no edge
4
5 struct Edge {

```

```

6     int w = INF, to = -1;
7 };
8
9 void prim() {
10     int total_weight = 0;
11     vector<bool> selected(n, false);
12     vector<Edge> min_e(n);
13     min_e[0].w = 0;
14
15     for (int i=0; i<n; ++i) {
16         int v = -1;
17         for (int j = 0; j < n; ++j) {
18             if (!selected[j] && (v == -1 || min_e[j].
w < min_e[v].w))
19                 v = j;
20         }
21
22         if (min_e[v].w == INF) {
23             cout << "No MST!" << endl;
24             exit(0);
25         }
26
27         selected[v] = true;
28         total_weight += min_e[v].w;
29         if (min_e[v].to != -1)
30             cout << v << " " << min_e[v].to << endl;
31
32         for (int to = 0; to < n; ++to) {
33             if (adj[v][to] < min_e[to].w)
34                 min_e[to] = {adj[v][to], v};
35         }
36     }
37
38     cout << total_weight << endl;
39 }

```

6.4 Ford Fulkerson Edmonds Karp

```

1 // Description:
2 // Obtains the maximum possible flow rate given a
   network. A network is a graph with a single
   source vertex and a single sink vertex in which
   each edge has a capacity
3
4 // Complexity:
5 //  $O(V * E^2)$  where V is the number of vertex and E
   is the number of edges
6
7 int n;
8 vector<vector<int>> capacity;
9 vector<vector<int>> adj;
10
11 int bfs(int s, int t, vector<int>& parent) {
12     fill(parent.begin(), parent.end(), -1);
13     parent[s] = -2;
14     queue<pair<int, int>> q;
15     q.push({s, INF});
16
17     while (!q.empty()) {
18         int cur = q.front().first;
19         int flow = q.front().second;
20         q.pop();
21
22         for (int next : adj[cur]) {
23             if (parent[next] == -1 && capacity[cur][
next]) {
24                 parent[next] = cur;
25                 int new_flow = min(flow, capacity[cur
][next]);
26
27                 if (next == t)
28                     return new_flow;
29                 q.push({next, new_flow});
30             }
31         }
32     }
33 }

```

```

30     }
31 }
32
33 return 0;
34 }
35
36 int maxflow(int s, int t) {
37     int flow = 0;
38     vector<int> parent(n);
39     int new_flow;
40
41     while (new_flow = bfs(s, t, parent)) {
42         flow += new_flow;
43         int cur = t;
44         while (cur != s) {
45             int prev = parent[cur];
46             capacity[prev][cur] -= new_flow;
47             capacity[cur][prev] += new_flow;
48             cur = prev;
49         }
50     }
51
52     return flow;
53 }

```

6.5 Floyd Warshall

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4 using ll = long long;
5
6 const int MAX = 507;
7 const long long INF = 0x3f3f3f3f3f3f3fLL;
8
9 ll dist[MAX][MAX];
10 int n;
11
12 void floyd_warshall() {
13     for (int i = 0; i < n; i++) {
14         for (int j = 0; j < n; j++) {
15             if (i == j) dist[i][j] = 0;
16             else if (!dist[i][j]) dist[i][j] = INF;
17         }
18     }
19
20     for (int k = 0; k < n; k++) {
21         for (int i = 0; i < n; i++) {
22             for (int j = 0; j < n; j++) {
23                 // trata o caso no qual o grafo tem
24                 arestas com peso negativo
25                 if (dist[i][k] < INF && dist[k][j] <
26                     INF){
27                     dist[i][j] = min(dist[i][j], dist
28                                     [i][k] + dist[k][j]);
29                 }
30             }
31         }
32     }
33 }

```

6.6 Lca

```

1 // Description:
2 // Find the lowest common ancestor between two nodes
3 // in a tree
4
5 // Problem:
6 // https://cses.fi/problemset/task/1688/
7
8 // Complexity:
9 // O(log n)

```

```

9
10 // How to use:
11 // preprocess(1);
12 // lca(a, b);
13
14 // Notes
15 // To calculate the distance between two nodes use
16 // the following formula
17 // dist[a] + dist[b] - 2*dist[lca(a, b)]
18
19 const int MAX = 2e5+17;
20 const int BITS = 32;
21
22 vector<int> adj[MAX];
23 // vector<pair<int, int>> adj[MAX];
24 // int dist[MAX];
25
26 int timer;
27 vector<int> tin, tout;
28 vector<vector<int>> up;
29
30 void dfs(int v, int p)
31 {
32     tin[v] = ++timer;
33     up[v][0] = p;
34
35     for (int i = 1; i <= BITS; ++i) {
36         up[v][i] = up[up[v][i-1]][i-1];
37     }
38
39     for (auto u : adj[v]) {
40         if (u != p) {
41             dfs(u, v);
42         }
43     }
44
45     /*for (auto [u, peso] : adj[v]) {
46         if (u != p) {
47             dist[u] = dist[v] + peso;
48             dfs(u, v);
49         }
50     }*/
51
52     tout[v] = ++timer;
53 }
54
55 bool is_ancestor(int u, int v)
56 {
57     return tin[u] <= tin[v] && tout[u] >= tout[v];
58 }
59
60 int lca(int u, int v)
61 {
62     if (is_ancestor(u, v))
63         return u;
64     if (is_ancestor(v, u))
65         return v;
66     for (int i = BITS; i >= 0; --i) {
67         if (!is_ancestor(up[u][i], v))
68             u = up[u][i];
69     }
70     return up[u][0];
71 }
72
73 void preprocess(int root) {
74     tin.resize(MAX);
75     tout.resize(MAX);
76     timer = 0;
77     up.assign(MAX, vector<int>(BITS + 1));
78     dfs(root, root);
79 }

```

6.7 Bellman Ford

```
1 struct edge
2 {
3     int a, b, cost;
4 };
5
6 int n, m, v;
7 vector<edge> e;
8 const int INF = 1000000000;
9
10 void solve()
11 {
12     vector<int> d (n, INF);
13     d[v] = 0;
14     for (int i=0; i<n-1; ++i)
15         for (int j=0; j<m; ++j)
16             if (d[e[j].a] < INF)
17                 d[e[j].b] = min (d[e[j].b], d[e[j].a]
18                     + e[j].cost);
19 }
```

6.8 Dinic

```
1 // Description:
2 // Obtains the maximum possible flow rate given a
3 // network. A network is a graph with a single
4 // source vertex and a single sink vertex in which
5 // each edge has a capacity
6
7 // Problem:
8 // https://codeforces.com/gym/103708/problem/J
9
10 // Complexity:
11 //  $O(V^2 * E)$  where V is the number of vertex and E
12 // is the number of edges
13
14 // Unit network
15 // A unit network is a network in which for any
16 // vertex except source and sink either incoming or
17 // outgoing edge is unique and has unit capacity (
18 // matching problem).
19
20 // Complexity on unit networks:  $O(E * \sqrt{V})$ 
21
22 // Unity capacity networks
23 // A more generic settings when all edges have unit
24 // capacities, but the number of incoming and
25 // outgoing edges is unbounded
26
27 // Complexity on unity capacity networks:  $O(E * \sqrt{E})$ 
28
29 // How to use:
30 // Dinic dinic = Dinic(num_vertex, source, sink);
31 // dinic.add_edge(vertex1, vertex2, capacity);
32 // cout << dinic.max_flow() << '\n';
33
34 #include <bits/stdc++.h>
35
36 #define pb push_back
37 #define mp make_pair
38 #define pii pair<int, int>
39 #define ff first
40 #define ss second
41 #define ll long long
42
43 using namespace std;
44
45 const ll INF = 1e18+10;
46
47 struct Edge {
48     int from;
49     int to;
```

```
50     ll capacity;
51     ll flow;
52     Edge* residual;
53
54     Edge() {}
55
56     Edge(int from, int to, ll capacity) : from(from),
57         to(to), capacity(capacity) {
58         flow = 0;
59     }
60
61     ll get_capacity() {
62         return capacity - flow;
63     }
64
65     ll get_flow() {
66         return flow;
67     }
68
69     void augment(ll bottleneck) {
70         flow += bottleneck;
71         residual->flow -= bottleneck;
72     }
73
74     void reverse(ll bottleneck) {
75         flow -= bottleneck;
76         residual->flow += bottleneck;
77     }
78
79     bool operator<(const Edge& e) const {
80         return true;
81     }
82 };
83
84 struct Dinic {
85     int source;
86     int sink;
87     int nodes;
88     ll flow;
89     vector<vector<Edge*>> adj;
90     vector<int> level;
91     vector<int> next;
92     vector<int> reach;
93     vector<bool> visited;
94     vector<vector<int>> path;
95
96     Dinic(int source, int sink, int nodes) : source(
97         source), sink(sink), nodes(nodes) {
98         adj.resize(nodes + 1);
99     }
100
101     void add_edge(int from, int to, ll capacity) {
102         Edge* e1 = new Edge(from, to, capacity);
103         Edge* e2 = new Edge(to, from, 0);
104         // Edge* e2 = new Edge(to, from, capacity);
105         e1->residual = e2;
106         e2->residual = e1;
107         adj[from].pb(e1);
108         adj[to].pb(e2);
109     }
110
111     bool bfs() {
112         level.assign(nodes + 1, -1);
113         queue<int> q;
114         q.push(source);
115         level[source] = 0;
116
117         while (!q.empty()) {
118             int node = q.front();
119             q.pop();
120
121             for (auto e : adj[node]) {
122                 if (level[e->to] == -1 && e->
```

```

110     get_capacity() > 0) {
111         level[e->to] = level[e->from] +
112         1;
113         q.push(e->to);
114     }
115 }
116 return level[sink] != -1;
117 }
118
119 ll dfs(int v, ll flow) {
120     if (v == sink)
121         return flow;
122
123     int sz = adj[v].size();
124     for (int i = next[v]; i < sz; i++) {
125         Edge* e = adj[v][i];
126         if (level[e->to] == level[e->from] + 1 &&
127             e->get_capacity() > 0) {
128             ll bottleneck = dfs(e->to, min(flow,
129             e->get_capacity()));
130             if (bottleneck > 0) {
131                 e->augment(bottleneck);
132                 return bottleneck;
133             }
134             next[v] = i + 1;
135         }
136     }
137     return 0;
138 }
139
140 ll max_flow() {
141     flow = 0;
142     while(bfs()) {
143         next.assign(nodes + 1, 0);
144         ll sent = -1;
145         while (sent != 0) {
146             sent = dfs(source, INF);
147             flow += sent;
148         }
149     }
150     return flow;
151 }
152
153 void reachable(int v) {
154     visited[v] = true;
155
156     for (auto e : adj[v]) {
157         if (!visited[e->to] && e->get_capacity()
158 > 0) {
159             reach.pb(e->to);
160             visited[e->to] = true;
161             reachable(e->to);
162         }
163     }
164 }
165
166 void print_min_cut() {
167     reach.clear();
168     visited.assign(nodes + 1, false);
169     reach.pb(source);
170     reachable(source);
171
172     for (auto v : reach) {
173         for (auto e : adj[v]) {
174             if (!visited[e->to] && e->
175 get_capacity() == 0) {
176                 cout << e->from << ' ' << e->to
177 << '\n';
178             }
179         }
180     }
181 }
182
183 ll build_path(int v, int id, ll flow) {
184     visited[v] = true;
185     if (v == sink) {
186         return flow;
187     }
188
189     for (auto e : adj[v]) {
190         if (!visited[e->to] && e->get_flow() > 0)
191         {
192             visited[e->to] = true;
193             ll bottleneck = build_path(e->to, id,
194             min(flow, e->get_flow()));
195             if (bottleneck > 0) {
196                 path[id].pb(e->to);
197                 e->reverse(bottleneck);
198                 return bottleneck;
199             }
200         }
201     }
202     return 0;
203 }
204
205 void print_flow_path() {
206     path.clear();
207     ll sent = -1;
208     int id = -1;
209     while (sent != 0) {
210         visited.assign(nodes + 1, false);
211         path.pb(vector<int>{});
212         sent = build_path(source, ++id, INF);
213         path[id].pb(source);
214     }
215     path.pop_back();
216
217     for (int i = 0; i < id; i++) {
218         cout << path[i].size() << '\n';
219         reverse(path[i].begin(), path[i].end());
220         for (auto e : path[i]) {
221             cout << e << ' ';
222         }
223         cout << '\n';
224     }
225 }
226
227 int main() {
228     ios::sync_with_stdio(false);
229     cin.tie(NULL);
230
231     int n, m; cin >> n >> m;
232
233     Dinic dinic = Dinic(1, n, n);
234
235     for (int i = 1; i <= m; i++) {
236         int v, u; cin >> v >> u;
237         dinic.add_edge(v, u, 1);
238     }
239
240     cout << dinic.max_flow() << '\n';
241     // dinic.print_min_cut();
242     // dinic.print_flow_path();
243
244     return 0;
245 }

```

6.9 2sat

1 // Description:

```

2 // Solves expression of the type (a v b) ^ (c v d) ^ (e v f)
3
4 // Problem:
5 // https://cses.fi/problemset/task/1684
6
7 // Complexity:
8 // O(n + m) where n is the number of variables and m
   is the number of clauses
9
10 #include <bits/stdc++.h>
11 #define pb push_back
12 #define mp make_pair
13 #define pii pair<int, int>
14 #define ff first
15 #define ss second
16
17 using namespace std;
18
19 struct SAT {
20     int nodes;
21     int curr = 0;
22     int component = 0;
23     vector<vector<int>> adj;
24     vector<vector<int>> rev;
25     vector<vector<int>> condensed;
26     vector<pii> departure;
27     vector<bool> visited;
28     vector<int> scc;
29     vector<int> order;
30
31     // 1 to nodes
32     // nodes + 1 to 2 * nodes
33     SAT(int nodes) : nodes(nodes) {
34         adj.resize(2 * nodes + 1);
35         rev.resize(2 * nodes + 1);
36         visited.resize(2 * nodes + 1);
37         scc.resize(2 * nodes + 1);
38     }
39
40     void add_imp(int a, int b) {
41         adj[a].pb(b);
42         rev[b].pb(a);
43     }
44
45     int get_not(int a) {
46         if (a > nodes) return a - nodes;
47         return a + nodes;
48     }
49
50     void add_or(int a, int b) {
51         add_imp(get_not(a), b);
52         add_imp(get_not(b), a);
53     }
54
55     void add_nor(int a, int b) {
56         add_or(get_not(a), get_not(b));
57     }
58
59     void add_and(int a, int b) {
60         add_or(get_not(a), b);
61         add_or(a, get_not(b));
62         add_or(a, b);
63     }
64
65     void add_nand(int a, int b) {
66         add_or(get_not(a), b);
67         add_or(a, get_not(b));
68         add_or(get_not(a), get_not(b));
69     }
70
71     void add_xor(int a, int b) {
72         add_or(a, b);
73
74         add_or(get_not(a), get_not(b));
75     }
76
77     void add_xnor(int a, int b) {
78         add_or(get_not(a), b);
79         add_or(a, get_not(b));
80     }
81
82     void departure_time(int v) {
83         visited[v] = true;
84
85         for (auto u : adj[v]) {
86             if (!visited[u]) departure_time(u);
87         }
88
89         departure.pb(mp(++curr, v));
90     }
91
92     void find_component(int v, int component) {
93         scc[v] = component;
94         visited[v] = true;
95
96         for (auto u : rev[v]) {
97             if (!visited[u]) find_component(u,
98 component);
99         }
100     }
101
102     void topological_order(int v) {
103         visited[v] = true;
104
105         for (auto u : condensed[v]) {
106             if (!visited[u]) topological_order(u);
107         }
108
109         order.pb(v);
110     }
111
112     bool is_possible() {
113         component = 0;
114         for (int i = 1; i <= 2 * nodes; i++) {
115             if (!visited[i]) departure_time(i);
116
117             sort(departure.begin(), departure.end(),
118 greater<pii>());
119
120             visited.assign(2 * nodes + 1, false);
121
122             for (auto [_ , node] : departure) {
123                 if (!visited[node]) find_component(node,
124 ++component);
125             }
126
127             for (int i = 1; i <= nodes; i++) {
128                 if (scc[i] == scc[i + nodes]) return
129 false;
130             }
131
132             return true;
133         }
134
135         int find_value(int e, vector<int> &ans) {
136             if (e > nodes && ans[e - nodes] != 2) return
137 !ans[e - nodes];
138             if (e <= nodes && ans[e + nodes] != 2) return
139 !ans[e + nodes];
140             return 0;
141         }
142
143         vector<int> find_ans() {
144             condensed.resize(component + 1);
145
146             add_or(get_not(a), get_not(b));
147         }
148     }

```

```

140     for (int i = 1; i <= 2 * nodes; i++) {
141         for (auto u : adj[i]) {
142             if (scc[i] != scc[u]) condensed[scc[i]
]].pb(scc[u]);
143         }
144     }
145
146     visited.assign(component + 1, false);
147
148     for (int i = 1; i <= component; i++) {
149         if (!visited[i]) topological_order(i);
150     }
151
152     reverse(order.begin(), order.end());
153
154     // 0 - false
155     // 1 - true
156     // 2 - no value yet
157     vector<int> ans(2 * nodes + 1, 2);
158
159     vector<vector<int>> belong(component + 1);
160
161     for (int i = 1; i <= 2 * nodes; i++) {
162         belong[scc[i]].pb(i);
163     }
164
165     for (auto p : order) {
166         for (auto e : belong[p]) {
167             ans[e] = find_value(e, ans);
168         }
169     }
170
171     return ans;
172 }
173 };
174
175 int main() {
176     ios::sync_with_stdio(false);
177     cin.tie(NULL);
178
179     int n, m; cin >> n >> m;
180
181     SAT sat = SAT(m);
182
183     for (int i = 0; i < n; i++) {
184         char op1, op2; int a, b; cin >> op1 >> a >>
op2 >> b;
185         if (op1 == '+' && op2 == '+') sat.add_or(a, b
);
186         if (op1 == '-' && op2 == '-') sat.add_or(sat.
get_not(a), sat.get_not(b));
187         if (op1 == '+' && op2 == '-') sat.add_or(a,
sat.get_not(b));
188         if (op1 == '-' && op2 == '+') sat.add_or(sat.
get_not(a), b);
189     }
190
191     if (!sat.is_possible()) cout << "IMPOSSIBLE\n";
192     else {
193         vector<int> ans = sat.find_ans();
194         for (int i = 1; i <= m; i++) {
195             cout << (ans[i] == 1 ? '+' : '-') << ' ';
196         }
197         cout << '\n';
198     }
199
200     return 0;
201 }

```

6.10 Find Cycle

```

1 bitset<MAX> visited;
2 vector<int> path;

```

```

3 vector<int> adj[MAX];
4
5 bool dfs(int u, int p){
6
7     if (visited[u]) return false;
8
9     path.pb(u);
10    visited[u] = true;
11
12    for (auto v : adj[u]){
13        if (visited[v] and u != v and p != v){
14            path.pb(v); return true;
15        }
16
17        if (dfs(v, u)) return true;
18    }
19
20    path.pop_back();
21    return false;
22 }
23
24 bool has_cycle(int N){
25
26    visited.reset();
27
28    for (int u = 1; u <= N; ++u){
29        path.clear();
30        if (not visited[u] and dfs(u, -1))
31            return true;
32    }
33
34
35    return false;
36 }

```

6.11 Cycle Path Recovery

```

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 (color[v] == 0 && 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 }

```

6.12 Centroid Decomposition

```

1  int n;
2  vector<set<int>> adj;
3  vector<char> ans;
4
5  vector<bool> removed;
6
7  vector<int> subtree_size;
8
9  int dfs(int u, int p = 0) {
10     subtree_size[u] = 1;
11
12     for(int v : adj[u]) {
13         if(v != p && !removed[v]) {
14             subtree_size[u] += dfs(v, u);
15         }
16     }
17
18     return subtree_size[u];
19 }
20
21 int get_centroid(int u, int sz, int p = 0) {
22     for(int v : adj[u]) {
23         if(v != p && !removed[v]) {
24             if(subtree_size[v]*2 > sz) {
25                 return get_centroid(v, sz, u);
26             }
27         }
28     }
29
30     return u;
31 }
32
33 char get_next(char c) {
34     if (c != 'Z') return c + 1;
35     return '$';
36 }
37
38 bool flag = true;
39
40 void solve(int node, char c) {
41     int center = get_centroid(node, dfs(node));
42     ans[center] = c;
43     removed[center] = true;
44
45     for (auto u : adj[center]) {
46         if (!removed[u]) {
47             char next = get_next(c);
48             if (next == '$') {
49                 flag = false;
50                 return;
51             }
52             solve(u, next);
53         }
54     }
55 }
56

```

```

57 int32_t main(){
58     ios::sync_with_stdio(false);
59     cin.tie(NULL);
60
61     cin >> n;
62     adj.resize(n + 1);
63     ans.resize(n + 1);
64     removed.resize(n + 1);
65     subtree_size.resize(n + 1);
66
67     for (int i = 1; i <= n - 1; i++) {
68         int u, v; cin >> u >> v;
69         adj[u].insert(v);
70         adj[v].insert(u);
71     }
72
73     solve(1, 'A');
74
75     if (!flag) cout << "Impossible!\n";
76     else {
77         for (int i = 1; i <= n; i++) {
78             cout << ans[i] << ' ';
79         }
80         cout << '\n';
81     }
82
83     return 0;
84 }

```

6.13 Tarjan Bridge

```

1  // Description:
2  // Find a bridge in a connected undirected graph
3  // A bridge is an edge so that if you remove that
   edge the graph is no longer connected
4
5  // Problem:
6  // https://cses.fi/problemset/task/2177/
7
8  // Complexity:
9  //  $O(V + E)$  where  $V$  is the number of vertices and  $E$ 
   is the number of edges
10
11 int n;
12 vector<vector<int>> adj;
13
14 vector<bool> visited;
15 vector<int> tin, low;
16 int timer;
17
18 void dfs(int v, int p) {
19     visited[v] = true;
20     tin[v] = low[v] = timer++;
21     for (int to : adj[v]) {
22         if (to == p) continue;
23         if (visited[to]) {
24             low[v] = min(low[v], tin[to]);
25         } else {
26             dfs(to, v);
27             low[v] = min(low[v], low[to]);
28             if (low[to] > tin[v]) {
29                 IS_BRIDGE(v, to);
30             }
31         }
32     }
33 }
34
35 void find_bridges() {
36     timer = 0;
37     visited.assign(n, false);
38     tin.assign(n, -1);
39     low.assign(n, -1);
40     for (int i = 0; i < n; ++i) {

```



```

41         if (!visited[i])
42             dfs(i, -1);
43     }
44 }

```

6.14 Small To Large

```

1 // Problem:
2 // https://codeforces.com/contest/600/problem/E
3
4 void process_colors(int curr, int parent) {
5
6     for (int n : adj[curr]) {
7         if (n != parent) {
8             process_colors(n, curr);
9
10            if (colors[curr].size() < colors[n].size
11                ()) {
12                sum_num[curr] = sum_num[n];
13                vmax[curr] = vmax[n];
14                swap(colors[curr], colors[n]);
15            }
16
17            for (auto [item, vzs] : colors[n]) {
18                if (colors[curr][item] + vzs > vmax[curr]
19                    ){
20                    vmax[curr] = colors[curr][item] +
21                        vzs;
22                    sum_num[curr] = item;
23                }
24                else if (colors[curr][item] + vzs ==
25                    vmax[curr]){
26                    sum_num[curr] += item;
27                }
28
29                colors[curr][item] += vzs;
30            }
31        }
32    }
33
34    int32_t main() {
35
36        int n; cin >> n;
37
38        for (int i = 1; i <= n; i++) {
39            int a; cin >> a;
40            colors[i][a] = 1;
41            vmax[i] = 1;
42            sum_num[i] = a;
43        }
44
45        for (int i = 1; i < n; i++) {
46            int a, b; cin >> a >> b;
47
48            adj[a].push_back(b);
49            adj[b].push_back(a);
50        }
51
52        process_colors(1, 0);
53
54        for (int i = 1; i <= n; i++) {
55            cout << sum_num[i] << (i < n ? " " : "\n");
56        }
57
58        return 0;
59 }
60

```

6.15 Tree Diameter

```

1 #include<bits/stdc++.h>
2
3 using namespace std;
4
5 const int MAX = 3e5+17;
6
7 vector<int> adj[MAX];
8 bool visited[MAX];
9
10 int max_depth = 0, max_node = 1;
11
12 void dfs (int v, int depth) {
13     visited[v] = true;
14
15     if (depth > max_depth) {
16         max_depth = depth;
17         max_node = v;
18     }
19
20     for (auto u : adj[v]) {
21         if (!visited[u]) dfs(u, depth + 1);
22     }
23 }
24
25 int tree_diameter() {
26     dfs(1, 0);
27     max_depth = 0;
28     for (int i = 0; i < MAX; i++) visited[i] = false;
29     dfs(max_node, 0);
30     return max_depth;
31 }

```

6.16 Dijkstra

```

1 const int MAX = 2e5+7;
2 const int INF = 1000000000;
3 vector<vector<pair<int, int>>> adj(MAX);
4
5 void dijkstra(int s, vector<int> & d, vector<int> & p
6 ) {
7     int n = adj.size();
8     d.assign(n, INF);
9     p.assign(n, -1);
10
11     d[s] = 0;
12     set<pair<int, int>> q;
13     q.insert({0, s});
14     while (!q.empty()) {
15         int v = q.begin()->second;
16         q.erase(q.begin());
17
18         for (auto edge : adj[v]) {
19             int to = edge.first;
20             int len = edge.second;
21
22             if (d[v] + len < d[to]) {
23                 q.erase({d[to], to});
24                 d[to] = d[v] + len;
25                 p[to] = v;
26                 q.insert({d[to], to});
27             }
28         }
29     }
30
31     vector<int> restore_path(int s, int t) {
32         vector<int> path;
33
34         for (int v = t; v != s; v = p[v])
35             path.push_back(v);
36     }
37 }

```

```

36     path.push_back(s);
37
38     reverse(path.begin(), path.end());
39     return path;
40 }
41
42 int adj[MAX][MAX];
43 int dist[MAX];
44 int minDistance(int dist[], bool sptSet[], int V) {
45     int min = INT_MAX, min_index;
46
47     for (int v = 0; v < V; v++)
48         if (sptSet[v] == false && dist[v] <= min)
49             min = dist[v], min_index = v;
50
51     return min_index;
52 }
53
54 void dijkstra(int src, int V) {
55
56     bool sptSet[V];
57     for (int i = 0; i < V; i++)
58         dist[i] = INT_MAX, sptSet[i] = false;
59
60     dist[src] = 0;
61
62     for (int count = 0; count < V - 1; count++) {
63         int u = minDistance(dist, sptSet, V);
64
65         sptSet[u] = true;
66
67         for (int v = 0; v < V; v++)
68             if (!sptSet[v] && adj[u][v]
69                 && dist[u] != INT_MAX
70                 && dist[u] + adj[u][v] < dist[v])
71                 dist[v] = dist[u] + adj[u][v];
72     }
73 }
74 }

```

6.17 Kruskal

```

1 struct DSU {
2     int n;
3     vector<int> link, sizes;
4
5     DSU(int n) {
6         this->n = n;
7         link.assign(n+1, 0);
8         sizes.assign(n+1, 1);
9
10        for (int i = 0; i <= n; i++)
11            link[i] = i;
12    }
13
14    int find(int x) {
15        while (x != link[x])
16            x = link[x];
17
18        return x;
19    }
20
21    bool same(int a, int b) {
22        return find(a) == find(b);
23    }
24
25    void unite(int a, int b) {
26        a = find(a);
27        b = find(b);
28
29        if (a == b) return;
30
31        if (sizes[a] < sizes[b])

```

```

32            swap(a, b);
33
34            sizes[a] += sizes[b];
35            link[b] = a;
36        }
37    };
38
39    struct Edge {
40        int u, v;
41        long long weight;
42
43        Edge() {}
44
45        Edge(int u, int v, long long weight) : u(u), v(v),
46            weight(weight) {}
47
48        bool operator<(const Edge& other) const {
49            return weight < other.weight;
50        }
51
52        bool operator>(const Edge& other) const {
53            return weight > other.weight;
54        }
55    };
56
57    vector<Edge> kruskal(vector<Edge> edges, int n) {
58        vector<Edge> result; // arestas da MST
59        long long cost = 0;
60
61        sort(edges.begin(), edges.end());
62
63        DSU dsu(n);
64
65        for (auto e : edges) {
66            if (!dsu.same(e.u, e.v)) {
67                cost += e.weight;
68                result.push_back(e);
69                dsu.unite(e.u, e.v);
70            }
71        }
72
73        return result;
74    }

```

7 Algorithms

7.1 Lis

```

1 int lis(vector<int> const& a) {
2     int n = a.size();
3     vector<int> d(n, 1);
4     for (int i = 0; i < n; i++) {
5         for (int j = 0; j < i; j++) {
6             if (a[j] < a[i])
7                 d[i] = max(d[i], d[j] + 1);
8         }
9     }
10
11    int ans = d[0];
12    for (int i = 1; i < n; i++) {
13        ans = max(ans, d[i]);
14    }
15    return ans;
16 }

```

7.2 Delta-encoding

```

1 #include <bits/stdc++.h>
2 using namespace std;
3
4 int main(){

```

```

5     int n, q;
6     cin >> n >> q;
7     int [n];
8     int delta[n+2];
9
10    while(q--){
11        int l, r, x;
12        cin >> l >> r >> x;
13        delta[l] += x;
14        delta[r+1] -= x;
15    }
16
17    int curr = 0;
18    for(int i=0; i < n; i++){
19        curr += delta[i];
20        v[i] = curr;
21    }
22
23    for(int i=0; i < n; i++){
24        cout << v[i] << ' ';
25    }
26    cout << '\n';
27
28    return 0;
29 }

```

7.3 Binary Search Last True

```

1 int last_true(int lo, int hi, function<bool(int)> f)
2 {
3     lo--;
4     while (lo < hi) {
5         int mid = lo + (hi - lo + 1) / 2;
6         if (f(mid)) {
7             lo = mid;
8         } else {
9             hi = mid - 1;
10        }
11    }
12    return lo;
13 }

```

7.4 Ternary Search

```

1 double ternary_search(double l, double r) {
2     double eps = 1e-9;           //set the error
3     while (r - l > eps) {
4         double m1 = l + (r - l) / 3;
5         double m2 = r - (r - l) / 3;
6         double f1 = f(m1);       //evaluates the
7         double f2 = f(m2);       //evaluates the
8         function at m1
9         function at m2
10        if (f1 < f2)
11            l = m1;
12        else
13            r = m2;
14    }
15    return f(l);                  //return the
16    maximum of f(x) in [l, r]
17 }

```

7.5 Binary Search First True

```

1 int first_true(int lo, int hi, function<bool(int)> f)
2 {
3     hi++;
4     while (lo < hi) {
5         int mid = lo + (hi - lo) / 2;
6         if (f(mid)) {
7             hi = mid;
8         }
9     }
10    return lo;
11 }

```

```

7     } else {
8         lo = mid + 1;
9     }
10 }
11 return lo;
12 }

```

7.6 Biggest K

```

1 // Description: Gets sum of k biggest or k smallest
2 // elements in an array
3 // Problem: https://atcoder.jp/contests/abc306/tasks/
4 // abc306_e
5 // Complexity: O(log n)
6
7 struct SetSum {
8     ll s = 0;
9     multiset<ll> mt;
10    void add(ll x){
11        mt.insert(x);
12        s += x;
13    }
14    int pop(ll x){
15        auto f = mt.find(x);
16        if(f == mt.end()) return 0;
17        mt.erase(f);
18        s -= x;
19        return 1;
20    }
21 };
22
23 struct BigK {
24     int k;
25     SetSum gt, mt;
26     BigK(int _k){
27         k = _k;
28     }
29     void balancear(){
30         while((int)gt.mt.size() < k && (int)mt.mt.
31         size()){
32             auto p = (prev(mt.mt.end()));
33             gt.add(*p);
34             mt.pop(*p);
35         }
36         while((int)mt.mt.size() && (int)gt.mt.size()
37         &&
38         *(gt.mt.begin()) < *(prev(mt.mt.end())) ){
39             ll u = *(gt.mt.begin());
40             ll v = *(prev(mt.mt.end()));
41             gt.pop(u); mt.pop(v);
42             gt.add(v); mt.add(u);
43         }
44     }
45     void add(ll x){
46         mt.add(x);
47         balancear();
48     }
49     void rem(ll x){
50         //x = -x;
51         if(mt.pop(x) == 0)
52             gt.pop(x);
53         balancear();
54     }
55 };
56
57 int main() {
58     ios::sync_with_stdio(false);
59     cin.tie(NULL);
60
61     int n, k, q; cin >> n >> k >> q;
62 }

```

```

61     BigK big = BigK(k);
62
63     int arr[n] = {};
64
65     while (q--) {
66         int pos, num; cin >> pos >> num;
67         pos--;
68         big.rem(arr[pos]);
69         arr[pos] = num;
70         big.add(arr[pos]);
71
72         cout << big.gt.s << '\n';
73     }
74
75     return 0;
76 }

```

8 Data Structures

8.1 Ordered Set

```

1 // Description:
2 // insert(k) - add element k to the ordered set
3 // erase(k) - remove element k from the ordered set
4 // erase(it) - remove element it points to from the
   ordered set
5 // order_of_key(k) - returns number of elements
   strictly smaller than k
6 // find_by_order(n) - return an iterator pointing to
   the k-th element in the ordered set (counting
   from zero).
7
8 // Problem:
9 // https://cses.fi/problemset/task/2169/
10
11 // Complexity:
12 // O(log n) for all operations
13
14 // How to use:
15 // ordered_set<int> os;
16 // cout << os.order_of_key(1) << '\n';
17 // cout << os.find_by_order(1) << '\n';
18
19 // Notes
20 // The ordered set only contains different elements
21 // By using less_equal<T> instead of less<T> on using
   ordered_set declaration
22 // The ordered_set becomes an ordered_multiset
23 // So the set can contain elements that are equal
24
25 #include <ext/pb_ds/assoc_container.hpp>
26 #include <ext/pb_ds/tree_policy.hpp>
27
28 using namespace __gnu_pbds;
29 template <typename T>
30 using ordered_set = tree<T,null_type,less<T>,
   rb_tree_tag,tree_order_statistics_node_update>;
31
32 void Erase(ordered_set<int>& a, int x){
33     int r = a.order_of_key(x);
34     auto it = a.find_by_order(r);
35     a.erase(it);
36 }

```

8.2 Priority Queue

```

1 // Description:
2 // Keeps the largest (by default) element at the top
   of the queue
3
4 // Problem:

```

```

5 // https://cses.fi/problemset/task/1164/
6
7 // Complexity:
8 // O(log n) for push and pop
9 // O(1) for looking at the element at the top
10
11 // How to use:
12 // priority_queue<int> pq;
13 // pq.push(1);
14 // pq.top();
15 // pq.pop()
16
17 // Notes
18 // To use the priority queue keeping the smallest
   element at the top
19
20 priority_queue<int, vector<int>, greater<int>>> pq;

```

8.3 Dsu

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4
5 const int MAX = 1e6+17;
6
7 struct DSU {
8     int n;
9     vector<int> link, sizes;
10
11     DSU(int n) {
12         this->n = n;
13         link.assign(n+1, 0);
14         sizes.assign(n+1, 1);
15
16         for (int i = 0; i <= n; i++)
17             link[i] = i;
18     }
19
20     int find(int x) {
21         while (x != link[x])
22             x = link[x];
23
24         return x;
25     }
26
27     bool same(int a, int b) {
28         return find(a) == find(b);
29     }
30
31     void unite(int a, int b) {
32         a = find(a);
33         b = find(b);
34
35         if (a == b) return;
36
37         if (sizes[a] < sizes[b])
38             swap(a, b);
39
40         sizes[a] += sizes[b];
41         link[b] = a;
42     }
43
44     int size(int x) {
45         return sizes[x];
46     }
47 };
48
49 int main() {
50     ios::sync_with_stdio(false);
51     cin.tie(NULL);
52
53     int cities, roads; cin >> cities >> roads;

```

```

54     vector<int> final_roads;
55     int ans = 0;
56     DSU dsu = DSU(cities);
57     for (int i = 0, a, b; i < roads; i++) {
58         cin >> a >> b;
59         dsu.unite(a, b);
60     }
61
62     for (int i = 2; i <= cities; i++) {
63         if (!dsu.same(1, i)) {
64             ans++;
65             final_roads.push_back(i);
66             dsu.unite(1, i);
67         }
68     }
69
70     cout << ans << '\n';
71     for (auto e : final_roads) {
72         cout << "1 " << e << '\n';
73     }
74 }
75 }

```

8.4 Two Sets

```

1 // Description
2 // The values are divided in two multisets so that
3 // one of them contain all values that are
4 // smaller than the median and the other one contains
5 // all values that are greater or equal to the
6 // median.
7
8 // Problem:
9 // https://atcoder.jp/contests/abc306/tasks/abc306_e
10 // Problem I - Maratona Feminina de çãProgramao da
11 // Unicamp 2023
12 // https://codeforces.com/group/WYIydkIPyE/contest
13 // /450037/attachments
14
15 // Complexity:
16 // Add and remove elements - O(log n)
17 // Return sum of biggest or smallest set or return
18 // the median - O(1)
19
20 using ll = long long;
21
22 struct TwoSets {
23     multiset<int> small;
24     multiset<int> big;
25     ll sums = 0;
26     ll sumb = 0;
27     int n = 0;
28
29     int size_small() {
30         return small.size();
31     }
32
33     int size_big() {
34         return big.size();
35     }
36
37     void balance() {
38         while (size_small() > n / 2) {
39             int v = *small.rbegin();
40             small.erase(prev(small.end()));
41             big.insert(v);
42             sums -= v;
43             sumb += v;
44         }
45         while (size_big() > n - n / 2) {
46             int v = *big.begin();
47             big.erase(big.begin());
48             small.insert(v);
49             sumb -= v;
50             sums += v;
51         }
52     }
53
54     ll sum_small() {
55         return sums;
56     }
57
58     ll sum_big() {
59         return sumb;
60     }
61
62     int median() {
63         return *big.begin();
64     }
65 };

```

```

43     sumb -= v;
44     sums += v;
45 }
46
47 void add(int x) {
48     n++;
49     small.insert(x);
50     sums += x;
51     while (!small.empty() && *small.rbegin() > *big.
52         begin()) {
53         int v = *small.rbegin();
54         small.erase(prev(small.end()));
55         big.insert(v);
56         sums -= v;
57         sumb += v;
58     }
59     balance();
60 }
61
62 bool rem(int x) {
63     n--;
64     auto it1 = small.find(x);
65     auto it2 = big.find(x);
66     bool flag = false;
67     if (it1 != small.end()) {
68         sums -= *it1;
69         small.erase(it1);
70         flag = true;
71     } else if (it2 != big.end()) {
72         sumb -= *it2;
73         big.erase(it2);
74         flag = true;
75     }
76     balance();
77     return flag;
78 }
79
80 ll sum_small() {
81     return sums;
82 }
83
84 ll sum_big() {
85     return sumb;
86 }
87
88 int median() {
89     return *big.begin();
90 }
91 };

```

8.5 Dynamic Implicit Sparse

```

1 // Description:
2 // Indexed at one
3
4 // When the indexes of the nodes are too big to be
5 // stored in an array
6 // and the queries need to be answered online so we
7 // can't sort the nodes and compress them
8 // we create nodes only when they are needed so there
9 // 'll be (Q*log(MAX)) nodes
10 // where Q is the number of queries and MAX is the
11 // maximum index a node can assume
12
13 // Query - get sum of elements from range (l, r)
14 // inclusive
15 // Update - update element at position id to a value
16 // val
17
18 // Problem:
19 // https://cses.fi/problemset/task/1648
20
21

```

```

15 // Complexity:
16 // O(log n) for both query and update
17
18 // How to use:
19 // MAX is the maximum index a node can assume
20
21 // Segtree seg = Segtree(MAX);
22
23 typedef long long ftype;
24
25 const int MAX = 1e9+17;
26
27 struct Segtree {
28     vector<ftype> seg, d, e;
29     const ftype NEUTRAL = 0;
30     int n;
31
32     Segtree(int n) {
33         this->n = n;
34         create();
35         create();
36     }
37
38     ftype f(ftype a, ftype b) {
39         return a + b;
40     }
41
42     ftype create() {
43         seg.push_back(0);
44         e.push_back(0);
45         d.push_back(0);
46         return seg.size() - 1;
47     }
48
49     ftype query(int pos, int ini, int fim, int p, int
50     q) {
51         if (q < ini || p > fim) return NEUTRAL;
52         if (pos == 0) return 0;
53         if (p <= ini && fim <= q) return seg[pos];
54         int m = (ini + fim) >> 1;
55         return f(query(e[pos], ini, m, p, q), query(d
56         [pos], m + 1, fim, p, q));
57     }
58
59     void update(int pos, int ini, int fim, int id,
60     int val) {
61         if (ini > id || fim < id) {
62             return;
63         }
64
65         if (ini == fim) {
66             seg[pos] = val;
67             return;
68         }
69
70         int m = (ini + fim) >> 1;
71
72         if (id <= m) {
73             if (e[pos] == 0) e[pos] = create();
74             update(e[pos], ini, m, id, val);
75         } else {
76             if (d[pos] == 0) d[pos] = create();
77             update(d[pos], m + 1, fim, id, val);
78         }
79
80         seg[pos] = f(seg[e[pos]], seg[d[pos]]);
81     }
82
83     ftype query(int p, int q) {
84         return query(1, 1, n, p, q);
85     }
86 }

```

```

85     void update(int id, int val) {
86         update(1, 1, n, id, val);
87     }
88 };

```

8.6 Segtree2d

```

1 // Description:
2 // Indexed at zero
3 // Given a N x M grid, where i represents the row and
4 // j the column, perform the following operations
5 // update(j, i) - update the value of grid[i][j]
6 // query(j1, j2, i1, i2) - return the sum of values
7 // inside the rectangle
8 // defined by grid[i1][j1] and grid[i2][j2] inclusive
9
10 // Problem:
11 // https://cses.fi/problemset/task/1739/
12
13 // Complexity:
14 // Time complexity:
15 // O(log N * log M) for both query and update
16 // O(N * M) for build
17 // Memory complexity:
18 // 4 * M * N
19
20 // How to use:
21 // Segtree2Dseg = Segtree2D(n, n);
22 // vector<vector<int>> v(n, vector<int>(n));
23 // seg.build(v);
24
25 // Notes
26 // Indexed at zero
27
28 struct Segtree2D {
29     const int MAXN = 1025;
30     int N, M;
31
32     vector<vector<int>> seg;
33
34     Segtree2D(int N, int M) {
35         this->N = N;
36         this->M = M;
37         seg.resize(2*MAXN, vector<int>(2*MAXN));
38     }
39
40     void buildY(int noX, int lX, int rX, int noY, int
41     lY, int rY, vector<vector<int>> &v){
42         if(lY == rY){
43             if(lX == rX){
44                 seg[noX][noY] = v[rX][rY];
45             }else{
46                 seg[noX][noY] = seg[2*noX+1][noY] +
47                 seg[2*noX+2][noY];
48             }
49         }else{
50             int m = (lY+rY)/2;
51
52             buildY(noX, lX, rX, 2*noY+1, lY, m, v);
53             buildY(noX, lX, rX, 2*noY+2, m+1, rY, v);
54
55             seg[noX][noY] = seg[noX][2*noY+1] + seg[
56             noX][2*noY+2];
57         }
58     }
59
60     void buildX(int noX, int lX, int rX, vector<
61     vector<int>> &v){
62         if(lX != rX){
63             int m = (lX+rX)/2;
64
65             buildX(2*noX+1, lX, m, v);
66             buildX(2*noX+2, m+1, rX, v);
67         }
68     }
69 }

```

```

61     }
62
63     buildY(noX, lX, rX, 0, 0, M - 1, v);
64 }
65
66 void updateY(int noX, int lX, int rX, int noY,
67 int lY, int rY, int y){
68     if(lY == rY){
69         if(lX == rX){
70             seg[noX][noY] = !seg[noX][noY];
71         }else{
72             seg[noX][noY] = seg[2*noX+1][noY] +
73             seg[2*noX+2][noY];
74         }
75     }else{
76         int m = (lY+rY)/2;
77
78         if(y <= m){
79             updateY(noX, lX, rX, 2*noY+1, lY, m, y
80 );
81         }else if(m < y){
82             updateY(noX, lX, rX, 2*noY+2, m+1, rY
83 , y);
84         }
85
86         seg[noX][noY] = seg[noX][2*noY+1] + seg[
87 noX][2*noY+2];
88     }
89 }
90
91 void updateX(int noX, int lX, int rX, int x, int
92 y){
93     int m = (lX+rX)/2;
94
95     if(lX != rX){
96         if(x <= m){
97             updateX(2*noX+1, lX, m, x, y);
98         }else if(m < x){
99             updateX(2*noX+2, m+1, rX, x, y);
100         }
101     }
102
103     updateY(noX, lX, rX, 0, 0, M - 1, y);
104 }
105
106 int queryY(int noX, int noY, int lY, int rY, int
107 aY, int bY){
108     if(aY <= lY && rY <= bY) return seg[noX][noY
109 ];
110
111     int m = (lY+rY)/2;
112
113     if(bY <= m) return queryY(noX, 2*noY+1, lY, m
114 , aY, bY);
115     if(m < aY) return queryY(noX, 2*noY+2, m+1,
116 rY, aY, bY);
117
118     return queryY(noX, 2*noY+1, lY, m, aY, bY) +
119 queryY(noX, 2*noY+2, m+1, rY, aY, bY);
120 }
121
122 int queryX(int noX, int lX, int rX, int aX, int
123 bX, int aY, int bY){
124     if(aX <= lX && rX <= bX) return queryY(noX,
125 0, 0, M - 1, aY, bY);
126
127     int m = (lX+rX)/2;
128
129     if(bX <= m) return queryX(2*noX+1, lX, m, aX,
130 bX, aY, bY);
131     if(m < aX) return queryX(2*noX+2, m+1, rX, aX
132 , bX, aY, bY);
133 }

```

```

119     return queryX(2*noX+1, lX, m, aX, bX, aY, bY)
120 + queryX(2*noX+2, m+1, rX, aX, bX, aY, bY);
121 }
122
123 void build(vector<vector<int>> &v) {
124     buildX(0, 0, N - 1, v);
125 }
126
127 int query(int aX, int bX, int aY, int bY) {
128     return queryX(0, 0, N - 1, aX, bX, aY, bY);
129 }
130
131 void update(int x, int y) {
132     updateX(0, 0, N - 1, x, y);
133 }
134 };

```

8.7 Minimum And Amount

```

1 // Description:
2 // Query - get minimum element in a range (l, r)
3 // inclusive
4 // and also the number of times it appears in that
5 // range
6 // Update - update element at position id to a value
7 // val
8
9 // Problem:
10 // https://codeforces.com/edu/course/2/lesson/4/1/
11 // practice/contest/273169/problem/C
12
13 // Complexity:
14 // O(log n) for both query and update
15
16 // How to use:
17 // Segtree seg = Segtree(n);
18 // seg.build(v);
19
20 #define pii pair<int, int>
21 #define mp make_pair
22 #define ff first
23 #define ss second
24
25 const int INF = 1e9+17;
26
27 typedef pii ftype;
28
29 struct Segtree {
30     vector<ftype> seg;
31     int n;
32     const ftype NEUTRAL = mp(INF, 0);
33
34     Segtree(int n) {
35         int sz = 1;
36         while (sz < n) sz *= 2;
37         this->n = sz;
38
39         seg.assign(2*sz, NEUTRAL);
40     }
41
42     ftype f(ftype a, ftype b) {
43         if (a.ff < b.ff) return a;
44         if (b.ff < a.ff) return b;
45
46         return mp(a.ff, a.ss + b.ss);
47     }
48
49     ftype query(int pos, int ini, int fim, int p, int
50 q) {
51     if (ini >= p && fim <= q) {
52         return seg[pos];
53     }

```

```

50     if (q < ini || p > fim) {
51         return NEUTRAL;
52     }
53
54     int e = 2*pos + 1;
55     int d = 2*pos + 2;
56     int m = ini + (fim - ini) / 2;
57
58     return f(query(e, ini, m, p, q), query(d, m +
59 1, fim, p, q));
60 }
61
62 void update(int pos, int ini, int fim, int id,
63 int val) {
64     if (ini > id || fim < id) {
65         return;
66     }
67
68     if (ini == id && fim == id) {
69         seg[pos] = mp(val, 1);
70         return;
71     }
72
73     int e = 2*pos + 1;
74     int d = 2*pos + 2;
75     int m = ini + (fim - ini) / 2;
76
77     update(e, ini, m, id, val);
78     update(d, m + 1, fim, id, val);
79
80     seg[pos] = f(seg[e], seg[d]);
81 }
82
83 void build(int pos, int ini, int fim, vector<int>
84 &v) {
85     if (ini == fim) {
86         if (ini < (int)v.size()) {
87             seg[pos] = mp(v[ini], 1);
88         }
89         return;
90     }
91
92     int e = 2*pos + 1;
93     int d = 2*pos + 2;
94     int m = ini + (fim - ini) / 2;
95
96     build(e, ini, m, v);
97     build(d, m + 1, fim, v);
98
99     seg[pos] = f(seg[e], seg[d]);
100 }
101
102 ftype query(int p, int q) {
103     return query(0, 0, n - 1, p, q);
104 }
105
106 void update(int id, int val) {
107     update(0, 0, n - 1, id, val);
108 }
109
110 void build(vector<int> &v) {
111     build(0, 0, n - 1, v);
112 }
113
114 void debug() {
115     for (auto e : seg) {
116         cout << e.ff << ' ' << e.ss << '\n';
117     }
118     cout << '\n';
119 }
120
121 };

```

8.8 Segment With Maximum Sum

```

1 // Description:
2 // Query - get sum of segment that is maximum among
3 // all segments
4 // E.g
5 // Array: 5 -4 4 3 -5
6 // Maximum segment sum: 8 because 5 + (-4) + 4 = 8
7 // Update - update element at position id to a value
8 // val
9
10 // Problem:
11 // https://codeforces.com/edu/course/2/lesson/4/2/
12 // practice/contest/273278/problem/A
13
14 // Complexity:
15 // O(log n) for both query and update
16
17 // How to use:
18 // Segtree seg = Segtree(n);
19 // seg.build(v);
20
21 // Notes
22 // The maximum segment sum can be a negative number
23 // In that case, taking zero elements is the best
24 // choice
25 // So we need to take the maximum between 0 and the
26 // query
27 // max(0LL, seg.query(0, n).max_seg)
28
29 using ll = long long;
30
31 typedef ll ftype_node;
32
33 struct Node {
34     ftype_node max_seg;
35     ftype_node pref;
36     ftype_node suf;
37     ftype_node sum;
38
39     Node(ftype_node max_seg, ftype_node pref,
40         ftype_node suf, ftype_node sum) : max_seg(max_seg),
41         pref(pref), suf(suf), sum(sum) {};
42 };
43
44 typedef Node ftype;
45
46 struct Segtree {
47     vector<ftype> seg;
48     int n;
49     const ftype NEUTRAL = Node(0, 0, 0, 0);
50
51     Segtree(int n) {
52         int sz = 1;
53         // potencia de dois mais proxima
54         while (sz < n) sz *= 2;
55         this->n = sz;
56
57         // numero de nos da seg
58         seg.assign(2*sz, NEUTRAL);
59     }
60
61     ftype f(ftype a, ftype b) {
62         ftype_node max_seg = max({a.max_seg, b.
63 max_seg, a.suf + b.pref});
64         ftype_node pref = max(a.pref, a.sum + b.pref);
65
66         ftype_node suf = max(b.suf, b.sum + a.suf);
67         ftype_node sum = a.sum + b.sum;
68
69         return Node(max_seg, pref, suf, sum);
70     }
71 }
72

```



```

63 ftype query(int pos, int ini, int fim, int p, int q) {
64     if (ini >= p && fim <= q) {
65         return seg[pos];
66     }
67
68     if (q < ini || p > fim) {
69         return NEUTRAL;
70     }
71
72     int e = 2*pos + 1;
73     int d = 2*pos + 2;
74     int m = ini + (fim - ini) / 2;
75
76     return f(query(e, ini, m, p, q), query(d, m +
77 1, fim, p, q));
78 }
79
80 void update(int pos, int ini, int fim, int id,
81 int val) {
82     if (ini > id || fim < id) {
83         return;
84     }
85
86     if (ini == id && fim == id) {
87         seg[pos] = Node(val, val, val, val);
88
89         return;
90     }
91
92     int e = 2*pos + 1;
93     int d = 2*pos + 2;
94     int m = ini + (fim - ini) / 2;
95
96     update(e, ini, m, id, val);
97     update(d, m + 1, fim, id, val);
98
99     seg[pos] = f(seg[e], seg[d]);
100 }
101
102 void build(int pos, int ini, int fim, vector<int>
103 &v) {
104     if (ini == fim) {
105         // se a posição existir no array original
106         // seg tamanho potencia de dois
107         if (ini < (int)v.size()) {
108             seg[pos] = Node(v[ini], v[ini], v[ini], v[ini]);
109         }
110         return;
111     }
112
113     int e = 2*pos + 1;
114     int d = 2*pos + 2;
115     int m = ini + (fim - ini) / 2;
116
117     build(e, ini, m, v);
118     build(d, m + 1, fim, v);
119
120     seg[pos] = f(seg[e], seg[d]);
121 }
122
123 ftype query(int p, int q) {
124     return query(0, 0, n - 1, p, q);
125 }
126
127 void update(int id, int val) {
128     update(0, 0, n - 1, id, val);
129 }
130
131 void build(vector<int> &v) {
132     build(0, 0, n - 1, v);
133 }
134
135 void debug() {
136     for (auto e : seg) {
137         cout << e.max_seg << ' ' << e.pref << ' '
138         << e.suf << ' ' << e.sum << '\n';
139     }
140     cout << '\n';
141 }
142
143 };

```

8.9 Range Query Point Update

```

1 // Description:
2 // Indexed at zero
3 // Query - get sum of elements from range (l, r)
4 // inclusive
5 // Update - update element at position id to a value
6 // val
7 // Problem:
8 // https://codeforces.com/edu/course/2/lesson/4/1/
9 // practice/contest/273169/problem/B
10 // Complexity:
11 // O(log n) for both query and update
12 // How to use:
13 // Segtree seg = Segtree(n);
14 // seg.build(v);
15
16 // Notes
17 // Change neutral element and f function to perform a
18 // different operation
19 // If you want to change the operations to point
20 // query and range update
21 // Use the same segtree, but perform the following
22 // operations
23 // Query - seg.query(0, id);
24 // Update - seg.update(l, v); seg.update(r + 1, -v);
25
26 typedef long long ftype;
27
28 struct Segtree {
29     vector<ftype> seg;
30     int n;
31     const ftype NEUTRAL = 0;
32
33     Segtree(int n) {
34         int sz = 1;
35         while (sz < n) sz *= 2;
36         this->n = sz;
37
38         seg.assign(2*sz, NEUTRAL);
39     }
40
41     ftype f(ftype a, ftype b) {
42         return a + b;
43     }
44
45     ftype query(int pos, int ini, int fim, int p, int
46 q) {
47         if (ini >= p && fim <= q) {
48             return seg[pos];
49         }
50
51         if (q < ini || p > fim) {
52             return NEUTRAL;
53         }
54
55         int e = 2*pos + 1;
56         int d = 2*pos + 2;
57         int m = ini + (fim - ini) / 2;

```

```

55         return f(query(e, ini, m, p, q), query(d, m + 1, fim, p, q));
56     }
57
58     void update(int pos, int ini, int fim, int id, int val) {
59         if (ini > id || fim < id) {
60             return;
61         }
62
63         if (ini == id && fim == id) {
64             seg[pos] = val;
65             return;
66         }
67
68         int e = 2*pos + 1;
69         int d = 2*pos + 2;
70         int m = ini + (fim - ini) / 2;
71
72         update(e, ini, m, id, val);
73         update(d, m + 1, fim, id, val);
74
75         seg[pos] = f(seg[e], seg[d]);
76     }
77
78     void build(int pos, int ini, int fim, vector<int> &v) {
79         if (ini == fim) {
80             if (ini < (int)v.size()) {
81                 seg[pos] = v[ini];
82             }
83             return;
84         }
85
86         int e = 2*pos + 1;
87         int d = 2*pos + 2;
88         int m = ini + (fim - ini) / 2;
89
90         build(e, ini, m, v);
91         build(d, m + 1, fim, v);
92
93         seg[pos] = f(seg[e], seg[d]);
94     }
95
96     ftype query(int p, int q) {
97         return query(0, 0, n - 1, p, q);
98     }
99
100     void update(int id, int val) {
101         update(0, 0, n - 1, id, val);
102     }
103
104     void build(vector<int> &v) {
105         build(0, 0, n - 1, v);
106     }
107
108     void debug() {
109         for (auto e : seg) {
110             cout << e << ' ';
111         }
112         cout << '\n';
113     }
114
115 };
116

```

8.10 Lazy

```

1 // Description:
2 // Query - get sum of elements from range (l, r) inclusive
3 // Update - add a value val to elementos from range (l, r) inclusive

```

```

4 // Problem:
5 // https://codeforces.com/edu/course/2/lesson/5/1/practice/contest/279634/problem/A
6
7 // Complexity:
8 // O(log n) for both query and update
9
10 // How to use:
11 // Segtree seg = Segtree(n);
12 // seg.build(v);
13
14 // Notes
15 // Change neutral element and f function to perform a different operation
16
17 typedef long long ftype;
18
19 struct Segtree {
20     vector<ftype> seg;
21     vector<ftype> lazy;
22     int n;
23     const ftype NEUTRAL = 0;
24     const ftype NEUTRAL_LAZY = -1;
25
26     Segtree(int n) {
27         int sz = 1;
28         while (sz < n) sz *= 2;
29         this->n = sz;
30
31         seg.assign(2*sz, NEUTRAL);
32         lazy.assign(2*sz, NEUTRAL_LAZY);
33     }
34
35     ftype apply_lazy(ftype a, ftype b, int len) {
36         if (b == NEUTRAL_LAZY) return a;
37         if (a == NEUTRAL_LAZY) return b * len;
38         else return a + b * len;
39     }
40
41     void propagate(int pos, int ini, int fim) {
42         if (ini == fim) {
43             return;
44         }
45
46         int e = 2*pos + 1;
47         int d = 2*pos + 2;
48         int m = ini + (fim - ini) / 2;
49
50         lazy[e] = apply_lazy(lazy[e], lazy[pos], 1);
51         lazy[d] = apply_lazy(lazy[d], lazy[pos], 1);
52
53         seg[e] = apply_lazy(seg[e], lazy[pos], m - ini + 1);
54         seg[d] = apply_lazy(seg[d], lazy[pos], fim - m);
55
56         lazy[pos] = NEUTRAL_LAZY;
57     }
58
59     ftype f(ftype a, ftype b) {
60         return a + b;
61     }
62
63     ftype query(int pos, int ini, int fim, int p, int q) {
64         propagate(pos, ini, fim);
65
66         if (ini >= p && fim <= q) {
67             return seg[pos];
68         }
69
70         if (q < ini || p > fim) {
71

```

```

72         return NEUTRAL;
73     }
74
75     int e = 2*pos + 1;
76     int d = 2*pos + 2;
77     int m = ini + (fim - ini) / 2;
78
79     return f(query(e, ini, m, p, q), query(d, m + 1, fim, p, q));
80 }
81
82 void update(int pos, int ini, int fim, int p, int q, int val) {
83     propagate(pos, ini, fim);
84
85     if (ini > q || fim < p) {
86         return;
87     }
88
89     if (ini >= p && fim <= q) {
90         lazy[pos] = apply_lazy(lazy[pos], val, 1);
91
92         seg[pos] = apply_lazy(seg[pos], val, fim - ini + 1);
93
94         return;
95     }
96
97     int e = 2*pos + 1;
98     int d = 2*pos + 2;
99     int m = ini + (fim - ini) / 2;
100
101     update(e, ini, m, p, q, val);
102     update(d, m + 1, fim, p, q, val);
103
104     seg[pos] = f(seg[e], seg[d]);
105 }
106
107 void build(int pos, int ini, int fim, vector<int> &v) {
108     if (ini == fim) {
109         if (ini < (int)v.size()) {
110             seg[pos] = v[ini];
111         }
112         return;
113     }
114
115     int e = 2*pos + 1;
116     int d = 2*pos + 2;
117     int m = ini + (fim - ini) / 2;
118
119     build(e, ini, m, v);
120     build(d, m + 1, fim, v);
121
122     seg[pos] = f(seg[e], seg[d]);
123 }
124
125 ftype query(int p, int q) {
126     return query(0, 0, n - 1, p, q);
127 }
128
129 void update(int p, int q, int val) {
130     update(0, 0, n - 1, p, q, val);
131 }
132
133 void build(vector<int> &v) {
134     build(0, 0, n - 1, v);
135 }
136
137 void debug() {
138     for (auto e : seg) {
139         cout << e << ' ';

```

```

140         cout << '\n';
141     }
142     for (auto e : lazy) {
143         cout << e << ' ';
144     }
145     cout << '\n';
146     cout << '\n';
147 }
148
149
150
151
152
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255
256

```

8.11 Lazy Dynamic Implicit Sparse

```

1 // Description:
2 // Indexed at one
3
4 // When the indexes of the nodes are too big to be
5 // stored in an array
6 // and the queries need to be answered online so we
7 // can't sort the nodes and compress them
8 // we create nodes only when they are needed so there
9 // 'll be (Q*log(MAX)) nodes
10 // where Q is the number of queries and MAX is the
11 // maximum index a node can assume
12
13 // Query - get sum of elements from range (l, r)
14 // inclusive
15 // Update - update element at position id to a value
16 // val
17
18 // Problem:
19 // https://oj.uz/problem/view/IZh012_apple
20
21 // Complexity:
22 // O(log n) for both query and update
23
24 // How to use:
25 // MAX is the maximum index a node can assume
26 // Create a default null node
27 // Create a node to be the root of the segtree
28
29 // Segtree seg = Segtree(MAX);
30 // seg.create();
31 // seg.create();
32
33 typedef long long ftype;
34
35 const int MAX = 1e9+17;
36
37 typedef long long ftype;
38
39 const int MAX = 1e9+17;
40
41 struct Segtree {
42     vector<ftype> seg, d, e, lazy;
43     const ftype NEUTRAL = 0;
44     const ftype NEUTRAL_LAZY = -1;
45     int n;
46
47     Segtree(int n) {
48         this->n = n;
49     }
50
51 ftype apply_lazy(ftype a, ftype b, int len) {
52     if (b == NEUTRAL_LAZY) return a;
53     else return b * len;
54 }
55
56 void propagate(int pos, int ini, int fim) {
57     if (seg[pos] == 0) return;
58
59     if (ini == fim) {
60         return;
61     }

```

```

57     int m = (ini + fim) >> 1;
58
59     if (e[pos] == 0) e[pos] = create();
60     if (d[pos] == 0) d[pos] = create();
61
62     lazy[e[pos]] = apply_lazy(lazy[e[pos]], lazy[
pos], 1);
63     lazy[d[pos]] = apply_lazy(lazy[d[pos]], lazy[
pos], 1);
64
65     seg[e[pos]] = apply_lazy(seg[e[pos]], lazy[
pos], m - ini + 1);
66     seg[d[pos]] = apply_lazy(seg[d[pos]], lazy[
pos], fim - m);
67
68     lazy[pos] = NEUTRAL_LAZY;
69 }
70
71 ftype f(ftype a, ftype b) {
72     return a + b;
73 }
74
75 ftype create() {
76     seg.push_back(0);
77     e.push_back(0);
78     d.push_back(0);
79     lazy.push_back(-1);
80     return seg.size() - 1;
81 }
82
83 ftype query(int pos, int ini, int fim, int p, int
q) {
84     propagate(pos, ini, fim);
85     if (q < ini || p > fim) return NEUTRAL;
86     if (pos == 0) return 0;
87     if (p <= ini && fim <= q) return seg[pos];
88     int m = (ini + fim) >> 1;
89     return f(query(e[pos], ini, m, p, q), query(d
[pos], m + 1, fim, p, q));
90 }
91
92 void update(int pos, int ini, int fim, int p, int
q, int val) {
93     propagate(pos, ini, fim);
94     if (ini > q || fim < p) {
95         return;
96     }
97
98     if (ini >= p && fim <= q) {
99         lazy[pos] = apply_lazy(lazy[pos], val, 1)
;
100         seg[pos] = apply_lazy(seg[pos], val, fim
- ini + 1);
101
102         return;
103     }
104
105     int m = (ini + fim) >> 1;
106
107     if (e[pos] == 0) e[pos] = create();
108     update(e[pos], ini, m, p, q, val);
109
110     if (d[pos] == 0) d[pos] = create();
111     update(d[pos], m + 1, fim, p, q, val);
112
113     seg[pos] = f(seg[e[pos]], seg[d[pos]]);
114 }
115
116 ftype query(int p, int q) {
117     return query(1, 1, n, p, q);
118 }
119
120 void update(int p, int q, int val) {

```

```

121     update(1, 1, n, p, q, val);
122 }
123 };

```

8.12 Persistent

```

1 // Description:
2 // Persistent segtree allows for you to save the
different versions of the segtree between each
update
3 // Indexed at one
4 // Query - get sum of elements from range (l, r)
inclusive
5 // Update - update element at position id to a value
val
6
7 // Problem:
8 // https://cses.fi/problemset/task/1737/
9
10 // Complexity:
11 // O(log n) for both query and update
12
13 // How to use:
14 // vector<int> raiz(MAX); // vector to store the
roots of each version
15 // Segtree seg = Segtree(INF);
16 // raiz[0] = seg.create(); // null node
17 // curr = 1; // keep track of the last version
18
19 // raiz[k] = seg.update(raiz[k], idx, val); //
updating version k
20 // seg.query(raiz[k], l, r) // querying version k
21 // raiz[++curr] = raiz[k]; // create a new version
based on version k
22
23 const int MAX = 2e5+17;
24 const int INF = 1e9+17;
25
26 typedef long long ftype;
27
28 struct Segtree {
29     vector<ftype> seg, d, e;
30     const ftype NEUTRAL = 0;
31     int n;
32
33     Segtree(int n) {
34         this->n = n;
35     }
36
37     ftype f(ftype a, ftype b) {
38         return a + b;
39     }
40
41     ftype create() {
42         seg.push_back(0);
43         e.push_back(0);
44         d.push_back(0);
45         return seg.size() - 1;
46     }
47
48     ftype query(int pos, int ini, int fim, int p, int
q) {
49         if (q < ini || p > fim) return NEUTRAL;
50         if (pos == 0) return 0;
51         if (p <= ini && fim <= q) return seg[pos];
52         int m = (ini + fim) >> 1;
53         return f(query(e[pos], ini, m, p, q), query(d
[pos], m + 1, fim, p, q));
54     }
55
56     int update(int pos, int ini, int fim, int id, int
val) {
57         int novo = create();

```

```

58         seg[novo] = seg[pos];
59         e[novo] = e[pos];
60         d[novo] = d[pos];
61
62         if (ini == fim) {
63             seg[novo] = val;
64             return novo;
65         }
66
67         int m = (ini + fim) >> 1;
68
69         if (id <= m) e[novo] = update(e[novo], ini, m
70 , id, val);
71         else d[novo] = update(d[novo], m + 1, fim, id
72 , val);
73         seg[novo] = f(seg[e[novo]], seg[d[novo]]);
74
75         return novo;
76     }
77
78     ftype query(int pos, int p, int q) {
79         return query(pos, 1, n, p, q);
80     }
81
82     int update(int pos, int id, int val) {
83         return update(pos, 1, n, id, val);
84     }
85 }

```