



# Notebook - Maratona de Programação

Lenhadoras de Segtree

## Contents

<b>1 Math</b>	<b>2</b>	<b>4 Strings</b>	<b>7</b>
1.1 Ceil . . . . .	2	4.1 Kmp . . . . .	7
1.2 To Decimal . . . . .	2	4.2 Generate All Permutations . . . . .	8
1.3 Matrix Exponentiation . . . . .	2	4.3 Generate All Sequences Length K . . . . .	8
1.4 Crt . . . . .	3	4.4 Lcs . . . . .	8
1.5 Binary To Decimal . . . . .	3	4.5 Trie . . . . .	8
1.6 Fast Exponentiation . . . . .	3	4.6 Z-function . . . . .	9
1.7 Linear Diophantine Equation . . . . .	3	<b>5 Misc</b>	<b>9</b>
1.8 Function Root . . . . .	4	5.1 Split . . . . .	9
1.9 Sieve Of Eratosthenes . . . . .	4	5.2 Int128 . . . . .	9
1.10 Horner Algorithm . . . . .	4	<b>6 Graphs</b>	<b>9</b>
1.11 Multiplicative Inverse . . . . .	4	6.1 Centroid Find . . . . .	9
1.12 Representation Arbitrary Base . . . . .	4	6.2 Bipartite . . . . .	9
1.13 Set Operations . . . . .	5	6.3 Prim . . . . .	10
1.14 Divisors . . . . .	5	6.4 Ford Fulkerson Edmonds Karp . . . . .	10
1.15 Check If Bit Is On . . . . .	5	6.5 Floyd Warshall . . . . .	10
1.16 Prime Factors . . . . .	5	6.6 Lca . . . . .	11
<b>2 DP</b>	<b>5</b>	6.7 Bellman Ford . . . . .	12
2.1 Knapsack With Index . . . . .	5	6.8 Dinic . . . . .	12
2.2 Substr Palindrome . . . . .	5	6.9 2sat . . . . .	13
2.3 Edit Distance . . . . .	6	6.10 Find Cycle . . . . .	15
2.4 Knapsack . . . . .	6	6.11 Cycle Path Recovery . . . . .	15
2.5 Digits . . . . .	6	6.12 Centroid Decomposition . . . . .	16
2.6 Coins . . . . .	6	6.13 Tarjan Bridge . . . . .	16
2.7 Minimum Coin Change . . . . .	6	6.14 Small To Large . . . . .	17
2.8 Kadane . . . . .	7	6.15 Tree Diameter . . . . .	17
<b>3 Template</b>	<b>7</b>	6.16 Dijkstra . . . . .	17
3.1 Template . . . . .	7	6.17 Kruskall . . . . .	18
3.2 Template Clean . . . . .	7	<b>7 Geometry</b>	<b>18</b>
		7.1 2d . . . . .	18

<b>8</b>	<b>Algorithms</b>	<b>21</b>
8.1	Lis . . . . .	21
8.2	Delta-encoding . . . . .	21
8.3	Subsets . . . . .	21
8.4	Binary Search Last True . . . . .	21
8.5	Ternary Search . . . . .	21
8.6	Binary Search First True . . . . .	21
8.7	Biggest K . . . . .	21
<b>9</b>	<b>Data Structures</b>	<b>22</b>
9.1	Ordered Set . . . . .	22
9.2	Priority Queue . . . . .	22
9.3	Dsu . . . . .	23
9.4	Two Sets . . . . .	23
9.5	Dynamic Implicit Sparse . . . . .	24
9.6	Segtree2d . . . . .	24
9.7	Minimum And Amount . . . . .	26
9.8	Lazy Addition To Segment . . . . .	26
9.9	Segment With Maximum Sum . . . . .	28
9.10	Range Query Point Update . . . . .	29
9.11	Lazy Assignment To Segment . . . . .	29
9.12	Lazy Dynamic Implicit Sparse . . . . .	30
9.13	Persistent . . . . .	31

# 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 To Decimal

```
1 long long to_decimal(const string& rep, long long
2     base) {
3     long long n = 0;
4     for (auto c : rep) {
5         // if the number can't be represented in this
6         // base
7         if (c > digits[base - 1]) return -1;
8         n *= base;
9         n += digits.find(c);
10    }
11    return n;
12 }
```

## 1.3 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)
```

```
38 // How to use:
39 // vector<vector<ll>> v = {{1, 1}, {1, 0}};
40 // Matriz transition = Matriz(v);
41 // cout << fexp(transition, n)[0][1] << '\n';
42
43 using ll = long long;
44
45 const int MOD = 1e9+7;
46
47 struct Matriz{
48     vector<vector<ll>> mat;
49     int rows, columns;
50
51     vector<ll> operator[](int i){
52         return mat[i];
53     }
54
55     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.columns, 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 }
```

```
105 }
```

## 1.4 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
            solution
8         ans = ans + x * ((a - ans) / g) % (b / g) *
            lcm;
9         lcm = lcm * (b / g);
10        ans = (ans % lcm + lcm) % lcm;
11    }
12    return ans;
13 }
```

## 1.5 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 }
```

## 1.6 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 }
```

## 1.7 Linear Diophantine Equation

```
1 // int a, b, c, x1, x2, y1, y2; cin >> a >> b >> c >>
    x1 >> x2 >> y1 >> y2;
2 // int ans = -1;
3 // if (a == 0 && b == 0) {
4 //     if (c != 0) ans = 0;
5 //     else ans = (x2 - x1 + 1) * (y2 - y1 + 1);
```

```
6 // }
7 // else if (a == 0) {
8 //     if (c % b == 0 && y1 <= c / b && y2 >= c / b)
9 //         ans = (x2 - x1 + 1);
10 //     else ans = 0;
11 // }
12 // else if (b == 0) {
13 //     if (c % a == 0 && x1 <= c / a && x2 >= c / a)
14 //         ans = (y2 - y1 + 1);
15 //     else ans = 0;
16 // }
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
23 // Problems:
24 // https://www.spoj.com/problems/CEQU/
25 // http://codeforces.com/problemsets/acmsguru/problem
26 // 99999/106
27
28 // consider trivial case a or b is 0
29 int gcd(int a, int b, int& x, int& y) {
30     if (b == 0) {
31         x = 1;
32         y = 0;
33         return a;
34     }
35     int x1, y1;
36     int d = gcd(b, a % b, x1, y1);
37     x = y1;
38     y = x1 - y1 * (a / b);
39     return d;
40 }
41
42 // x and y are one solution and g is the gcd, all
43 // passed as reference
44 // minx <= x <= maxx miny <= y <= maxy
45 bool find_any_solution(int a, int b, int c, int &x0,
46     int &y0, int &g) {
47     g = gcd(abs(a), abs(b), x0, y0);
48     if (c % g) {
49         return false;
50     }
51
52     x0 *= c / g;
53     y0 *= c / g;
54     if (a < 0) x0 = -x0;
55     if (b < 0) y0 = -y0;
56     return true;
57 }
58
59 void shift_solution(int &x, int &y, int a, int b,
60     int cnt) {
61     x += cnt * b;
62     y -= cnt * a;
63 }
64
65 // return number of solutions in the interval
66 int find_all_solutions(int a, int b, int c, int minx,
67     int maxx, int miny, int maxy) {
68     int x, y, g;
69     if (!find_any_solution(a, b, c, x, y, g))
70         return 0;
71
72     a /= g;
73     b /= g;
74
75     int sign_a = a > 0 ? +1 : -1;
76     int sign_b = b > 0 ? +1 : -1;
77
78     shift_solution(x, y, a, b, (minx - x) / b);
```

```

71     if (x < minx)
72         shift_solution(x, y, a, b, sign_b);
73     if (x > maxx)
74         return 0;
75     int lx1 = x;
76
77     shift_solution(x, y, a, b, (maxx - x) / b);
78     if (x > maxx)
79         shift_solution(x, y, a, b, -sign_b);
80     int rx1 = x;
81
82     shift_solution(x, y, a, b, -(miny - y) / a);
83     if (y < miny)
84         shift_solution(x, y, a, b, -sign_a);
85     if (y > maxy)
86         return 0;
87     int lx2 = x;
88
89     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 }

```

## 1.8 Function Root

```

1  const ld EPS1 = 1e-9; // iteration precision error
2  const ld EPS2 = 1e-4; // output precision error
3
4  ld f(ld x) {
5      // exp(-x) == e^(-x)
6      return p * exp(-x) + q * sin(x) + r * cos(x) + s *
7          tan(x) + t * x * x + u;
8  }
9
10 ld root(ld a, ld b) {
11     while (b - a >= EPS1) {
12         ld c = (a + b) / 2.0;
13         ld y = f(c);
14
15         if (y < 0) b = c;
16         else a = c;
17     }
18     return (a + b) / 2;
19 }
20
21 int main() {
22     ld ans = root(0, 1);
23     if (abs(f(ans)) <= EPS2) cout << fixed <<
24         setprecision(4) << ans << '\n';
25     else cout << "No solution\n";
26
27     return 0;
28 }

```

## 1.9 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 }

```

## 1.10 Horner Algorithm

```

1  // Description:
2  // Evaluates y = f(x)
3
4  // Problem:
5  // https://onlinejudge.org/index.php?option=
6  // com_onlinejudge&Itemid=8&page=show_problem&
7  // problem=439
8
9  // Complexity:
10 // O(n)
11
12 using polynomial = std::vector<int>;
13
14 polynomial p {6, -5, 2}; // p(x) = x^2 - 5x + 6;
15
16 int degree(const polynomial& p) {
17     return p.size() - 1;
18 }
19
20 int evaluate(const polynomial& p, int x) {
21     int y = 0, N = degree(p);
22
23     for (int i = N; i >= 0; --i) {
24         y *= x;
25         y += p[i];
26     }
27
28     return y;
29 }

```

## 1.11 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 }

```

## 1.12 Representation Arbitrary Base

```

1 const string digits { "0123456789
   ABCDEFGHIJKLMNOPQRSTUVWXYZ" };
2
3 string representation(int n, int b) {
4     string rep;
5
6     do {
7         rep.push_back(digits[n % b]);
8         n /= b;
9     } while (n);
10
11     reverse(rep.begin(), rep.end());
12
13     return rep;
14 }

```

### 1.13 Set Operations

```

1 // Complexity;
2 // O(n * m) being n and m the sizes of the two sets
3 // 2*(count1+count2)-1 (where countX is the distance
   between firstX and lastX):
4
5 vector<int> res;
6 set_union(s1.begin(), s1.end(), s2.begin(), s2.end(),
   inserter(res, res.begin()));
7 set_intersection(s1.begin(), s1.end(), s2.begin(), s2
   .end(), inserter(res, res.begin()));
8 // present in the first set, but not in the second
9 set_difference(s1.begin(), s1.end(), s2.begin(), s2.
   end(), inserter(res, res.begin()));
10 // present in one of the sets, but not in the other
11 set_symmetric_difference(s1.begin(), s1.end(), s2.
   begin(), s2.end(), inserter(res, res.begin()));

```

### 1.14 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 }

```

### 1.15 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 }

```

### 1.16 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
18    int res = K[n][W];
19    cout<< res << endl;
20
21    w = W;
22    for (i = n; i > 0 && res > 0; i--) {
23        if (res == K[i - 1][w])
24            continue;
25        else {
26            cout<<" "<<wt[i - 1] ;
27            res = res - val[i - 1];
28            w = w - wt[i - 1];
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 índices i e j
2 // é um palindromo ou ãno.
3
4 char s[MAX];
5 int calculado[MAX][MAX]; // inciado 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][MAXS];
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
  soma seja a maior possivel
2 // nesse caso vc precisa multiplicar exatamente 1
  elemento da subsequencia
3 // e achar a maior soma com isso
4
5 int n, x, arr[MAX], tab[MAX][2]; // tab[maior
  resposta no intervalo][foi multiplicado ou ão]
6
7 int dp(int i, bool mult) {
8     if (i == n-1) {
9         if (!mult) return arr[n-1]*x;
10        return arr[n-1];
11    }
12    if (tab[i][mult] != -1) return tab[i][mult];
13
14    int res;
15
16    if (mult) {
17        res = max(arr[i], arr[i] + dp(i+1, 1));
18    }
19    else {
20        res = max({
21            arr[i]*x,
22            arr[i]*x + dp(i+1, 1),
23            arr[i] + dp(i+1, 0)
24        });
25    }
26
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);
  cin.tie(NULL);
6 #define vi vector<int>
7 #define ll long long
8 #define pb push_back
9 #define mp make_pair
10 #define ff first
11 #define ss second
12 #define pii pair<int, int>
13 #define MOD 1000000007
14 #define sqr(x) ((x) * (x))
15 #define all(x) (x).begin(), (x).end()
16 #define FOR(i, j, n) for (int i = j; i < n; i++)
17 #define qle(i, n) (i == n ? "\n" : " ")
18 #define endl "\n"
19 const int oo = 1e9;
20 const int MAX = 1e6;
21
22 int32_t main(){ optimize;
23
24     return 0;
25 }

```

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

```

## 4.4 Lcs

```

1 // Description:
2 // Finds the longest common subsequence between two
   string
3
4 // Problem:
5 // https://codeforces.com/gym/103134/problem/B
6
7 // Complexity:
8 // O(mn) where m and n are the length of the strings
9
10 string lcsAlgo(string s1, string s2, int m, int n) {
11     int LCS_table[m + 1][n + 1];
12
13     for (int i = 0; i <= m; i++) {
14         for (int j = 0; j <= n; j++) {
15             if (i == 0 || j == 0)
16                 LCS_table[i][j] = 0;
17             else if (s1[i - 1] == s2[j - 1])

```

```

18                 LCS_table[i][j] = LCS_table[i - 1][j - 1] +
19                 1;
20             else
21                 LCS_table[i][j] = max(LCS_table[i - 1][j],
22                 LCS_table[i][j - 1]);
23         }
24     }
25
26     int index = LCS_table[m][n];
27     char lcsAlgo[index + 1];
28     lcsAlgo[index] = '\0';
29
30     int i = m, j = n;
31     while (i > 0 && j > 0) {
32         if (s1[i - 1] == s2[j - 1]) {
33             lcsAlgo[index - 1] = s1[i - 1];
34             i--;
35             j--;
36             index--;
37         }
38         else if (LCS_table[i - 1][j] > LCS_table[i][j -
39         1])
40             i--;
41         else
42             j--;
43     }
44     return lcsAlgo;
45 }

```

## 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     }
42 }

```

```

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              ])
9              ++z[i];
10         if (i + z[i] - 1 > r)
11             l = i, r = i + z[i] - 1;
12     }
13     return z;
14 }

```

## 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     if(palTemp.size() > 0)
18         ans.push_back(palTemp);
19
20     return ans;
21 }
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  // Problem:
7  // https://cses.fi/problemset/task/2079/
8
9  // Complexity:
10 // O(n)
11
12 // How to use:
13 // get_subtree_size(0);
14 // cout << get_centroid(0) + 1 << endl;
15
16 int n;
17 vector<int> adj[MAX];
18 int subtree_size[MAX];
19
20 int get_subtree_size(int node, int par = -1) {
21     int &res = subtree_size[node];
22     res = 1;
23     for (int i : adj[node]) {
24         if (i == par) continue;
25         res += get_subtree_size(i, node);
26     }
27     return res;
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
35             get_centroid(i, node); }
36     }
37     return node;
38 }
39
40 int main() {
41     cin >> n;
42     for (int i = 0; i < n - 1; i++) {
43         int u, v; cin >> u >> v;
44         u--; v--;
45         adj[u].push_back(v);
46         adj[v].push_back(u);
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
36     return true;
37 }

```

### 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                 if (next == t)
27                     return new_flow;
28                 q.push({next, new_flow});
29             }
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/1135
7
8 // Complexity:
9 // O(log n)
10
11 // How to use:
12 // preprocess();
13 // lca(a, b);
14
15 // Notes
16 // To calculate the distance between two nodes use
17 // the following formula
18 // level_peso[a] + level_peso[b] - 2*level_peso[lca(a
19 // , b)]
20
21 const int MAX = 2e5+10;
22 const int BITS = 30;
23
24 vector<pii> adj[MAX];
25 vector<bool> visited(MAX);
26
27 int up[MAX][BITS + 1];
28 int level[MAX];
29 int level_peso[MAX];
30
31 void find_level() {
32     queue<pii> q;
33
34     q.push(mp(1, 0));
35     visited[1] = true;
36
37     while (!q.empty()) {

```

```

35     auto [v, depth] = q.front();
36     q.pop();
37     level[v] = depth;
38
39     for (auto [u, d] : adj[v]) {
40         if (!visited[u]) {
41             visited[u] = true;
42             up[u][0] = v;
43             q.push(mp(u, depth + 1));
44         }
45     }
46 }
47
48 void find_level_peso() {
49     queue<pii> q;
50
51     q.push(mp(1, 0));
52     visited[1] = true;
53
54     while (!q.empty()) {
55         auto [v, depth] = q.front();
56         q.pop();
57         level_peso[v] = depth;
58
59         for (auto [u, d] : adj[v]) {
60             if (!visited[u]) {
61                 visited[u] = true;
62                 up[u][0] = v;
63                 q.push(mp(u, depth + d));
64             }
65         }
66     }
67 }
68
69 int lca(int a, int b) {
70     // get the nodes to the same level
71     int mn = min(level[a], level[b]);
72
73     for (int j = 0; j <= BITS; j++) {
74         if (a != -1 && ((level[a] - mn) & (1 << j))) a
75 = up[a][j];
76         if (b != -1 && ((level[b] - mn) & (1 << j))) b
77 = up[b][j];
78     }
79
80     // special case
81     if (a == b) return a;
82
83     // binary search
84     for (int j = BITS; j >= 0; j--) {
85         if (up[a][j] != up[b][j]) {
86             a = up[a][j];
87             b = up[b][j];
88         }
89     }
90     return up[a][0];
91 }
92
93 void preprocess() {
94     visited = vector<bool>(MAX, false);
95     find_level();
96     visited = vector<bool>(MAX, false);
97     find_level_peso();
98
99     for (int j = 1; j <= BITS; j++) {
100         for (int i = 1; i <= n; i++) {
101             if (up[i][j - 1] != -1) up[i][j] = up[up[i][j -
102 1]][j - 1];
103         }
104     }
105 }

```

## 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     }

```

```

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                sum_num[curr] = sum_num[n];
12                vmax[curr] = vmax[n];
13                swap(colors[curr], colors[n]);
14            }
15
16            for (auto [item, vzs] : colors[n]) {
17                if (colors[curr][item] + vzs > vmax[curr]) {
18                    vmax[curr] = colors[curr][item] +
19                    vzs;
20                    sum_num[curr] = item;
21                }
22                else if (colors[curr][item] + vzs ==
23                vmax[curr]) {
24                    sum_num[curr] += item;
25                }
26
27                colors[curr][item] += vzs;
28            }
29        }
30    }
31
32    int32_t main() {
33
34        int n; cin >> n;
35
36        for (int i = 1; i <= n; i++) {
37            int a; cin >> a;
38            colors[i][a] = 1;
39            vmax[i] = 1;
40            sum_num[i] = a;
41        }
42
43        for (int i = 1; i < n; i++) {
44            int a, b; cin >> a >> b;
45
46            adj[a].push_back(b);
47            adj[b].push_back(a);
48        }
49
50        process_colors(1, 0);
51
52        for (int i = 1; i <= n; i++) {
53            cout << sum_num[i] << (i < n ? " " : "\n");
54        }
55
56        return 0;
57    }
58 }
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), weight(weight) {}
46
47        bool operator<(const Edge& other) const {
48            return weight < other.weight;
49        }
50
51        bool operator>(const Edge& other) const {
52            return weight > other.weight;
53        }
54    };
55
56    vector<Edge> kruskal(vector<Edge> edges, int n) {
57        vector<Edge> result; // arestas da MST
58        long long cost = 0;
59
60        sort(edges.begin(), edges.end());
61
62        DSU dsu(n);
63
64        for (auto e : edges) {
65            if (!dsu.same(e.u, e.v)) {
66                cost += e.weight;
67                result.push_back(e);
68                dsu.unite(e.u, e.v);
69            }
70        }
71
72        return result;
73    }

```

## 7 Geometry

### 7.1 2d

```

1 #define vp vector<point>
2 #define ld long double
3 const ld EPS = 1e-6;
4 const ld PI = acos(-1);
5
6 // typedef ll cod;
7 // bool eq(cod a, cod b){ return (a==b); }
8 typedef ld cod;
9 bool eq(cod a, cod b){ return abs(a - b) <= EPS; }
10
11 struct point{
12     cod x, y;
13     int id;
14     point(cod x=0, cod y=0): x(x), y(y){}
15
16     point operator+(const point &o) const{ return {x+o.x, y+o.y}; }
17     point operator-(const point &o) const{ return {x-o.x, y-o.y}; }
18     point operator*(cod t) const{ return {x*t, y*t}; }
19     point operator/(cod t) const{ return {x/t, y/t}; }
20 }

```

```

20     cod operator*(const point &o) const{ return x * o.87     for(int i=0;i<len;i++)
      .x + y * o.y; }      88         c=c+A[i];
21     cod operator^(const point &o) const{ return x * o.89     return c/len;
      .y - y * o.x; }      90 }
22     bool operator<(const point &o) const{      91
23         return (eq(x, o.x) ? y < o.y : x < o.x);      92     point forca_mod(point p, ld m){
24     }      93         ld cm = norm(p);
25     bool operator==(const point &o) const{      94         if(cm<EPS) return point();
26         return eq(x, o.x) and eq(y, o.y);      95         return point(p.x*m/cm,p.y*m/cm);
27     }      96 }
28     friend ostream& operator<<(ostream& os, point p) {      97
29         return os << "(" << p.x << "," << p.y << ")"; }      98     ld param(point a, point b, point v){
30     };      99         // v = t*(b-a) + a // return t;
31      100         // assert(line(a, b).inside_seg(v));
32     int ccw(point a, point b, point e){ // -1=dir; 0=      101         return ((v-a) * (b-a)) / ((b-a) * (b-a));
33         collinear; 1=esq;      102 }
34         cod tmp = (b-a) ^ (e-a); // vector from a to b      103
35         return (tmp > EPS) - (tmp < -EPS);      104     bool simetric(vp &a){ //ordered
36     }      105         int n = a.size();
37     ld norm(point a){ // Modulo      106         point c = center(a);
38         return sqrt(a * a);      107         if(n&1) return false;
39     }      108         for(int i=0;i<n/2;i++)
40     cod norm2(point a){      109             if(ccw(a[i], a[i+n/2], c) != 0)
41         return a * a;      110             return false;
42     }      111         return true;
43     bool nulo(point a){      112 }
44         return (eq(a.x, 0) and eq(a.y, 0));      113
45     }      114     point mirror(point m1, point m2, point p){
46     point rotccw(point p, ld a){      115         // mirror point p around segment m1m2
47         // a = PI*a/180; // graus      116         point seg = m2-m1;
48         return point((p.x*cos(a)-p.y*sin(a)), (p.y*cos(a)      117         ld t0 = ((p-m1)*seg) / (seg*seg);
49         +p.x*sin(a)));      118         point ort = m1 + seg*t0;
50     }      119         point pm = ort-(p-ort);
51     point rot90cw(point a) { return point(a.y, -a.x); };      120         return pm;
52     point rot90ccw(point a) { return point(-a.y, a.x); };      121 }
53     ld proj(point a, point b){ // a sobre b      122
54         return a*b/norm(b);      123
55     }      124     ////////////
56     ld angle(point a, point b){ // em radianos      125     // Line //
57         ld ang = a*b / norm(a) / norm(b);      126     ////////////
58         return acos(max(min(ang, (ld)1), (ld)-1));      127
59     }      128     struct line{
60     ld angle_vec(point v){      129         point p1, p2;
61         // return 180/PI*atan2(v.x, v.y); // graus      130         cod a, b, c; // ax+by+c = 0;
62         return atan2(v.x, v.y);      131         // y-y1 = ((y2-y1)/(x2-x1))(x-x1)
63     }      132         line(point p1=0, point p2=0): p1(p1), p2(p2){
64     ld order_angle(point a, point b){ // from a to b ccw      133             a = p1.y - p2.y;
65         (a in front of b)      134             b = p2.x - p1.x;
66         ld aux = angle(a,b)*180/PI;      135             c = p1 ^ p2;
67         return ((a^b)<=0 ? aux:360-aux);      136         }
68     }      137         line(cod a=0, cod b=0, cod c=0): a(a), b(b), c(c)
69     bool angle_less(point a1, point b1, point a2, point      138         {
70         b2){ // ang(a1,b1) <= ang(a2,b2)      139             // Gera os pontos p1 p2 dados os coeficientes
71         point p1((a1*b1), abs((a1^b1)));      140             // isso aqui eh um lixo mas quebra um galho
72         point p2((a2*b2), abs((a2^b2)));      141             kkkkkk
73         return (p1^p2) <= 0;      142             if(b==0){
74     }      143                 p1 = point(1, -c/a);
75     ld area(vp &p){ // (points sorted)      144                 p2 = point(0, -c/a);
76         ld ret = 0;      145             }else{
77         for(int i=2;i<(int)p.size();i++)      146                 p1 = point(1, (-c-a*1)/b);
78             ret += (p[i]-p[0])^(p[i-1]-p[0]);      147                 p2 = point(0, -c/b);
79         return abs(ret/2);      148             }
80     }      149         }
81     ld areaT(point &a, point &b, point &c){      150         cod eval(point p){
82         return abs((b-a)^(c-a))/2.0;      151             return a*p.x+b*p.y+c;
83     }      152         }
84     point center(vp &a){      153         bool inside(point p){
85         point c = point();      154             return eq(eval(p), 0);
86         int len = A.size();      155         }
      156         point normal(){
      157             return point(a, b);
      158         }

```

```

158     bool inside_seg(point p){
159         return (
160             ((p1-p) ^ (p2-p)) == 0 and
161             ((p1-p) * (p2-p)) <= 0
162         );
163     };
164 }
165
166 };
167
168 // be careful with precision error
169 vp inter_line(line l1, line l2){
170     ld det = l1.a*l2.b - l1.b*l2.a;
171     if(det==0) return {};
172     ld x = (l1.b*l2.c - l1.c*l2.b)/det;
173     ld y = (l1.c*l2.a - l1.a*l2.c)/det;
174     return {point(x, y)};
175 }
176
177 // segments not collinear
178 vp inter_seg(line l1, line l2){
179     vp ans = inter_line(l1, l2);
180     if(ans.empty() or !l1.inside_seg(ans[0]) or !l2.
181         inside_seg(ans[0]))
182         return {};
183     return ans;
184 }
185
186 bool seg_has_inter(line l1, line l2){
187     return ccw(l1.p1, l1.p2, l2.p1) * ccw(l1.p1, l1.
188         p2, l2.p2) < 0 and
189         ccw(l2.p1, l2.p2, l1.p1) * ccw(l2.p1, l2.
190         p2, l1.p2) < 0;
191 }
192
193 ld dist_seg(point p, point a, point b){ // point -
194     seg
195     if((p-a)*(b-a) < EPS) return norm(p-a);
196     if((p-b)*(a-b) < EPS) return norm(p-b);
197     return abs((p-a)^(b-a)) / norm(b-a);
198 }
199
200 ld dist_line(point p, line l){ // point - line
201     return abs(l.eval(p))/sqrt(l.a*l.a + l.b*l.b);
202 }
203
204 line bisector(point a, point b){
205     point d = (b-a)*2;
206     return line(d.x, d.y, a*a - b*b);
207 }
208
209 line perpendicular(line l, point p){ // passes
210     through p
211     return line(l.b, -l.a, -l.b*p.x + l.a*p.y);
212 }
213
214 // Circle
215
216 struct circle{
217     point c; cod r;
218     circle() : c(0, 0), r(0){}
219     circle(const point o) : c(o), r(0){}
220     circle(const point a, const point b){
221         c = (a+b)/2;
222         r = norm(a-c);
223     }
224     circle(const point a, const point b, const point
225         cc){
226         assert(ccw(a, b, cc) != 0);
227         c = inter_line(bisector(a, b), bisector(b, c
228         ))[0];
229
230         r = norm(a-c);
231     }
232     bool inside(const point &a) const{
233         return norm(a - c) <= r + EPS;
234     }
235 };
236
237 pair<point, point> tangent_points(circle cr, point p)
238 {
239     ld d1 = norm(p-cr.c), theta = asin(cr.r/d1);
240     point p1 = rotccw(cr.c-p, -theta);
241     point p2 = rotccw(cr.c-p, theta);
242     assert(d1 >= cr.r);
243     p1 = p1 * (sqrt(d1*d1-cr.r*cr.r) / d1) + p;
244     p2 = p2 * (sqrt(d1*d1-cr.r*cr.r) / d1) + p;
245     return {p1, p2};
246 }
247
248 circle incircle(point p1, point p2, point p3){
249     ld m1 = norm(p2-p3);
250     ld m2 = norm(p1-p3);
251     ld m3 = norm(p1-p2);
252     point c = (p1*m1 + p2*m2 + p3*m3)*(1/(m1+m2+m3));
253     ld s = 0.5*(m1+m2+m3);
254     ld r = sqrt(s*(s-m1)*(s-m2)*(s-m3)) / s;
255     return circle(c, r);
256 }
257
258 circle circumcircle(point a, point b, point c) {
259     circle ans;
260     point u = point((b-a).y, -(b-a).x);
261     point v = point((c-a).y, -(c-a).x);
262     point n = (c-b)*0.5;
263     ld t = (u^v)/(v^u);
264     ans.c = ((a+c)*0.5) + (v*t);
265     ans.r = norm(ans.c-a);
266     return ans;
267 }
268
269 vp inter_circle_line(circle C, line L){
270     point ab = L.p2 - L.p1, p = L.p1 + ab * ((C.c-L.
271         p1)*(ab) / (ab*ab));
272     ld s = (L.p2-L.p1)^(C.c-L.p1), h2 = C.r*C.r - s*s
273         / (ab*ab);
274     if (h2 < -EPS) return {};
275     if (eq(h2, 0)) return {p};
276     point h = (ab/norm(ab)) * sqrt(h2);
277     return {p - h, p + h};
278 }
279
280 vp inter_circle(circle C1, circle C2){
281     if(C1.c == C2.c) { assert(C1.r != C2.r); return
282         {}; }
283     point vec = C2.c - C1.c;
284     ld d2 = vec*vec, sum = C1.r+C2.r, dif = C1.r-C2.r
285         ;
286     ld p = (d2 + C1.r*C1.r - C2.r*C2.r)/(d2*2), h2 =
287         C1.r*C1.r - p*p*d2;
288     if (sum*sum < d2 or dif*dif > d2) return {};
289     point mid = C1.c + vec*p, per = point(-vec.y, vec
290         .x) * sqrt(max((ld)0, h2) / d2);
291     if(eq(per.x, 0) and eq(per.y, 0)) return {mid};
292     return {mid + per, mid - per};
293 }
294
295 // minimum circle cover O(n) amortizado
296 circle min_circle_cover(vp v){
297     random_shuffle(v.begin(), v.end());
298     circle ans;
299     int n = v.size();
300     for(int i=0;i<n;i++) if(!ans.inside(v[i])){
301         ans = circle(v[i]);
302     }
303 }

```

```

290     for(int j=0;j<i;j++) if(!ans.inside(v[j])){
291         ans = circle(v[i], v[j]);
292         for(int k=0;k<j;k++) if(!ans.inside(v[k])){
293             ans = circle(v[i], v[j], v[k]);
294         }
295     }
296 }
297 return ans;
298 }

```

## 8 Algorithms

### 8.1 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 }

```

### 8.2 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 }

```

### 8.3 Subsets

```

1 void subsets(vector<int>& nums){
2     int n = nums.size();
3     int powSize = 1 << n;
4
5     for(int counter = 0; counter < powSize; counter++){

```

```

6         for(int j = 0; j < n; j++){
7             if((counter & (1LL << j)) != 0) {
8                 cout << nums[j] << ' ';
9             }
10        }
11        cout << '\n';
12    }
13 }

```

### 8.4 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 }

```

### 8.5 Ternary Search

```

1 double ternary_search(double l, double r) {
2     double eps = 1e-9; //set the error
3     limit here
4     while (r - l > eps) {
5         double m1 = l + (r - l) / 3;
6         double m2 = r - (r - l) / 3;
7         double f1 = f(m1); //evaluates the
8         function at m1
9         double f2 = f(m2); //evaluates the
10        function at m2
11        if (f1 < f2)
12            l = m1;
13        else
14            r = m2;
15    }
16    return f(l); //return the
17    maximum of f(x) in [l, r]
18 }

```

### 8.6 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         } else {
9             lo = mid + 1;
10        }
11    }
12    return lo;
13 }

```

### 8.7 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.size()){
31             auto p = (prev(mt.mt.end()));
32             gt.add(*p);
33             mt.pop(*p);
34         }
35         while((int)mt.mt.size() && (int)gt.mt.size()
&&
36             *(gt.mt.begin()) < *(prev(mt.mt.end())) ){
37             ll u = *(gt.mt.begin());
38             ll v = *(prev(mt.mt.end()));
39             gt.pop(u); mt.pop(v);
40             gt.add(v); mt.add(u);
41         }
42     }
43     void add(ll x){
44         mt.add(x);
45         balancear();
46     }
47     void rem(ll x){
48         //x = -x;
49         if(mt.pop(x) == 0)
50             gt.pop(x);
51         balancear();
52     }
53 };
54
55 int main() {
56     ios::sync_with_stdio(false);
57     cin.tie(NULL);
58
59     int n, k, q; cin >> n >> k >> q;
60
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 }

```

## 9 Data Structures

### 9.1 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 }

```

### 9.2 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;

```

## 9.3 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 }
```

## 9.4 Two Sets

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

```

## 9.5 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 // 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
27 // Segtree seg = Segtree(MAX);
28
29 typedef long long ftype;
30
31 const int MAX = 1e9+17;
32
33 struct Segtree {
34     vector<ftype> seg, d, e;
35     const ftype NEUTRAL = 0;
36     int n;
37
38     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
68         return;
69     }
70
71     int m = (ini + fim) >> 1;
72
73     if (id <= m) {
74         if (e[pos] == 0) e[pos] = create();
75         update(e[pos], ini, m, id, val);
76     } else {
77         if (d[pos] == 0) d[pos] = create();
78         update(d[pos], m + 1, fim, id, val);
79     }
80
81     seg[pos] = f(seg[e[pos]], seg[d[pos]]);
82 }
83
84 ftype query(int p, int q) {
85     return query(1, 1, n, p, q);
86 }
87
88 void update(int id, int val) {
89     update(1, 1, n, id, val);
90 }
91 };

```

## 9.6 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/

```

```

10
11 // Complexity:
12 // Time complexity:
13 // O(log N * log M) for both query and update
14 // O(N * M) for build
15 // Memory complexity:
16 // 4 * M * N
17
18 // How to use:
19 // Segtree2D seg = Segtree2D(n, n);
20 // vector<vector<int>> v(n, vector<int>(n));
21 // seg.build(v);
22
23 // Notes
24 // Indexed at zero
25
26 struct Segtree2D {
27     const int MAXN = 1025;
28     int N, M;
29
30     vector<vector<int>> seg;
31
32     Segtree2D(int N, int M) {
33         this->N = N;
34         this->M = M;
35         seg.resize(2*MAXN, vector<int>(2*MAXN));
36     }
37
38     void buildY(int noX, int lX, int rX, int noY, int
        lY, int rY, vector<vector<int>> &v){
39         if(lY == rY){
40             if(lX == rX){
41                 seg[noX][noY] = v[rX][rY];
42             }else{
43                 seg[noX][noY] = seg[2*noX+1][noY] +
44                 seg[2*noX+2][noY];
45             }
46         }else{
47             int m = (lY+rY)/2;
48
49             buildY(noX, lX, rX, 2*noY+1, lY, m, v);
50             buildY(noX, lX, rX, 2*noY+2, m+1, rY, v);
51
52             seg[noX][noY] = seg[noX][2*noY+1] + seg[
53             noX][2*noY+2];
54         }
55     }
56
57     void buildX(int noX, int lX, int rX, vector<
58     vector<int>> &v){
59         if(lX != rX){
60             int m = (lX+rX)/2;
61
62             buildX(2*noX+1, lX, m, v);
63             buildX(2*noX+2, m+1, rX, v);
64         }
65
66         buildY(noX, lX, rX, 0, 0, M - 1, v);
67     }
68
69     void updateY(int noX, int lX, int rX, int noY,
70     int lY, int rY, int y){
71         if(lY == rY){
72             if(lX == rX){
73                 seg[noX][noY] = !seg[noX][noY];
74             }else{
75                 seg[noX][noY] = seg[2*noX+1][noY] +
76                 seg[2*noX+2][noY];
77             }
78         }else{
79             int m = (lY+rY)/2;
80
81             if(y <= m){
82                 updateY(noX, lX, rX, 2*noY+1, lY, m, y);
83             }else if(m < y){
84                 updateY(noX, lX, rX, 2*noY+2, m+1, rY
85                 , y);
86             }
87
88             seg[noX][noY] = seg[noX][2*noY+1] + seg[
89             noX][2*noY+2];
90         }
91     }
92
93     void updateX(int noX, int lX, int rX, int x, int
94     y){
95         int m = (lX+rX)/2;
96
97         if(lX != rX){
98             if(x <= m){
99                 updateX(2*noX+1, lX, m, x, y);
100             }else if(m < x){
101                 updateX(2*noX+2, m+1, rX, x, y);
102             }
103         }
104
105         updateY(noX, lX, rX, 0, 0, M - 1, y);
106     }
107
108     int queryY(int noX, int noY, int lY, int rY, int
109     aY, int bY){
110         if(aY <= lY && rY <= bY) return seg[noX][noY
111         ];
112
113         int m = (lY+rY)/2;
114
115         if(bY <= m) return queryY(noX, 2*noY+1, lY, m
116         , aY, bY);
117         if(m < aY) return queryY(noX, 2*noY+2, m+1,
118         rY, aY, bY);
119
120         return queryY(noX, 2*noY+1, lY, m, aY, bY) +
121         queryY(noX, 2*noY+2, m+1, rY, aY, bY);
122     }
123
124     int queryX(int noX, int lX, int rX, int aX, int
125     bX, int aY, int bY){
126         if(aX <= lX && rX <= bX) return queryY(noX,
127         0, 0, M - 1, aY, bY);
128
129         int m = (lX+rX)/2;
130
131         if(bX <= m) return queryX(2*noX+1, lX, m, aX,
132         bX, aY, bY);
133         if(m < aX) return queryX(2*noX+2, m+1, rX, aX
134         , bX, aY, bY);
135
136         return queryX(2*noX+1, lX, m, aX, bX, aY, bY)
137         + queryX(2*noX+2, m+1, rX, aX, bX, aY, bY);
138     }
139
140     void build(vector<vector<int>> &v) {
141         buildX(0, 0, N - 1, v);
142     }
143
144     int query(int aX, int bX, int aY, int bY) {
145         return queryX(0, 0, N - 1, aX, bX, aY, bY);
146     }
147
148     void update(int x, int y) {
149         updateX(0, 0, N - 1, x, y);
150     }
151 }

```

## 9.7 Minimum And Amount

```
1 // Description:
2 // Query - get minimum element in a range (l, r)
   inclusive
3 // and also the number of times it appears in that
   range
4 // Update - update element at position id to a value
   val
5
6 // Problem:
7 // https://codeforces.com/edu/course/2/lesson/4/1/
   practice/contest/273169/problem/C
8
9 // Complexity:
10 // O(log n) for both query and update
11
12 // How to use:
13 // Segtree seg = Segtree(n);
14 // seg.build(v);
15
16 #define pii pair<int, int>
17 #define mp make_pair
18 #define ff first
19 #define ss second
20
21 const int INF = 1e9+17;
22
23 typedef pii ftype;
24
25 struct Segtree {
26     vector<ftype> seg;
27     int n;
28     const ftype NEUTRAL = mp(INF, 0);
29
30     Segtree(int n) {
31         int sz = 1;
32         while (sz < n) sz *= 2;
33         this->n = sz;
34
35         seg.assign(2*sz, NEUTRAL);
36     }
37
38     ftype f(ftype a, ftype b) {
39         if (a.ff < b.ff) return a;
40         if (b.ff < a.ff) return b;
41
42         return mp(a.ff, a.ss + b.ss);
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;
58
59         return f(query(e, ini, m, p, q), query(d, m +
60         1, fim, p, q));
61
62     }
63
64     void update(int pos, int ini, int fim, int id,
65     int val) {
66         if (ini > id || fim < id) {
67             return;
68         }
69     }
```

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

## 9.8 Lazy Addition To Segment

```
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
5 // Problem:
6 // https://codeforces.com/edu/course/2/lesson/5/1/
   practice/contest/279634/problem/A
7
8 // Complexity:
9 // O(log n) for both query and update
10
11 // How to use:
12 // Segtree seg = Segtree(n);
```

```

13 // seg.build(v);
14
15 // Notes
16 // Change neutral element and f function to perform a
    different operation
17
18 const long long INF = 1e18+10;
19
20 typedef long long ftype;
21
22 struct Segtree {
23     vector<ftype> seg;
24     vector<ftype> lazy;
25     int n;
26     const ftype NEUTRAL = 0;
27     const ftype NEUTRAL_LAZY = -1; // change to -INF
    if there are negative numbers
28
29     Segtree(int n) {
30         int sz = 1;
31         while (sz < n) sz *= 2;
32         this->n = sz;
33
34         seg.assign(2*sz, NEUTRAL);
35         lazy.assign(2*sz, NEUTRAL_LAZY);
36     }
37
38     ftype apply_lazy(ftype a, ftype b, int len) {
39         if (b == NEUTRAL_LAZY) return a;
40         if (a == NEUTRAL_LAZY) return b * len;
41         else return a + b * len;
42     }
43
44     void propagate(int pos, int ini, int fim) {
45         if (ini == fim) {
46             return;
47         }
48
49         int e = 2*pos + 1;
50         int d = 2*pos + 2;
51         int m = ini + (fim - ini) / 2;
52
53         lazy[e] = apply_lazy(lazy[e], lazy[pos], 1);
54         lazy[d] = apply_lazy(lazy[d], lazy[pos], 1);
55
56         seg[e] = apply_lazy(seg[e], lazy[pos], m -
ini + 1);
57         seg[d] = apply_lazy(seg[d], lazy[pos], fim -
m);
58
59         lazy[pos] = NEUTRAL_LAZY;
60     }
61
62     ftype f(ftype a, ftype b) {
63         return a + b;
64     }
65
66     ftype query(int pos, int ini, int fim, int p, int
q) {
67         propagate(pos, ini, fim);
68
69         if (ini >= p && fim <= q) {
70             return seg[pos];
71         }
72
73         if (q < ini || p > fim) {
74             return NEUTRAL;
75         }
76
77         int e = 2*pos + 1;
78         int d = 2*pos + 2;
79         int m = ini + (fim - ini) / 2;
80
81         return f(query(e, ini, m, p, q), query(d, m +
1, fim, p, q));
82     }
83
84     void update(int pos, int ini, int fim, int p, int
q, int val) {
85         propagate(pos, ini, fim);
86
87         if (ini > q || fim < p) {
88             return;
89         }
90
91         if (ini >= p && fim <= q) {
92             lazy[pos] = apply_lazy(lazy[pos], val, 1)
;
93             seg[pos] = apply_lazy(seg[pos], val, fim
- ini + 1);
94
95             return;
96         }
97
98         int e = 2*pos + 1;
99         int d = 2*pos + 2;
100         int m = ini + (fim - ini) / 2;
101
102         update(e, ini, m, p, q, val);
103         update(d, m + 1, fim, p, q, val);
104
105         seg[pos] = f(seg[e], seg[d]);
106     }
107
108     void build(int pos, int ini, int fim, vector<int>
&v) {
109         if (ini == fim) {
110             if (ini < (int)v.size()) {
111                 seg[pos] = v[ini];
112             }
113             return;
114         }
115
116         int e = 2*pos + 1;
117         int d = 2*pos + 2;
118         int m = ini + (fim - ini) / 2;
119
120         build(e, ini, m, v);
121         build(d, m + 1, fim, v);
122
123         seg[pos] = f(seg[e], seg[d]);
124     }
125
126     ftype query(int p, int q) {
127         return query(0, 0, n - 1, p, q);
128     }
129
130     void update(int p, int q, int val) {
131         update(0, 0, n - 1, p, q, val);
132     }
133
134     void build(vector<int> &v) {
135         build(0, 0, n - 1, v);
136     }
137
138     void debug() {
139         for (auto e : seg) {
140             cout << e << ' ';
141         }
142         cout << '\n';
143         for (auto e : lazy) {
144             cout << e << ' ';
145         }
146         cout << '\n';
147         cout << '\n';
148     }

```

```
149 };
```

## 9.9 Segment With Maximum Sum

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

```
61 }
62
63 ftype query(int pos, int ini, int fim, int p, int
64 q) {
65     if (ini >= p && fim <= q) {
66         return seg[pos];
67     }
68
69     if (q < ini || p > fim) {
70         return NEUTRAL;
71     }
72
73     int e = 2*pos + 1;
74     int d = 2*pos + 2;
75     int m = ini + (fim - ini) / 2;
76
77     return f(query(e, ini, m, p, q), query(d, m +
78 1, fim, p, q));
79 }
80
81 void update(int pos, int ini, int fim, int id,
82 int val) {
83     if (ini > id || fim < id) {
84         return;
85     }
86
87     if (ini == id && fim == id) {
88         seg[pos] = Node(val, val, val, val);
89     }
90
91     return;
92
93     int e = 2*pos + 1;
94     int d = 2*pos + 2;
95     int m = ini + (fim - ini) / 2;
96
97     update(e, ini, m, id, val);
98     update(d, m + 1, fim, id, val);
99
100     seg[pos] = f(seg[e], seg[d]);
101 }
102
103 void build(int pos, int ini, int fim, vector<int>
104 &v) {
105     if (ini == fim) {
106         // se a çãposio existir no array original
107         // seg tamanho potencia de dois
108         if (ini < (int)v.size()) {
109             seg[pos] = Node(v[ini], v[ini], v[ini],
110 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 id, int val) {
130     update(0, 0, n - 1, id, val);
131 }
132
133 void build(vector<int> &v) {
134 }
```

```

129     build(0, 0, n - 1, v);
130 }
131
132 void debug() {
133     for (auto e : seg) {
134         cout << e.max_seg << ' ' << e.pref << ' '
135         << e.suf << ' ' << e.sum << '\n';
136     }
137     cout << '\n';
138 };

```

## 9.10 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             int e = 2*pos + 1;

```

```

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

```

## 9.11 Lazy Assignment To Segment

```

1 const long long INF = 1e18+10;
2
3 typedef long long ftype;

```

```

4
5 struct Segtree {
6     vector<ftype> seg;
7     vector<ftype> lazy;
8     int n;
9     const ftype NEUTRAL = 0;
10    const ftype NEUTRAL_LAZY = -1; // Change to -INF
    if there are negative numbers
11
12    Segtree(int n) {
13        int sz = 1;
14        // potencia de dois mais proxima
15        while (sz < n) sz *= 2;
16        this->n = sz;
17
18        // numero de nos da seg
19        seg.assign(2*sz, NEUTRAL);
20        lazy.assign(2*sz, NEUTRAL_LAZY);
21    }
22
23    ftype apply_lazy(ftype a, ftype b, int len) {
24        if (b == NEUTRAL_LAZY) return a;
25        if (a == NEUTRAL_LAZY) return b * len;
26        else return b * len;
27    }
28
29    void propagate(int pos, int ini, int fim) {
30        if (ini == fim) {
31            return;
32        }
33
34        int e = 2*pos + 1;
35        int d = 2*pos + 2;
36        int m = ini + (fim - ini) / 2;
37
38        lazy[e] = apply_lazy(lazy[e], lazy[pos], 1);
39        lazy[d] = apply_lazy(lazy[d], lazy[pos], 1);
40
41        seg[e] = apply_lazy(seg[e], lazy[pos], m -
42        ini + 1);
43        seg[d] = apply_lazy(seg[d], lazy[pos], fim -
44        m);
45
46        lazy[pos] = NEUTRAL_LAZY;
47    }
48
49    ftype f(ftype a, ftype b) {
50        return a + b;
51    }
52
53    ftype query(int pos, int ini, int fim, int p, int
54    q) {
55        propagate(pos, ini, fim);
56
57        if (ini >= p && fim <= q) {
58            return seg[pos];
59        }
60
61        if (q < ini || p > fim) {
62            return NEUTRAL;
63        }
64
65        int e = 2*pos + 1;
66        int d = 2*pos + 2;
67        int m = ini + (fim - ini) / 2;
68
69        return f(query(e, ini, m, p, q), query(d, m
70        + 1, fim, p, q));
71    }
72
73    void update(int pos, int ini, int fim, int p, int
74    q, int val) {
75        propagate(pos, ini, fim);
76
77        if (ini > q || fim < p) {
78            return;
79        }
80
81        if (ini >= p && fim <= q) {
82            lazy[pos] = apply_lazy(lazy[pos], val, 1)
83            ;
84            seg[pos] = apply_lazy(seg[pos], val, fim
85            - ini + 1);
86
87            return;
88        }
89
90        int e = 2*pos + 1;
91        int d = 2*pos + 2;
92        int m = ini + (fim - ini) / 2;
93
94        update(e, ini, m, p, q, val);
95        update(d, m + 1, fim, p, q, val);
96
97        seg[pos] = f(seg[e], seg[d]);
98    }
99
100    void build(int pos, int ini, int fim, vector<int>
101    &v) {
102        if (ini == fim) {
103            // se a posição existir no array original
104            // seg tamanho potencia de dois
105            if (ini < (int)v.size()) {
106                seg[pos] = v[ini];
107            }
108            return;
109        }
110
111        int e = 2*pos + 1;
112        int d = 2*pos + 2;
113        int m = ini + (fim - ini) / 2;
114
115        build(e, ini, m, v);
116        build(d, m + 1, fim, v);
117
118        seg[pos] = f(seg[e], seg[d]);
119    }
120
121    ftype query(int p, int q) {
122        return query(0, 0, n - 1, p, q);
123    }
124
125    void update(int p, int q, int val) {
126        update(0, 0, n - 1, p, q, val);
127    }
128
129    void build(vector<int> &v) {
130        build(0, 0, n - 1, v);
131    }
132
133    void debug() {
134        for (auto e : seg) {
135            cout << e << ' ';
136        }
137        cout << '\n';
138        for (auto e : lazy) {
139            cout << e << ' ';
140        }
141        cout << '\n';
142        cout << '\n';
143    }
144
145    1 // Description:

```

## 9.12 Lazy Dynamic Implicit Sparse

```

2 // Indexed at one
3
4 // When the indexes of the nodes are too big to be
5 // and the queries need to be answered online so we
6 // we create nodes only when they are needed so there
7 // where Q is the number of queries and MAX is the
8 // maximum index a node can assume
9 // Query - get sum of elements from range (l, r)
10 // Update - update element at position id to a value
11 // Problem:
12 // https://oj.uz/problem/view/IZh012_apple
13 // Complexity:
14 // O(log n) for both query and update
15 // How to use:
16 // MAX is the maximum index a node can assume
17 // Create a default null node
18 // Create a node to be the root of the segtree
19 // Segtree seg = Segtree(MAX);
20
21 const int MAX = 1e9+10;
22 const long long INF = 1e18+10;
23
24 typedef long long ftype;
25
26 struct Segtree {
27     vector<ftype> seg, d, e, lazy;
28     const ftype NEUTRAL = 0;
29     const ftype NEUTRAL_LAZY = -1; // change to -INF
30     if the elements can be negative
31     int n;
32
33     Segtree(int n) {
34         this->n = n;
35         create();
36         create();
37     }
38
39     ftype apply_lazy(ftype a, ftype b, int len) {
40         if (b == NEUTRAL_LAZY) return a;
41         else return b * len; // change to a + b * len
42         to add to an element instead of updating it
43     }
44
45     void propagate(int pos, int ini, int fim) {
46         if (seg[pos] == 0) return;
47
48         if (ini == fim) {
49             return;
50         }
51
52         int m = (ini + fim) >> 1;
53
54         if (e[pos] == 0) e[pos] = create();
55         if (d[pos] == 0) d[pos] = create();
56
57         lazy[e[pos]] = apply_lazy(lazy[e[pos]], lazy[
58 pos], 1);
59         lazy[d[pos]] = apply_lazy(lazy[d[pos]], lazy[
60 pos], 1);
61
62         seg[e[pos]] = apply_lazy(seg[e[pos]], lazy[
63 pos], m - ini + 1);
64         seg[d[pos]] = apply_lazy(seg[d[pos]], lazy[
65 pos], fim - m);
66
67         lazy[pos] = NEUTRAL_LAZY;
68     }
69
70     ftype f(ftype a, ftype b) {
71         return a + b;
72     }
73
74     ftype create() {
75         seg.push_back(0);
76         e.push_back(0);
77         d.push_back(0);
78         lazy.push_back(-1);
79         return seg.size() - 1;
80     }
81
82     ftype query(int pos, int ini, int fim, int p, int
83 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
90 [pos], m + 1, fim, p, q));
91     }
92
93     void update(int pos, int ini, int fim, int p, int
94 q, int val) {
95         propagate(pos, ini, fim);
96         if (ini > q || fim < p) {
97             return;
98         }
99
100         if (ini >= p && fim <= q) {
101             lazy[pos] = apply_lazy(lazy[pos], val, 1)
102 ;
103             seg[pos] = apply_lazy(seg[pos], val, fim
104 - ini + 1);
105         }
106
107         return;
108
109         int m = (ini + fim) >> 1;
110
111         if (e[pos] == 0) e[pos] = create();
112         update(e[pos], ini, m, p, q, val);
113
114         if (d[pos] == 0) d[pos] = create();
115         update(d[pos], m + 1, fim, p, q, val);
116
117         seg[pos] = f(seg[e[pos]], seg[d[pos]]);
118     }
119
120     ftype query(int p, int q) {
121         return query(1, 1, n, p, q);
122     }
123
124     void update(int p, int q, int val) {
125         update(1, 1, n, p, q, val);
126     }
127 };

```

## 9.13 Persistent

```

1 // Description:
2 // Persistent segtree allows for you to save the
3 // different versions of the segtree between each
4 // update
5 // Indexed at one
6 // Query - get sum of elements from range (l, r)
7 // 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
59         seg[novo] = seg[pos];
60         e[novo] = e[pos];
61         d[novo] = d[pos];
62
63         if (ini == fim) {
64             seg[novo] = val;
65             return novo;
66         }
67
68         int m = (ini + fim) >> 1;
69
70         if (id <= m) e[novo] = update(e[novo], ini, m
    , id, val);
71         else d[novo] = update(d[novo], m + 1, fim, id
    , val);
72
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 };

```