

# Faculty of Computer and Information Sciences, Ain Shams University: Too Wrong to Pass Too Correct to Fail

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## 1 Combinatorics

### 1.1 Burnside Lemma

```

1
2 // |Classes|=sum (k ^C(pi)) / |G|
3
4 // C(pi) the number of cycles in the permutation pi
5
6 // |G| the number of permutations

```

### 1.2 Catlan Numbers

```

1 const int MOD = ....
2 const int MAX = ....
3 int catalan[MAX];
4 void init() {
5     catalan[0] = catalan[1] = 1;
6     for (int i=2; i<=n; i++) {
7         catalan[i] = 0;
8         for (int j=0; j < i; j++) {
9             catalan[i] += (catalan[j] * catalan[i-j-1]) % MOD;
10            if (catalan[i] >= MOD) {
11                catalan[i] -= MOD;
12            }
13        }
14    }
15 }
16

```

```

17 // 1- Number of correct bracket sequence consisting of n opening and n closing
    brackets.
18 // 2- The number of rooted full binary trees with n+1 leaves (vertices are not
    numbered).
19 //   A rooted binary tree is full if every vertex has either two children or no
    children.
20 // 3- The number of ways to completely parenthesize n+1 factors.
21 // 4- The number of triangulations of a convex polygon with n+2 sides
22 //   (i.e. the number of partitions of polygon into disjoint triangles by using
    the diagonals).
23 // 5- The number of ways to connect the 2n points on a circle to form n disjoint
    chords.
24 // 6- The number of non-isomorphic full binary trees with n internal nodes (i.e.
    nodes having at least one son).
25 // 7- The number of monotonic lattice paths from point (0,0) to point (n,n) in a
    square lattice of size nxn,
26 //   which do not pass above the main diagonal (i.e. connecting (0,0) to (n,n))
    .
27 // 8- Number of permutations of length n that can be stack sorted
28 //   (i.e. it can be shown that the rearrangement is stack sorted if and only
    if
29 //     there is no such index i<j<k, such that ak<ai<aj ).
30 // 9- The number of non-crossing partitions of a set of n elements.
31 // 10- The number of ways to cover the ladder 1..n using n rectangles
32 //   (The ladder consists of n columns, where ith column has a height i).

```

## 2 Algebra

### 2.1 Primitive Roots

```

1  int powmod (int a, int b, int p) {
2      int res = 1;
3      while (b)
4          if (b & 1)
5              res = int (res * 1ll * a % p), --b;
6          else
7              a = int (a * 1ll * a % p), b >>= 1;
8      return res;
9  }
10
11 int generator (int p) {
12     vector<int> fact;
13     int phi = p - 1, n = phi;
14     for (int i = 2; i * i <= n; ++i)
15         if (n % i == 0) {
16             fact.push_back (i);
17             while (n % i == 0)
18                 n /= i;
19         }
20     if (n > 1)
21         fact.push_back (n);
22
23     for (int res = 2; res <= p; ++res) {
24         bool ok = true;
25         for (size_t i = 0; i < fact.size() && ok; ++i)
26             ok &= powmod (res, phi / fact[i], p) != 1;
27         if (ok) return res;
28     }
29     return -1;
30 }

```

### 2.2 Discrete Logarithm

```

1 // Returns minimum x for which a ^ x % m = b % m, a and m are coprime.
2 int solve(int a, int b, int m) {
3     a %= m, b %= m;
4     int n = sqrt(m) + 1;

```

```

5
6     int an = 1;
7     for (int i = 0; i < n; ++i)
8         an = (an * 1ll * a) % m;
9
10    unordered_map<int, int> vals;
11    for (int q = 0, cur = b; q <= n; ++q) {
12        vals[cur] = q;
13        cur = (cur * 1ll * a) % m;
14    }
15
16    for (int p = 1, cur = 1; p <= n; ++p) {
17        cur = (cur * 1ll * an) % m;
18        if (vals.count(cur)) {
19            int ans = n * p - vals[cur];
20            return ans;
21        }
22    }
23    return -1;
24 }
25
26 //When a and m are not coprime
27 // Returns minimum x for which a ^ x % m = b % m.
28 int solve(int a, int b, int m) {
29     a %= m, b %= m;
30     int k = 1, add = 0, g;
31     while ((g = gcd(a, m)) > 1) {
32         if (b == k)
33             return add;
34         if (b % g)
35             return -1;
36         b /= g, m /= g, ++add;
37         k = (k * 1ll * a / g) % m;
38     }
39
40     int n = sqrt(m) + 1;
41     int an = 1;
42     for (int i = 0; i < n; ++i)
43         an = (an * 1ll * a) % m;
44
45     unordered_map<int, int> vals;
46     for (int q = 0, cur = b; q <= n; ++q) {
47         vals[cur] = q;
48         cur = (cur * 1ll * a) % m;
49     }
50
51     for (int p = 1, cur = k; p <= n; ++p) {
52         cur = (cur * 1ll * an) % m;
53         if (vals.count(cur)) {
54             int ans = n * p - vals[cur] + add;
55             return ans;
56         }
57     }
58     return -1;
59 }

```

### 2.3 Iteration over submasks

```

1 int s = m;
2 while (s > 0) {
3     ... you can use s ...
4     s = (s-1) & m;
5 }

```

### 2.4 Totient function

```

1 void phi_1_to_n(int n) {
2     vector<int> phi(n + 1);
3     phi[0] = 0;

```

```

4  phi[1] = 1;
5  for (int i = 2; i <= n; i++)
6      phi[i] = i;
7
8  for (int i = 2; i <= n; i++) {
9      if (phi[i] == i) {
10         for (int j = i; j <= n; j += i)
11             phi[j] -= phi[j] / i;
12     }
13 }
14 }

```

## 2.5 CRT and EEGCD

```

1  ll extended(ll a, ll b, ll &x, ll &y) {
2
3      if(b == 0) {
4          x = 1;
5          y = 0;
6          return a;
7      }
8      ll x0, y0;
9      ll g = extended(b, a % b, x0, y0);
10     x = y0;
11     y = x0 - a / b * y0;
12
13     return g;
14 }
15 ll de(ll a, ll b, ll c, ll &x, ll &y) {
16
17     ll g = extended(abs(a), abs(b), x, y);
18     if(c % g) return -1;
19
20     x *= c / g;
21     y *= c / g;
22
23     if(a < 0) x = -x;
24     if(b < 0) y = -y;
25     return g;
26 }
27 pair<ll, ll> CRT(vector<ll> r, vector<ll> m) {
28
29     ll r1 = r[0], m1 = m[0];
30
31     for(int i = 1; i < r.size(); i++) {
32
33         ll r2 = r[i], m2 = m[i];
34         ll x0, y0;
35         ll g = de(m1, -m2, r2 - r1, x0, y0);
36
37         if(g == -1) return {-1, -1};
38
39         ll nr = x0 * m1 + r1;
40         ll nm = m1 / g * m2;
41
42         r1 = (nr % nm + nm) % nm;
43         m1 = nm;
44     }
45     return {r1, m1};
46 }

```

## 2.6 FFT

```

1  #include<iostream>
2  #include <bits/stdc++.h>
3  #define ll long long
4  #define ld long double
5  #define rep(i, a, b) for(int i = a; i < (b); ++i)
6  #define all(x) begin(x), end(x)
7  #define sz(x) (int)(x).size()

```

```

8  #define IO ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
9  using namespace std;
10 typedef complex<double> C;
11 typedef vector<double> vd;
12 typedef vector<int> vi;
13 typedef pair<int, int> pii;
14 void fft(vector<C>& a) {
15     int n = sz(a), L = 31 - __builtin_clz(n);
16     static vector<complex<long double>> R(2, 1);
17     static vector<C> rt(2, 1); // (~ 10% faster if double)
18     for (static int k = 2; k < n; k *= 2) {
19         R.resize(n);
20         rt.resize(n);
21         auto x = polar(1.0L, acos(-1.0L) / k);
22         rep(i, k, 2 * k) rt[i] = R[i] = i & 1 ? R[i / 2] * x : R[i / 2];
23     }
24     vi rev(n);
25     rep(i, 0, n) rev[i] = (rev[i / 2] | (i & 1) << L) / 2;
26     rep(i, 0, n) if (i < rev[i]) swap(a[i], a[rev[i]]);
27     for (int k = 1; k < n; k *= 2)
28         for (int i = 0; i < n; i += 2 * k) rep(j, 0, k) {
29             C z = rt[j + k] * a[i + j + k]; //
30             a[i + j + k] = a[i + j] - z;
31             a[i + j] += z;
32         }
33 }
34 vd conv(const vd& a, const vd& b) {
35     if (a.empty() || b.empty()) return {};
36     vd res(sz(a) + sz(b) - 1);
37     int L = 32 - __builtin_clz(sz(res)), n = 1 << L;
38     vector<C> in(n), out(n);
39     copy(all(a), begin(in));
40     rep(i, 0, sz(b)) in[i].imag(b[i]);
41     fft(in);
42     for (C& x : in) x *= x;
43     rep(i, 0, n) out[i] = in[-i & (n - 1)] - conj(in[i]);
44     fft(out);
45     rep(i, 0, sz(res)) res[i] = imag(out[i]) / (4 * n);
46     return res;
47 }
48
49 int main() {
50     IO
51     //Applications
52     //1-All possible sums
53
54     //2-All possible scalar products
55     // We are given two arrays a[] and b[] of length n.
56     //We have to compute the products of a with every cyclic shift of b.
57     //We generate two new arrays of size 2n: We reverse a and append n zeros to
58     //it.
59     //And we just append b to itself. When we multiply these two arrays as
60     //polynomials,
61     //and look at the coefficients c[n-1], c[n], ..., c[2n-2] of the product c,
62     //we get:
63     //c[k]=sum i+j=k a[i]b[j]
64
65     //3-Two stripes
66     //We are given two Boolean stripes (cyclic arrays of values 0 and 1) a and b
67     //We want to find all ways to attach the first stripe to the second one,
68     //such that at no position we have a 1 of the first stripe next to a 1 of
69     //the second stripe.

```

## 2.7 Fibonacci

```

1
2
3  // F(n-1) * F(n+1) - F(n)^2 = (-1)^n
4
5  // F(n+k) = F(k) * F(n+1) + F(k-1) * F(n)

```

```

6 // F(2*n) = F(n) * (F(n+1) + F(n-1))
7
8
9 //GCD ( F(m) , F(n) ) = F(GCD(n,m))

```

## 2.8 Gauss Determinant

```

1 const double EPS = 1E-9;
2 int n;
3 vector < vector<double> > a (n, vector<double> (n));
4
5 double det = 1;
6 for (int i=0; i<n; ++i) {
7     int k = i;
8     for (int j=i+1; j<n; ++j)
9         if (abs (a[j][i]) > abs (a[k][i]))
10             k = j;
11     if (abs (a[k][i]) < EPS) {
12         det = 0;
13         break;
14     }
15     swap (a[i], a[k]);
16     if (i != k)
17         det = -det;
18     det *= a[i][i];
19     for (int j=i+1; j<n; ++j)
20         a[i][j] /= a[i][i];
21     for (int j=0; j<n; ++j)
22         if (j != i && abs (a[j][i]) > EPS)
23             for (int k=i+1; k<n; ++k)
24                 a[j][k] -= a[i][k] * a[j][i];
25 }
26
27 cout << det;

```

## 2.9 GAUSS SLAE

```

1 const double EPS = 1e-9;
2 const int INF = 2; // it doesn't actually have to be infinity or a big number
3
4 int gauss (vector < vector<double> > a, vector<double> & ans) {
5     int n = (int) a.size();
6     int m = (int) a[0].size() - 1;
7
8     vector<int> where (m, -1);
9     for (int col = 0, row = 0; col < m && row < n; ++col) {
10         int sel = row;
11         for (int i = row; i < n; ++i)
12             if (abs (a[i][col]) > abs (a[sel][col]))
13                 sel = i;
14         if (abs (a[sel][col]) < EPS)
15             continue;
16         for (int i = col; i <= m; ++i)
17             swap (a[sel][i], a[row][i]);
18         where[col] = row;
19
20         for (int i = 0; i < n; ++i)
21             if (i != row) {
22                 double c = a[i][col] / a[row][col];
23                 for (int j = col; j <= m; ++j)
24                     a[i][j] -= a[row][j] * c;
25             }
26         ++row;
27     }
28
29     ans.assign (m, 0);
30     for (int i = 0; i < m; ++i)
31         if (where[i] != -1)
32             ans[i] = a[where[i]][m] / a[where[i]][i];

```

```

33     for (int i = 0; i < n; ++i) {
34         double sum = 0;
35         for (int j = 0; j < m; ++j)
36             sum += ans[j] * a[i][j];
37         if (abs (sum - a[i][m]) > EPS)
38             return 0;
39     }
40
41     for (int i = 0; i < m; ++i)
42         if (where[i] == -1)
43             return INF;
44     return 1;
45 }

```

## 2.10 Matrix Inverse

```

1 // Sometimes, the questions are complicated - and the answers are simple. //
2 #pragma GCC optimize ("O3")
3 #pragma GCC optimize ("unroll-loops")
4 #include <bits/stdc++.h>
5 #define ll long long
6 #define ld long double
7 #define IO ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
8 using namespace std;
9 vector < vector<double> > gauss (vector < vector<double> > a) {
10
11     int n = (int) a.size();
12     vector<vector<double> > ans(n, vector<double>(n, 0));
13
14     for(int i = 0; i < n; i++)
15         ans[i][i] = 1;
16     for(int i = 0; i < n; i++) {
17         for(int j = i + 1; j < n; j++)
18             if(a[j][i] > a[i][i]) {
19                 swap(a[j], a[i]);
20                 swap(ans[j], ans[i]);
21             }
22         double val = a[i][i];
23         for(int j = 0; j < n; j++) {
24             a[i][j] /= val;
25             ans[i][j] /= val;
26         }
27         for(int j = 0; j < n; j++) {
28             if(j == i)continue;
29             val = a[j][i];
30             for(int k = 0; k < n; k++) {
31                 a[j][k] -= val * a[i][k];
32                 ans[j][k] -= val * ans[i][k];
33             }
34         }
35     }
36     return ans;
37 }
38 int main() {
39
40     IO
41     vector<vector<double> > v(3, vector<double>(3));
42     for(int i = 0; i < 3; i++)
43         for(int j = 0; j < 3; j++)
44             cin >> v[i][j];
45
46     for(auto i : gauss(v)) {
47         for(auto j : i)
48             cout << j << " ";
49         cout << "\n";
50     }
51 }

```

## 2.11 NTT

```

1 struct NTT {
2     int mod ;
3     int root ;
4     int root_1 ;
5     int root_pw ;
6
7     NTT(int _mod, int primitive_root, int NTT_Len) {
8
9         mod = _mod;
10        root_pw = NTT_Len;
11        root = fastpower(primitive_root, (mod - 1) / root_pw);
12        root_1 = fastpower(root, mod - 2);
13    }
14    void fft(vector<int> & a, bool invert) {
15        int n = a.size();
16
17        for (int i = 1, j = 0; i < n; i++) {
18            int bit = n >> 1;
19            for (; j & bit; bit >>= 1)
20                j ^= bit;
21            j ^= bit;
22
23            if (i < j)
24                swap(a[i], a[j]);
25        }
26
27        for (int len = 2; len <= n; len <= 1) {
28            int wlen = invert ? root_1 : root;
29            for (int i = len; i < root_pw; i <= 1)
30                wlen = (int)(1LL * wlen * wlen % mod);
31
32            for (int i = 0; i < n; i += len) {
33                int w = 1;
34                for (int j = 0; j < len / 2; j++) {
35                    int u = a[i + j], v = (int)(1LL * a[i + j + len / 2] * w %
36                        mod);
37                    a[i + j] = u + v < mod ? u + v : u + v - mod;
38                    a[i + j + len / 2] = u - v >= 0 ? u - v : u - v + mod;
39                    w = (int)(1LL * w * wlen % mod);
40                }
41            }
42        }
43
44        if (invert) {
45            int n_1 = fastpower(n, mod - 2);
46            for (int & x : a)
47                x = (int)(1LL * x * n_1 % mod);
48        }
49    }
50    vector<int> multiply(vector<int> &a, vector<int> &b) {
51        vector<int> fa(a.begin(), a.end()), fb(b.begin(), b.end());
52        int n = 1;
53        while(n < a.size() + b.size())
54            n <= 1;
55
56        fa.resize(n);
57        fb.resize(n);
58
59        fft(fa, 0);
60        fft(fb, 0);
61
62        for(int i = 0; i < n; i++)
63            fa[i] = 1LL * fa[i] * fb[i] % mod;
64        fft(fa, 1);
65        return fa;
66    }
67 };

```

## 2.12 NTT of KACTL

```
1  ///(Note faster than the other NTT)
```

```

2  ///If the mod changes don't forget to calculate the primitive root
3  using ll = long long;
4  const ll mod = (119 << 23) + 1, root = 3; // = 998244353
5  // For p < 2^30 there is also e.g. 5 << 25, 7 << 26, 479 << 21
6  // and 483 << 21 (same root). The last two are > 10^9.
7  typedef vector<ll> vl;
8
9  ll modpow(ll b, ll e) {
10     ll ans = 1;
11     for (; e; b = b * b % mod, e /= 2)
12         if (e & 1) ans = ans * b % mod;
13     return ans;
14 }
15 void ntt(vl &a) {
16     int n = sz(a), L = 31 - __builtin_clz(n);
17     static vl rt(2, 1);
18     for (static int k = 2, s = 2; k < n; k *= 2, s++) {
19         rt.resize(n);
20         ll z[] = {1, modpow(root, mod >> s)};
21         f(i,k,2*k) rt[i] = rt[i / 2] * z[i & 1] % mod;
22     }
23     vector<int> rev(n);
24     f(i,0,n) rev[i] = (rev[i / 2] | (i & 1) << L) / 2;
25     f(i,0,n) if (i < rev[i]) swap(a[i], a[rev[i]]);
26     for (int k = 1; k < n; k *= 2)
27         for (int i = 0; i < n; i += 2 * k) f(j,0,k) {
28             ll z = rt[j + k] * a[i + j + k] % mod, &ai = a[i + j];
29             a[i + j + k] = ai - z + (z > ai ? mod : 0);
30             ai += (ai + z >= mod ? z - mod : z);
31         }
32 }
33 vl conv(const vl &a, const vl &b) {
34     if (a.empty() || b.empty()) return {};
35     int s = sz(a) + sz(b) - 1, B = 32 - __builtin_clz(s), n = 1 << B;
36     int inv = modpow(n, mod - 2);
37     vl L(a), R(b), out(n);
38     L.resize(n), R.resize(n);
39     ntt(L), ntt(R);
40     f(i,0,n) out[-i & (n - 1)] = (ll)L[i] * R[i] % mod * inv % mod;
41     ntt(out);
42     return {out.begin(), out.begin() + s};
43 }
44 vector<int> v;
45 vector<ll> solve(int s, int e) {
46     if(s==e) {
47         vector<ll> res(2);
48         res[0] = 1;
49         res[1] = v[s];
50         return res;
51     }
52     int md = (s + e) >> 1;
53     return conv(solve(s,md),solve(md+1,e));
54 }

```

## 3 Data Structures

### 3.1 2D BIT

```

1 void upd(int x, int y, int val) {
2     for(int i = x; i <= n; i += i & -i)
3         for(int j = y; j <= m; j += j & -j)
4             bit[i][j] += val;
5 }
6 int get(int x, int y) {
7     int ans = 0;
8     for(int i = x; i; i -= i & -i)
9         for(int j = y; j; j -= j & -j)
10             ans += bit[i][j];
11 }

```

## 3.2 2D Sparse table

```

1  /*
2   note this isn't the best cache-wise version
3   query O(1), Build O(NMlgNlgM)
4   be careful when using it and note the he build a dimension above another
5   i.e he builds a sparse table for each row
6   the build sparse table over each row's sparse table
7  */
8  const int N = 505, LG = 10;
9
10 int st[N][N][LG][LG];
11 int a[N][N], lg2[N];
12
13 int yo(int x1, int y1, int x2, int y2) {
14     x2++;
15     y2++;
16     int a = lg2[x2 - x1], b = lg2[y2 - y1];
17     return max(
18         max(st[x1][y1][a][b], st[x2 - (1 << a)][y1][a][b]),
19         max(st[x1][y2 - (1 << b)][a][b], st[x2 - (1 << a)][y2 - (1 << b)][a][b]
20     );
21 }
22
23 void build(int n, int m) { // 0 indexed
24     for (int i = 2; i < N; i++) lg2[i] = lg2[i >> 1] + 1;
25     for (int i = 0; i < n; i++) {
26         for (int j = 0; j < m; j++) {
27             st[i][j][0][0] = a[i][j];
28         }
29     }
30     for (int a = 0; a < LG; a++) {
31         for (int b = 0; b < LG; b++) {
32             if (a + b == 0) continue;
33             for (int i = 0; i + (1 << a) <= n; i++) {
34                 for (int j = 0; j + (1 << b) <= m; j++) {
35                     if (!a) {
36                         st[i][j][a][b] = max(st[i][j][a][b - 1], st[i][j + (1 << (b - 1))][a][b - 1]);
37                     } else {
38                         st[i][j][a][b] = max(st[i][j][a - 1][b], st[i + (1 << (a - 1))][j][a - 1][b]);
39                     }
40                 }
41             }
42         }
43     }
44 }

```

## 3.3 hillbert Order

```

1  ///Faster Sorting MO
2
3  const int infinity = (int)1e9 + 42;
4  const int64_t llInfinity = (int64_t)1e18 + 256;
5  const int module = (int)1e9 + 7;
6  const long double eps = 1e-8;
7
8  inline int64_t gilbertOrder(int x, int y, int pow, int rotate) {
9      if (pow == 0) {
10         return 0;
11     }
12     int hpow = 1 << (pow-1);
13     int seg = (x < hpow) ? (
14         (y < hpow) ? 0 : 3
15     ) : (
16         (y < hpow) ? 1 : 2
17     );
18     seg = (seg + rotate) & 3;

```

```

19     const int rotateDelta[4] = {3, 0, 0, 1};
20     int nx = x & (x ^ hpow), ny = y & (y ^ hpow);
21     int nrot = (rotate + rotateDelta[seg]) & 3;
22     int64_t subSquareSize = int64_t(1) << (2*pow - 2);
23     int64_t ans = seg * subSquareSize;
24     int64_t add = gilbertOrder(nx, ny, pow-1, nrot);
25     ans += (seg == 1 || seg == 2) ? add : (subSquareSize - add - 1);
26     return ans;
27 }
28
29 struct Query {
30     int l, r, idx;
31     int64_t ord;
32
33     inline void calcOrder() {
34         ord = gilbertOrder(l, r, 21, 0);
35     }
36 };
37
38 inline bool operator<(const Query &a, const Query &b) {
39     return a.ord < b.ord;
40 }
41
42 signed main() {
43     #ifndef USE_FILE_IO
44         ios_base::sync_with_stdio(false);
45     #endif
46
47     mt19937 rnd(42);
48
49     int n, m, k; cin >> n >> m; k = rnd() % 1048576;
50     vector<int> p(n+1);
51     for (int i = 0; i < n; i++) {
52         int val = rnd() % 1048576;
53         p[i+1] = p[i] ^ val;
54     }
55
56     vector<Query> qry(m);
57     for (int i = 0; i < m; i++) {
58         int l = rnd() % n + 1, r = rnd() % n + 1;
59         if (l > r) {
60             swap(l, r);
61         }
62         qry[i].l = l; qry[i].r = r;
63         qry[i].idx = i;
64         qry[i].calcOrder();
65     }
66
67     int64_t ans = 0;
68     vector<int64_t> res(m);
69     vector<int64_t> cnt((int)2e6, 0);
70     sort(qry.begin(), qry.end());
71     int l = 0, r = 1;
72     ans = (p[1] == k);
73     cnt[p[0]]++; cnt[p[1]]++;
74
75     for (Query q: qry) {
76         q.l--;
77         while (l > q.l) {
78             l--;
79             ans += cnt[p[l] ^ k];
80             cnt[p[l]]++;
81         }
82         while (r < q.r) {
83             r++;
84             ans += cnt[p[r] ^ k];
85             cnt[p[r]]++;
86         }
87         while (l < q.l) {
88             cnt[p[l]]--;
89             ans -= cnt[p[l] ^ k];
90             l++;
91         }
92         while (r > q.r) {
93             cnt[p[r]]--;

```

```

94         ans -= cnt[p[r] ^ k];
95         r--;
96     }
97     res[q.idx] = ans;
98 }
99
100 uint64_t rhsh = 0;
101 for (int i = 0; i < m; i++) {
102     rhsh *= (uint64_t)1e9 + 7;
103     rhsh += (uint64_t)res[i];
104 }
105 cout << rhsh << "\n";
106
107 return 0;
108 }

```

### 3.4 Merge Sort Bit with updates

```

1  //O(log ^ 2 N) updates and queries
2
3
4  #include <ext/pb_ds/tree_policy.hpp>
5  #include <ext/pb_ds/assoc_container.hpp>
6  #include <ext/rope>
7
8  using namespace std;
9  using namespace __gnu_pbds;
10 using namespace __gnu_cxx;
11
12 template<class T> using Tree = tree<T, null_type, less<T>, rb_tree_tag,
13     tree_order_statistics_node_update>;
14
15 Tree<int> t[N];
16
17 void add(int idx, int v){
18     for(int x = ++idx; x < N; x += x & -x){
19         t[x].insert(v);
20     }
21 }
22
23 void erase(int idx, int v){
24     for(int x = ++idx; x < N; x += x & -x){
25         t[x].erase(v);
26     }
27
28 int get(int idx, int limit){
29     int ret = 0;
30     for(int x = ++idx; x; x -= x & -x){
31         ret += (t[x].order_of_key(limit+1));
32     }
33     return ret;
34 }

```

### 3.5 Mo's

```

1  #include <bits/stdc++.h>
2
3  int n, qq, arr[N], sz = 1000; // sz is the size of the bucket
4  int co[N], ans = 0, ansq[N];
5  int cul = 1, cur = 1;
6
7  void add(int x) {
8      co[arr[x]]++;
9      if (co[arr[x]] == 1)
10         ans++;
11     else if (co[arr[x]] == 2)
12         ans--;
13 }
14
15 void remove(int x) {
16     co[arr[x]]--;

```

```

17     if (co[arr[x]] == 1)
18         ans--;
19     else if (co[arr[x]] == 0)
20         ans--;
21 }
22
23 void solve(int l, int r, int ind) {
24     r+=1;
25     while (cul < l) remove(cul++);
26     while (cul > l) add(--cul);
27     while (cur < r) add(cur++);
28     while (cur > r) remove(--cur);
29     ansq[ind] = ans;
30 }
31
32
33 int main() {
34     FIO
35     cin >> qq;
36     // {l/sz,r}, {l, ind}
37     priority_queue<pair<pair<int, int>, pair<int, int>>, vector<pair<pair<int,
38         int>, pair<int, int>>>, greater<pair<pair<int, int>, pair<int, int>>>> q;
39
40     for (int i = 0; i < qq; i++) {
41         int l, r;
42         cin >> l >> r;
43         q.push({{l / sz, r}, {l, i}});
44     }
45     while (q.size()) {
46         int ind=q.top().second.second,l=q.top().second.first,r=q.top().first.
47             second;
48         solve(l, r, ind);
49         q.pop();
50     }
51     for (int i = 0; i < qq; i++)
52         cout << ansq[i] << endl;
53
54     return 0;
55 }

```

### 3.6 Mo With Updates

```

1
2  ///O(N^5/3) note that the block size is not a standard size
3
4  #pragma GCC optimize ("O3")
5  #pragma GCC target ("sse4")
6
7  #include <bits/stdc++.h>
8
9  using namespace std;
10
11 using ll = long long;
12
13 const int N = 1e5 + 5;
14 const int M = 2 * N;
15 const int blk = 2155;
16 const int mod = 1e9 + 7;
17 struct Query{
18     int l, r, t, idx;
19     Query(int a = 0, int b = 0, int c = 0, int d = 0){l=a,r=b,t=c,idx = d;}
20     bool operator < (Query o){
21         if(r / blk == o.r / blk && l / blk == o.l / blk) return t < o.t;
22         if(r / blk == o.r / blk) return l < o.l;
23         return r < o.r;
24     }
25 } Q[N];
26
27 int a[N], b[N];
28 int cnt1[M], cnt2[N];
29 int L = 0, R = -1, K = -1;

```

```

30 void add(int x){ ///add item to range
31 // cout << x << '\n';
32 cnt2[cnt1[x]]--;
33 cnt1[x]++;
34 cnt2[cnt1[x]]++;
35 }
36 void del(int x){ ///delete item from range
37 cnt2[cnt1[x]]--;
38 cnt1[x]--;
39 cnt2[cnt1[x]]++;
40 }
41 map<int,int>id;
42 int cnt;
43 int ans[N];
44 int p[N], nxt[N];
45 int prv[N];
46 void upd(int idx){ ///update item value
47 if(p[idx] >= L && p[idx] <= R)
48 del(a[p[idx]]), add(nxt[idx]);
49 a[p[idx]] = nxt[idx];
50 }
51 void err(int idx){
52 if(p[idx] >= L && p[idx] <= R)
53 del(a[p[idx]]), add(prv[idx]);
54 a[p[idx]] = prv[idx];
55 }
56 int main(){
57
58 int n, q, l, r, tp;
59
60 scanf("%d%d", &n, &q);
61
62 for(int i = 0; i < n; i++){
63 scanf("%d", &a[i]);
64 if(id.count(a[i]) == 0)
65 id[a[i]] = cnt++;
66 a[i] = id[a[i]];
67 b[i] = a[i];
68 }
69 int qIdx = 0;
70 int ord = 0;
71 while(q--){
72
73 scanf("%d", &tp);
74 if(tp == 1){
75 /// ADD Query
76 scanf("%d%d", &l, &r); --l, --r;
77 Q[qIdx] = Query(l,r,ord-1,qIdx); qIdx++;
78 } else{
79 /// ADD Update
80 scanf("%d%d",p + ord, nxt + ord); --p[ord];
81 if(id.count(nxt[ord]) == 0)
82 id[nxt[ord]] = cnt++;
83 nxt[ord] = id[nxt[ord]];
84 prv[ord] = b[p[ord]];
85 b[p[ord]] = nxt[ord];
86 ++ord;
87 }
88 }
89 sort(Q,Q+qIdx);
90 for(int i = 0; i < qIdx; i++){
91 while(L < Q[i].l)del(a[L++]);
92 while(L > Q[i].l)add(a[--L]);
93 while(R < Q[i].r)add(a[++R]);
94 while(R > Q[i].r)del(a[R--]);
95 while(K < Q[i].t)upd(++K);
96 while(K > Q[i].t)err(K--);
97 ///Solve Query I
98 }
99
100 for(int i = 0; i < qIdx; i++)
101 printf("%d\n", ans[i]);
102
103
104 return 0;

```

105 }

### 3.7 Ordered Set

```

1 #include <ext/pb_ds/assoc_container.hpp>
2 #include <ext/pb_ds/tree_policy.hpp>
3 using namespace __gnu_pbds;
4
5 #define ordered_set tree<int, null_type,less<int>, rb_tree_tag,
6     tree_order_statistics_node_update>
7
8 // order_of_key(k): returns the number of elements in the set strictly less than
9     k
10 // find_by_order(k): returns an iterator to the k-th element (zero-based) in the
11     set

```

### 3.8 Persistent Seg Tree

```

1
2 int val[ N * 60 ], L[ N * 60 ], R[ N * 60 ], ptr, tree[N]; /// N * lgN
3 int upd(int root, int s, int e, int idx) {
4     int ret = ++ptr;
5     val[ret] = L[ret] = R[ret] = 0;
6     if (s == e) {
7         val[ret] = val[root] + 1;
8         return ret;
9     }
10    int md = (s + e) >> 1;
11    if (idx <= md) {
12        L[ret] = upd(L[root], s, md, idx), R[ret] = R[root];
13    } else {
14        R[ret] = upd(R[root], md + 1, e, idx), L[ret] = L[root];
15    }
16    val[ret] = max(val[L[ret]], val[R[ret]]);
17    return ret;
18 }
19 int qry(int node, int s, int e, int l, int r){
20     if(r < s || e < l || !node)return 0; ///Punishment Value
21     if(l <= s && e <= r){
22         return val[node];
23     }
24     int md = (s+e)>>1;
25     return max(qry(L[node], s, md, l, r), qry(R[node],md+1,e,l,r));
26 }
27 int merge(int x, int y, int s, int e) {
28     if(!x||!y)return x | y;
29     if(s == e) {
30         val[x] += val[y];
31         return x;
32     }
33     int md = (s + e) >> 1;
34     L[x] = merge(L[x], L[y], s, md);
35     R[x] = merge(R[x], R[y], md+1,e);
36     val[x] = val[L[x]] + val[R[x]];
37     return x;
38 }

```

### 3.9 Sqrt Decomposition

```

1 // Source: https://cp-algorithms.com/data_structures/sqrt_decomposition.html
2
3 // input data
4 int n;
5 vector<int> a (n);
6
7 // preprocessing

```



```

8  int len = (int) sqrt (n + .0) + 1; // size of the block and the number of blocks
9  vector<int> b (len);
10 for (int i=0; i<n; ++i)
11     b[i / len] += a[i];
12
13 // answering the queries
14 for (;;) {
15     int l, r;
16     // read input data for the next query
17     int sum = 0;
18     for (int i=l; i<=r; )
19         if (i % len == 0 && i + len - 1 <= r) {
20             // if the whole block starting at i belongs to [l, r]
21             sum += b[i / len];
22             i += len;
23         }
24         else {
25             sum += a[i];
26             ++i;
27         }
28     }
29
30 // If you're getting TLE and can't optimize more, you could reduce the number of
    slow division operations using the following code:
31
32 int sum = 0;
33 int c_l = l / len, c_r = r / len;
34 if (c_l == c_r)
35     for (int i=l; i<=r; ++i)
36         sum += a[i];
37 else {
38     for (int i=l, end=(c_l+1)*len-1; i<=end; ++i)
39         sum += a[i];
40     for (int i=c_l*len+1; i<=c_r*len-1; ++i)
41         sum += b[i];
42     for (int i=c_r*len; i<=r; ++i)
43         sum += a[i];
44 }

```

### 3.10 Treap

```

1  typedef struct item * pitem;
2  struct item {
3      int prior, value, cnt;
4      bool rev;
5      pitem l, r;
6      item(int x, int y, int z){
7          value = x;
8          prior = y;
9          cnt = z;
10         rev = 0;
11         l = r = NULL;
12     }
13 };
14
15 int cnt (pitem it) {
16     return it ? it->cnt : 0;
17 }
18
19 void upd_cnt (pitem it) {
20     if (it)
21         it->cnt = cnt(it->l) + cnt(it->r) + 1;
22 }
23
24 void push (pitem it) {
25     if (it && it->rev) {
26         it->rev = false;
27         swap (it->l, it->r);
28         if (it->l) it->l->rev ^= true;
29         if (it->r) it->r->rev ^= true;
30     }
31 }

```

```

32
33 void merge (pitem & t, pitem l, pitem r) {
34     push (l);
35     push (r);
36     if (!l || !r)
37         t = l ? l : r;
38     else if (l->prior > r->prior)
39         merge (l->r, l->r, r), t = l;
40     else
41         merge (r->l, l, r->l), t = r;
42     upd_cnt (t);
43 }
44
45 void split (pitem t, pitem & l, pitem & r, int key, int add = 0) {
46     if (!t)
47         return void( l = r = 0 );
48     push (t);
49     int cur_key = add + cnt(t->l);
50     if (key <= cur_key)
51         split (t->l, l, t->l, key, add), r = t;
52     else
53         split (t->r, t->r, r, key, add + 1 + cnt(t->l)), l = t;
54     upd_cnt (t);
55 }
56
57 void reverse (pitem t, int l, int r) {
58     pitem t1, t2, t3;
59     split (t, t1, t2, l);
60     split (t2, t2, t3, r-1+1);
61     t2->rev ^= true;
62     merge (t, t1, t2);
63     merge (t, t, t3);
64 }
65
66 void output (pitem t) {
67     if (!t) return;
68     push (t);
69     output (t->l);
70     printf ("%c", char(t->value));
71     output (t->r);
72 }
73
74 pitem gettreap(string s){
75     pitem ret=NULL;
76     int i;
77     for(i=0;i<s.size();i++)merge(ret,ret,new item(s[i],(rand()<<15)+rand(),
78         1));
79     return ret;

```

### 3.11 Wavelet Tree

```

1  // remember your array and values must be 1-based
2  struct wavelet_tree {
3      int lo, hi;
4      wavelet_tree *l, *r;
5      vector<int> b;
6
7      //nos are in range [x,y]
8      //array indices are [from, to]
9      wavelet_tree(int *from, int *to, int x, int y) {
10         lo = x, hi = y;
11         if (lo == hi or from >= to)
12             return;
13         int mid = (lo + hi) / 2;
14         auto f = [mid](int x) {
15             return x <= mid;
16         };
17         b.reserve(to - from + 1);
18         b.pb(0);
19         for (auto it = from; it != to; it++)
20             b.pb(b.back() + f(*it));

```

```

21 //see how lambda function is used here
22 auto pivot = stable_partition(from, to, f);
23 l = new wavelet_tree(from, pivot, lo, mid);
24 r = new wavelet_tree(pivot, to, mid + 1, hi);
25 }
26
27 //kth smallest element in [l, r]
28 int kth(int l, int r, int k) {
29     if (l > r)
30         return 0;
31     if (lo == hi)
32         return lo;
33     int inLeft = b[r] - b[l - 1];
34     int lb = b[l - 1]; //amt of nos in first (l-1) nos that go in left
35     int rb = b[r]; //amt of nos in first (r) nos that go in left
36     if (k <= inLeft)
37         return this->l->kth(lb + 1, rb, k);
38     return this->r->kth(l - lb, r - rb, k - inLeft);
39 }
40
41 //count of nos in [l, r] Less than or equal to k
42 int LTE(int l, int r, int k) {
43     if (l > r or k < lo)
44         return 0;
45     if (hi <= k)
46         return r - l + 1;
47     int lb = b[l - 1], rb = b[r];
48     return this->l->LTE(lb + 1, rb, k) + this->r->LTE(l - lb, r - rb, k);
49 }
50
51 //count of nos in [l, r] equal to k
52 int count(int l, int r, int k) {
53     if (l > r or k < lo or k > hi)
54         return 0;
55     if (lo == hi)
56         return r - l + 1;
57     int lb = b[l - 1], rb = b[r], mid = (lo + hi) / 2;
58     if (k <= mid)
59         return this->l->count(lb + 1, rb, k);
60     return this->r->count(l - lb, r - rb, k);
61 }
62 };

```

## 4 DP

### 4.1 Dynamic Convex Hull Trick

```

1 #include<iostream>
2 #include <bits/stdc++.h>
3 #define ll long long
4 #define ld long double
5 #define IO ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
6 using namespace std;
7 struct Line
8 {
9     ll m, b;
10     mutable function<const Line*> succ;
11     bool operator<(const Line& other) const
12     {
13         return m < other.m;
14     }
15     bool operator<(const ll &x) const
16     {
17         const Line* s = succ();
18         if (!s)
19             return 0;
20         return b - s->b < (s->m - m) * x;
21     }
22 };
23 // will maintain upper hull for maximum

```

```

24 struct HullDynamic : public multiset<Line, less<>>
25 {
26     bool bad(iterator y)
27     {
28         auto z = next(y);
29         if (y == begin())
30         {
31             if (z == end())
32                 return 0;
33             return y->m == z->m && y->b <= z->b;
34         }
35         auto x = prev(y);
36         if (z == end())
37             return y->m == x->m && y->b <= x->b;
38         return (ld) (x->b - y->b) * (z->m - y->m) >= (ld) (y->b - z->b) * (y->m - x->m);
39     }
40     void insert_line(ll m, ll b)
41     {
42         auto y = insert({ m, b });
43         y->succ = [=] { return next(y) == end() ? 0 : &*next(y); };
44         if (bad(y))
45         {
46             erase(y);
47             return;
48         }
49         while (next(y) != end() && bad(next(y)))
50             erase(next(y));
51         while (y != begin() && bad(prev(y)))
52             erase(prev(y));
53     }
54     ll query(ll x)
55     {
56         auto l = *lower_bound(x);
57         return l.m * x + l.b;
58     }
59 };
60
61 int main()
62 {
63     IO
64 }

```

### 4.2 Dynamic Connectivity with SegTree

```

1 /// MANGA
2 #pragma GCC optimize("O3")
3 #pragma GCC optimize ("unroll-loops")
4 #pragma GCC target ("avx,avx2,fma")
5 using namespace std;
6
7 #include "bits/stdc++.h"
8
9 #define pb push_back
10 #define F first
11 #define S second
12 #define f(i, a, b) for(int i = a; i < b; i++)
13 #define all(a) a.begin(),a.end()
14 #define rall(a) a.rbegin(),a.rend()
15 #define sz(x) (int)(x).size()
16 //#define mp make_pair
17 #define popCnt(x) (__builtin_popcountll(x))
18 typedef long long ll;
19 typedef pair<int, int> ii;
20 using ull = unsigned long long;
21 const int N = 1e5+5, LG = 17, MOD = 1e9 + 7;
22 const long double PI = acos(-1);
23 struct PT{
24     ll x, y;
25     PT() {}

```

```

26     PT(ll a, ll b):x(a), y(b){}
27     PT operator - (const PT & o) {return PT{x-o.x,y-o.y};}
28     bool operator < (const PT & o) const {return make_pair(x,y) < make_pair(o.x,
29         o.y);}
30 }
31 ll cross(PT x, PT y) {
32     return x.x * y.y - x.y * y.x;
33 }
34 PT val[300005];
35 bool in[300005];
36 bool ask[300005];
37 ll ans[N];
38 vector<PT> t[300005 * 4]; //segment tree holding points to queries
39 void update(int node, int s, int e, int l, int r, PT x) {
40     if(r < s || e < l) return;
41     if(l <= s && e <= r) { //add this point to maximize it with queries in
42         this range
43         t[node].pb(x);
44         return;
45     }
46     int md = (s + e) >> 1;
47     update(node<<1,s,md,l,r,x);
48     update(node<<1|1,md+1,e,l,r,x);
49 }
50 vector<PT> stk;
51 inline void addPts(vector<PT> v) {
52     stk.clear(); //reset the data structure you are using
53     sort(all(v));
54     //build upper envelope
55     for(int i = 0; i < v.size(); i++) {
56         while(sz(stk) > 1 && cross(v[i] - stk.back(), stk.back() - stk[stk.size
57             ()-2]) <= 0)
58             stk.pop_back();
59         stk.push_back(v[i]);
60     }
61 }
62 inline ll calc(PT x, ll val) {
63     //mb+y
64     return x.x * val + x.y;
65 }
66 ll query(ll x) {
67     if(stk.empty())
68         return LLONG_MIN;
69     int lo = 0, hi = stk.size() - 1;
70     while(lo + 10 < hi) {
71         int md = lo + (hi-lo) / 2;
72         if(calc(stk[md+1],x) > calc(stk[md],x))
73             lo = md + 1;
74         else
75             hi = md;
76     }
77     ll ans = LLONG_MIN;
78     for(int i = lo; i <= hi; i++)
79         ans = max(ans, calc(stk[i], x));
80     return ans;
81 }
82 void solve(int node, int s, int e) { //Solve queries
83     addPts(t[node]); //note that there is no need to add/delete just build
84     for t[node]
85         f(i,s,e+1){
86             if(ask[i]) {
87                 ans[i] = max(ans[i], query(qr[i]));
88             }
89             if(s==e) return;
90             int md = (s + e) >> 1;
91             solve(node<<1,s,md);
92             solve(node<<1|1,md+1,e);
93 }
94 void doWork() {
95     int n;

```

```

96     cin >> n;
97     stk.reserve(n);
98     f(i,1,n+1) {
99         int tp;
100         cin >> tp;
101         if(tp == 1) { //Add Query
102             int x, y;
103             cin >> x >> y;
104             val[i] = PT(x, y);
105             in[i] = 1;
106         } else if(tp == 2) { //Delete Query
107             int x;
108             cin >> x;
109             if(in[x]) update(1, 1, n, x, i - 1, val[x]);
110             in[x] = 0;
111         } else {
112             cin >> qr[i];
113             ask[i] = true;
114         }
115     }
116     f(i,1,n+1) //Finalize Query
117         if(in[i])
118             update(1, 1, n, i, n, val[i]);
119 }
120 f(i,1,n+1) ans[i] = LLONG_MIN;
121 solve(1, 1, n);
122 f(i,1,n+1)
123 if(ask[i]) {
124     if(ans[i] == LLONG_MIN)
125         cout << "EMPTY SET\n";
126     else
127         cout << ans[i] << '\n';
128 }
129 }
130 }
131 int32_t main() {
132     #ifdef ONLINE_JUDGE
133         ios_base::sync_with_stdio(0);
134         cin.tie(0);
135     #endif // ONLINE_JUDGE
136     int t = 1;
137     // cin >> t;
138     while (t--) {
139         doWork();
140     }
141     return 0;
142 }

```

### 4.3 Li Chao Tree

```

1  #include<iostream>
2  #include <bits/stdc++.h>
3  #define ll long long
4  #define ld long double
5  #define IO ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
6  using namespace std;
7  struct Line
8  {
9      ll m, b;
10     Line(ll m, ll b) : m(m), b(b) {}
11     ll operator()(ll x)
12     {
13         return m * x + b;
14     }
15 };
16 struct node
17 {
18     node * left,* right ;
19     Line line ;
20     node(node * left, node *right, Line line):left(left), right(right), line(
21         line) {}
22     node * getLeft()

```

```

22 {
23     if(left==NULL)
24         left= new node (NULL,NULL,Line(0,1e18)) ;
25     return left ;
26 }
27 node * getright ()
28 {
29     if(right==NULL)
30         right= new node (NULL,NULL,Line(0,1e18)) ;
31     return right ;
32 }
33 void insert(Line newline, int l, int r)
34 {
35     int m=(l+r)/2;
36     bool lef=newline(l)<line(l);
37     bool mid=newline(m)<line(m);
38
39     if(mid)
40         swap(line,newline);
41     if(r-l==1)
42         return ;
43     else if(lef!=mid)
44         getLeft()->insert(newline,l,m);
45     else
46         getright()->insert(newline,m,r);
47 }
48 ll query(int x, int l, int r)
49 {
50     int m = (l + r) / 2;
51     if(r - l == 1)
52         return line(x);
53     else if(x < m)
54         return min(line(x), getLeft()->query(x, l, m));
55     else
56         return min(line(x), getright()->query(x, m, r));
57 }
58 void deletee()
59 {
60     if(left!=NULL)
61         left->deletee();
62     if(right!=NULL)
63         right->deletee();
64     free(this);
65 }
66 };
67 int main()
68 {
69     IO
70     node * root = new node(NULL,NULL,Line(0,5));
71     root->insert(Line(1,-3),1,100);
72
73     for(int i=1; i<=10; i++)
74         cout<<root->query(i,1,100)<<"\n";
75 }

```

## 4.4 CHT Line Container

```

1 struct Line
2 {
3     mutable ll m, b, p;
4     bool operator<(const Line& o) const
5     {
6         return m < o.m;
7     }
8     bool operator<(ll x) const
9     {
10         return p < x;
11     }
12 };
13
14 struct LineContainer : multiset<Line, less<>>
15 {

```

```

16 // (for doubles, use inf = 1/.0, div(a,b) = a/b)
17 static const ll inf = LLONG_MAX;
18 ll div(ll db, ll dm) // floored division
19 {
20     return db / dm - ((db ^ dm) < 0 && db % dm);
21 }
22 bool isect(iterator x, iterator y)
23 {
24     if (y == end())
25     {
26         x->p = inf;
27         return false;
28     }
29     if (x->m == y->m)
30         x->p = x->b > y->b ? inf : -inf;
31     else
32         x->p = div(y->b - x->b, x->m - y->m);
33     return x->p >= y->p;
34 }
35 void add(ll m, ll b)
36 {
37     auto z = insert({m, b, 0}), y = z++, x = y;
38     while (isect(y, z))
39         z = erase(z);
40     if (x != begin() && isect(--x, y))
41         isect(x, y = erase(y));
42     while ((y = x) != begin() && (--x)->p >= y->p)
43         isect(x, erase(y));
44 }
45 ll query(ll x)
46 {
47     assert(!empty());
48     auto l = *lower_bound(x);
49     return l.m * x + l.b;
50 }
51 };

```

## 5 Geometry

### 5.1 Convex Hull

```

1 struct point {
2     ll x, y;
3     point(ll x, ll y) : x(x), y(y) {}
4     point operator -(point other) {
5         return point(x - other.x, y - other.y);
6     }
7     bool operator <(const point &other) const {
8         return x != other.x ? x < other.x : y < other.y;
9     }
10 };
11 ll cross(point a, point b) {
12     return a.x * b.y - a.y * b.x;
13 }
14 ll dot(point a, point b) {
15     return a.x * b.x + a.y * b.y;
16 }
17 struct sortCCW {
18     point center;
19
20     sortCCW(point center) : center(center) {}
21
22     bool operator() (point a, point b) {
23         ll res = cross(a - center, b - center);
24         if(res)
25             return res > 0;
26         return dot(a - center, a - center) < dot(b - center, b - center);
27     }
28 };
29 vector<point> hull(vector<point> v) {

```

```

30     sort(v.begin(), v.end());
31     sort(v.begin() + 1, v.end(), sortCCW(v[0]));
32     v.push_back(v[0]);
33     vector<point> ans;
34     for(auto i : v) {
35         int sz = ans.size();
36         while(sz > 1 && cross(i - ans[sz - 1], ans[sz - 2] - ans[sz - 1]) <= 0)
37             ans.pop_back(), sz--;
38         ans.push_back(i);
39     }
40     ans.pop_back();
41     return ans;
42 }

```

## 5.2 Geometry Template

```

1  using ptype = double edit this first;
2  double EPS = 1e-9;
3  struct point {
4
5      ptype x, y;
6      point(ptype x, ptype y) : x(x), y(y) {}
7
8      point operator -(const point & other) const {
9          return point(x - other.x, y - other.y);
10     }
11
12     point operator +(const point & other) const {
13         return point(x + other.x, y + other.y);
14     }
15
16     point operator *(ptype c) const {
17         return point(x * c, y * c);
18     }
19
20     point operator /(ptype c) const {
21         return point(x / c, y / c);
22     }
23     point prep() {
24         return point(-y, x);
25     }
26 };
27
28 ptype cross(point a, point b) {
29     return a.x * b.y - a.y * b.x;
30 }
31
32 ptype dot(point a, point b) {
33     return a.x * b.x + a.y * b.y;
34 }
35
36 double abs(point a) {
37     return sqrt(dot(a, a));
38 }
39
40 // angle between [0, pi]
41 double angle (point a, point b) {
42     return acos(dot(a, b) / abs(a) / abs(b));
43 }
44
45 // a : point in Line
46 // d : Line direction
47 point LineLineIntersect(point a1, point d1, point a2, point d2) {
48     return a1 + d1 * cross(a2 - a1, d2) / cross(d1, d2);
49 }
50
51 // Line a---b
52 // point C
53 point ProjectPointLine(point a, point b, point c) {
54     return a + (b - a) * 1.0 * dot(c - a, b - a) / dot(b - a, b - a);
55 }
56
57 // segment a---b
58 // point C
59 point ProjectPointSegment(point a, point b, point c) {
60     double r = dot(c - a, b - a) / dot(b - a, b - a);
61     if(r < 0)

```

```

57     return a;
58     if(r > 1)
59         return b;
60     return a + (b - a) * r;
61 }
62 // Line a---b
63 // point p
64 point reflectAroundLine(point a, point b, point p) {
65     // (proj-p) * 2 + p
66     return ProjectPointLine(a, b, p) * 2 - p;
67 }
68 // Around origin
69 point RotateCCW(point p, double t) {
70     return point(p.x * cos(t) - p.y * sin(t),
71                 p.x * sin(t) + p.y * cos(t));
72 }
73 // Line a---b
74 vector<point> CircleLineIntersect(point a, point b, point center, double r) {
75     a = a - center;
76     b = b - center;
77     point p = ProjectPointLine(a, b, point(0, 0)); // project point from center
78     // to the Line
79     if(dot(p, p) > r * r)
80         return {};
81     double len = sqrt(r * r - dot(p, p));
82     if(len < EPS)
83         return {center + p};
84
85     point d = (a - b) / abs(a - b);
86     return {center + p + d * len, center + p - d * len};
87 }
88
89 vector<point> CircleCircleIntersect(point c1, double r1, point c2, double r2) {
90     if(r1 < r2) {
91         swap(r1, r2);
92         swap(c1, c2);
93     }
94     double d = abs(c1 - c2); // distance between c1, c2
95     if(d > r1 + r2 || d < r1 - r2)
96         return {};
97     double angle = acos(min((d * d + r1 * r1 - r2 * r2) / (2 * r1 * d), 1.0));
98     point p = (c2 - c1) / d * r1;
99
100     if(angle < EPS)
101         return {p};
102
103     return {RotateCCW(p, angle), RotateCCW(p, -angle)};
104 }
105
106 point circumcircle(point p1, point p2, point p3) {
107     return LineLineIntersect((p1 + p2) / 2, (p1 - p2).prep(),
108                             (p1 + p3) / 2, (p1 - p3).prep());
109 }
110
111 // S : Area.
112 // I : number points with integer coordinates lying strictly inside the polygon.
113 // B : number of points lying on polygon sides by B.
114 // S = I + B/2 - 1

```

## 5.3 Half Plane Intersection

```

1  // Redefine epsilon and infinity as necessary. Be mindful of precision errors.
2  const long double eps = 1e-9, inf = 1e9;
3
4  // Basic point/vector struct.
5  struct Point {
6
7      long double x, y;
8      explicit Point(long double x = 0, long double y = 0) : x(x), y(y) {}
9
10     // Addition, subtraction, multiply by constant, cross product.

```

```

11
12 friend Point operator + (const Point& p, const Point& q) {
13     return Point(p.x + q.x, p.y + q.y);
14 }
15
16 friend Point operator - (const Point& p, const Point& q) {
17     return Point(p.x - q.x, p.y - q.y);
18 }
19
20 friend Point operator * (const Point& p, const long double& k) {
21     return Point(p.x * k, p.y * k);
22 }
23
24 friend long double cross(const Point& p, const Point& q) {
25     return p.x * q.y - p.y * q.x;
26 }
27 };
28
29 // Basic half-plane struct.
30 struct Halfplane {
31
32     // 'p' is a passing point of the line and 'pq' is the direction vector of
33     // the line.
34     Point p, pq;
35     long double angle;
36
37     Halfplane() {}
38     Halfplane(const Point& a, const Point& b) : p(a), pq(b - a) {
39         angle = atan2l(pq.y, pq.x);
40     }
41
42     // Check if point 'r' is outside this half-plane.
43     // Every half-plane allows the region to the LEFT of its line.
44     bool out(const Point& r) {
45         return cross(pq, r - p) < -eps;
46     }
47
48     // Comparator for sorting.
49     // If the angle of both half-planes is equal, the leftmost one should go
50     // first.
51     bool operator < (const Halfplane& e) const {
52         if (fabsl(angle - e.angle) < eps) return cross(pq, e.p - p) < 0;
53         return angle < e.angle;
54     }
55
56     // We use equal comparator for std::unique to easily remove parallel half-
57     // planes.
58     bool operator == (const Halfplane& e) const {
59         return fabsl(angle - e.angle) < eps;
60     }
61
62     // Intersection point of the lines of two half-planes. It is assumed they're
63     // never parallel.
64     friend Point inter(const Halfplane& s, const Halfplane& t) {
65         long double alpha = cross((t.p - s.p), t.pq) / cross(s.pq, t.pq);
66         return s.p + (s.pq * alpha);
67     }
68 };
69
70 // Actual algorithm
71 vector<Point> hp_intersect(vector<Halfplane>& H) {
72
73     Point box[4] = { // Bounding box in CCW order
74         Point(-inf, -inf),
75         Point(inf, -inf),
76         Point(inf, inf),
77         Point(-inf, inf),
78     };
79
80     for(int i = 0; i < 4; i++) { // Add bounding box half-planes.
81         Halfplane aux(box[i], box[(i+1) % 4]);
82         H.push_back(aux);
83     }

```

```

82
83 // Sort and remove duplicates
84 sort(H.begin(), H.end());
85 H.erase(unique(H.begin(), H.end(), H.end()), H.end());
86
87 deque<Halfplane> dq;
88 int len = 0;
89 for(int i = 0; i < int(H.size()); i++) {
90
91     // Remove from the back of the deque while last half-plane is redundant
92     while (len > 1 && H[i].out(inter(dq[len-1], dq[len-2]))) {
93         dq.pop_back();
94         --len;
95     }
96
97     // Remove from the front of the deque while first half-plane is
98     // redundant
99     while (len > 1 && H[i].out(inter(dq[0], dq[1]))) {
100         dq.pop_front();
101         --len;
102     }
103
104     // Add new half-plane
105     dq.push_back(H[i]);
106     ++len;
107 }
108
109 // Final cleanup: Check half-planes at the front against the back and vice-
110 // versa
111 while (len > 2 && dq[0].out(inter(dq[len-1], dq[len-2]))) {
112     dq.pop_back();
113     --len;
114 }
115
116 while (len > 2 && dq[len-1].out(inter(dq[0], dq[1]))) {
117     dq.pop_front();
118     --len;
119 }
120
121 // Report empty intersection if necessary
122 if (len < 3) return vector<Point>();
123
124 // Reconstruct the convex polygon from the remaining half-planes.
125 vector<Point> ret(len);
126 for(int i = 0; i+1 < len; i++) {
127     ret[i] = inter(dq[i], dq[i+1]);
128 }
129 ret.back() = inter(dq[len-1], dq[0]);
130 return ret;

```

## 5.4 Segments Intersection

```

1 const double EPS = 1E-9;
2
3 struct pt {
4     double x, y;
5 };
6
7 struct seg {
8     pt p, q;
9     int id;
10
11     double get_y(double x) const {
12         if (abs(p.x - q.x) < EPS)
13             return p.y;
14         return p.y + (q.y - p.y) * (x - p.x) / (q.x - p.x);
15     }
16 };
17
18 bool intersectld(double l1, double r1, double l2, double r2) {
19     if (l1 > r1)

```

```

20     swap(l1, r1);
21     if (l2 > r2)
22         swap(l2, r2);
23     return max(l1, l2) <= min(r1, r2) + EPS;
24 }
25
26 int vec(const pt& a, const pt& b, const pt& c) {
27     double s = (b.x - a.x) * (c.y - a.y) - (b.y - a.y) * (c.x - a.x);
28     return abs(s) < EPS ? 0 : s > 0 ? +1 : -1;
29 }
30
31 bool intersect(const seg& a, const seg& b)
32 {
33     return intersectld(a.p.x, a.q.x, b.p.x, b.q.x) &&
34         intersectld(a.p.y, a.q.y, b.p.y, b.q.y) &&
35         vec(a.p, a.q, b.p) * vec(a.p, a.q, b.q) <= 0 &&
36         vec(b.p, b.q, a.p) * vec(b.p, b.q, a.q) <= 0;
37 }
38
39 bool operator<(const seg& a, const seg& b)
40 {
41     double x = max(min(a.p.x, a.q.x), min(b.p.x, b.q.x));
42     return a.get_y(x) < b.get_y(x) - EPS;
43 }
44
45 struct event {
46     double x;
47     int tp, id;
48
49     event() {}
50     event(double x, int tp, int id) : x(x), tp(tp), id(id) {}
51
52     bool operator<(const event& e) const {
53         if (abs(x - e.x) > EPS)
54             return x < e.x;
55         return tp > e.tp;
56     }
57 };
58
59 set<seg> s;
60 vector<set<seg>::iterator> where;
61
62 set<seg>::iterator prev(set<seg>::iterator it) {
63     return it == s.begin() ? s.end() : --it;
64 }
65
66 set<seg>::iterator next(set<seg>::iterator it) {
67     return ++it;
68 }
69
70 pair<int, int> solve(const vector<seg>& a) {
71     int n = (int)a.size();
72     vector<event> e;
73     for (int i = 0; i < n; ++i) {
74         e.push_back(event(min(a[i].p.x, a[i].q.x), +1, i));
75         e.push_back(event(max(a[i].p.x, a[i].q.x), -1, i));
76     }
77     sort(e.begin(), e.end());
78
79     s.clear();
80     where.resize(a.size());
81     for (size_t i = 0; i < e.size(); ++i) {
82         int id = e[i].id;
83         if (e[i].tp == +1) {
84             set<seg>::iterator nxt = s.lower_bound(a[id]), prv = prev(nxt);
85             if (nxt != s.end() && intersect(*nxt, a[id]))
86                 return make_pair(nxt->id, id);
87             if (prv != s.end() && intersect(*prv, a[id]))
88                 return make_pair(prv->id, id);
89             where[id] = s.insert(nxt, a[id]);
90         } else {
91             set<seg>::iterator nxt = next(where[id]), prv = prev(where[id]);
92             if (nxt != s.end() && prv != s.end() && intersect(*nxt, *prv))
93                 return make_pair(prv->id, nxt->id);
94             s.erase(where[id]);

```

```

95     }
96 }
97
98     return make_pair(-1, -1);
99 }

```

---

## 5.5 Rectangles Union

```

1  #include<bits/stdc++.h>
2  #define P(x,y) make_pair(x,y)
3  using namespace std;
4  class Rectangle {
5  public:
6      int x1, y1, x2, y2;
7      static Rectangle empty;
8      Rectangle() {
9          x1 = y1 = x2 = y2 = 0;
10     }
11     Rectangle(int X1, int Y1, int X2, int Y2) {
12         x1 = X1;
13         y1 = Y1;
14         x2 = X2;
15         y2 = Y2;
16     }
17 };
18 struct Event {
19     int x, y1, y2, type;
20     Event() {}
21     Event(int x, int y1, int y2, int type) : x(x), y1(y1), y2(y2), type(type) {}
22 };
23 bool operator < (const Event&A, const Event&B) {
24     //if(A.x != B.x)
25     return A.x < B.x;
26     //if(A.y1 != B.y1) return A.y1 < B.y1;
27     //if(A.y2 != B.y2()) A.y2 < B.y2;
28 }
29 const int MX = (1 << 17);
30 struct Node {
31     int prob, sum, ans;
32     Node() {}
33     Node(int prob, int sum, int ans) : prob(prob), sum(sum), ans(ans) {}
34 };
35 Node tree[MX * 4];
36 int interval[MX];
37 void build(int x, int a, int b) {
38     tree[x] = Node(0, 0, 0);
39     if(a == b) {
40         tree[x].sum += interval[a];
41         return;
42     }
43     build(x * 2, a, (a + b) / 2);
44     build(x * 2 + 1, (a + b) / 2 + 1, b);
45     tree[x].sum = tree[x * 2].sum + tree[x * 2 + 1].sum;
46 }
47 int ask(int x) {
48     if(tree[x].prob)
49         return tree[x].sum;
50     return tree[x].ans;
51 }
52 int st, en, V;
53 void update(int x, int a, int b) {
54     if(st > b || en < a)
55         return;
56     if(a >= st && b <= en) {
57         tree[x].prob += V;
58         return;
59     }
60     update(x * 2, a, (a + b) / 2);
61     update(x * 2 + 1, (a + b) / 2 + 1, b);
62     tree[x].ans = ask(x * 2) + ask(x * 2 + 1);
63 }
64 Rectangle Rectangle::empty = Rectangle();

```

```

65 vector < Rectangle > Rect;
66 vector < int > sorted;
67 vector < Event > sweep;
68 void compressncalc() {
69     sweep.clear();
70     sorted.clear();
71     for(auto R : Rect) {
72         sorted.push_back(R.y1);
73         sorted.push_back(R.y2);
74     }
75     sort(sorted.begin(), sorted.end());
76     sorted.erase(unique(sorted.begin(), sorted.end(), sorted.end()), sorted.end());
77     int sz = sorted.size();
78     for(int j = 0; j < sorted.size() - 1; j++)
79         interval[j + 1] = sorted[j + 1] - sorted[j];
80     for(auto R : Rect) {
81         sweep.push_back(Event(R.x1, R.y1, R.y2, 1));
82         sweep.push_back(Event(R.x2, R.y1, R.y2, -1));
83     }
84     sort(sweep.begin(), sweep.end());
85     build(1, 1, sz - 1);
86 }
87 long long ans;
88 void Sweep() {
89     ans = 0;
90     if(sorted.empty() || sweep.empty())
91         return;
92     int last = 0, sz_ = sorted.size();
93     for(int j = 0; j < sweep.size(); j++) {
94         ans += 1ll * (sweep[j].x - last) * ask(1);
95         last = sweep[j].x;
96         V = sweep[j].type;
97         st = lower_bound(sorted.begin(), sorted.end(), sweep[j].y1) - sorted.
            begin() + 1;
98         en = lower_bound(sorted.begin(), sorted.end(), sweep[j].y2) - sorted.
            begin();
99         update(1, 1, sz_ - 1);
100     }
101 }
102 int main() {
103     // freopen("in.in", "r", stdin);
104     int n;
105     scanf("%d", &n);
106     for(int j = 1; j <= n; j++) {
107         int a, b, c, d;
108         scanf("%d %d %d %d", &a, &b, &c, &d);
109         Rect.push_back(Rectangle(a, b, c, d));
110     }
111     compressncalc();
112     Sweep();
113     cout << ans << endl;
114 }

```

## 6 Graphs

### 6.1 2 SAD

```

1 /**
2  * Author: Emil Lenngren, Simon Lindholm
3  * Date: 2011-11-29
4  * License: CC0
5  * Source: folklore
6  * Description: Calculates a valid assignment to boolean variables a, b, c,...
   to a 2-SAT problem, so that an expression of the type $(a\|\b)\&\&(!a\|\
   c)\&\&(d\|\b)\&\&...$ becomes true, or reports that it is unsatisfiable.
7  * Negated variables are represented by bit-inversions (\texttt{\tilde{x}}).
8  * Usage:
9  * TwoSat ts(number of boolean variables);
10  * ts.either(0, \tilde{3}); // Var 0 is true or var 3 is false
11  * ts.setValue(2); // Var 2 is true

```

```

12 * ts.atMostOne({0,\tilde{1},2}); // <= 1 of vars 0, \tilde{1} and 2 are true
13 * ts.solve(); // Returns true iff it is solvable
14 * ts.values[0..N-1] holds the assigned values to the vars
15 * Time: O(N+E), where N is the number of boolean variables, and E is the number
   of clauses.
16 * Status: stress-tested
17 */
18 #pragma once
19
20 struct TwoSat {
21     int N;
22     vector<vi> gr;
23     vi values; // 0 = false, 1 = true
24
25     TwoSat(int n = 0) : N(n), gr(2*n) {}
26
27     int addVar() { // (optional)
28         gr.emplace_back();
29         gr.emplace_back();
30         return N++;
31     }
32
33     void either(int f, int j) {
34         f = max(2*f, -1-2*f);
35         j = max(2*j, -1-2*j);
36         gr[f].push_back(j^1);
37         gr[j].push_back(f^1);
38     }
39     void setValue(int x) { either(x, x); }
40
41     void atMostOne(const vi& li) { // (optional)
42         if (sz(li) <= 1) return;
43         int cur = ~li[0];
44         rep(i, 2, sz(li)) {
45             int next = addVar();
46             either(cur, ~li[i]);
47             either(cur, next);
48             either(~li[i], next);
49             cur = ~next;
50         }
51         either(cur, ~li[1]);
52     }
53
54     vi val, comp, z; int time = 0;
55     int dfs(int i) {
56         int low = val[i] = ++time, x; z.push_back(i);
57         for(int e : gr[i]) if (!comp[e])
58             low = min(low, val[e] ?: dfs(e));
59         if (low == val[i]) do {
60             x = z.back(); z.pop_back();
61             comp[x] = low;
62             if (values[x>>1] == -1)
63                 values[x>>1] = x&1;
64         } while (x != i);
65         return val[i] = low;
66     }
67
68     bool solve() {
69         values.assign(N, -1);
70         val.assign(2*N, 0); comp = val;
71         rep(i, 0, 2*N) if (!comp[i]) dfs(i);
72         rep(i, 0, N) if (comp[2*i] == comp[2*i+1]) return 0;
73         return 1;
74     }
75 };

```

### 6.2 Articulation Point

```

1 vector<int> adj[N];
2 int dfsn[N], low[N], instack[N], ar_point[N], timer;
3 stack<int> st;
4

```



```

5 void dfs(int node, int par){
6     dfsn[node] = low[node] = ++timer;
7     int kam = 0;
8     for(auto i: adj[node]){
9         if(i == par) continue;
10        if(dfsn[i] == 0){
11            kam++;
12            dfs(i, node);
13            low[node] = min(low[node], low[i]);
14            if(dfsn[node] <= low[i] && par != 0) ar_point[node] = 1;
15        }
16        else low[node] = min(low[node], dfsn[i]);
17    }
18    if(par == 0 && kam > 1) ar_point[node] = 1;
19 }
20
21 void init(int n){
22     for(int i = 1; i <= n; i++){
23         adj[i].clear();
24         low[i] = dfsn[i] = 0;
25         instack[i] = 0;
26         ar_point[i] = 0;
27     }
28     timer = 0;
29 }
30
31 int main(){
32     int tt;
33     cin >> tt;
34     while(tt--){
35         // Input
36         init(n);
37         for(int i = 1; i <= n; i++){
38             if(dfsn[i] == 0) dfs(i, 0);
39         }
40         int c = 0;
41         for(int i = 1; i <= n; i++){
42             if(ar_point[i]) c++;
43         }
44         cout << c << '\n';
45     }
46     return 0;
47 }

```

### 6.3 Bridges Tree and Diameter

```

1 #include <bits/stdc++.h>
2 #define ll long long
3 using namespace std;
4 const int N = 3e5 + 5, mod = 1e9 + 7;
5
6 vector<int> adj[N], bridge_tree[N];
7 int dfsn[N], low[N], cost[N], timer, cnt, comp_id[N], kam[N], ans;
8 stack<int> st;
9
10 void dfs(int node, int par){
11     dfsn[node] = low[node] = ++timer;
12     st.push(node);
13     for(auto i: adj[node]){
14         if(i == par) continue;
15         if(dfsn[i] == 0){
16             dfs(i, node);
17             low[node] = min(low[node], low[i]);
18         }
19         else low[node] = min(low[node], dfsn[i]);
20     }
21     if(dfsn[node] == low[node]){
22         cnt++;
23         while(1){
24             int cur = st.top();
25             st.pop();
26

```

```

27         comp_id[cur] = cnt;
28         if(cur == node) break;
29     }
30 }
31
32 void dfs2(int node, int par){
33     kam[node] = 0;
34     int mx = 0, second_mx = 0;
35     for(auto i: bridge_tree[node]){
36         if(i == par) continue;
37         dfs2(i, node);
38         kam[node] = max(kam[node], 1 + kam[i]);
39         if(kam[i] > mx){
40             second_mx = mx;
41             mx = kam[i];
42         }
43         else second_mx = max(second_mx, kam[i]);
44     }
45     ans = max(ans, kam[node]);
46     if(second_mx) ans = max(ans, 2 + mx + second_mx);
47 }
48
49 int main(){
50     ios_base::sync_with_stdio(0);cin.tie(0);cout.tie(0);
51     int n, m;
52     cin >> n >> m;
53     while(m--){
54         int u, v;
55         cin >> u >> v;
56         adj[u].push_back(v);
57         adj[v].push_back(u);
58     }
59     dfs(1, 0);
60     for(int i = 1; i <= n; i++){
61         for(auto j: adj[i]){
62             if(comp_id[i] != comp_id[j]){
63                 bridge_tree[comp_id[i]].push_back(comp_id[j]);
64             }
65         }
66     }
67     dfs2(1, 0);
68     cout << ans;
69
70     return 0;
71 }
72 }

```

### 6.4 Dinic With Scalling

```

1 //O(ElgFlow) on Bipartite Graphs and O(EVlgFlow) on other graphs (I think)
2 struct Dinic {
3     #define vi vector<int>
4     #define rep(i,a,b) f(i,a,b)
5     struct Edge {
6         int to, rev;
7         ll c, oc;
8         int id;
9         ll flow() { return max(oc - c, 0LL); } // if you need flows
10    };
11    vi lvl, ptr, q;
12    vector<vector<Edge>> adj;
13    Dinic(int n) : lvl(n), ptr(n), q(n), adj(n) {}
14    void addEdge(int a, int b, ll c, int id, ll rcap = 0) {
15        adj[a].push_back({b, sz(adj[b]), c, c, id});
16        adj[b].push_back({a, sz(adj[a]) - 1, rcap, rcap, id});
17    }
18    ll dfs(int v, int t, ll f) {
19        if (v == t || !f) return f;
20        for (int& i = ptr[v]; i < sz(adj[v]); i++) {
21            Edge& e = adj[v][i];
22            if (lvl[e.to] == lvl[v] + 1)
23                if (ll p = dfs(e.to, t, min(f, e.c))) {

```

```

24         e.c -= p, adj[e.to][e.rev].c += p;
25         return p;
26     }
27     return 0;
28 }
29
30 ll calc(int s, int t) {
31     ll flow = 0; q[0] = s;
32     rep(L, 0, 31) do { // 'int L=30' maybe faster for random data
33         lvl = ptr = vi[sz(q)];
34         int qi = 0, qe = lvl[s] = 1;
35         while (qi < qe && !lvl[t]) {
36             int v = q[qi++];
37             for (Edge e : adj[v])
38                 if (!lvl[e.to] && e.c >> (30 - L))
39                     q[qe++] = e.to, lvl[e.to] = lvl[v] + 1;
40         }
41         while (ll p = dfs(s, t, LLONG_MAX)) flow += p;
42     } while (lvl[t]);
43     return flow;
44 }
45 bool leftOfMinCut(int a) { return lvl[a] != 0; }
46 };

```

## 6.5 Gomory Hu

```

1  /**
2   * Author: chilli, Takanori MAEHARA
3   * Date: 2020-04-03
4   * License: CC0
5   * Source: https://github.com/spaghetti-source/algorithm/blob/master/graph/
6   *          gomory_hu_tree.cc#L102
7   * Description: Given a list of edges representing an undirected flow graph,
8   * returns edges of the Gomory-Hu tree. The max flow between any pair of
9   * vertices is given by minimum edge weight along the Gomory-Hu tree path.
10  * Time:  $\mathcal{O}(V)$  Flow Computations
11  * Status: Tested on CERC 2015 J, stress-tested
12  *
13  * Details: The implementation used here is not actually the original
14  * Gomory-Hu, but Gusfield's simplified version: "Very simple methods for all
15  * pairs network flow analysis". PushRelabel is used here, but any flow
16  * implementation that supports 'leftOfMinCut' also works.
17  */
18 #pragma once
19 #include "PushRelabel.h"
20
21 typedef array<ll, 3> Edge;
22 vector<Edge> gomoryHu(int N, vector<Edge> ed) {
23     vector<Edge> tree;
24     vi par(N);
25     rep(i, 1, N) {
26         PushRelabel D(N); // Dinic also works
27         for (Edge t : ed) D.addEdge(t[0], t[1], t[2], t[2]);
28         tree.push_back({i, par[i], D.calc(i, par[i])});
29         rep(j, i+1, N)
30             if (par[j] == par[i] && D.leftOfMinCut(j)) par[j] = i;
31     }
32     return tree;
33 }

```

## 6.6 HopcraftKarp BPM

```

1  /**
2   * Author: Chen Xing
3   * Date: 2009-10-13
4   * License: CC0
5   * Source: N/A
6   * Description: Fast bipartite matching algorithm. Graph  $g$  should be a list

```

```

7   * of neighbors of the left partition, and  $btoa$  should be a vector full of
8   * -1's of the same size as the right partition. Returns the size of
9   * the matching.  $btoa[i]$  will be the match for vertex  $i$  on the right side,
10  * or -1 if it's not matched.
11  * Usage: vi btoa(m, -1); hopcroftKarp(g, btoa);
12  * Time:  $\mathcal{O}(\sqrt{V}E)$ 
13  * Status: stress-tested by MinimumVertexCover, and tested on oldkattis.
14  *          adkbipmatch and SPOJ:MATCHING
15  */
16 #pragma once
17
18 bool dfs(int a, int L, vector<vi>& g, vi& btoa, vi& A, vi& B) {
19     if (A[a] != L) return 0;
20     A[a] = -1;
21     for (int b : g[a]) if (B[b] == L + 1) {
22         B[b] = 0;
23         if (btoa[b] == -1 || dfs(btoa[b], L + 1, g, btoa, A, B))
24             return btoa[b] = a, 1;
25     }
26     return 0;
27 }
28
29 int hopcroftKarp(vector<vi>& g, vi& btoa) {
30     int res = 0;
31     vi A(g.size(), B(btoa.size(), cur, next);
32     for (;;) {
33         fill(all(A), 0);
34         fill(all(B), 0);
35         /// Find the starting nodes for BFS (i.e. layer 0).
36         cur.clear();
37         for (int a : btoa) if (a != -1) A[a] = -1;
38         rep(a, 0, sz(g)) if (A[a] == 0) cur.push_back(a);
39         /// Find all layers using bfs.
40         for (int lay = 1; lay++ <= g.size()) {
41             bool islast = 0;
42             next.clear();
43             for (int a : cur) for (int b : g[a]) {
44                 if (btoa[b] == -1) {
45                     B[b] = lay;
46                     islast = 1;
47                 }
48                 else if (btoa[b] != a && !B[b]) {
49                     B[b] = lay;
50                     next.push_back(btoa[b]);
51                 }
52             }
53             if (islast) break;
54             if (next.empty()) return res;
55             for (int a : next) A[a] = lay;
56             cur.swap(next);
57         }
58         /// Use DFS to scan for augmenting paths.
59         rep(a, 0, sz(g))
60             res += dfs(a, 0, g, btoa, A, B);
61     }
62 }

```

## 6.7 Hungarian

```

1  /**
2   * Notes:
3   * note that n must be <= m
4   * so in case in your problem n >= m, just swap
5   * also note this
6   * void set(int x, int y, ll v){a[x+1][y+1]=v;}
7   * the algorithm assumes you're using 0-index
8   * but it's using 1-based
9  */
10 struct Hungarian {
11     const ll INF = 1000000000000000000; ///10^18
12     int n, m;
13     vector<vector<ll>> > a;

```

```

14 vector<ll> u,v;vector<int> p,way;
15 Hungarian(int n, int m):
16 n(n),m(m),a(n+1,vector<ll>(m+1,INF-1)),u(n+1),v(m+1),p(m+1),way(m+1){}
17 void set(int x, int y, ll v){a[x+1][y+1]=v;}
18 ll assign(){
19     for(int i = 1; i <= n; i++){
20         int j0=0;p[0]=i;
21         vector<ll> minv(m+1,INF);
22         vector<char> used(m+1,false);
23         do {
24             used[j0]=true;
25             int i0=p[j0],j1;ll delta=INF;
26             for(int j = 1; j <= m; j++){if(!used[j]){
27                 ll cur=a[i0][j]-u[i0]-v[j];
28                 if(cur<minv[j])minv[j]=cur,way[j]=j0;
29                 if(minv[j]<delta)delta=minv[j],j1=j;
30             }
31             for(int j = 0; j <= m; j++){
32                 if(used[j])u[p[j]]+=delta,v[j]-=delta;
33                 else minv[j]-=delta;
34             }
35             j0=j1;
36         } while(p[j0]);
37         do {
38             int j1=way[j0];p[j0]=p[j1];j0=j1;
39         } while(j0);
40     }
41     return -v[0];
42 }
43 vector<int> restoreAnswer() { ///run it after assign
44     vector<int> ans (n+1);
45     for (int j=1; j<=m; ++j)
46         ans[p[j]] = j;
47     return ans;
48 };

```

## 6.8 Kosaraju

```

1  /*
2   g : Adjacency List of the original graph
3   rg : Reversed Adjacency List
4   vis : A bitset to mark visited nodes
5   adj : Adjacency List of the super graph
6   stk : holds dfs ordered elements
7   cmp[i] : holds the component of node i
8   go[i] : holds the nodes inside the strongly connected component i
9  */
10
11 #define FOR(i,a,b) for(int i = a; i < b; i++)
12 #define pb push_back
13
14 const int N = 1e5+5;
15
16 vector<vector<int>>g, rg;
17 vector<vector<int>>go;
18 bitset<N>vis;
19 vector<vector<int>>adj;
20 stack<int>stk;
21 int n, m, cmp[N];
22 void add_edge(int u, int v){
23     g[u].push_back(v);
24     rg[v].push_back(u);
25 }
26 void dfs(int u){
27     vis[u]=1;
28     for(auto v : g[u])if(!vis[v])dfs(v);
29     stk.push(u);
30 }
31 void rdfs(int u,int c){
32     vis[u] = 1;
33     cmp[u] = c;
34     go[c].push_back(u);

```

```

35     for(auto v : rg[u])if(!vis[v])rdfs(v,c);
36 }
37 int scc(){
38     vis.reset();
39     for(int i = 0; i < n; i++)if(!vis[i])
40         dfs(i);
41     vis.reset();
42     int c = 0;
43     while(stk.size()){
44         auto cur = stk.top();
45         stk.pop();
46         if(!vis[cur])
47             rdfs(cur,c++);
48     }
49     return c;
50 }
51 }

```

## 6.9 Krichoff

```

1  /*
2   Count number of spanning trees in a graph
3  */
4  int power(long long n, long long k) {
5      int ans = 1;
6      while (k) {
7          if (k & 1) ans = (long long) ans * n % mod;
8          n = (long long) n * n % mod;
9          k >>= 1;
10     }
11     return ans;
12 }
13 int det(vector<vector<int>> a) {
14     int n = a.size(), m = (int)a[0].size();
15     int free_var = 0;
16     const long long MODSQ = (long long)mod * mod;
17     int det = 1, rank = 0;
18     for (int col = 0, row = 0; col < m && row < n; col++) {
19         int mx = row;
20         for (int k = row; k < n; k++) if (a[k][col] > a[mx][col]) mx = k;
21         if (a[mx][col] == 0) {
22             det = 0;
23             continue;
24         }
25         for (int j = col; j < m; j++) swap(a[mx][j], a[row][j]);
26         if (row != mx) det = det == 0 ? 0 : mod - det;
27         det = 1LL * det * a[row][col] % mod;
28         int inv = power(a[row][col], mod - 2);
29         for (int i = 0; i < n && inv; i++) {
30             if (i != row && a[i][col]) {
31                 int x = ((long long)a[i][col] * inv) % mod;
32                 for (int j = col; j < m && x; j++) {
33                     if (a[row][j]) a[i][j] = (MODSQ + a[i][j] - ((long long)a[row][j] * x)
34                         ) % mod;
35                 }
36             }
37             row++;
38             ++rank;
39         }
40         return det;
41     }

```

## 6.10 Manhattan MST

```

1  #include<bits/stdc++.h>
2  using namespace std;
3
4  const int N = 2e5 + 9;

```

```

5
6 int n;
7 vector<pair<int, int>> g[N];
8 struct PT {
9     int x, y, id;
10     bool operator < (const PT &p) const {
11         return x == p.x ? y < p.y : x < p.x;
12     }
13 } p[N];
14 struct node {
15     int val, id;
16 } t[N];
17 struct DSU {
18     int p[N];
19     void init(int n) { for (int i = 1; i <= n; i++) p[i] = i; }
20     int find(int u) { return p[u] == u ? u : p[u] = find(p[u]); }
21     void merge(int u, int v) { p[find(u)] = find(v); }
22 } dsu;
23 struct edge {
24     int u, v, w;
25     bool operator < (const edge &p) const { return w < p.w; }
26 };
27 vector<edge> edges;
28 int query(int x) {
29     int r = 2e9 + 10, id = -1;
30     for (; x <= n; x += (x & -x)) if (t[x].val < r) r = t[x].val, id = t[x].id;
31     return id;
32 }
33 void modify(int x, int w, int id) {
34     for (; x > 0; x -= (x & -x)) if (t[x].val > w) t[x].val = w, t[x].id = id;
35 }
36 int dist(PT &a, PT &b) {
37     return abs(a.x - b.x) + abs(a.y - b.y);
38 }
39 void add(int u, int v, int w) {
40     edges.push_back({u, v, w});
41 }
42 long long Kruskal() {
43     dsu.init(n);
44     sort(edges.begin(), edges.end());
45     long long ans = 0;
46     for (edge e : edges) {
47         int u = e.u, v = e.v, w = e.w;
48         if (dsu.find(u) != dsu.find(v)) {
49             ans += w;
50             g[u].push_back({v, w});
51             //g[v].push_back({u, w});
52             dsu.merge(u, v);
53         }
54     }
55     return ans;
56 }
57 void Manhattan() {
58     for (int i = 1; i <= n; ++i) p[i].id = i;
59     for (int dir = 1; dir <= 4; ++dir) {
60         if (dir == 2 || dir == 4) {
61             for (int i = 1; i <= n; ++i) swap(p[i].x, p[i].y);
62         }
63         else if (dir == 3) {
64             for (int i = 1; i <= n; ++i) p[i].x = -p[i].x;
65         }
66         sort(p + 1, p + 1 + n);
67         vector<int> v;
68         static int a[N];
69         for (int i = 1; i <= n; ++i) a[i] = p[i].y - p[i].x, v.push_back(a[i]);
70         sort(v.begin(), v.end());
71         v.erase(unique(v.begin(), v.end()), v.end());
72         for (int i = 1; i <= n; ++i) a[i] = lower_bound(v.begin(), v.end(), a[i]) -
73             v.begin() + 1;
74         for (int i = 1; i <= n; ++i) t[i].val = 2e9 + 10, t[i].id = -1;
75         for (int i = n; i >= 1; --i) {
76             int pos = query(a[i]);
77             if (pos != -1) add(p[i].id, p[pos].id, dist(p[i], p[pos]));
78             modify(a[i], p[i].x + p[i].y, i);
79         }
80     }
81 }

```

```

78     }
79 }
80 }
81 int32_t main() {
82     ios_base::sync_with_stdio(0);
83     cin.tie(0);
84     cin >> n;
85     for (int i = 1; i <= n; i++) cin >> p[i].x >> p[i].y;
86     Manhattan();
87     cout << Kruskal() << '\n';
88     for (int u = 1; u <= n; u++) {
89         for (auto x: g[u]) cout << u - 1 << ' ' << x.first - 1 << '\n';
90     }
91     return 0;
92 }

```

## 6.11 Maximum Clique

```

1 //Complexity O(3 ^ (N/3)) i.e works for 50
2 //you can change it to maximum independent set by flipping the edges 0->1, 1->0
3 //if you want to extract the nodes they are 1-bits in R
4 int g[60][60];
5 int res;
6 long long edges[60];
7 void BronKerbosch(int n, long long R, long long P, long long X) {
8     if (P == 0LL && X == 0LL) { //here we will find all possible maximal cliques (
9         //not maximum) i.e. there is no node which can be included in this set
10         int t = __builtin_popcountll(R);
11         res = max(res, t);
12         return;
13     }
14     int u = 0;
15     while (!(1LL << u) & (P | X)) u++;
16     for (int v = 0; v < n; v++) {
17         if ((1LL << v) & P) && !(1LL << v) & edges[u]) {
18             BronKerbosch(n, R | (1LL << v), P & edges[v], X & edges[v]);
19             P |= (1LL << v);
20             X |= (1LL << v);
21         }
22     }
23 }
24 int max_clique(int n) {
25     res = 0;
26     for (int i = 1; i <= n; i++) {
27         edges[i - 1] = 0;
28         for (int j = 1; j <= n; j++) if (g[i][j]) edges[i - 1] |= (1LL << (j - 1));
29     }
30     BronKerbosch(n, 0, (1LL << n) - 1, 0);
31     return res;
32 }

```

## 6.12 MCMF

```

1 /*
2     Notes:
3     make sure you notice the #define int ll
4     focus on the data types of the max flow everything inside is integer
5     addEdge(u,v,cap,cost)
6     note that for min cost max flow the cost is sum of cost * flow over all
7     edges
8 */
9 struct Edge {
10     int to;
11     int cost;
12     int cap, flow, backEdge;
13 };
14

```

```

15 struct MCMF {
16
17     const int inf = 1000000010;
18     int n;
19     vector<vector<Edge>> g;
20
21     MCMF(int _n) {
22         n = _n + 1;
23         g.resize(n);
24     }
25
26     void addEdge(int u, int v, int cap, int cost) {
27         Edge e1 = {v, cost, cap, 0, (int) g[v].size()};
28         Edge e2 = {u, -cost, 0, 0, (int) g[u].size()};
29         g[u].push_back(e1);
30         g[v].push_back(e2);
31     }
32
33     pair<int, int> minCostMaxFlow(int s, int t) {
34         int flow = 0;
35         int cost = 0;
36         vector<int> state(n), from(n), from_edge(n);
37         vector<int> d(n);
38         deque<int> q;
39         while (true) {
40             for (int i = 0; i < n; i++)
41                 state[i] = 2, d[i] = inf, from[i] = -1;
42             state[s] = 1;
43             q.clear();
44             q.push_back(s);
45             d[s] = 0;
46             while (!q.empty()) {
47                 int v = q.front();
48                 q.pop_front();
49                 state[v] = 0;
50                 for (int i = 0; i < (int) g[v].size(); i++) {
51                     Edge e = g[v][i];
52                     if (e.flow >= e.cap || (d[e.to] <= d[v] + e.cost))
53                         continue;
54                     int to = e.to;
55                     d[to] = d[v] + e.cost;
56                     from[to] = v;
57                     from_edge[to] = i;
58                     if (state[to] == 1) continue;
59                     if (!state[to] || (!q.empty() && d[q.front()] > d[to]))
60                         q.push_front(to);
61                     else q.push_back(to);
62                     state[to] = 1;
63                 }
64             }
65             if (d[t] == inf) break;
66             int it = t, addflow = inf;
67             while (it != s) {
68                 addflow = min(addflow,
69                             g[from[it]][from_edge[it]].cap
70                             - g[from[it]][from_edge[it]].flow);
71                 it = from[it];
72             }
73             it = t;
74             while (it != s) {
75                 g[from[it]][from_edge[it]].flow += addflow;
76                 g[it][g[from[it]][from_edge[it]].backEdge].flow -= addflow;
77                 cost += g[from[it]][from_edge[it]].cost * addflow;
78                 it = from[it];
79             }
80             flow += addflow;
81         }
82         return {cost, flow};
83     }
84 };

```

## 6.13 Minimum Arbrosce in a Graph

```

1  const int maxn = 2510, maxm = 7000000;
2  const ll maxint = 0x3f3f3f3f3f3f3f3fLL;
3
4  int n, ec, ID[maxn], pre[maxn], vis[maxn];
5  ll in[maxn];
6
7  struct edge_t {
8      int u, v;
9      ll w;
10 } edge[maxm];
11 void add(int u, int v, ll w) {
12     edge[++ec].u = u, edge[ec].v = v, edge[ec].w = w;
13 }
14
15 ll arborecence(int n, int root) {
16     ll res = 0, index;
17     while (true) {
18         for (int i = 1; i <= n; ++i) {
19             in[i] = maxint, vis[i] = -1, ID[i] = -1;
20         }
21         for (int i = 1; i <= ec; ++i) {
22             int u = edge[i].u, v = edge[i].v;
23             if (u == v || in[v] <= edge[i].w) continue;
24             in[v] = edge[i].w, pre[v] = u;
25         }
26         pre[root] = root, in[root] = 0;
27         for (int i = 1; i <= n; ++i) {
28             res += in[i];
29             if (in[i] == maxint) return -1;
30         }
31         index = 0;
32         for (int i = 1; i <= n; ++i) {
33             if (vis[i] != -1) continue;
34             int u = i, v;
35             while (vis[u] == -1) {
36                 vis[u] = i;
37                 u = pre[u];
38             }
39             if (vis[u] != i || u == root) continue;
40             for (v = u, u = pre[u], ++index; u != v; u = pre[u]) ID[u] = index;
41             ID[v] = index;
42         }
43         if (index == 0) return res;
44         for (int i = 1; i <= n; ++i) if (ID[i] == -1) ID[i] = ++index;
45         for (int i = 1; i <= ec; ++i) {
46             int u = edge[i].u, v = edge[i].v;
47             edge[i].u = ID[u], edge[i].v = ID[v];
48             edge[i].w -= in[v];
49         }
50         n = index, root = ID[root];
51     }
52     return res;
53 }

```

## 6.14 Minmimum Vertex Cover (Bipartite)

```

1  int myrandom (int i) { return std::rand()%i; }
2
3  struct MinimumVertexCover {
4      int n, id;
5      vector<vector<int>> g;
6      vector<int> color, m, seen;
7      vector<int> comp[2];
8      MinimumVertexCover() {}
9      MinimumVertexCover(int n, vector<vector<int>> g) {
10
11         this->n = n;
12         this->g = g;
13         color = m = vector<int>(n, -1);

```

```

14     seen = vector<int>(n, 0);
15     makeBipartite();
16 }
17
18 void dfsBipartite(int node, int col) {
19     if (color[node] != -1) {
20         assert(color[node] == col); /* MSH BIPARTITE YA BASHMOHANDES */
21         return;
22     }
23     color[node] = col;
24     comp[col].push_back(node);
25     for (int i = 0; i < int(g[node].size()); i++)
26         dfsBipartite(g[node][i], 1 - col);
27 }
28
29 void makeBipartite() {
30     for (int i = 0; i < n; i++)
31         if (color[i] == -1)
32             dfsBipartite(i, 0);
33 }
34
35 // match a node
36 bool dfs(int node) {
37     random_shuffle(g[node].begin(), g[node].end());
38     for (int i = 0; i < g[node].size(); i++) {
39         int child = g[node][i];
40         if (m[child] == -1) {
41             m[node] = child;
42             m[child] = node;
43             return true;
44         }
45         if (seen[child] == id)
46             continue;
47         seen[child] = id;
48         int enemy = m[child];
49         m[node] = child;
50         m[child] = node;
51         m[enemy] = -1;
52         if (dfs(enemy))
53             return true;
54         m[node] = -1;
55         m[child] = enemy;
56         m[enemy] = child;
57     }
58     return false;
59 }
60
61 void makeMatching() {
62     for (int j = 0; j < 5; j++)
63         random_shuffle(comp[0].begin(), comp[0].end(), myrandom);
64     for (int i = 0; i < int(comp[0].size()); i++) {
65         id++;
66         if (m[comp[0][i]] == -1)
67             dfs(comp[0][i]);
68     }
69 }
70
71
72 void recurse(int node, int x, vector<int> &minCover, vector<int> &done) {
73     if (m[node] != -1)
74         return;
75     if (done[node]) return;
76     done[node] = 1;
77     for (int i = 0; i < int(g[node].size()); i++) {
78         int child = g[node][i];
79         int newnode = m[child];
80         if (done[child]) continue;
81         if (newnode == -1) {
82             continue;
83         }
84         done[child] = 2;
85         minCover.push_back(child);
86         m[newnode] = -1;
87         recurse(newnode, x, minCover, done);

```

```

88     }
89 }
90
91 vector<int> getAnswer() {
92     vector<int> minCover, maxIndep;
93     vector<int> done(n, 0);
94     makeMatching();
95     for (int x = 0; x < 2; x++)
96         for (int i = 0; i < int(comp[x].size()); i++) {
97             int node = comp[x][i];
98             if (m[node] == -1)
99                 recurse(node, x, minCover, done);
100         }
101
102     for (int i = 0; i < int(comp[0].size()); i++)
103         if (!done[comp[0][i]]) {
104             minCover.push_back(comp[0][i]);
105         }
106     return minCover;
107 }
108 };

```

## 6.15 Prufer Code

```

1  #include<bits/stdc++.h>
2  using namespace std;
3
4  const int N = 3e5 + 9;
5
6  /*
7  prufer code is a sequence of length n-2 to uniquely determine a labeled tree
8  with n vertices
9  Each time take the leaf with the lowest number and add the node number the leaf
10 is connected to
11 the sequence and remove the leaf. Then break the algo after n-2 iterations
12 */
13 //0-indexed
14 int n;
15 vector<int> g[N];
16 int parent[N], degree[N];
17
18 void dfs (int v) {
19     for (size_t i = 0; i < g[v].size(); ++i) {
20         int to = g[v][i];
21         if (to != parent[v]) {
22             parent[to] = v;
23             dfs (to);
24         }
25     }
26 }
27
28 vector<int> prufer_code() {
29     parent[n - 1] = -1;
30     dfs (n - 1);
31     int ptr = -1;
32     for (int i = 0; i < n; ++i) {
33         degree[i] = (int) g[i].size();
34         if (degree[i] == 1 && ptr == -1) ptr = i;
35     }
36     vector<int> result;
37     int leaf = ptr;
38     for (int iter = 0; iter < n - 2; ++iter) {
39         int next = parent[leaf];
40         result.push_back (next);
41         --degree[next];
42         if (degree[next] == 1 && next < ptr) leaf = next;
43         else {
44             ++ptr;
45             while (ptr < n && degree[ptr] != 1) ++ptr;
46             leaf = ptr;
47         }
48     }
49 }

```

```

47     return result;
48 }
49 vector < pair<int, int> > prufer_to_tree(const vector<int> & prufer_code) {
50     int n = (int) prufer_code.size() + 2;
51     vector<int> degree (n, 1);
52     for (int i = 0; i < n - 2; ++i) ++degree[prufer_code[i]];
53
54     int ptr = 0;
55     while (ptr < n && degree[ptr] != 1) ++ptr;
56     int leaf = ptr;
57     vector < pair<int, int> > result;
58     for (int i = 0; i < n - 2; ++i) {
59         int v = prufer_code[i];
60         result.push_back (make_pair (leaf, v));
61         --degree[leaf];
62         if (--degree[v] == 1 && v < ptr) leaf = v;
63         else {
64             ++ptr;
65             while (ptr < n && degree[ptr] != 1) ++ptr;
66             leaf = ptr;
67         }
68     }
69     for (int v = 0; v < n - 1; ++v) if (degree[v] == 1) result.push_back (
70         make_pair (v, n - 1));
71     return result;
72 }
73 int32_t main() {
74
75     return 0;
76 }

```

## 6.16 Push Relabel Max Flow

```

1  struct edge
2  {
3      int from, to, cap, flow, index;
4      edge(int from, int to, int cap, int flow, int index):
5          from(from), to(to), cap(cap), flow(flow), index(index) {}
6  };
7
8  struct PushRelabel
9  {
10     int n;
11     vector<vector<edge> > g;
12     vector<long long> excess;
13     vector<int> height, active, count;
14     queue<int> Q;
15
16     PushRelabel(int n):
17         n(n), g(n), excess(n), height(n), active(n), count(2*n) {}
18
19     void addEdge(int from, int to, int cap)
20     {
21         g[from].push_back(edge(from, to, cap, 0, g[to].size()));
22         if(from==to)
23             g[from].back().index++;
24         g[to].push_back(edge(to, from, 0, 0, g[from].size()-1));
25     }
26
27     void enqueue(int v)
28     {
29         if(!active[v] && excess[v] > 0)
30         {
31             active[v]=true;
32             Q.push(v);
33         }
34     }
35
36     void push(edge &e)
37     {
38         int amt=(int)min(excess[e.from], (long long)e.cap - e.flow);

```

```

39         if(height[e.from]<=height[e.to] || amt==0)
40             return;
41         e.flow += amt;
42         g[e.to][e.index].flow -= amt;
43         excess[e.to] += amt;
44         excess[e.from] -= amt;
45         enqueue(e.to);
46     }
47
48     void relabel(int v)
49     {
50         count[height[v]]--;
51         int d=2*n;
52         for(auto &it:g[v])
53         {
54             if(it.cap-it.flow>0)
55                 d=min(d, height[it.to]+1);
56         }
57         height[v]=d;
58         count[height[v]]++;
59         enqueue(v);
60     }
61
62     void gap(int k)
63     {
64         for(int v=0;v<n;v++)
65         {
66             if(height[v]<k)
67                 continue;
68             count[height[v]]--;
69             height[v]=max(height[v], n+1);
70             count[height[v]]++;
71             enqueue(v);
72         }
73     }
74
75     void discharge(int v)
76     {
77         for(int i=0; excess[v]>0 && i<g[v].size(); i++)
78             push(g[v][i]);
79         if(excess[v]>0)
80         {
81             if(count[height[v]]==1)
82                 gap(height[v]);
83             else
84                 relabel(v);
85         }
86     }
87
88     long long max_flow(int source, int dest)
89     {
90         count[0] = n-1;
91         count[n] = 1;
92         height[source] = n;
93         active[source] = active[dest] = 1;
94         for(auto &it:g[source])
95         {
96             excess[source]+=it.cap;
97             push(it);
98         }
99
100         while(!Q.empty())
101         {
102             int v=Q.front();
103             Q.pop();
104             active[v]=false;
105             discharge(v);
106         }
107
108         long long max_flow=0;
109         for(auto &e:g[source])
110             max_flow+=e.flow;
111
112         return max_flow;
113     }

```

114 };

## 6.17 Tarjan Algo

```

1  vector< vector<int> > scc;
2  vector<int> adj[N];
3  int dfsn[N], low[N], cost[N], timer, in_stack[N];
4  stack<int> st;
5
6  // to detect all the components (cycles) in a directed graph
7  void tarjan(int node){
8      dfsn[node] = low[node] = ++timer;
9      in_stack[node] = 1;
10     st.push(node);
11     for(auto i: adj[node]){
12         if(dfsn[i] == 0){
13             tarjan(i);
14             low[node] = min(low[node], low[i]);
15         }
16         else if(in_stack[i]) low[node] = min(low[node], dfsn[i]);
17     }
18     if(dfsn[node] == low[node]){
19         scc.push_back(vector<int>());
20         while(1){
21             int cur = st.top();
22             st.pop();
23             in_stack[cur] = 0;
24             scc.back().push_back(cur);
25             if(cur == node) break;
26         }
27     }
28 }
29 int main(){
30     int m;
31     cin >> m;
32     while(m--){
33         int u, v;
34         cin >> u >> v;
35         adj[u].push_back(v);
36     }
37     for(int i = 1; i <= n; i++){
38         if(dfsn[i] == 0){
39             tarjan(i);
40         }
41     }
42
43     return 0;
44 }

```

## 6.18 Bipartite Matching

```

1  #include<iostream>
2  #include <bits/stdc++.h>
3  #define ll long long
4  #define ld long double
5  #define IO ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
6  using namespace std;
7  struct graph
8  {
9      int L, R;
10     vector<vector<int> > adj;
11     graph(int l, int r) : L(l), R(r), adj(l+1) {}
12     void add_edge(int u, int v)
13     {
14         adj[u].push_back(v+L);
15     }
16     int maximum_matching()
17     {
18         vector<int> mate(L+R+1, -1), level(L+1);

```

```

19     function<bool (void)> levelize = [&]()
20     {
21         queue<int> q;
22         for(int i=1; i<=L; i++)
23         {
24             level[i]=-1;
25             if(mate[i]<0)
26                 q.push(i), level[i]=0;
27         }
28         while(!q.empty())
29         {
30             int node=q.front();
31             q.pop();
32             for(auto i : adj[node])
33             {
34                 int v=mate[i];
35                 if(v<0)
36                     return true;
37                 if(level[v]<0)
38                 {
39                     level[v]=level[node]+1;
40                     q.push(v);
41                 }
42             }
43         }
44         return false;
45     };
46     function<bool (int)> augment = [&](int node)
47     {
48         for(auto i : adj[node])
49         {
50             int v=mate[i];
51             if(v<0 || (level[v]>level[node] && augment(v)))
52             {
53                 mate[node]=i;
54                 mate[i]=node;
55                 return true;
56             }
57         }
58         return false;
59     };
60     int match=0;
61     while(levelize())
62         for(int i=1; i<=L; i++)
63             if(mate[i] < 0 && augment(i))
64                 match++;
65     return match;
66 }
67 };
68
69 int main()
70 {
71     IO
72     int L, R, m;
73     cin>>L>>R>>m;
74     graph g(L, R);
75     for (int i = 0; i < m; ++i)
76     {
77         int u, v;
78         cin>>u>>v;
79         g.add_edge(u, v);
80     }
81     cout<<g.maximum_matching();
82 }

```

## 7 Math

### 7.1 Xor With Gauss

1 /\*



```

2      Some applications
3      If you want to find the maximum in xor subset
4      just ans = max(ans, ans ^ p[i]) for all i
5      if you want to count the number of subsets with a certain value
6      check all different subsets of p
7  */
8  ll p[66];
9  bool add(ll x) {
10     for(int i = 60; (~i) && x; --i) {
11         if(x >> i & 1) {
12             if(!p[i]) {
13                 p[i] = x;
14                 return true;
15             } else {
16                 x ^= p[i];
17             }
18         }
19     }
20     return false;
21 }

```

## 7.2 Josephus

```

1  // n = total person
2  // will kill every kth person, if k = 2, 2,4,6,...
3  // returns the mth killed person
4  ll josephus(ll n, ll k, ll m) {
5      m = n - m;
6      if (k <= 1) return n - m;
7      ll i = m;
8      while (i < n) {
9          ll r = (i - m + k - 2) / (k - 1);
10         if ((i + r) > n) r = n - i;
11         else if (!r) r = 1;
12         i += r;
13         m = (m + (r * k)) % i;
14         return m + 1;
15     }

```

## 7.3 Matrix Power/Multiplication

```

1  struct Matrix {
2
3      const static int D = 100;
4      int a[D][D];
5
6      Matrix(int val) {
7          for(int i = 0; i < D; i++)
8              for(int j = 0; j < D; j++)
9                  a[i][j] = val;
10     }
11     void clear() {
12         memset(a, 0, sizeof a);
13     }
14     void initIdentity() {
15         clear();
16         for(int i = 0; i < D; i++)
17             a[i][i] = 1;
18     }
19     int * operator [] (int r) {
20         return a[r];
21     }
22     const int * operator [] (int r) const {
23         return a[r];
24     }
25
26     friend Matrix operator * (const Matrix & a, const Matrix & b) {
27         Matrix ret(0);
28         for(int k = 0; k < D; k++)

```

```

29             for(int i = 0; i < D; i++) if(a[i][k])
30                 for(int j = 0; j < D; j++)
31                     ret[i][j] = (ret[i][j] + 1ll * a[i][k] * b[k][j]) % MOD;
32             return ret;
33     }
34 };
35
36 Matrix raiseMatrix(Matrix trans, ll k) {
37     Matrix res(0);
38     res.initIdentity();
39     for(; k >= 1; trans = trans * trans)
40         if(k & 1)
41             res = res * trans;
42     return res;
43 }

```

## 7.4 Rabin Miller Primality check

```

1
2  // n < 4,759,123,141          3 : 2, 7, 61
3  // n < 1,122,004,669,633      4 : 2, 13, 23, 1662803
4  // n < 3,474,749,660,383      6 : pirms <= 13
5  // n < 3,825,123,056,546,413,051 9 : primes <= 23
6
7  int testPrimes[] = {2,3,5,7,11,13,17,19,23};
8
9  struct MillerRabin{
10     //change K according to n
11     const int K = 9;
12     ll mult(ll s, ll m, ll mod){
13         if(!m) return 0;
14         ll ret = mult(s, m/2, mod);
15         ret = (ret + ret) % mod;
16         if(m & 1) ret = (ret + s) % mod;
17         return ret;
18     }
19
20     ll power(ll x, ll p, ll mod){
21         ll s = 1, m = x;
22         while(p){
23             if(p&1) s = mult(s, m, mod);
24             p >>= 1;
25             m = mult(m, m, mod);
26         }
27         return s;
28     }
29
30     bool witness(ll a, ll n, ll u, int t){
31         ll x = power(a, u, n), nx;
32         for(int i = 0; i < t; i++){
33             nx = mult(x, x, n);
34             if(nx == 1 and x != 1 and x != n-1) return 1;
35             x = nx;
36         }
37         return x != 1;
38     }
39
40     bool isPrime(ll n){ // return 1 if prime, 0 otherwise
41         if(n < 2) return 0;
42         if(!(n&1)) return n == 2;
43         for(int i = 0; i < K; i++) if(n == testPrimes[i]) return 1;
44         ll u = n-1; int t = 0;
45
46         while(u&1) u >>= 1, t++; // n-1 = u*2^t
47
48         for(int i = 0; i < K; i++) if(witness(testPrimes[i], n, u, t)) return 0;
49         return 1;
50     }
51 }tester;

```

## 8 Strings

### 8.1 Aho-Corasick Mostafa

```
1 struct AC_FSM {
2 #define ALPHABET_SIZE 26
3
4 struct Node {
5     int child[ALPHABET_SIZE], failure = 0, match_parent = -1;
6     vector<int> match;
7
8     Node() {
9         for (int i = 0; i < ALPHABET_SIZE; ++i) child[i] = -1;
10    }
11 };
12
13 vector<Node> a;
14
15 AC_FSM() {
16     a.push_back(Node());
17 }
18
19 void construct_automaton(vector<string> &words) {
20     for (int w = 0, n = 0; w < words.size(); ++w, n = 0) {
21         for (int i = 0; i < words[w].size(); ++i) {
22             if (a[n].child[words[w][i] - 'a'] == -1) {
23                 a[n].child[words[w][i] - 'a'] = a.size();
24                 a.push_back(Node());
25             }
26             n = a[n].child[words[w][i] - 'a'];
27         }
28         a[n].match.push_back(w);
29     }
30     queue<int> q;
31     for (int k = 0; k < ALPHABET_SIZE; ++k) {
32         if (a[0].child[k] == -1) a[0].child[k] = 0;
33         else if (a[0].child[k] > 0) {
34             a[a[0].child[k]].failure = 0;
35             q.push(a[0].child[k]);
36         }
37     }
38     while (!q.empty()) {
39         int r = q.front();
40         q.pop();
41         for (int k = 0, arck; k < ALPHABET_SIZE; ++k) {
42             if ((arck = a[r].child[k]) != -1) {
43                 q.push(arck);
44                 int v = a[r].failure;
45                 while (a[v].child[k] == -1) v = a[v].failure;
46                 a[arck].failure = a[v].child[k];
47                 a[arck].match_parent = a[v].child[k];
48                 while (a[arck].match_parent != -1 &&
49                     a[a[arck].match_parent].match.empty())
50                     a[arck].match_parent =
51                         a[a[arck].match_parent].match_parent;
52             }
53         }
54     }
55 }
56
57 void aho_corasick(string &sentence, vector<string> &words,
58     vector<vector<int>> &matches) {
59     matches.assign(words.size(), vector<int>());
60     int state = 0, ss = 0;
61     for (int i = 0; i < sentence.length(); ++i, ss = state) {
62         while (a[ss].child[sentence[i] - 'a'] == -1)
63             ss = a[ss].failure;
64         state = a[ss].child[sentence[i] - 'a'] = a[ss].child[sentence[i]
65             - 'a'];
66         for (ss = state; ss != -1; ss = a[ss].match_parent)
67             for (int w: a[ss].match)
68                 matches[w].push_back(i + 1 - words[w].length());
```

```
69     }
70 };
```

### 8.2 Aho-Corasick Anany

```
1 int trie[N][A];
2 int go[N][A]; ///holds the node that you will go to after failure and stuff
3 int ptr;
4 ll ans[N]; ///this node is a string terminator;
5 int fail[N]; ///the failure function for each
6 void BFS() {
7     queue<int> q;
8     f(0,0,A) {
9         if(trie[0][i]) {
10             q.push(trie[0][i]);
11             fail[trie[0][i]] = 0;
12         }
13         go[0][i] = trie[0][i];
14     }
15
16     while(q.size()) {
17         auto node = q.front();
18         q.pop();
19         ans[node] += ans[fail[node]]; ///propagate fail[i] to ans[i]
20         for(int i = 0; i < A; i++) {
21             if(trie[node][i]) ///calculate failure for you child
22                 int to = trie[node][i];
23                 int cur = fail[node]; ///int g = pi[i-1]
24                 while(cur && !trie[cur][i]) ///while(g && s[g] != s[i])
25                     cur = fail[cur]; ///g = pi[g-1]
26                 if(trie[cur][i]) cur = trie[cur][i]; ///g += s[i] == s[g]
27                 fail[to] = cur; ///pi[i] = g
28                 q.push(to);
29                 go[node][i] = trie[node][i];
30             } else {
31                 go[node][i] = go[fail[node]][i];
32             }
33         }
34     }
35 }
36 void ins(string s, ll val) {
37     int cur = 0;
38     string sx = "";
39     for(char c : s) {
40         sx.push_back(c);
41         if(!trie[cur][c - 'a']) {
42             trie[cur][c - 'a'] = ++ptr;
43         }
44         cur = trie[cur][c - 'a'];
45     }
46     ans[cur] += val;
47 }
```

### 8.3 KMP Anany

```
1 vector<int> fail(string s) {
2     int n = s.size();
3     vector<int> pi(n);
4     for(int i = 1; i < n; i++) {
5         int g = pi[i-1];
6         while(g && s[i] != s[g])
7             g = pi[g-1];
8         g += s[i] == s[g];
9         pi[i] = g;
10    }
11    return pi;
12 }
13 vector<int> KMP(string s, string t) {
14     vector<int> pi = fail(t);
```

```

15 vector<int> ret;
16 for(int i = 0, g = 0; i < s.size(); i++) {
17     while (g && s[i] != t[g])
18         g = pi[g-1];
19     g += s[i] == t[g];
20     if(g == t.size()) { ///occurrence found
21         ret.push_back(i-t.size()+1);
22         g = pi[g-1];
23     }
24 }
25 return ret;
26 }

```

## 8.4 Manacher Kactl

```

1 // If the size of palindrome centered at i is x, then dl[i] stores (x+1)/2.
2
3 vector<int> dl(n);
4 for (int i = 0, l = 0, r = -1; i < n; i++) {
5     int k = (i > r) ? 1 : min(dl[l + r - i + 1], r - i + 1);
6     while (0 <= i - k && i + k < n && s[i - k] == s[i + k]) {
7         k++;
8     }
9     dl[i] = k--;
10    if (i + k > r) {
11        l = i - k;
12        r = i + k;
13    }
14 }
15
16 // If the size of palindrome centered at i is x, then d2[i] stores x/2
17
18 vector<int> d2(n);
19 for (int i = 0, l = 0, r = -1; i < n; i++) {
20     int k = (i > r) ? 0 : min(d2[l + r - i + 1], r - i + 1);
21     while (0 <= i - k - 1 && i + k < n && s[i - k - 1] == s[i + k]) {
22         k++;
23     }
24     d2[i] = k--;
25     if (i + k > r) {
26         l = i - k - 1;
27         r = i + k;
28     }
29 }
30 }

```

## 8.5 Suffix Array Kactl

```

1 struct SuffixArray {
2     using vi = vector<int>;
3     #define rep(i,a,b) for(int i = a; i < b; i++)
4     /*
5      * Note this code is considers also the empty suffix
6      * so hear sa[0] = n and sa[1] is the smallest non empty suffix
7      * and sa[n] is the largest non empty suffix
8      * also LCP[i] = LCP(sa[i-1], sa[i]), meaning LCP[0] = LCP[1] = 0
9      * if you want to get LCP(i..j) you need to build a mapping between
10     * sa[i] and i, and build a min sparse table to calculate the minimum
11     * note that this minimum should consider sa[i+1...j] since you don't want
12     * to consider LCP(sa[i], sa[i-1])
13
14     * you should also print the suffix array and lcp at the beginning of the
15     * contest
16     * to clarify this stuff
17     */
18     vi sa, lcp;
19     SuffixArray(string& s, int lim=256) { /// or basic_string<int>
20         int n = sz(s) + 1, k = 0, a, b;
21         vi x(all(s)+1), y(n), ws(max(n, lim)), rank(n);

```

```

21 sa = lcp = y, iota(all(sa), 0);
22 for (int j = 0, p = 0; p < n; j = max(1, j * 2), lim = p) {
23     p = j, iota(all(y), n - j);
24     rep(i,0,n) if (sa[i] >= j) y[p++] = sa[i] - j;
25     fill(all(ws), 0);
26     rep(i,0,n) ws[x[i]]++;
27     rep(i,1,lim) ws[i] += ws[i - 1];
28     for (int i = n; i--;) sa[--ws[x[y[i]]]] = y[i];
29     swap(x, y), p = 1, x[sa[0]] = 0;
30     rep(i,1,n) a = sa[i - 1], b = sa[i], x[b] =
31         (y[a] == y[b] && y[a + j] == y[b + j]) ? p - 1 : p++;
32 }
33 rep(i,1,n) rank[sa[i]] = i;
34 for (int i = 0, j; i < n - 1; lcp[rank[i+1]] = k)
35     for (k && k--, j = sa[rank[i] - 1];
36          s[i + k] == s[j + k]; k++);
37 }
38 };

```

## 8.6 Suffix Automaton Anany

```

1 ///Note it's better to use addNode to clear a node before using it
2 ///at the start of each test case use initAutomaton
3
4 int last = 0, cntState = 1;
5 int nxt[N * 2][26];
6 int len[N * 2], link[N * 2], firstPos[N * 2], cnt[N * 2];
7
8 void addNode(int i) {
9     memset(nxt[i], 0, sizeof nxt[i]);
10    link[i] = -1;
11    cnt[i] = 0;
12 }
13
14 void initAutomaton() {
15     cntState = 1;
16     last = 0;
17     addNode(last);
18 }
19
20 int addChar(char c) {
21
22     c -= 'a'; ///note this offset
23     int p = last;
24     int cur = cntState++;
25     addNode(cur);
26     cnt[cur] = 1; ///extra
27     len[cur] = len[p] + 1;
28     firstPos[cur] = len[cur] - 1; ///extra
29     while(p != -1 && nxt[p][c] == 0) {
30         nxt[p][c] = cur;
31         p = link[p];
32     }
33
34     if(p == -1) {
35         link[cur] = 0;
36     } else {
37         int q = nxt[p][c];
38         if(len[q] == len[p] + 1) {
39             link[cur] = q;
40         } else {
41             int clone = cntState++;
42             link[clone] = link[q];
43             firstPos[clone] = firstPos[q]; ///extra
44             len[clone] = len[p] + 1;
45             link[q] = link[cur] = clone;
46             memcpy(nxt[clone], nxt[q], sizeof nxt[q]);
47             cnt[clone] = 0; ///extra
48             f(1,0,26)nxt[clone][i] = nxt[q][i];
49             while(p != -1 && nxt[p][c] == q) {
50                 nxt[p][c] = clone;
51                 p = link[p];

```

```

52     }
53 }
54 }
55 last = cur;
56 return cur;
57 }

```

## 8.7 Suffix Automaton Mostafa

```

1  #include <bits/stdc++.h>
2
3  #define FIO ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
4  using namespace std;
5  typedef long long ll;
6  typedef long double ld;
7  const int N = 2e6 + 9, M = 5e5 + 9;
8
9  struct SA {
10     struct node {
11         int to[26];
12         int link, len, co = 0;
13
14         node() {
15             memset(to, 0, sizeof to);
16             co = 0, link = 0, len = 0;
17         }
18     };
19
20     int last, sz;
21     vector<node> v;
22
23     SA() {
24         v = vector<node>(1);
25         last = 0, sz = 1;
26     }
27
28     void add_letter(int c) {
29         int p = last;
30         last = sz++;
31         v.push_back({});
32         v[last].len = v[p].len + 1;
33         v[last].co = 1;
34         for (; v[p].to[c] == 0; p = v[p].link)
35             v[p].to[c] = last;
36         if (v[p].to[c] == last) {
37             v[last].link = 0;
38             return;
39         }
40         int q = v[p].to[c];
41         if (v[q].len == v[p].len + 1) {
42             v[last].link = q;
43             return;
44         }
45         int cl = sz++;
46         v.push_back(v[q]);
47         v.back().co = 0;
48         v.back().len = v[p].len + 1;
49         v[last].link = v[q].link = cl;
50
51         for (; v[p].to[c] == q; p = v[p].link)
52             v[p].to[c] = cl;
53     }
54
55     void build_co() {
56         priority_queue<pair<int, int>> q;
57         for (int i = sz - 1; i > 0; i--)
58             q.push({v[i].len, i});
59         while (q.size()) {
60             int i = q.top().second;
61             q.pop();
62             v[v[i].link].co += v[i].co;
63         }

```

```

64     }
65 };
66
67 int main() {
68     FIO
69
70     return 0;
71 }

```

## 8.8 Suffix Automaton With Rollback Mostafa

```

1  #include <bits/stdc++.h>
2
3  #define FIO ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
4  using namespace std;
5  typedef long long ll;
6  typedef long double ld;
7  const int N = 2e6 + 9, M = 5e5 + 9;
8
9  struct SA {
10     struct node {
11         int to[26];
12         int link, len, co = 0;
13
14         node() {
15             memset(to, 0, sizeof to);
16             co = 0, link = 0, len = 0;
17         }
18     };
19
20     struct LogNode {
21         int last, sz;
22         vector<pair<pair<int, int>, int>> edges;
23         pair<int, int> LinksUpdate = {0, 0};
24     };
25
26     int last, sz;
27     vector<node> v;
28     vector<LogNode> logs;
29
30     SA() {
31         v = vector<node>(1);
32         last = 0, sz = 1;
33     }
34
35     void add_letter(int c) {
36         logs.push_back({});
37         logs.back().last = last;
38         logs.back().sz = sz;
39
40         int p = last;
41         last = sz++;
42         v.push_back({});
43         v[last].len = v[p].len + 1;
44         v[last].co = 1;
45         for (; v[p].to[c] == 0; p = v[p].link) {
46             logs.back().edges.push_back({p, c, 0});
47             v[p].to[c] = last;
48         }
49         if (v[p].to[c] == last) {
50             v[last].link = 0;
51             return;
52         }
53         int q = v[p].to[c];
54         if (v[q].len == v[p].len + 1) {
55             v[last].link = q;
56             return;
57         }
58         int cl = sz++;
59         v.push_back(v[q]);
60         v.back().co = 0;
61         v.back().len = v[p].len + 1;

```

```

62     logs.back().LinksUpdate = {q, v[q].link};
63     v[last].link = v[q].link = cl;
64     for (; v[p].to[c] == q; p = v[p].link) {
65         logs.back().edges.push_back({p, c}, q});
66         v[p].to[c] = cl;
67     }
68 }
69 void rollback() {
70     assert(logs.size());
71     auto log = logs.back();
72     while (v.size() > log.sz)
73         v.pop_back();
74     for (auto edge: log.edges)
75         v[edge.first.first].to[edge.first.second] = edge.second;
76     if (log.LinksUpdate.first != 0)
77         v[log.LinksUpdate.first].link = log.LinksUpdate.second;
78     last = log.last;
79     sz = log.sz;
80     logs.pop_back();
81 }
82 };
83
84 int main() {
85     FIO
86
87     return 0;
88 }

```

## 8.9 Zalgo Anany

```

1  int z[N], n;
2  void Zalgo(string s) {
3      int L = 0, R = 0;
4      for(int i = 1; i < n; i++) {
5          if(i <= R && z[i-L] < R - i + 1) z[i] = z[i-L];
6          else {
7              L = i;
8              R = max(R, i);
9              while (R < n && s[R-L] == s[R]) R++;
10             z[i] = R-L; --R;
11         }
12     }
13 }

```

## 9 Trees

### 9.1 Centroid Decomposition

```

1  /*
2   Properties:
3   1. consider path(a,b) can be decomposed to path(a,lca(a,b)) and path(b,
4      lca(a,b))
5   2. Each one of the n^2 paths is the concatenation of two paths in a set
6      of O(n lg(n))
7   3. paths from a node to all its ancestors in the centroid decomposition.
8   3. Ancestor of a node in the original tree is either an ancestor in the
9      CD tree or
10     a descendant
11 */
12 vector<int> adj[N]; //adjacency list of original graph
13 int n;
14 int sz[N];
15 bool used[N];
16 int centPar[N]; //parent in centroid
17 void init(int node, int par) { //initialize size
18     sz[node] = 1;

```

```

17     for(auto p : adj[node])
18         if(p != par && !used[p]) {
19             init(p, node);
20             sz[node] += sz[p];
21         }
22 }
23 int centroid(int node, int par, int limit) { //get centroid
24     for(int p : adj[node])
25         if(!used[p] && p != par && sz[p] * 2 > limit)
26             return centroid(p, node, limit);
27     return node;
28 }
29 int decompose(int node) {
30     init(node, node); //calculate size
31     int c = centroid(node, node, sz[node]); //get centroid
32     used[c] = true;
33     for(auto p : adj[c]) if(!used[p.F]) { //initialize parent for others and
34         decompose
35         centPar[decompose(p.F)] = c;
36     }
37     return c;
38 }
39 void update(int node, int distance, int col) {
40     int centroid = node;
41     while(centroid) {
42         //solve
43         centroid = centPar[centroid];
44     }
45     int query(int node) {
46         int ans = 0;
47
48         int centroid = node;
49         while(centroid) {
50             //solve
51             centroid = centPar[centroid];
52         }
53     }
54     return ans;
55 }
56 }

```

### 9.2 Dsu On Trees

```

1  const int N = 1e5 + 9;
2  vector<int> adj[N];
3  int bigChild[N], sz[N];
4  void dfs(int node, int par) {
5      for(auto v : adj[node]) if(v != par) {
6          dfs(v, node);
7          sz[node] += sz[v];
8          if(!bigChild[node] || sz[v] > sz[bigChild[node]]) {
9              bigChild[node] = v;
10         }
11     }
12 }
13 void add(int node, int par, int bigChild, int delta) {
14     //modify node to data structure
15
16     for(auto v : adj[node])
17         if(v != par && v != bigChild)
18             add(v, node, bigChild, delta);
19 }
20
21 void dfs2(int node, int par, bool keep) {
22     for(auto v : adj[node]) if(v != par && v != bigChild[node]) {
23         dfs2(v, node, 0);
24     }
25     if(bigChild[node]) {
26         dfs2(bigChild[node], node, true);
27     }
28 }

```

```

29     add(node, par, bigChild[node], 1);
30     ///process queries
31     if(!keep) {
32         add(node, par, -1, -1);
33     }
34 }

```

### 9.3 Heavy Light Decomposition (Along with Euler Tour)

```

1  /*
2  Notes:
3  1. 0-based
4  2. solve function iterates over segments and handles them separately
5  3. if you're gonna use it make sure you know what you're doing
6  4. to update/query segment in[node], out[node]
7  5. to update/query chain in[nxt[node]], in[node]
8  6. nxt[node]: is the head of the chain so to go to the next chain node =
9     par[nxt[node]]
10 */
11 int sz[mxN], nxt[mxN];
12 int in[N], out[N], rin[N];
13 vector<int> g[mxN];
14 int par[mxN];
15 void dfs_sz(int v = 0, int p = -1) {
16     sz[v] = 1;
17     par[v] = p;
18     for (auto &u : g[v]) {
19         if (u == p) continue;
20         dfs_sz(u, v);
21         sz[v] += sz[u];
22         if (sz[u] > sz[g[v][0]])
23             swap(u, g[v][0]);
24     }
25     if (v != 0)
26         g[v].pop_back();
27 }
28 void dfs_hld(int v = 0) {
29     in[v] = t++;
30     rin[in[v]] = v;
31     for (auto u : g[v]) {
32         if (u == par[v]) continue;
33         dfs_hld(u);
34     }
35     out[v] = t;
36 }
37 int n;
38 bool isChild(int p, int u) {
39     return in[p] <= in[u] && out[u] <= out[p];
40 }
41 int solve(int u, int v) {
42     vector<pair<int, int>> segv;
43     vector<pair<int, int>> segu;
44     if (isChild(u, v)) {
45         while (nxt[u] != nxt[v]) {
46             segv.push_back(make_pair(in[nxt[v]], in[v]));
47             v = par[nxt[v]];
48         }
49         segu.push_back({in[u], in[v]});
50     } else if (isChild(v, u)) {
51         while (nxt[u] != nxt[v]) {
52             segu.push_back(make_pair(in[nxt[u]], in[u]));
53             u = par[nxt[u]];
54         }
55         segv.push_back({in[v], in[u]});
56     } else {
57         while (u != v) {

```

```

63         if (nxt[u] == nxt[v]) {
64             if (in[u] < in[v]) segv.push_back({in[u], in[v]}), R.push_back({u+1, v+1});
65             else segu.push_back({in[v], in[u]}), L.push_back({v+1, u+1});
66             u = v;
67             break;
68         } else if (in[u] > in[v]) {
69             segu.push_back({in[nxt[u]], in[u]}), L.push_back({nxt[u]+1, u+1});
70             u = par[nxt[u]];
71         } else {
72             segv.push_back({in[nxt[v]], in[v]}), R.push_back({nxt[v]+1, v+1});
73             v = par[nxt[v]];
74         }
75     }
76     reverse(segv.begin(), segv.end());
77     int res = 0, state = 0;
78     for (auto p : segu) {
79         qry(1, 1, 0, n-1, p.first, p.second, state, res);
80     }
81     for (auto p : segv) {
82         qry(0, 1, 0, n-1, p.first, p.second, state, res);
83     }
84     return res;
85 }
86 }

```

### 9.4 LCA

```

1  const int N = 1e5 + 5;
2  const int LG = 18;
3
4  vector<int> adj[N];
5  int pa[N][LG], lvl[N];
6  int in[N], out[N], timer;
7  void dfs(int u, int p) {
8      in[u] = ++timer;
9      for (int k = 1; k < LG; k++)
10         pa[u][k] = pa[pa[u][k-1]][k-1];
11     for (auto v : adj[u])
12         if (v != p) {
13             lvl[v] = lvl[u] + 1;
14             pa[v][0] = u;
15             dfs(v, u);
16         }
17     out[u] = timer;
18 }
19 int LCA(int u, int v) {
20     if (lvl[u] > lvl[v])
21         swap(u, v);
22     int d = lvl[v] - lvl[u];
23     for (int k = 0; k < LG; k++)
24         if (d >= 1 && k < LG) {
25             v = pa[v][k];
26             d--;
27         }
28     if (pa[u][d] != pa[v][d]) {
29         u = pa[u][d];
30         v = pa[v][d];
31     }
32     return pa[u][d];
33 }

```

### 9.5 Mo on Trees

```

1  int BL[N << 1], ID[N << 1];
2  int lvl[N], par[17][N];
3  int ans[N];
4  vector<ii> adj[N];
5  struct query{

```

```

6  int id, l, r, lc;
7  bool operator < (const query & rhs){
8      return (BL[l] == BL[rhs.l]) ? (r < rhs.r) : (BL[l] < BL[rhs.l]);
9  }
10 }Q[N];
11 int in[N], out[N], val[N], timer;
12 void dfs(int node, int p){
13     in[node] = ++timer; ID[timer] = node;
14     for(int i = 1; i < 17; i++) par[i][node] = par[i-1][par[i-1][node]];
15     for(auto child : adj[node]) if(child.F != p){
16         lvl[child.F] = lvl[node] + 1;
17         par[0][child.F] = node;
18         val[child.F] = child.S;
19         dfs(child.F, node);
20     }
21     out[node] = ++timer; ID[timer] = node;
22 }
23 int LCA(int u, int v){
24     if(lvl[u] > lvl[v]) swap(u,v);
25     for(int k = 0; k < 17; k++)
26         if((lvl[v] - lvl[u]) >> k & 1)
27             v = par[k][v];
28     if(u == v)
29         return u;
30     for(int i = 16; i >= 0; --i)
31         if(par[i][u] != par[i][v])
32             u = par[i][u], v = par[i][v];
33     return par[0][u];
34 }
35 bool vis[N];
36 int inSet[N];
37 void add(int node, int & res){
38     if(val[node] > N) return;
39     if(!vis[node]){
40         inSet[val[node]]++;
41         while(inSet[res]) res++;
42     } else {
43         inSet[val[node]]--;
44         if(!inSet[val[node]] && val[node] < res)
45             res = val[node];
46     }
47     vis[node] ^= 1;
48 }
49 //-----Adding Queries-----/
50 f(i,0,q){
51     int u, v;
52     cin >> u >> v; if(lvl[u] > lvl[v]) swap(u, v);
53     int lca = LCA(u, v);
54     Q[i].id = i;
55     Q[i].lc = lca;
56     if(lca == u) Q[i].l = in[u], Q[i].r = in[v];
57     else {
58         Q[i].l = out[u];
59         Q[i].r = in[v];
60     }
61 }
62 //-----Processing Queries-----/
63 f(i,0,q){
64     while (curL < Q[i].l) add(ID[curL++], res);
65     while (curL > Q[i].l) add(ID[--curL], res);
66     while (curR < Q[i].r) add(ID[++curR], res);
67     while (curR > Q[i].r) add(ID[curR--], res);
68     int u = ID[Q[i].l];
69     int v = ID[Q[i].r];
70     if(Q[i].lc == u) add(Q[i].lc, res);
71     ans[Q[i].id] = res;
72     if(Q[i].lc == u) add(Q[i].lc, res);
73 }

```

## 10 Numerical

### 10.1 Lagrange Polynomial

```

1  class LagrangePoly {
2  public:
3      LagrangePoly(std::vector<long long> _a) {
4          //f(i) = _a[i]
5          //interpola o vetor em um polinomio de grau y.size() - 1
6          y = _a;
7          den.resize(y.size());
8          int n = (int) y.size();
9          for(int i = 0; i < n; i++) {
10             y[i] = (y[i] % MOD + MOD) % MOD;
11             den[i] = ifat[n - i - 1] * ifat[i] % MOD;
12             if((n - i - 1) % 2 == 1) {
13                 den[i] = (MOD - den[i]) % MOD;
14             }
15         }
16     }
17
18     long long getVal(long long x) {
19         int n = (int) y.size();
20         x = (x % MOD + MOD) % MOD;
21         if(x < n) {
22             //return y[(int) x];
23         }
24         std::vector<long long> l, r;
25         l.resize(n);
26         l[0] = 1;
27         for(int i = 1; i < n; i++) {
28             l[i] = l[i - 1] * (x - (i - 1) + MOD) % MOD;
29         }
30         r.resize(n);
31         r[n - 1] = 1;
32         for(int i = n - 2; i >= 0; i--) {
33             r[i] = r[i + 1] * (x - (i + 1) + MOD) % MOD;
34         }
35         long long ans = 0;
36         for(int i = 0; i < n; i++) {
37             long long coef = l[i] * r[i] % MOD;
38             ans = (ans + coef * y[i] % MOD * den[i]) % MOD;
39         }
40         return ans;
41     }
42
43 private:
44     std::vector<long long> y, den;
45 };

```

## 11 formulas

### 11.1 Geometry

- Lattice points on line:  $\gcd(dx, dy) + 1$
- Pick's theorem:  $A = I + \frac{B}{2} - 1$
- sine rule:  $\frac{A}{\sin(a)} = \frac{B}{\sin(b)} = \frac{C}{\sin(c)}$
- cosine rule:  $C^2 = A^2 + B^2 - 2AB \times \cos(c)$
- Dot product =  $|A||B| \times \cos(a)$
- Cross product =  $|A||B| \times \sin(a)$

- Rotation around axis:  $R = (\cos(a) \times Id + \sin(a) \times \text{cross}U + (1 - \cos(a)) \times \text{outer}U)$
- Angle of regular polygon =  $\frac{180 \times (n-2)}{n}$
- # Diagonals of regular polygon =  $\frac{n(n-3)}{2}$
- Triangulation of n-gon = Catalan (n-2)

## 11.2 Area

- triangle =  $\frac{B \times H}{2}$
- triangle =  $\sqrt{(S \times (S - A) \times (S - B) \times (S - C))}$ ,  $S = \text{PERIMETER}/2$
- triangle =  $r \times S$ ,  $r$  = radius of inscribed circle
- circle =  $R^2 \times \pi$
- ellipse =  $\pi \times r_1 \times r_2$
- sector =  $\frac{(r^2 \times a)}{2}$
- circular cap =  $\frac{R^2 \times (a - \sin(a))}{2}$
- trapezoid =  $\frac{(B1+B2)}{2} \times H$
- prsim =  $\text{perimeter}(B)L + 2\text{area}(B)$
- sphere =  $4\pi r^2$

## 11.3 Volume

- Right circular cylinder =  $\pi r^2 h$
- Pyramid =  $\frac{Bh}{3}$
- Right circular cone =  $\frac{\pi r^2 h}{3}$
- Sphere =  $\frac{4}{3}\pi r^3$
- Sphere sector =  $\frac{2}{3}\pi r^2 h = \frac{2}{3}\pi r^3(1 - \cos(a))$
- Sphere cap =  $\frac{\pi h^2(3r-h)}{3}$

## 11.4 Combinatorics

- Cayley formula: number of forest with  $k$  trees where first  $k$  nodes belongs to different trees =  $k n^{n-k-1}$ . Multinomial theorem for trees of given degree sequence  $\binom{n}{d_i}$
- Prufer sequence (M5da calls it parent array)
- K-Cyclic permutation =  $\binom{n}{k} \times (k-1)!$
- Stirling numbers  $S(n, k) = k \times S(n-1, k) + S(n, k-1)$  number of way to partition  $n$  in  $k$  sets.
- Bell number  $B_n = \sum_1^n (n-1, k) B_k$
- Arithmetic-geometric-progression  $S_n = \frac{A_1 \times G_1 - A_{n+1} \times G_{n+1}}{1-r} + \frac{dr}{(1-r)^2} \times (G_1 - G_{n+1})$

## 11.5 Graph Theory

- Graph realization problem: sorted decreasing degrees:  $\sum_1^k d_i = k(k-1) + \sum_{k+1}^n \min(d_i, k)$  (first  $k$  form clique and all other nodes are connected to them).
- Euler formula:  $v + f = e + c + 1$
- # perfect matching in bipartite graph,  $DP[S][j] = DP[S][j-1] + DP[S/v][j-1]$  for all  $v$  connected to the  $j$  node.

## 11.6 Max flow with lower bound

- feasible flow in a network with both upper and lower capacity constraints, no source or sink: capacities are changed to upper bound - lower bound. Add a new source and a sink. let  $M[v] = (\text{sum of lower bounds of ingoing edges to } v) - (\text{sum of lower bounds of outgoing edges from } v)$ . For all  $v$ , if  $M[v] > 0$  then add edge  $(S, v)$  with capacity  $M[v]$ , otherwise add  $(v, T)$  with capacity  $-M[v]$ . If all outgoing edges from  $S$  are full, then a feasible flow exists, it is the flow plus the original lower bounds.
- maximum flow in a network with both upper and lower capacity constraints, with source  $s$  and sink  $t$ : add edge  $(t, s)$  with capacity infinity. Binary search for the lower bound, check whether a feasible exists for a network WITHOUT source or sink  $(B)$ .



## 11.7 Sum of floor function

```

Algorithm:
  t = GCD(p, q)
  p = p/t
  q = q/t
  s = 0
  z = 1
  while (q > 0) and (n > 0)
    (point A)
    t = [p/q]
    s = s + ztn(n+1)/2
    p = p - qt
    (point B)
    t = [n/q]
    s = s + zp(n+1) - zt(pqt + p+q-1)/2
    n = n - qt
    (point C)
    t = [np/q]

```

```

s = s + ztn
n = t
swap p and q
z = -z

```

## 11.8 Joseph problem

$$g(n, k) = \begin{cases} 0 & \text{if } n = 1 \\ (g(n-1, k) + k) \bmod n & \text{if } 1 < n < k \\ \left\lfloor \frac{k((g(n', k) - n \bmod k) \bmod n')}{k-1} \right\rfloor & \text{where } n' = n - \left\lfloor \frac{n}{k} \right\rfloor \text{ if } k \leq n \end{cases}$$