

Contents

1	Setting	1
1.1	PS	1
2	Math	2
2.1	Basic Arithmetics	2
2.2	Convex Hull Trick	3
2.3	Luca Theorem	3
2.4	Pollard Rho	4
2.5	Primality Test	4
2.6	Matrix Operations	4
2.7	Gaussian Elimination	5
2.8	Sieve	5
2.9	FFT	5
2.10	Chinese Remainder	6
3	Data Structure	6
3.1	Order Statistic Tree	6
3.2	Fenwick Tree	6
3.3	Fenwick Tree 2D	6
3.4	Merge Sort Tree	7
3.5	SegmentTree Lazy Propagation	7
3.6	Treap	8
3.7	Splay Tree	8
4	Geometry	9
4.1	Basic Operations	9
4.2	Convex Hull	11
4.3	Poiont in Polygon	11
4.4	Polygon Cut	11
4.5	Rotating Calipers	12
4.6	Seperating Axis Theorem	12
4.7	Two Far Point	13
4.8	Two Nearest Point	13
5	Graph	13
5.1	Dijkstra	13
5.2	Bellman-Ford	14
5.3	Spfa	14
5.4	Topological Sort	15
5.5	Strongly Connected Component	15
5.6	2-SAT	15
5.7	Union Find	16

5.8	MST Prim	17
5.9	Lowest Common Ancestor	17
5.10	Maxflow dinic	18
5.11	Maxflow Edmonds-Karp	18
5.12	MCMF SPFA	19
5.13	MCMF	20
6	String	21
6.1	KMP	21
6.2	Manacher	21
6.3	Suffix Array	22
6.4	Trie	22
6.5	Aho-Corasick	22
6.6	Z Algorithm	23
7	Dynamic Programming	23
7.1	LIS	23
7.2	LIS only length	23
7.3	KnapSack	24
7.4	Coin Change	24
7.5	Bit Field DP	24
7.6	Knuth Optimization	24

1 Setting

1.1 PS

```
#include <bits/stdc++.h>

using namespace std;

#define for1(s, e) for(int i = s; i < e; i++)
#define for1j(s, e) for(int j = s; j < e; j++)
#define foreach(k) for(auto i : k)
#define foreachj(k) for(auto j : k)
#define sz(vct) vct.size()
#define all(vct) vct.begin(), vct.end()
#define sortv(vct) sort(vct.begin(), vct.end())
#define uniq(vct) sort(all(vct));vct.erase(unique(all(vct)), vct.end())
#define fi first
#define se second
#define INF (1ll << 60ll)

typedef unsigned long long ull;
typedef long long ll;
typedef ll llint;
typedef unsigned int uint;
typedef unsigned long long int ull;
```

```

typedef ull ullint;

typedef pair<int, int> pii;
typedef pair<ll, ll> pll;
typedef pair<double, double> pdd;
typedef pair<double, int> pdi;
typedef pair<string, string> pss;

typedef vector<int> iv1;
typedef vector<iv1> iv2;
typedef vector<ll> llv1;
typedef vector<llv1> llv2;

typedef vector<pii> piiv1;
typedef vector<piiv1> piiv2;
typedef vector<pll> pll1;
typedef vector<pll1> pll2;
typedef vector<pdd> pdd1;
typedef vector<pdd1> pdd2;

const double EPS = 1e-8;
const double PI = acos(-1);

template<typename T>
T sq(T x) { return x * x; }

int sign(ll x) { return x < 0 ? -1 : x > 0 ? 1 : 0; }
int sign(int x) { return x < 0 ? -1 : x > 0 ? 1 : 0; }
int sign(double x) { return abs(x) < EPS ? 0 : x < 0 ? -1 : 1; }

void solve() {

}

int main() {
    ios::sync_with_stdio(0);
    cin.tie(NULL); cout.tie(NULL);
    int tc = 1; // cin >> tc;
    while(tc--) solve();
}

```

2 Math

2.1 Basic Arithmetics

```

typedef long long ll;
typedef unsigned long long ull;

// calculate lg2(a)
inline int lg2(ll a) {
    return 63 - __builtin_clzll(a);
}

// calculate the number of 1-bits

```

```

inline int bitcount(ll a) {
    return __builtin_popcountll(a);
}

// calculate ceil(a/b)
// |a|, |b| <= (2^63)-1 (does not cover -2^63)
ll ceildiv(ll a, ll b) {
    if (b < 0) return ceildiv(-a, -b);
    if (a < 0) return (-a) / b;
    return ((ull)a + (ull)b - 1ull) / b;
}

// calculate floor(a/b)
// |a|, |b| <= (2^63)-1 (does not cover -2^63)
ll floordiv(ll a, ll b) {
    if (b < 0) return floordiv(-a, -b);
    if (a >= 0) return a / b;
    return -(ll)(((ull)(-a) + b - 1) / b);
}

// calculate a*b % m
// x86-64 only
ll large_mod_mul(ll a, ll b, ll m) {
    return ll((__int128)a*(__int128)b%m);
}

// calculate a*b % m
// |m| < 2^62, x86 available
// O(logb)
ll large_mod_mul(ll a, ll b, ll m) {
    a %= m; b %= m; ll r = 0, v = a;
    while (b) {
        if (b&1) r = (r + v) % m;
        b >>= 1;
        v = (v << 1) % m;
    }
    return r;
}

// calculate n^k % m
ll modpow(ll n, ll k, ll m) {
    ll ret = 1;
    n %= m;
    while (k) {
        if (k & 1) ret = large_mod_mul(ret, n, m);
        n = large_mod_mul(n, n, m);
        k /= 2;
    }
    return ret;
}

// calculate gcd(a, b)
ll gcd(ll a, ll b) {
    return b == 0 ? a : gcd(b, a % b);
}

```

```
// find a pair (c, d) s.t. ac + bd = gcd(a, b)
pair<ll, ll> extended_gcd(ll a, ll b) {
    if (b == 0) return { 1, 0 };
    auto t = extended_gcd(b, a % b);
    return { t.second, t.first - t.second * (a / b) };
}

// find x in [0, m) s.t. ax == gcd(a, m) (mod m)
ll modinverse(ll a, ll m) {
    return (extended_gcd(a, m).first % m + m) % m;
}

// calculate modular inverse for 1 ~ n
void calc_range_modinv(int n, int mod, int ret[]) {
    ret[1] = 1;
    for (int i = 2; i <= n; ++i)
        ret[i] = (ll)(mod - mod/i) * ret[mod%i] % mod;
}
```

```
// p is prime
// calculate a^b % p
ll pow(ll a, ll b){
    if(b == 0) return 1;
    ll n = pow(a, b/2) % p;
    ll temp = (n * n) % p;

    if(b%2==0) return temp;
    return (a * temp) % p;
}

// p is prime
// calculate a/b % p
ll fermat(ll a, ll b){
    return a % p * pow(b, p-2) % p;
}
```

2.2 Convex Hull Trick

```
struct CHTLinear {
    struct Line {
        long long a, b;
        long long y(long long x) const { return a * x + b; }
    };
    vector<Line> stk;
    int qpt;
    CHTLinear() : qpt(0) { }
    // when you need maximum : (previous L).a < (now L).a
    // when you need minimum : (previous L).a > (now L).a
    void pushLine(const Line& l) {
        while (stk.size() > 1) {
            Line& l0 = stk[stk.size() - 1];
            Line& l1 = stk[stk.size() - 2];
            if ((l0.b - l1.b) * (l0.a - l1.a) > (l1.b - l0.b) * (l.a - l0.a))
```

```
                break;
            stk.pop_back();
        }
        stk.push_back(l);
    }
    // (previous x) <= (current x)
    // it calculates max/min at x
    long long query(long long x) {
        while (qpt + 1 < stk.size()) {
            Line& l0 = stk[qpt];
            Line& l1 = stk[qpt + 1];
            if (l1.a - l0.a > 0 && (l0.b - l1.b) > x * (l1.a - l0.a)) break;
            if (l1.a - l0.a < 0 && (l0.b - l1.b) < x * (l1.a - l0.a)) break;
            ++qpt;
        }
        return stk[qpt].y(x);
    }
};
```

2.3 Luca Theorem

```
// calculate nCm % p when p is prime
int lucas_theorem(const char *n, const char *m, int p) {
    vector<int> np, mp;
    int i;
    for (i = 0; n[i]; i++) {
        if (n[i] == '0' && np.empty()) continue;
        np.push_back(n[i] - '0');
    }
    for (i = 0; m[i]; i++) {
        if (m[i] == '0' && mp.empty()) continue;
        mp.push_back(m[i] - '0');
    }

    int ret = 1;
    int ni = 0, mi = 0;
    while (ni < np.size() || mi < mp.size()) {
        int nmod = 0, mmod = 0;
        for (i = ni; i < np.size(); i++) {
            if (i + 1 < np.size())
                np[i + 1] += (np[i] % p) * 10;
            else
                nmod = np[i] % p;
            np[i] /= p;
        }
        for (i = mi; i < mp.size(); i++) {
            if (i + 1 < mp.size())
                mp[i + 1] += (mp[i] % p) * 10;
            else
                mmod = mp[i] % p;
            mp[i] /= p;
        }
        while (ni < np.size() && np[ni] == 0) ni++;
        while (mi < mp.size() && mp[mi] == 0) mi++;
        // implement binomial. binomial(m,n) = 0 if m < n
```

```

        ret = (ret * binomial(nmod, mmod)) % p;
    }
    return ret;
}

```

2.4 Pollard Rho

```

ll pollard_rho(ll n) {
    random_device rd;
    mt19937 gen(rd());
    uniform_int_distribution<ll> dis(1, n - 1);
    ll x = dis(gen);
    ll y = x;
    ll c = dis(gen);
    ll g = 1;
    while (g == 1) {
        x = (modmul(x, x, n) + c) % n;
        y = (modmul(y, y, n) + c) % n;
        y = (modmul(y, y, n) + c) % n;
        g = gcd(abs(x - y), n);
    }
    return g;
}

```

```

// integer factorization
// O(n^0.25 * Logn)
void factorize(ll n, vector<ll>& fl) {
    if (n == 1) {
        return;
    }
    if (n % 2 == 0) {
        fl.push_back(2);
        factorize(n / 2, fl);
    }
    else if (is_prime(n)) {
        fl.push_back(n);
    }
    else {
        ll f = pollard_rho(n);
        factorize(f, fl);
        factorize(n / f, fl);
    }
}

```

2.5 Primality Test

```

bool test_witness(ull a, ull n, ull s) {
    if (a >= n) a %= n;
    if (a <= 1) return true;
    ull d = n >> s;
    ull x = modpow(a, d, n);
    if (x == 1 || x == n-1) return true;
    while (s-- > 1) {
        x = large_mod_mul(x, x, n);

```

```

        if (x == 1) return false;
        if (x == n-1) return true;
    }
    return false;
}

```

```

// test whether n is prime
// based on miller-rabin test
// O(Logn*Logn)
bool is_prime(ull n) {
    if (n == 2) return true;
    if (n < 2 || n % 2 == 0) return false;

    ull d = n >> 1, s = 1;
    for(;; (d&1) == 0; s++) d >>= 1;

#define T(a) test_witness(a##ull, n, s)
    if (n < 4759123141ull) return T(2) && T(7) && T(61);
    return T(2) && T(325) && T(9375) && T(28178)
        && T(450775) && T(9780504) && T(1795265022);
#undef T
}

```

2.6 Matrix Operations

```

const int MATSZ = 100;

inline bool is_zero(double a) { return fabs(a) < 1e-9; }

// out = A^(-1), returns det(A)
// A becomes invalid after call this
// O(n^3)
double inverse_and_det(int n, double A[][MATSZ], double out[][MATSZ]) {
    double det = 1;
    for (int i = 0; i < n; i++) {
        for (int j = 0; j < n; j++) out[i][j] = 0;
        out[i][i] = 1;
    }
    for (int i = 0; i < n; i++) {
        if (is_zero(A[i][i])) {
            double maxv = 0;
            int maxid = -1;
            for (int j = i + 1; j < n; j++) {
                auto cur = fabs(A[j][i]);
                if (maxv < cur) {
                    maxv = cur;
                    maxid = j;
                }
            }
            if (maxid == -1 || is_zero(A[maxid][i])) return 0;
            for (int k = 0; k < n; k++) {
                A[i][k] += A[maxid][k];
                out[i][k] += out[maxid][k];
            }
        }
    }
}

```

```

    det *= A[i][i];
    double coeff = 1.0 / A[i][i];
    for (int j = 0; j < n; j++) A[i][j] *= coeff;
    for (int j = 0; j < n; j++) out[i][j] *= coeff;
    for (int j = 0; j < n; j++) if (j != i) {
        double mp = A[j][i];
        for (int k = 0; k < n; k++) A[j][k] -= A[i][k] * mp;
        for (int k = 0; k < n; k++) out[j][k] -= out[i][k] * mp;
    }
}
return det;
}

```

2.7 Gaussian Elimination

```

const double EPS = 1e-10;
typedef vector<vector<double>> VVD;

// Gauss-Jordan elimination with full pivoting.
// solving systems of linear equations (AX=B)
// INPUT:  a[][] = an n*n matrix
//         b[][] = an n*m matrix
// OUTPUT: X      = an n*m matrix (stored in b[][])
//         A^{-1} = an n*n matrix (stored in a[][])
// O(n^3)
bool gauss_jordan(VVD& a, VVD& b) {
    const int n = a.size();
    const int m = b[0].size();
    vector<int> irow(n), icol(n), ipiv(n);

    for (int i = 0; i < n; i++) {
        int pj = -1, pk = -1;
        for (int j = 0; j < n; j++) if (!ipiv[j])
            for (int k = 0; k < n; k++) if (!ipiv[k])
                if (pj == -1 || fabs(a[j][k]) > fabs(a[pj][pk])) { pj = j; pk = k; }
        if (fabs(a[pj][pk]) < EPS) return false; // matrix is singular
        ipiv[pj]++;
        swap(a[pj], a[pk]);
        swap(b[pj], b[pk]);
        irow[i] = pj;
        icol[i] = pk;

        double c = 1.0 / a[pk][pk];
        a[pk][pk] = 1.0;
        for (int p = 0; p < n; p++) a[pk][p] *= c;
        for (int p = 0; p < m; p++) b[pk][p] *= c;
        for (int p = 0; p < n; p++) if (p != pk) {
            c = a[p][pk];
            a[p][pk] = 0;
            for (int q = 0; q < n; q++) a[p][q] -= a[pk][q] * c;
            for (int q = 0; q < m; q++) b[p][q] -= b[pk][q] * c;
        }
    }
    for (int p = n - 1; p >= 0; p--) if (irow[p] != icol[p]) {

```

```

        for (int k = 0; k < n; k++) swap(a[k][irow[p]], a[k][icol[p]]);
    }
    return true;
}

```

2.8 Sieve

```

// find prime numbers in 1 ~ n
// ret[x] = false -> x is prime
// O(n*loglogn)
void sieve(int n, bool ret[]) {
    for (int i = 2; i * i <= n; ++i)
        if (!ret[i])
            for (int j = i * i; j <= n; j += i)
                ret[j] = true;
}

// calculate number of divisors for 1 ~ n
// when you need to calculate sum, change += 1 to += i
// O(n*logn)
void num_of_divisors(int n, int ret[]) {
    for (int i = 1; i <= n; ++i)
        for (int j = i; j <= n; j += i)
            ret[j] += 1;
}

// calculate euler totient function for 1 ~ n
// phi(n) = number of x s.t. 0 < x < n && gcd(n, x) = 1
// O(n*loglogn)
void euler_phi(int n, int ret[]) {
    for (int i = 1; i <= n; ++i) ret[i] = i;
    for (int i = 2; i <= n; ++i)
        if (ret[i] == i)
            for (int j = i; j <= n; j += i)
                ret[j] -= ret[j] / i;
}

// FFT
void fft(int sign, int n, double *real, double *imag) {
    double theta = sign * 2 * pi / n;
    for (int m = n; m >= 2; m >= 1, theta *= 2) {
        double wr = 1, wi = 0, c = cos(theta), s = sin(theta);
        for (int i = 0, mh = m >> 1; i < mh; ++i) {
            for (int j = i; j < n; j += m) {
                int k = j + mh;
                double xr = real[j] - real[k], xi = imag[j] - imag[k];
                real[j] += real[k], imag[j] += imag[k];
                real[k] = wr * xr - wi * xi, imag[k] = wr * xi + wi * xr;
            }
            double _wr = wr * c - wi * s, _wi = wr * s + wi * c;
            wr = _wr, wi = _wi;
        }
    }
}

```

```

    for (int i = 1, j = 0; i < n; ++i) {
        for (int k = n >> 1; k > (j ^= k); k >>= 1);
        if (j < i) swap(real[i], real[j]), swap(imag[i], imag[j]);
    }
}
// Compute Poly(a)*Poly(b), write to r; Indexed from 0
// O(n*logn)
int mult(int *a, int n, int *b, int m, int *r) {
    const int maxn = 100;
    static double ra[maxn], rb[maxn], ia[maxn], ib[maxn];
    int fn = 1;
    while (fn < n + m) fn <= 1; // n + m: interested length
    for (int i = 0; i < n; ++i) ra[i] = a[i], ia[i] = 0;
    for (int i = n; i < fn; ++i) ra[i] = ia[i] = 0;
    for (int i = 0; i < m; ++i) rb[i] = b[i], ib[i] = 0;
    for (int i = m; i < fn; ++i) rb[i] = ib[i] = 0;
    fft(1, fn, ra, ia);
    fft(1, fn, rb, ib);
    for (int i = 0; i < fn; ++i) {
        double real = ra[i] * rb[i] - ia[i] * ib[i];
        double imag = ra[i] * ib[i] + rb[i] * ia[i];
        ra[i] = real, ia[i] = imag;
    }
    fft(-1, fn, ra, ia);
    for (int i = 0; i < fn; ++i) r[i] = (int)floor(ra[i] / fn + 0.5);
    return fn;
}

```

2.10 Chinese Remainder

```

// find x s.t.  x === a[0] (mod n[0])
//              === a[1] (mod n[1])
//              ...
// assumption: gcd(n[i], n[j]) = 1
ll chinese_remainder(ll* a, ll* n, int size) {
    if (size == 1) return *a;
    ll tmp = modinverse(n[0], n[1]);
    ll tmp2 = (tmp * (a[1] - a[0]) % n[1] + n[1]) % n[1];
    ll ora = a[1];
    ll tgcd = gcd(n[0], n[1]);
    a[1] = a[0] + n[0] / tgcd * tmp2;
    n[1] *= n[0] / tgcd;
    ll ret = chinese_remainder(a + 1, n + 1, size - 1);
    n[1] /= n[0] / tgcd;
    a[1] = ora;
    return ret;
}

```

3 Data Structure

3.1 Order Statistic Tree

```

#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>

```

```

#include <ext/pb_ds/detail/standard_policies.hpp>
#include <functional>
#include <iostream>
using namespace __gnu_pbds;
using namespace std;

// tree<key_type, value_type(set if null), comparator, ...>
using ordered_set = tree<int, null_type, less<int>, rb_tree_tag,
    tree_order_statistics_node_update>;

int main()
{
    ordered_set X;
    for (int i = 1; i < 10; i += 2) X.insert(i); // 1 3 5 7 9

    cout << boolalpha;
    cout << *X.find_by_order(2) << endl; // 5
    cout << *X.find_by_order(4) << endl; // 9
    cout << (X.end() == X.find_by_order(5)) << endl; // true

    cout << X.order_of_key(-1) << endl; // 0
    cout << X.order_of_key(1) << endl; // 0
    cout << X.order_of_key(5) << endl; // 2
    X.erase(3);
    cout << X.order_of_key(4) << endl; // 1
    for (int t : X) printf("%d ", t); // 1 5 7 9
}

```

3.2 Fenwick Tree

```

const int TSIZE = 100000;
int tree[TSIZE + 1];

// Returns the sum from index 1 to p, inclusive
int query(int p) {
    int ret = 0;
    for (; p > 0; p -= p & -p) ret += tree[p];
    return ret;
}

// Adds val to element with index pos
void add(int p, int val) {
    for (; p <= TSIZE; p += p & -p) tree[p] += val;
}

```

3.3 Fenwick Tree 2D

```

struct FenwickTree2D {
    ll size;
    llv2 data;

    FenwickTree2D(ll N) {
        size = N;
        data = llv2(size+1, llv1(size+1));
    }
}

```

```

}

void update(int x, int y, ll val) {
    ll dv = val - sum(x, y, x, y);
    while(x <= size) {
        int y2 = y;
        while(y2 <= size) {
            data[x][y2] += dv;
            y2 += y2 & -y2;
        }
        x += x & -x;
    }
}

ll sum(int x, int y) {
    ll ret = 0;
    while(x) {
        int y2 = y;
        while(y2) {
            ret += data[x][y2];
            y2 -= y2 & -y2;
        }
        x -= x & -x;
    }
    return ret;
}

ll sum(int x1, int y1, int x2, int y2) {
    return sum(x2, y2) + sum(x1 - 1, y1 - 1) - sum(x1 - 1, y2) - sum(x2, y1 - 1);
}
};

```

3.4 Merge Sort Tree

```

llv1 a;
llv1 mTree[Mx];
void makeTree(ll idx, ll ss, ll se) {
    if (ss == se) {
        mTree[idx].push_back(a[ss]);
        return;
    }
    ll mid = (ss + se) / 2;
    makeTree(2 * idx + 1, ss, mid);
    makeTree(2 * idx + 2, mid + 1, se);
    merge(mTree[2 * idx + 1].begin(), mTree[2 * idx + 1].end(), mTree[2 * idx + 2].begin(), mTree[2 * idx + 2].end(), back_inserter(mTree[idx]));
}

ll query(ll node, ll start, ll end, ll q_s, ll q_e, ll k) {
    // i j k: Ai, Ai+1, ..., 로Aj 이루어진부분수열중에서보다 k 큰원소의개수를출력한
    // 다 .
    if (q_s > end || start > q_e) return 0;
    if (q_s <= start && q_e >= end) {
        return mTree[node].size() - (upper_bound(mTree[node].begin(), mTree[node].end(), k) - mTree[node].begin());
    }
}

```

```

ll mid = (start + end) / 2;
ll p1 = query(2 * node + 1, start, mid, q_s, q_e, k);
ll p2 = query(2 * node + 2, mid + 1, end, q_s, q_e, k);
return p1 + p2;
}

```

3.5 SegmentTree Lazy Propagation

```

// example implementation of sum tree
const int TSIZE = 131072; // always 2^k form && n <= TSIZE
int segtree[TSIZE * 2], prop[TSIZE * 2];
void seg_init(int nod, int l, int r) {
    if (l == r) segtree[nod] = dat[l];
    else {
        int m = (l + r) >> 1;
        seg_init(nod << 1, l, m);
        seg_init(nod << 1 | 1, m + 1, r);
        segtree[nod] = segtree[nod << 1] + segtree[nod << 1 | 1];
    }
}

void seg_relax(int nod, int l, int r) {
    if (prop[nod] == 0) return;
    if (l < r) {
        int m = (l + r) >> 1;
        segtree[nod << 1] += (m - l + 1) * prop[nod];
        prop[nod << 1] += prop[nod];
        segtree[nod << 1 | 1] += (r - m) * prop[nod];
        prop[nod << 1 | 1] += prop[nod];
    }
    prop[nod] = 0;
}

int seg_query(int nod, int l, int r, int s, int e) {
    if (r < s || e < l) return 0;
    if (s <= l && r <= e) return segtree[nod];
    seg_relax(nod, l, r);
    int m = (l + r) >> 1;
    return seg_query(nod << 1, l, m, s, e) + seg_query(nod << 1 | 1, m + 1, r, s, e);
}

void seg_update(int nod, int l, int r, int s, int e, int val) {
    if (r < s || e < l) return;
    if (s <= l && r <= e) {
        segtree[nod] += (r - l + 1) * val;
        prop[nod] += val;
        return;
    }
    seg_relax(nod, l, r);
    int m = (l + r) >> 1;
    seg_update(nod << 1, l, m, s, e, val);
    seg_update(nod << 1 | 1, m + 1, r, s, e, val);
    segtree[nod] = segtree[nod << 1] + segtree[nod << 1 | 1];
}

// usage:
// seg_update(1, 0, n - 1, qs, qe, val);
// seg_query(1, 0, n - 1, qs, qe);

```

3.6 Treap

```
// Treap* root = NULL;
// root = insert(root, new Treap(3));
typedef int type;
struct Treap {
    Treap* left = NULL, * right = NULL;
    int size = 1, prio = rand();
    type key;
    Treap(type key) : key(key) { }
    void calcSize() {
        size = 1;
        if (left != NULL) size += left->size;
        if (right != NULL) size += right->size;
    }
    void setLeft(Treap* l) { left = l, calcSize(); }
    void setRight(Treap* r) { right = r, calcSize(); }
};
typedef pair<Treap*, Treap*> TPair;
TPair split(Treap* root, type key) {
    if (root == NULL) return TPair(NULL, NULL);
    if (root->key < key) {
        TPair rs = split(root->right, key);
        root->setRight(rs.first);
        return TPair(root, rs.second);
    }
    TPair ls = split(root->left, key);
    root->setLeft(ls.second);
    return TPair(ls.first, root);
}
Treap* insert(Treap* root, Treap* node) {
    if (root == NULL) return node;
    if (root->prio < node->prio) {
        TPair s = split(root, node->key);
        node->setLeft(s.first);
        node->setRight(s.second);
        return node;
    }
    else if (node->key < root->key)
        root->setLeft(insert(root->left, node));
    else
        root->setRight(insert(root->right, node));
    return root;
}
Treap* merge(Treap* a, Treap* b) {
    if (a == NULL) return b;
    if (b == NULL) return a;
    if (a->prio < b->prio) {
        b->setLeft(merge(a, b->left));
        return b;
    }
    a->setRight(merge(a->right, b));
    return a;
}
Treap* erase(Treap* root, type key) {
```

```
if (root == NULL) return root;
if (root->key == key) {
    Treap* ret = merge(root->left, root->right);
    delete root;
    return ret;
}
if (key < root->key)
    root->setLeft(erase(root->left, key));
else
    root->setRight(erase(root->right, key));
return root;
}
Treap* kth(Treap* root, int k) { // kth key
    int l_size = 0;
    if (root->left != NULL) l_size += root->left->size;
    if (k <= l_size) return kth(root->left, k);
    if (k == l_size + 1) return root;
    return kth(root->right, k - l_size - 1);
}
int countLess(Treap* root, type key) { // count less than key
    if (root == NULL) return 0;
    if (root->key >= key)
        return countLess(root->left, key);
    int ls = (root->left ? root->left->size : 0);
    return ls + 1 + countLess(root->right, key);
}
```

3.7 Splay Tree

```
// example : https://www.acmicpc.net/problem/13159
struct node {
    node* l, * r, * p;
    int cnt, min, max, val;
    long long sum;
    bool inv;
    node(int _val) :
        cnt(1), sum(_val), min(_val), max(_val), val(_val), inv(false),
        l(nullptr), r(nullptr), p(nullptr) {
    }
};
node* root;

void update(node* x) {
    x->cnt = 1;
    x->sum = x->min = x->max = x->val;
    if (x->l) {
        x->cnt += x->l->cnt;
        x->sum += x->l->sum;
        x->min = min(x->min, x->l->min);
        x->max = max(x->max, x->l->max);
    }
    if (x->r) {
        x->cnt += x->r->cnt;
        x->sum += x->r->sum;
        x->min = min(x->min, x->r->min);
    }
}
```



```

        x->max = max(x->max, x->r->max);
    }
}

void rotate(node* x) {
    node* p = x->p;
    node* b = nullptr;
    if (x == p->l) {
        p->l = b = x->r;
        x->r = p;
    }
    else {
        p->r = b = x->l;
        x->l = p;
    }
    x->p = p->p;
    p->p = x;
    if (b) b->p = p;
    x->p ? (p == x->p->l ? x->p->l : x->p->r) = x : (root = x);
    update(p);
    update(x);
}

// make x into root
void splay(node* x) {
    while (x->p) {
        node* p = x->p;
        node* g = p->p;
        if (g) rotate((x == p->l) == (p == g->l) ? p : x);
        rotate(x);
    }
}

void relax_lazy(node* x) {
    if (!x->inv) return;
    swap(x->l, x->r);
    x->inv = false;
    if (x->l) x->l->inv = !x->l->inv;
    if (x->r) x->r->inv = !x->r->inv;
}

// find kth node in splay tree
void find_kth(int k) {
    node* x = root;
    relax_lazy(x);
    while (true) {
        while (x->l && x->l->cnt > k) {
            x = x->l;
            relax_lazy(x);
        }
        if (x->l) k -= x->l->cnt;
        if (!k--) break;
        x = x->r;
        relax_lazy(x);
    }
}

```

```

    splay(x);
}

// collect [l, r] nodes into one subtree and return its root
node* interval(int l, int r) {
    find_kth(l - 1);
    node* x = root;
    root = x->r;
    root->p = nullptr;
    find_kth(r - l + 1);
    x->r = root;
    root->p = x;
    root = x;
    return root->r->l;
}

void traverse(node* x) {
    relax_lazy(x);
    if (x->l) {
        traverse(x->l);
    }
    // do something
    if (x->r) {
        traverse(x->r);
    }
}

void uptree(node* x) {
    if (x->p) {
        uptree(x->p);
    }
    relax_lazy(x);
}

```

4 Geometry

4.1 Basic Operations

```

const double eps = 1e-9;

inline int diff(double lhs, double rhs) {
    if (lhs - eps < rhs && rhs < lhs + eps) return 0;
    return (lhs < rhs) ? -1 : 1;
}

inline bool is_between(double check, double a, double b) {
    if (a < b)
        return (a - eps < check && check < b + eps);
    else
        return (b - eps < check && check < a + eps);
}

struct Point {
    double x, y;
}

```

```

bool operator==(const Point& rhs) const {
    return diff(x, rhs.x) == 0 && diff(y, rhs.y) == 0;
}
Point operator+(const Point& rhs) const {
    return Point{ x + rhs.x, y + rhs.y };
}
Point operator-(const Point& rhs) const {
    return Point{ x - rhs.x, y - rhs.y };
}
Point operator*(double t) const {
    return Point{ x * t, y * t };
}
};

struct Circle {
    Point center;
    double r;
};

struct Line {
    Point pos, dir;
};

inline double inner(const Point& a, const Point& b) {
    return a.x * b.x + a.y * b.y;
}

inline double outer(const Point& a, const Point& b) {
    return a.x * b.y - a.y * b.x;
}

inline int ccw_line(const Line& line, const Point& point) {
    return diff(outer(line.dir, point - line.pos), 0);
}

inline int ccw(const Point& a, const Point& b, const Point& c) {
    return diff(outer(b - a, c - a), 0);
}

inline double dist(const Point& a, const Point& b) {
    return sqrt(inner(a - b, a - b));
}

inline double dist2(const Point &a, const Point &b) {
    return inner(a - b, a - b);
}

inline double dist(const Line& line, const Point& point, bool segment = false) {
    double c1 = inner(point - line.pos, line.dir);
    if (segment && diff(c1, 0) <= 0) return dist(line.pos, point);
    double c2 = inner(line.dir, line.dir);
    if (segment && diff(c2, c1) <= 0) return dist(line.pos + line.dir, point);
    return dist(line.pos + line.dir * (c1 / c2), point);
}

```

```

bool get_cross(const Line& a, const Line& b, Point& ret) {
    double mdet = outer(b.dir, a.dir);
    if (diff(mdet, 0) == 0) return false;
    double t2 = outer(a.dir, b.pos - a.pos) / mdet;
    ret = b.pos + b.dir * t2;
    return true;
}

bool get_segment_cross(const Line& a, const Line& b, Point& ret) {
    double mdet = outer(b.dir, a.dir);
    if (diff(mdet, 0) == 0) return false;
    double t1 = -outer(b.pos - a.pos, b.dir) / mdet;
    double t2 = outer(a.dir, b.pos - a.pos) / mdet;
    if (!is_between(t1, 0, 1) || !is_between(t2, 0, 1)) return false;
    ret = b.pos + b.dir * t2;
    return true;
}

Point inner_center(const Point &a, const Point &b, const Point &c) {
    double wa = dist(b, c), wb = dist(c, a), wc = dist(a, b);
    double w = wa + wb + wc;
    return Point{ (wa * a.x + wb * b.x + wc * c.x) / w, (wa * a.y + wb * b.y +
        wc * c.y) / w };
}

Point outer_center(const Point &a, const Point &b, const Point &c) {
    Point d1 = b - a, d2 = c - a;
    double area = outer(d1, d2);
    double dx = d1.x * d1.x * d2.y - d2.x * d2.x * d1.y
        + d1.y * d2.y * (d1.y - d2.y);
    double dy = d1.y * d1.y * d2.x - d2.y * d2.y * d1.x
        + d1.x * d2.x * (d1.x - d2.x);
    return Point{ a.x + dx / area / 2.0, a.y - dy / area / 2.0 };
}

vector<Point> circle_line(const Circle& circle, const Line& line) {
    vector<Point> result;
    double a = 2 * inner(line.dir, line.dir);
    double b = 2 * (line.dir.x * (line.pos.x - circle.center.x)
        + line.dir.y * (line.pos.y - circle.center.y));
    double c = inner(line.pos - circle.center, line.pos - circle.center)
        - circle.r * circle.r;
    double det = b * b - 2 * a * c;
    int pred = diff(det, 0);
    if (pred == 0)
        result.push_back(line.pos + line.dir * (-b / a));
    else if (pred > 0) {
        det = sqrt(det);
        result.push_back(line.pos + line.dir * ((-b + det) / a));
        result.push_back(line.pos + line.dir * ((-b - det) / a));
    }
    return result;
}

vector<Point> circle_circle(const Circle& a, const Circle& b) {

```

```

vector<Point> result;
int pred = diff(dist(a.center, b.center), a.r + b.r);
if (pred > 0) return result;
if (pred == 0) {
    result.push_back((a.center * b.r + b.center * a.r) * (1 / (a.r + b.r)));
    return result;
}
double aa = a.center.x * a.center.x + a.center.y * a.center.y - a.r * a.r;
double bb = b.center.x * b.center.x + b.center.y * b.center.y - b.r * b.r;
double tmp = (bb - aa) / 2.0;
Point cdiff = b.center - a.center;
if (diff(cdiff.x, 0) == 0) {
    if (diff(cdiff.y, 0) == 0)
        return result; // if (diff(a.r, b.r) == 0): same circle
    return circle_line(a, Line{ Point{ 0, tmp / cdiff.y }, Point{ 1, 0 } });
}
return circle_line(a,
    Line{ Point{ tmp / cdiff.x, 0 }, Point{ -cdiff.y, cdiff.x } });
}

Circle circle_from_3pts(const Point& a, const Point& b, const Point& c) {
    Point ba = b - a, cb = c - b;
    Line p{ (a + b) * 0.5, Point{ ba.y, -ba.x } };
    Line q{ (b + c) * 0.5, Point{ cb.y, -cb.x } };
    Circle circle;
    if (!get_cross(p, q, circle.center))
        circle.r = -1;
    else
        circle.r = dist(circle.center, a);
    return circle;
}

Circle circle_from_2pts_rad(const Point& a, const Point& b, double r) {
    double det = r * r / dist2(a, b) - 0.25;
    Circle circle;
    if (det < 0)
        circle.r = -1;
    else {
        double h = sqrt(det);
        // center is to the left of a->b
        circle.center = (a + b) * 0.5 + Point{ a.y - b.y, b.x - a.x } * h;
        circle.r = r;
    }
    return circle;
}

```

4.2 Convex Hull

```

// find convex hull
// O(n*logn)
vector<Point> convex_hull(vector<Point>& dat) {
    if (dat.size() <= 3) return dat;
    vector<Point> upper, lower;
    sort(dat.begin(), dat.end(), [](const Point& a, const Point& b) {
        return (a.x == b.x) ? a.y < b.y : a.x < b.x;
    });
}

```

```

});
for (const auto& p : dat) {
    while (upper.size() >= 2 && ccw(++upper.rbegin(), *upper.rbegin(), p)
        >= 0) upper.pop_back();
    while (lower.size() >= 2 && ccw(++lower.rbegin(), *lower.rbegin(), p)
        <= 0) lower.pop_back();
    upper.emplace_back(p);
    lower.emplace_back(p);
}
upper.insert(upper.end(), ++lower.rbegin(), --lower.rend());
return upper;
}

```

4.3 Point in Polygon

```

typedef double coord_t;

inline coord_t is_left(Point p0, Point p1, Point p2) {
    return (p1.x - p0.x) * (p2.y - p0.y) - (p2.x - p0.x) * (p1.y - p0.y);
}

// point in polygon test
// http://geomalgorithms.com/a03-_inclusion.html
bool is_in_polygon(Point p, vector<Point>& poly) {
    int wn = 0;
    for (int i = 0; i < poly.size(); ++i) {
        int ni = (i + 1 == poly.size()) ? 0 : i + 1;
        if (poly[i].y <= p.y) {
            if (poly[ni].y > p.y) {
                if (is_left(poly[i], poly[ni], p) > 0) {
                    ++wn;
                }
            }
        }
        else {
            if (poly[ni].y <= p.y) {
                if (is_left(poly[i], poly[ni], p) < 0) {
                    --wn;
                }
            }
        }
    }
    return wn != 0;
}

```

4.4 Polygon Cut

```

// Left side of a->b
vector<Point> cut_polygon(const vector<Point>& polygon, Line line) {
    if (!polygon.size()) return polygon;
    typedef vector<Point>::const_iterator piter;
    piter la, lan, fi, fip, i, j;
    la = lan = fi = fip = polygon.end();
    i = polygon.end() - 1;
}

```

```

bool lastin = diff(ccw_line(line, polygon[polygon.size() - 1]), 0) > 0;
for (j = polygon.begin(); j != polygon.end(); j++) {
    bool thisin = diff(ccw_line(line, *j), 0) > 0;
    if (lastin && !thisin) {
        la = i;
        lan = j;
    }
    if (!lastin && thisin) {
        fi = j;
        fip = i;
    }
    i = j;
    lastin = thisin;
}
if (fi == polygon.end()) {
    if (!lastin) return vector<Point>();
    return polygon;
}
vector<Point> result;
for (i = fi; i != lan; i++) {
    if (i == polygon.end()) {
        i = polygon.begin();
        if (i == lan) break;
    }
    result.push_back(*i);
}
Point lc, fc;
get_cross(Line{ *la, *lan - *la }, line, lc);
get_cross(Line{ *fip, *fi - *fip }, line, fc);
result.push_back(lc);
if (diff(dist2(lc, fc), 0) != 0) result.push_back(fc);
return result;
}

```

4.5 Rotating Calipers

```

// get all antipodal pairs
// O(n)
void antipodal_pairs(vector<Point>& pt) {
    // calculate convex hull
    sort(pt.begin(), pt.end(), [](const Point& a, const Point& b) {
        return (a.x == b.x) ? a.y < b.y : a.x < b.x;
    });
    vector<Point> up, lo;
    for (const auto& p : pt) {
        while (up.size() >= 2 && ccw(++up.rbegin(), *up.rbegin(), p) >= 0) up.pop_back();
        while (lo.size() >= 2 && ccw(++lo.rbegin(), *lo.rbegin(), p) <= 0) lo.pop_back();
        up.emplace_back(p);
        lo.emplace_back(p);
    }

    for (int i = 0, j = (int)lo.size() - 1; i + 1 < up.size() || j > 0; ) {
        get_pair(up[i], lo[j]); // DO WHAT YOU WANT
    }
}

```

```

if (i + 1 == up.size()) {
    --j;
}
else if (j == 0) {
    ++i;
}
else if ((long long)(up[i + 1].y - up[i].y) * (lo[j].x - lo[j - 1].x)
        > (long long)(up[i + 1].x - up[i].x) * (lo[j].y - lo[j - 1].y)) {
    ++i;
}
else {
    --j;
}
}
}
}

```

4.6 Separating Axis Theorem

```

pair<double, double> get_projection(vector<Vector2> &points, Vector2 &axis) {
    double min_val = axis.dot(points[0]);
    double max_val = min_val;
    for (int i = 1; i < points.size(); i++) {
        double projected = axis.dot(points[i]);
        min_val = min(min_val, projected);
        max_val = max(max_val, projected);
    }
    return {min_val, max_val};
}

vector<Vector2> get_normals(vector<Vector2> &points) {
    vector<Vector2> ret;
    if (points.size() == 1)
        return ret;
    for (int i = 0; i < points.size(); i++) {
        Vector2 &a = points[i];
        Vector2 &b = points[(i + 1) % points.size()];
        ret.push_back(Vector2((b - a).y, -(b - a).x));
    }
    return ret;
}

bool can_separate(vector<Vector2> &A, vector<Vector2> &B) {
    if (A.size() == 1 && B.size() == 1)
        return true;
    auto c_a = get_convex_hull(A);
    auto c_b = get_convex_hull(B);
    auto n_a = get_normals(c_a);
    auto n_b = get_normals(c_b);

    n_a.insert(n_a.end(), n_b.begin(), n_b.end());
    if (c_a.size() > 1) n_a.push_back(Vector2(c_a[1] - c_a[0]));
    if (c_b.size() > 1) n_a.push_back(Vector2(c_b[1] - c_b[0]));

    for (Vector2 &axis : n_a) {
        auto p_a = get_projection(c_a, axis);
    }
}

```

```

    auto p_b = get_projection(c_b, axis);
    if (!(p_a.second >= p_b.first) && (p_b.second >= p_a.first)) return true;
}
return false;
}

```

4.7 Two Far Point

```

pair<Vector2, Vector2> get_max_points(vector<Vector2> &points) {
    int left = 0, right = max_element(points.begin(), points.end()) - points.begin();
    int ret1 = left, ret2 = right;
    double max_len = (points[right] - points[left]).norm();
    int end = right;
    Vector2 left_dir = Vector2(0, -1.0);
    vector<Vector2> edges;
    for (int i = 0; i < points.size(); i++)
        edges.push_back((points[(i + 1) % points.size()] - points[i]).normalized());
    while (right != 0 || left != end) {
        double next1 = left_dir.dot(edges[left]);
        double next2 = -left_dir.dot(edges[right]);
        if (left != end && (right == 0 || next1 > next2)) {
            left_dir = edges[left];
            left = (left + 1) % points.size();
        } else {
            left_dir = -edges[right];
            right = (right + 1) % points.size();
        }
        double len = (points[right] - points[left]).norm();
        if (len > max_len) {
            ret1 = left;
            ret2 = right;
            max_len = len;
        }
    }
    return {points[ret1], points[ret2]};
}

```

4.8 Two Nearest Point

```

int dist(Point &p, Point &q) {
    return (p.x - q.x) * (p.x - q.x) + (p.y - q.y) * (p.y - q.y);
}
struct Comp {
    bool comp_in_x;
    Comp(bool b) : comp_in_x(b) {}
    bool operator()(Point &p, Point &q) {
        return (this->comp_in_x ? p.x < q.x : p.y < q.y);
    }
};
int nearest(vector<Point>::iterator it, int n) {
    if (n == 2) return dist(it[0], it[1]);
    if (n == 3) return min({dist(it[0], it[1]), dist(it[1], it[2]), dist(it[2], it[0])});
}

```

```

int line = (it[n / 2 - 1].x + it[n / 2].x) / 2;
int d = min(nearest(it, n / 2), nearest(it + n / 2, n - n / 2));
vector<Point> mid;
for (int i = 0; i < n; i++) {
    int t = line - it[i].x;
    if (t * t < d) mid.push_back(it[i]);
}
sort(mid.begin(), mid.end(), Comp(false));
int mid_sz = mid.size();
for (int i = 0; i < mid_sz - 1; i++)
    for (int j = i + 1; j < mid_sz && (mid[j].y - mid[i].y) * (mid[j].y - mid[i].y) < d; j++)
        d = min(d, dist(mid[i], mid[j]));
return d;
}

```

5 Graph

5.1 Dijkstra

```

template<typename T> struct Dijkstra {
    /*
    T: 간선가중치타입
    */
    struct Edge {
        ll node;
        T cost;
        bool operator<(const Edge &to) const {
            return cost > to.cost;
        }
    };

    ll n;
    vector<vector<Edge>> adj;
    vector<ll> prev;

    Dijkstra(ll n) : n{n}, adj(n+1) {}

    void addEdge(ll s, ll e, T cost) {
        adj[s].push_back(Edge(e, cost));
    }

    void addUndirectedEdge(ll s, ll e, T cost) {
        addEdge(s, e, cost);
        addEdge(e, s, cost);
    }

    vector<ll> dijkstra(ll s) {
        vector<ll> dist(n+1, INF);
        prev.resize(n+1, -1);
        priority_queue<edge> pq;
        pq.push({s, 0ll});
        dist[s] = 0;
        while (!pq.empty()) {

```

```

    edge cur = pq.top();
    pq.pop();
    if (cur.cost > dist[cur.node]) continue;
    for (auto &nxt : adj[cur.node])
        if (dist[cur.node] + nxt.cost < dist[nxt.node]) {
            prev[nxt.node] = cur.node;
            dist[nxt.node] = dist[cur.node] + nxt.cost;
            pq.push({ nxt.node, dist[nxt.node] });
        }
    }
    return dist;
}

vector<ll> getPath(ll s, ll e) {
    vector<ll> ret;
    ll current = e;
    while(current != -1) {
        ret.push_back(current);
        current = prev[current];
    }
    reverse(ret.begin(), ret.end());
    return ret;
}
};

```

5.2 Bellman-Ford

```

struct BellmanFord {
    struct BellmanEdge {
        ll to, cost;

        BellmanEdge(ll to, ll cost) : to(to), cost(cost) {}
    };

    ll N;
    vector<vector< BellmanEdge > > adj;
    llv1 D;
    vector<ll> prev;

    BellmanFord(ll N) : N(N) {
        adj.resize(N + 1);
    }

    void addEdge(ll s, ll e, ll cost) {
        adj[s].push_back(BellmanEdge(e, cost));
    }

    bool run(ll start_point) {
        // 음수간선 cycle 유무를반환합니다 .
        // 거리정보는 D 벡터에저장됩니다 .
        // O(V * E)

        D.resize(N + 1, INF);
        prev.resize(N + 1, -1);
        D[start_point] = 0;
    }
};

```

```

bool isCycle = false;

for(1, N + 1) {
    for(1, N + 1) {
        for(int k=0; k < sz(adj[j]); k++) {
            BellmanEdge p = adj[j][k];
            int end = p.to;
            ll dist = D[j] + p.cost;

            if (D[j] != INF && D[end] > dist) {
                D[end] = dist;
                if (i == N) isCycle = true;
            }
        }
    }
}

return isCycle;
}

llv1 getPath(ll s, ll e) {
    vector<ll> ret;
    ll current = e;
    while(current != -1) {
        ret.push_back(current);
        current = prev[current];
    }
    reverse(ret.begin(), ret.end());
    return ret;
}
};

```

5.3 Spfa

// shortest path faster algorithm
// average for random graph : O(E) , worst : O(VE)

```

const int MAXN = 20001;
const int INF = 100000000;
int n, m;
vector<pii> graph[MAXN];

bool inqueue[MAXN];
int dist[MAXN];

void spfa(int start) {
    for (int i = 0; i < n; ++i) dist[i] = INF;
    dist[start] = 0;

    queue<int> q;
    q.push(start);
    inqueue[start] = true;

    while (!q.empty()) {
        int here = q.front();
    }
}

```

```

    q.pop();

    inqueue[here] = false;
    for (auto& nxt : graph[here]) {
        if (dist[here] + nxt.second < dist[nxt.first]) {
            dist[nxt.first] = dist[here] + nxt.second;
            if (!inqueue[nxt.first]) {
                q.push(nxt.first);
                inqueue[nxt.first] = true;
            }
        }
    }
}
}
};

```

5.4 Topological Sort

```

struct TopologicalSort {
    // 1-index

    int n;
    iv1 in_degree;
    iv2 graph;
    iv1 result;

    TopologicalSort(int n) : n(n) {
        in_degree.resize(n + 1, 0);
        graph.resize(n + 1);
    }

    void addEdge(int s, int e) {
        graph[s].push_back(e);
        in_degree[e]++;
    }

    void run() {
        queue<int> q;

        for(1, n+1) {
            if(in_degree[i] == 0) q.push(i);
        }
        while(!q.empty()) {
            int here = q.front(); q.pop();
            result.push_back(here);

            for(0, sz(graph[here])) {
                int there = graph[here][i];

                if(--in_degree[there]==0) q.push(there);
            }
        }
    }
};

```

5.5 Strongly Connected Component

```

struct SCC {
    // 1-index
    // run() 후에 components 결과가담김 .

    ll V;
    llv2 edges, reversed_edges, components;
    vector<bool> visited;
    stack<ll> visit_log;

    SCC(ll V): V(V) {
        edges.resize(V + 1);
        reversed_edges.resize(V + 1);
    }

    void addEdge(int s, int e) {
        edges[s].push_back(e);
        reversed_edges[e].push_back(s);
    }

    void dfs(int node) {
        visited[node] = true;

        for (int next : edges[node])
            if (!visited[next]) dfs(next);
        visit_log.push(node);
    }

    void dfs2(int node) {
        visited[node] = true;
        for (int next:reversed_edges[node])
            if (!visited[next]) dfs2(next);
        components.back().push_back(node);
    }

    void run() {
        visited = vector<bool>(V + 1, false);
        for (int node = 1; node <= V; node++)
            if (!visited[node]) dfs(node);

        visited = vector<bool>(V + 1, false);
        while (!visit_log.empty()) {
            ll node = visit_log.top(); visit_log.pop();
            if (!visited[node]) {
                components.push_back(llv1());
                dfs2(node);
            }
        }
    }
};

```

5.6 2-SAT

```

struct Graph {
    int V;

```

```

vector<bool> visited;
stack<int> visit_stack;
vector<int> component_number, source_components;
vector<vector<int>> edges, reversed_edges, components, components_edges;

Graph(int V) : V(V) {
    edges.resize(V);
    reversed_edges.resize(V);
}

void append(int u, int v) {
    edges[u].push_back(v);
    reversed_edges[v].push_back(u);
}

void dfs(int node) {
    visited[node] = true;
    for (int next : edges[node])
        if (!visited[next])
            dfs(next);
    visit_stack.push(node);
}

void scc(int node) {
    visited[node] = true;
    for (int next : reversed_edges[node])
        if (!visited[next])
            scc(next);
    components.back().push_back(node);
}

void build_scc() {
    visited = vector<bool>(V, false);
    for (int node = 0; node < V; node++)
        if (!visited[node]) dfs(node);
    visited = vector<bool>(V, false);
    while (!visit_stack.empty()) {
        int node = visit_stack.top();
        visit_stack.pop();
        if (!visited[node]) {
            components.push_back(vector<int>());
            scc(node);
        }
    }
    component_number.resize(V);
    for (int i = 0; i < components.size(); i++)
        for (int node : components[i]) component_number[node] = i;
    vector<bool> is_source = vector<bool>(components.size(), true);
    components_edges.resize(components.size());
    for (int u = 0; u < V; u++)
        for (int v : edges[u]) {
            int cu = component_number[u];
            int cv = component_number[v];
            if (cu == cv) continue;
            components_edges[cu].push_back(cv);
            is_source[cv] = false;
        }
    for (int component = 0; component < components.size(); component++) {
        if (is_source[component]) source_components.push_back(component);
    }
}

```

```

    }
}

int main(void) {
    int V, E;
    cin >> V >> E;
    Graph graph(2 * V + 1);
    for (int i = 0; i < E; i++) {
        int u, v;
        cin >> u >> v;
        graph.append(-u + V, v + V);
        graph.append(-v + V, u + V);
    }
    graph.build_scc();
    vector<int> last_component(2 * V + 1, -1);
    bool is_answer = true;
    for (int i = 0; i < graph.components.size(); i++) {
        for (int node : graph.components[i]) {
            int negation = -(node - V) + V;
            if (last_component[negation] == i) is_answer = false;
            last_component[node] = i;
        }
    }
    if (is_answer) {
        vector<int> result(V);
        for (int i = 1; i <= V; i++) {
            int val = i + V;
            int negation = -i + V;
            result[i - 1] = graph.component_number[val] > graph.component_number[
                negation];
        }
        for (int val : result) cout << val << " ";
        cout << "\n";
    }
}

```

5.7 Union Find

```

struct UnionFind {
    int n;
    vector<int> u;

    UnionFind(int n) : n(n) {
        u.resize(n + 1);
        for (int i = 1; i <= n; i++) {
            u[i] = i;
        }
    }

    int find(int k) {
        if (u[u[k]] == u[k]) return u[k];
        else return u[k] = find(u[k]);
    }
}

```



```
void uni(int a, int b) {
    a = find(a);
    b = find(b);
    if(a < b) u[b] = a;
    else u[a] = b;
}
};
```

5.8 MST Prim

```
struct edge {
    ll crt;
    ll node, cost;
};

struct WGraph {
    ll V;
    vector<edge> adj[MAX];
    vector<ll> prev;
    WGraph(ll V) : V{V} {}
    void addEdge(ll s, ll e, ll cost) {
        adj[s].push_back({s, e, cost});
        adj[e].push_back({e, s, cost});
    }

    ll prim(vector<edge> &selected) { // 예selected 선택된간선정보 vector 담김
        selected.clear();

        vector<bool> added(V, false);
        llv1 minWeight(V, INF), parent(V, -1);

        ll ret = 0;
        minWeight[0] = parent[0] = 0;
        for (int iter = 0; iter < V; iter++) {
            int u = -1;
            for (int v = 0; v < V; v++) {
                if (!added[v] && (u == -1 || minWeight[u] > minWeight[v]))
                    u = v;
            }

            if (parent[u] != u)
                selected.push_back({parent[u], u, minWeight[u]});

            ret += minWeight[u];
            added[u] = true;

            forl(0, sz(adj[u])) {
                int v = adj[u][i].node, weight = adj[u][i].cost;
                if (!added[v] && minWeight[v] > weight) {
                    parent[v] = u;
                    minWeight[v] = weight;
                }
            }
        }
        return ret;
    }
};
```

```
};
}
```

5.9 Lowest Common Ancestor

```
#define MAX_DEGREE 20

struct LCA {
    // root: 트리의루트설정 , n: 트리의노드개수
    // addEdge -> init -> query(0(Log(n))

    ll root, n;
    llv1 depth;
    llv2 adj;
    llv2 parent; // n X MAX_DEGREE

    LCA(ll root, ll n) : root(root), n(n) {
        depth.resize(n + 1);
        adj.resize(n + 1);
        parent.resize(n + 1, llv1(MAX_DEGREE, 0));
    }

    void addEdge(ll a, ll b) {
        adj[a].push_back(b);
        adj[b].push_back(a);
    }

    void init() {
        dfs(root, 0, 1);

        for(int i = 1; i < MAX_DEGREE; i++) {
            for(int j = 1; j <= n; j++) {
                parent[j][i] = parent[parent[j][i-1]][i-1];
            }
        }
    }

    void dfs(int here, int par, int d) {
        depth[here] = d;
        parent[here][0] = par;

        for(int there : adj[here]) {
            if(depth[there] > 0) continue;

            dfs(there, here, d + 1);
        }
    }

    int query(int a, int b) {
        if(depth[a] > depth[b]) {
            swap(a, b);
        }

        for(int i = MAX_DEGREE - 1; i >= 0; i--) {
            if (depth[b] - depth[a] >= (1 << i)) {

```

```

        b = parent[b][i];
    }
}

if(a == b) {
    return a;
}

for(int i = MAX_DEGREE - 1; i >= 0; i--) {
    if(parent[a][i] != parent[b][i]) {
        a = parent[a][i];
        b = parent[b][i];
    }
}

return parent[a][0];
}
};

```

5.10 Maxflow dinic

```

// usage:
// MaxFlowDinic::init(n);
// MaxFlowDinic::add_edge(0, 1, 100, 100); // for bidirectional edge
// MaxFlowDinic::add_edge(1, 2, 100); // directional edge
// result = MaxFlowDinic::solve(0, 2); // source -> sink
// graph[i][edgeIndex].res -> residual
//
// in order to find out the minimum cut, use `l'.
// if l[i] == 0, i is unreachble.
//
// O(V*V*E)
// with unit capacities, O(min(V^(2/3), E^(1/2)) * E)
struct MaxFlowDinic {
    typedef int flow_t;
    struct Edge {
        int next;
        size_t inv; /* inverse edge index */
        flow_t res; /* residual */
    };
};

int n;
vector<vector<Edge>> graph;
vector<int> q, l, start;

void init(int _n) {
    n = _n;
    graph.resize(n);
    for (int i = 0; i < n; i++) graph[i].clear();
}

void add_edge(int s, int e, flow_t cap, flow_t caprev = 0) {
    Edge forward{ e, graph[e].size(), cap };
    Edge reverse{ s, graph[s].size(), caprev };
    graph[s].push_back(forward);
    graph[e].push_back(reverse);
}

```

```

bool assign_level(int source, int sink) {
    int t = 0;
    memset(&l[0], 0, sizeof(l[0]) * l.size());
    l[source] = 1;
    q[t++] = source;
    for (int h = 0; h < t && !l[sink]; h++) {
        int cur = q[h];
        for (const auto& e : graph[cur]) {
            if (l[e.next] || e.res == 0) continue;
            l[e.next] = l[cur] + 1;
            q[t++] = e.next;
        }
    }
    return l[sink] != 0;
}

flow_t block_flow(int cur, int sink, flow_t current) {
    if (cur == sink) return current;
    for (int& i = start[cur]; i < graph[cur].size(); i++) {
        auto& e = graph[cur][i];
        if (e.res == 0 || l[e.next] != l[cur] + 1) continue;
        if (flow_t res = block_flow(e.next, sink, min(e.res, current))) {
            e.res -= res;
            graph[e.next][e.inv].res += res;
            return res;
        }
    }
    return 0;
}

flow_t solve(int source, int sink) {
    q.resize(n);
    l.resize(n);
    start.resize(n);
    flow_t ans = 0;
    while (assign_level(source, sink)) {
        memset(&start[0], 0, sizeof(start[0]) * n);
        while (flow_t flow = block_flow(source, sink, numeric_limits<flow_t>::max()))
            ans += flow;
    }
    return ans;
}
};

```

5.11 Maxflow Edmonds-Karp

```

struct MaxFlowEdgeDemands
{
    MaxFlowDinic mf;
    using flow_t = MaxFlowDinic::flow_t;

    vector<flow_t> ind, outd;
    flow_t D; int n;

    void init(int _n) {
        n = _n; D = 0; mf.init(n + 2);
    }
};

```

```

    ind.clear(); outd.clear();
    ind.resize(n, 0); outd.resize(n, 0);
}

void add_edge(int s, int e, flow_t cap, flow_t demands = 0) {
    mf.add_edge(s, e, cap - demands);
    D += demands; ind[e] += demands; outd[s] += demands;
}

// returns { false, 0 } if infeasible
// { true, maxflow } if feasible
pair<bool, flow_t> solve(int source, int sink) {
    mf.add_edge(sink, source, numeric_limits<flow_t>::max());

    for (int i = 0; i < n; i++) {
        if (ind[i]) mf.add_edge(n, i, ind[i]);
        if (outd[i]) mf.add_edge(i, n + 1, outd[i]);
    }

    if (mf.solve(n, n + 1) != D) return{ false, 0 };

    for (int i = 0; i < n; i++) {
        if (ind[i]) mf.graph[i].pop_back();
        if (outd[i]) mf.graph[i].pop_back();
    }

    return{ true, mf.solve(source, sink) };
}
};

```

5.12 MCMF SPFA

```

struct MCMF {
    struct Edge {
        ll to;
        ll capacity;
        ll cost;

        Edge* rev;
        Edge(ll to, ll capacity, ll cost) : to(to), capacity(capacity), cost(cost) {}
    };

    ll n;
    ll source, sink;
    vector<vector<Edge*>> graph;
    vector<bool> check;
    vector<ll> distance;
    vector<pair<ll, ll>> from;

    MCMF(ll n, ll source, ll sink): n(n), source(source), sink(sink) {
        // source: 시작점
        // sink: 도착점
        // n: 모델링한그래프의정점개수
    }
};

```

```

    graph.resize(n + 1);
    check.resize(n + 1);
    from.resize(n + 1, make_pair(-1, -1));
    distance.resize(n + 1);
};

void addEdge(ll u, ll v, ll cap, ll cost) {
    Edge *ori = new Edge(v, cap, cost);
    Edge *rev = new Edge(u, 0, -cost);

    ori->rev = rev;
    rev->rev = ori;

    graph[u].push_back(ori);
    graph[v].push_back(rev);
}

void addEdgeFromSrc(ll v, ll cap, ll cost) {
    // 출발지점에서출발하는간선추가
    addEdge(source, v, cap, cost);
}

void addEdgeToSink(ll u, ll cap, ll cost) {
    // 도착지점으로가는간선추가
    addEdge(u, sink, cap, cost);
}

bool spfa(ll &total_flow, ll &total_cost) {
    // spfa 기반의 MCMF

    fill(check.begin(), check.end(), false);
    fill(distance.begin(), distance.end(), INF);
    fill(from.begin(), from.end(), make_pair(-1, -1));

    distance[source] = 0;
    queue<ll> q;
    q.push(source);

    while(!q.empty()) {
        ll x = q.front(); q.pop();

        check[x] = false;

        for(ll i = 0; i < graph[x].size(); i++) {
            Edge* e = graph[x][i];
            ll y = e->to;

            if(e->capacity > 0 && distance[x] + e->cost < distance[y]) {
                distance[y] = distance[x] + e->cost;
                from[y] = make_pair(x, i);

                if(!check[y]) {
                    check[y] = true;
                    q.push(y);
                }
            }
        }
    }
}

```

```

    }
}

if(distance[sink] == INF) return false;

// 간선들에서부터 sink 역추적하여경로를만든다 .
ll x = sink;
ll c = graph[from[x].first][from[x].second]->capacity;

while(from[x].first != -1) {
    if(c > graph[from[x].first][from[x].second]->capacity) {
        c = graph[from[x].first][from[x].second]->capacity;
    }
    x = from[x].first;
}

// 만든경로를따라유량을흘린다 .
x = sink;
while(from[x].first != -1) {
    Edge* e = graph[from[x].first][from[x].second];
    e->capacity -= c;
    e->rev->capacity += c;
    x = from[x].first;
}

total_flow += c;
total_cost += c * distance[sink];

return true;
}

pair <ll, ll> flow() {
    ll total_flow = 0;
    ll total_cost = 0;

    while(spfa(total_flow, total_cost));

    return make_pair(total_flow, total_cost);
}
};

```

5.13 MCMF

```

// precondition: there is no negative cycle.
// usage:
// MinCostFlow mcf(n);
// for(each edges) mcf.addEdge(from, to, cost, capacity);
// mcf.solve(source, sink); // min cost max flow
// mcf.solve(source, sink, 0); // min cost flow
// mcf.solve(source, sink, goal_flow); // min cost flow with total_flow >=
// goal_flow if possible
struct MinCostFlow {
    typedef int cap_t;

```

```

    typedef int cost_t;

    bool iszerocap(cap_t cap) { return cap == 0; }

    struct edge {
        int target;
        cost_t cost;
        cap_t residual_capacity;
        cap_t orig_capacity;
        size_t revid;
    };

    int n;
    vector<vector<edge>> graph;

    MinCostFlow(int n) : graph(n), n(n) {}

    void addEdge(int s, int e, cost_t cost, cap_t cap) {
        if (s == e) return;
        edge forward{ e, cost, cap, cap, graph[e].size() };
        edge backward{ s, -cost, 0, 0, graph[s].size() };
        graph[s].emplace_back(forward);
        graph[e].emplace_back(backward);
    }

    pair<cost_t, cap_t> augmentShortest(int s, int e, cap_t flow_limit) {
        auto infinite_cost = numeric_limits<cost_t>::max();
        auto infinite_flow = numeric_limits<cap_t>::max();
        vector<pair<cost_t, cap_t>> dist(n, make_pair(infinite_cost, 0));
        vector<int> from(n, -1), v(n);

        dist[s] = pair<cost_t, cap_t>(0, infinite_flow);
        queue<int> q;
        v[s] = 1; q.push(s);
        while(!q.empty()) {
            int cur = q.front();
            v[cur] = 0; q.pop();
            for (const auto& e : graph[cur]) {
                if (iszerocap(e.residual_capacity)) continue;
                auto next = e.target;
                auto ncost = dist[cur].first + e.cost;
                auto nflow = min(dist[cur].second, e.residual_capacity);
                if (dist[next].first > ncost) {
                    dist[next] = make_pair(ncost, nflow);
                    from[next] = e.revid;
                    if (v[next]) continue;
                    v[next] = 1; q.push(next);
                }
            }
        }

        auto p = e;
        auto pathcost = dist[p].first;
        auto flow = dist[p].second;
        if (iszerocap(flow) || (flow_limit <= 0 && pathcost >= 0)) return pair<

```

```

    cost_t, cap_t>(0, 0);
    if (flow_limit > 0) flow = min(flow, flow_limit);

    while (from[p] != -1) {
        auto nedge = from[p];
        auto np = graph[p][nedge].target;
        auto fedge = graph[p][nedge].revid;
        graph[p][nedge].residual_capacity += flow;
        graph[np][fedge].residual_capacity -= flow;
        p = np;
    }
    return make_pair(pathcost * flow, flow);
}

pair<cost_t, cap_t> solve(int s, int e, cap_t flow_minimum = numeric_limits<
cap_t>::max()) {
    cost_t total_cost = 0;
    cap_t total_flow = 0;
    for(;;) {
        auto res = augmentShortest(s, e, flow_minimum - total_flow);
        if (res.second <= 0) break;
        total_cost += res.first;
        total_flow += res.second;
    }
    return make_pair(total_cost, total_flow);
}
};

```

6 String

6.1 KMP

```

struct KMP {
    /*
     * s 문자열에서 문자열을 o 찾습니다. 매칭이 시작되는 인덱스 목록을 반환합니다
     *
     * Time: O(n + m)
     */
    vector<int> result;
    int MX;
    string s, o;
    int n, m; // n : s.length(), m : o.length();
    vector<int> fail;

    KMP(string s, string o) : s(s), o(o) {
        n = s.length();
        m = o.length();
        MX = max(n, m) + 1;
        fail.resize(MX, 0);

        run();
    }

    void run() {

```

```

        for(int i = 1, j = 0; i < m; i++){
            while(j > 0 && o[i] != o[j]) j = fail[j-1];
            if(o[i] == o[j]) fail[i] = ++j;
        }
        for(int i = 0, j = 0; i < n; i++) {
            while(j > 0 && s[i] != o[j]) {
                j = fail[j - 1];
            }
            if(s[i] == o[j]) {
                if(j == m - 1) {
                    // matching OK;
                    result.push_back(i - m + 1);
                    j = fail[j];
                }
                else {
                    j++;
                }
            }
        }
    }
};

```

6.2 Manacher

// Use space to insert space between each character
 // To get even length palindromes!
 // O(|str|)

```

vector<int> manacher(string &s) {
    int n = s.size(), R = -1, p = -1;
    vector<int> A(n);
    for (int i = 0; i < n; i++) {
        if (i <= R) A[i] = min(A[2 * p - i], R - i);
        while (i - A[i] - 1 >= 0 && i + A[i] + 1 < n && s[i - A[i] - 1] == s[i + A[i]
            ] + 1))
            A[i]++;
        if (i + A[i] > R)
            R = i + A[i], p = i;
    }
    return A;
}

string space(string &s) {
    string t;
    for (char c : s) t += c, t += ' ';
    t.pop_back();
    return t;
}

int maxpalin(vector<int> &M, int i) {
    if (i % 2) return (M[i] + 1) / 2 * 2;
    return M[i] / 2 * 2 + 1;
}

```

6.3 Suffix Array

```
typedef char T;
```

```
// calculates suffix array.
```

```
// O(n*logn)
```

```
vector<int> suffix_array(const vector<T>& in) {
    int n = (int)in.size(), c = 0;
    vector<int> temp(n), pos2bckt(n), bckt(n), bpos(n), out(n);
    for (int i = 0; i < n; i++) out[i] = i;
    sort(out.begin(), out.end(), [&](int a, int b) { return in[a] < in[b]; });
    for (int i = 0; i < n; i++) {
        bckt[i] = c;
        if (i + 1 == n || in[out[i]] != in[out[i + 1]]) c++;
    }
    for (int h = 1; h < n && c < n; h <= 1) {
        for (int i = 0; i < n; i++) pos2bckt[out[i]] = bckt[i];
        for (int i = n - 1; i >= 0; i--) bpos[bckt[i]] = i;
        for (int i = 0; i < n; i++)
            if (out[i] >= n - h) temp[bpos[bckt[i]]++] = out[i];
        for (int i = 0; i < n; i++)
            if (out[i] >= h) temp[bpos[pos2bckt[out[i] - h]]++] = out[i] - h;
        c = 0;
        for (int i = 0; i + 1 < n; i++) {
            int a = (bckt[i] != bckt[i + 1]) || (temp[i] >= n - h)
                || (pos2bckt[temp[i + 1] + h] != pos2bckt[temp[i] + h]);
            bckt[i] = c;
            c += a;
        }
        bckt[n - 1] = c++;
        temp.swap(out);
    }
    return out;
}
```

```
// calculates lcp array. it needs suffix array & original sequence.
```

```
// O(n)
```

```
vector<int> lcp(const vector<T>& in, const vector<int>& sa) {
    int n = (int)in.size();
    if (n == 0) return vector<int>();
    vector<int> rank(n), height(n - 1);
    for (int i = 0; i < n; i++) rank[sa[i]] = i;
    for (int i = 0, h = 0; i < n; i++) {
        if (rank[i] == 0) continue;
        int j = sa[rank[i] - 1];
        while (i + h < n && j + h < n && in[i + h] == in[j + h]) h++;
        height[rank[i] - 1] = h;
        if (h > 0) h--;
    }
    return height;
}
```

6.4 Trie

```
int chToIdx(char ch) { return ch - 'a'; }
```

```
struct Trie {
    int terminal = -1;
    Trie *fail; // fail, 은output 아호코라식에서사용
    vector<int> output;
    Trie *chil[ALPHABETS];
    Trie() {
        for (int i = 0; i < ALPHABETS; i++)
            chil[i] = NULL;
    }
    // number -> 문자열번호 (ith string)
    void insert(string &s, int number, int idx) {
        if (idx == s.size()) {
            terminal = number;
            return;
        }
        int next = chToIdx(s[idx]);
        if (chil[next] == NULL)
            chil[next] = new Trie();
        chil[next]->insert(s, number, idx + 1);
    }
    int find(string &s, int idx = 0) {
        if (idx == s.size())
            return terminal;
        int next = chToIdx(s[idx]);
        if (chil[next] == NULL)
            return false;
        return chil[next]->find(s, idx + 1);
    }
};
```

6.5 Aho-Corasick

```
void computeFail(Trie *root) {
    queue<Trie *> q;
    root->fail = root;
    q.push(root);
    while (!q.empty()) {
        Trie *here = q.front();
        q.pop();
        for (int i = 0; i < ALPHABETS; i++) {
            Trie *child = here->chil[i];
            if (!child) continue;
            if (here == root) child->fail = root;
            else {
                Trie *t = here->fail;
                while (t != root && t->chil[i] == NULL) t = t->fail;
                if (t->chil[i]) t = t->chil[i];
                child->fail = t;
            }
            child->output = child->fail->output;
            if (child->terminal != -1) child->output.push_back(child->terminal);
            q.push(child);
        }
    }
}
```

```
vector<pair<int, int>> ahoCorasick(string &s, Trie *root) {
    vector<pair<int, int>> ret;
    Trie *state = root;
    for (int i = 0; i < s.size(); i++) {
        int idx = chToIdx(s[i]);
        while (state != root && state->chil[idx] == NULL) state = state->fail;
        if (state->chil[idx]) state = state->chil[idx];
        for (int j = 0; j < state->output.size(); j++) ret.push_back({i, state->output[j]});
    }
    return ret;
}
```

6.6 Z Algorithm

```
// Z[i] : maximum common prefix length of &s[0] and &s[i]
// O(|s|)
using seq_t = string;
vector<int> z_func(const seq_t &s) {
    vector<int> z(s.size());
    z[0] = s.size();
    int l = 0, r = 0;

    for (int i = 1; i < s.size(); i++) {
        if (i > r) {
            int j;
            for (j = 0; i + j < s.size() && s[i + j] == s[j]; j++) ;
            z[i] = j; l = i; r = i + j - 1;
        } else if (z[i - l] < r - i + 1) {
            z[i] = z[i - l];
        } else {
            int j;
            for (j = 1; r + j < s.size() && s[r + j] == s[r - i + j]; j++) ;
            z[i] = r - i + j; l = i; r += j - 1;
        }
    }

    return z;
}
```

7 Dynamic Programming

7.1 LIS

```
struct LIS {
    llv1 ar;

    llv1 v, buffer;
    llv1::iterator vv;
    vector<pair<ll, ll> > d;

    void perform() {
        v.pb(2000000000ll);
```

```
ll n = sz(ar);

for1(0, n){
    if (ar[i] > *v.rbegin()) {
        v.pb(ar[i]);
        d.push_back({ v.size() - 1, ar[i] });
    }
    else {
        vv = lower_bound(v.begin(), v.end(), ar[i]);
        *vv = ar[i];
        d.push_back({ vv - v.begin(), ar[i] });
    }
}

for(int i = sz(d) - 1; i > -1; i--){
    if(d[i].first == sz(v)-1){
        buffer.pb(d[i].second);
        v.pop_back();
    }
}

reverse(buffer.begin(), buffer.end());

ll length() {
    return buffer.size();
}

llv1 result() {
    return buffer;
}
};
```

7.2 LIS only length

```
ll lis(llv1& ar) {
    llv1 v, buffer;
    llv1::iterator vv;
    v.pb(2000000000ll);

    ll n = sz(ar);

    for1(0, n){
        if(ar[i] > *v.rbegin()) {
            v.pb(ar[i]);
        }
        else{
            vv = lower_bound(v.begin(), v.end(), ar[i]);
            *vv = ar[i];
        }
    }
    return sz(v);
}
```

7.3 Knapsack

```
ll N, maxWeight, ans;
ll D[2][11000];
ll weight[110], cost[110];
void knapsack() {
    for (int x = 1; x <= N; x++) {
        for (int y = 0; y <= maxWeight; y++) {
            if (y >= weight[x]) {
                D[x % 2][y] = max(D[(x + 1) % 2][y], D[(x + 1) % 2][y - weight[x]] + cost[x]);
            } else {
                D[x % 2][y] = D[(x + 1) % 2][y];
            }
            ans = max(ans, D[x % 2][y]);
        }
    }
}
void input() {
    cin >> N >> maxWeight;
    for (int x = 1; x <= N; x++) {
        cin >> weight[x] >> cost[x];
    }
}
```

7.4 Coin Change

```
// 경우의수
ll CC(ll v1 &coin, ll money, ll MX) {
    ll D[MX];
    fill(D, D + MX, 0);
    D[0] = 1;
    for (int i = coin.size() - 1; i >= 0; i--) {
        for (int j = coin[i]; j <= money; j++) {
            D[j] += D[j - coin[i]];
            D[j] %= MOD;
        }
    }
    return D[money] % MOD;
}
```

7.5 Bit Field DP

```
#define MOD 9901;

int dp[1 << 14 + 1][200];
int n, m;

int solve(int pos, int check, int dep) {
    if (dp[check][pos] != 0) return dp[check][pos];
    int &ret = dp[check][pos];
    if (dep == n * m) return ret = 1;
    if ((check & 1)) return ret = solve(pos - 1, check >> 1, dep) % MOD;

    int sum = 0;
```

```
    if (!(check & 1) && (pos - 1) / m > 0)
        sum += solve(pos - 1, (check >> 1) | (1 << (m - 1)), dep + 2) % MOD;
    if (!(check & 1) && pos % m != 1 && !(check & 2) && pos >= 2 && m > 1)
        sum += solve(pos - 2, check >> 2, dep + 2) % MOD;
    // cout<<pos<<" "<<check<<" "<<dep<<" "<<sum<<endl;

    return ret = sum % MOD;
}
int main() {
    cin >> n >> m;

    if (n * m % 2 == 1)
        cout << 0;
    else
        cout << solve(n * m, 0, 0) % MOD;

    return 0;
}
```

7.6 Knuth Optimization

```
int solve(int n) {
    for (int m = 2; m <= n; m++) {
        for (int i = 0; m + i <= n; i++) {
            int j = i + m;
            for (int k = K[i][j - 1]; k <= K[i + 1][j]; k++) {
                int now = dp[i][k] + dp[k][j] + sum[j] - sum[i];
                if (dp[i][j] > now)
                    dp[i][j] = now, K[i][j] = k;
            }
        }
    }
    return dp[0][n];
}

int main() {
    int n;
    cin >> n;
    fill(&dp[0][0], &dp[MAX-1][MAX-1], INF);
    for (int i = 1; i <= n; i++){
        cin >> arr[i];
        sum[i] = sum[i - 1] + arr[i];
        K[i - 1][i] = i;
        dp[i - 1][i] = 0;
    }
    cout << solve(n) << "\n";
}

/*
if
C[a][c] + C[b][d] <= C[a][d] + C[b][c] (a<=b<=c<=d)
C[b][c] <= C[a][d] (a<=b<=c<=d)

then
dp[i][j] = min(dp[i][k] + dp[k][j]) + C[i][j]
```


range of k: A[i, j-1] <= A[i][j]=k <= A[i+1][j]
 */