

# Содержание

## 1 Common

- 1 Setup . . . . .
- 2 Template . . . . .
- 3 Stress . . . . .
- 4 Java . . . . .

## 2 Big numbers

- 5 Big Int . . . . .
- 6 FFT . . . . .
- 7 FFT by mod and FFT with digits up to  $10^6$  . . . . .

## 3 Data Structures

- 8 Centroid Decomposition . . . . .
- 9 Convex Hull Trick . . . . .
- 10 DSU . . . . .
- 11 Fenwick Tree . . . . .
- 12 Hash Table . . . . .
- 13 Heavy Light Decomposition . . . . .
- 14 Next Greater in Segment Tree . . . . .
- 15 Sparse Table . . . . .
- 16 Fenwick Tree 2D . . . . .

## 4 Dynamic Programming

- 17 LIS . . . . .
- 18 DP tree . . . . .
- 19 Masks tricks . . . . .

## 5 Flows

- 20 Utilities . . . . .
- 21 Ford-Fulkerson . . . . .
- 22 Dinic . . . . .
- 23 Hungarian . . . . .
- 24 Min Cost Max Flow . . . . .

## 6 Games

- 25 Retrograde Analysis . . . . .

## 7 Geometry

- 26 ClosestPoints (SweepLine) . . . . .
- 27 ConvexHull . . . . .
- 28 GeometryBase . . . . .
- 29 GeometryInterTangent . . . . .
- 30 GeometrySimple . . . . .
- 31 Halfplanes Intersection . . . . .

## 8 Graphs

- 32 2-SAT . . . . .
- 33 Bridges . . . . .
- 34 Cut Points . . . . .
- 35 Eulerian Cycle . . . . .
- 36 Euler Tour Tree . . . . .
- 37 Hamilton Cycle . . . . .
- 38 Karp with cycle . . . . .
- 39 Kuhn's algorithm . . . . .
- 40 LCA . . . . .
- 41 LCA offline (Tarjan) . . . . .

## 9 Math

- 42 CRT (KTO) . . . . .
- 43 Discrete Logarithm . . . . .
- 44 Discrete Root . . . . .
- 45 Eratosthenes . . . . .
- 46 Factorial . . . . .
- 47 Gauss . . . . .
- 48 Gauss binary . . . . .
- 49 Gcd . . . . .
- 50 Gray . . . . .
- 51 Miller-Rabin Test . . . . .
- 52 Phi . . . . .
- 53 Pollard . . . . .
- 54 Power And Mul . . . . .

- 55 Primitive Root . . . . .
- 56 Simpson . . . . .

## 10. Strings

- 57. Aho-Corasick . . . . .
- 58. Prefix-function . . . . .
- 59. Z-function . . . . .
- 60 Hashes . . . . .
- 61 Manaker . . . . .
- 62. Palindromic Tree . . . . .
- 63. Suffix Array (+stable) . . . . .
- 64. Suffix Automaton . . . . .
- 65 Suffix Tree . . . . .

## 11. C++ Tricks

- 66. Fast allocation . . . . .
- 67. Hash of pair . . . . .
- 68. Ordered Set . . . . .
- 69. Hash Map . . . . .
- 70. Fast I/O (short) . . . . .
- 71. Fast I/O (long) . . . . .

## 12. Notes

- 72 Работа с деревьями . . . . .
- 73 Маски . . . . .
- 74. Гранди . . . . .
- 75. Потоки . . . . .
- 76. ДП . . . . .
- 77 Комбинаторика . . . . .

2

2

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# 1 Common

## 1 Setup

1. Terminal: font Monospace 12
2. Gedit: Oblivion, font Monospace 12, auto indent, display line numbers, tab 4, highlight matching brackets, highlight current line, F9 (side panel)
3. `/bashrc: export CXXFLAGS='-Wall -Wshadow -Wextra -Wconversion -Wno-unused-result -Wno-deprecated-declarations -O2 -std=gnu++11 -g -DLOCAL'`
4. `for i in {A..K}; do mkdir $i; cp main.cpp $i/$i.cpp; done`

## 2 Template

main.cpp:

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

using namespace std;

#define pb push_back
#define mp make_pair
#define fst first
#define snd second
#define sz(x) (int) ((x).size())
#define forn(i, n) for (int i = 0; i < (n); ++i)
#define fornr(i, n) for (int i = (n) - 1; i >= 0; --i)
#define forab(i, a, b) for (int i = (a); i < (b); ++i)
#define all(c) (c).begin(), (c).end()

using ll = long long;
using vi = vector<int>;
using pii = pair<int, int>;

#define FNAME ""

int main() {
#ifdef LOCAL
    freopen(FNAME".in", "r", stdin);
    freopen(FNAME".out", "w", stdout);
#endif
    cin.tie(0);
    ios_base::sync_with_stdio(0);

    return 0;
}
```

## 3 Stress

stress.sh:

```
#!/bin/bash

for ((i = 0;; i++)); do
    ./gen $i >in || exit
    ./main <in >out1 || exit
    ./stupid <in >out2 || exit
    diff out1 out2 || exit
    echo $i OK
done
```

## 4 Java

Java template:

```
import java.io.BufferedReader;
import java.io.FileNotFoundException;
import java.io.FileReader;
```

```
import java.io.IOException;
import java.io.InputStreamReader;
import java.io.PrintWriter;
import java.util.*;
```

```
public class Main {
    IFastScanner in;
    IPrintWriter out;
```

```
Ivoid solve() {
    Iint a = in.nextInt();
    Iint b = in.nextInt();
    Iout.print(a + b);
    I}

Ivoid run() {
    Itry {
        IIn = new FastScanner("input.txt");
        Iout = new PrintWriter("output.txt");
        Isolve();
        Iout.flush();
        Iout.close();
        Icatch (FileNotFoundException e) {
            Ie.printStackTrace();
            ISystem.exit(1);
        I}

        Iclass FastScanner {
            IBufferedReader br;
            IStringTokenizer st;
```

```
Ipublic FastScanner() {
    Ibr = new BufferedReader(new
        InputStreamReader(System.in));
    I}

    Ipublic FastScanner(String s) {
        Itry {
            Ibr = new BufferedReader(new FileReader(s));
            Icatch (FileNotFoundException e) {
                Ie.printStackTrace();
            I}

            IString nextToken() {
                Iwhile (st == null || !st.hasMoreElements()) {
                    Itry {
                        Ist = new StringTokenizer(br.readLine());
                        Icatch (IOException e) {
                            Ie.printStackTrace();
                        I}

                        Ireturn st.nextToken();
                    I}

                    Iint nextInt() {
                        Ireturn Integer.parseInt(nextToken());
                    I}

                    Ilong nextLong() {
                        Ireturn Long.parseLong(nextToken());
                    I}

                    Idouble nextDouble() {
                        Ireturn Double.parseDouble(nextToken());
                    I}

                    Ichar nextChar() {
                        Itry {
                            Ireturn (char) (br.read());
                        Icatch (IOException e) {
                            Ie.printStackTrace();
                        I}
                    I}
                I}
            I}
        I}
    I}
}
```

```
I}

Ipublic FastScanner() {
    Ibr = new BufferedReader(new
        InputStreamReader(System.in));
    I}

    Ipublic FastScanner(String s) {
        Itry {
            Ibr = new BufferedReader(new FileReader(s));
            Icatch (FileNotFoundException e) {
                Ie.printStackTrace();
            I}

            IString nextToken() {
                Iwhile (st == null || !st.hasMoreElements()) {
                    Itry {
                        Ist = new StringTokenizer(br.readLine());
                        Icatch (IOException e) {
                            Ie.printStackTrace();
                        I}

                        Ireturn st.nextToken();
                    I}

                    Iint nextInt() {
                        Ireturn Integer.parseInt(nextToken());
                    I}

                    Ilong nextLong() {
                        Ireturn Long.parseLong(nextToken());
                    I}

                    Idouble nextDouble() {
                        Ireturn Double.parseDouble(nextToken());
                    I}

                    Ichar nextChar() {
                        Itry {
                            Ireturn (char) (br.read());
                        Icatch (IOException e) {
                            Ie.printStackTrace();
                        I}
                    I}
                I}
            I}
        I}
    I}
}
```

```
Iint nextInt() {
    Ireturn Integer.parseInt(nextToken());
    I}

Ilong nextLong() {
    Ireturn Long.parseLong(nextToken());
    I}

Idouble nextDouble() {
    Ireturn Double.parseDouble(nextToken());
    I}

Ichar nextChar() {
    Itry {
        Ireturn (char) (br.read());
    Icatch (IOException e) {
        Ie.printStackTrace();
    I}
    I}
}
```

```
Ilong nextLong() {
    Ireturn Long.parseLong(nextToken());
    I}

Idouble nextDouble() {
    Ireturn Double.parseDouble(nextToken());
    I}

Ichar nextChar() {
    Itry {
        Ireturn (char) (br.read());
    Icatch (IOException e) {
        Ie.printStackTrace();
    I}
    I}
}
```

```
Idouble nextDouble() {
    Ireturn Double.parseDouble(nextToken());
    I}

Ichar nextChar() {
    Itry {
        Ireturn (char) (br.read());
    Icatch (IOException e) {
        Ie.printStackTrace();
    I}
    I}
}
```

```
Ichar nextChar() {
    Itry {
        Ireturn (char) (br.read());
    Icatch (IOException e) {
        Ie.printStackTrace();
    I}
    I}
}
```

```

~I~I~I} catch (IOException e) {
~I~I~I~Ie.printStackTrace();
~I~I~I}
~I~I~Ireturn 0;
~I~I~I}

~I~I~IString nextLine() {
~I~I~I~Itry {
~I~I~I~I~Ireturn br.readLine();
~I~I~I~I} catch (IOException e) {
~I~I~I~I~Ie.printStackTrace();
~I~I~I~I}
~I~I~I~Ireturn "";
~I~I~I}
~I~I}

~I~Ipublic static void main(String[] args) {
~I~I~Inew Main().run();
~I~I}
}

```

## 2 Big numbers

### 5 Big Int

```

const int BASE_LEN = 9;
const int NUM_LEN = 50000 / BASE_LEN + 2; // LEN <= NUM_LEN *
↳ BASE_LEN
const int BASE = pow(10, BASE_LEN);
const ll INF = 8e18, ADD = INF / BASE;

struct num {
    ll a[NUM_LEN];
    int len; // always > 0

    inline const ll& operator [] ( int i ) const { return a[i];
    ↳ }
    inline ll& operator [] ( int i ) { return a[i]; }

    num& operator = ( const num &x ) { // copy
        len = x.len;
        memcpy(a, x.a, sizeof(a[0]) * len);
        return *this;
    }

    num( const num &x ) { *this = x; } // copy

    num() { len = 1, a[0] = 0; } // 0
    num( ll x ) { // x
        len = 0;
        while (!len || x) {
            assert(len < NUM_LEN); // to catch overflow
            a[len++] = x % BASE, x /= BASE;
        }
    }

    num& cor() {
        while (a[len - 1] >= BASE) {
            assert(len < NUM_LEN); // to catch overflow
            if (a[len - 1] >= 2 * BASE)
                a[len] = a[len - 1] / BASE, a[len - 1] %= BASE;
            else
                a[len] = 1, a[len - 1] -= BASE;
            len++;
        }
        while (len > 1 && !a[len - 1])
            len--;
        return *this;
    }
}

```

```

int length() {
    if (!len)
        return 0;
    int x = a[len - 1], res = 0;
    assert(x);
    while (x || !res)
        x /= 10, res++;
    return res + (len - 1) * BASE_LEN;
}

void out() const {
    int i = len - 1;
    printf("%d", (int)a[i--]);
    while (i >= 0)
        printf("%0*d", BASE_LEN, (int)a[i--]);
    puts("");
}

void init( const char *s ) {
    int sn = strlen(s);
    while (sn && s[sn - 1] <= 32)
        sn--;
    len = (sn + BASE_LEN - 1) / BASE_LEN;
    memset(a, 0, sizeof(a[0]) * len);
    forn(i, sn) {
        ll &r = a[(sn - i - 1) / BASE_LEN];
        r = r * 10 + (s[i] - '0');
    }
}

bool read() {
    static const int L = NUM_LEN * BASE_LEN + 1;
    static char s[L];
    if (!fgets(s, L, stdin))
        return 0;
    assert(!s[L - 2]);
    init(s);
    return 1;
}

void mul2() {
    forn(i, len)
        a[i] <<= 1;
    forn(i, len - 1)
        if (a[i] >= BASE)
            a[i + 1]++, a[i] -= BASE;
    cor();
}

void div2() {
    for (int i = len - 1; i >= 0; i--) {
        if (i && (a[i] & 1))
            a[i - 1] += BASE;
        a[i] >>= 1;
    }
    cor();
}

static ll cmp( ll *a, ll *b, int n ) {
    while (n--)
        if (a[n] != b[n])
            return a[n] - b[n];
    return 0;
}

int cmp( const num &b ) const {
    if (len != b.len)
        return len - b.len;
    for (int i = len - 1; i >= 0; i--)
        if (a[i] != b[i])
            return a[i] - b[i];
}

```

```

    return 0;
}

bool zero() {
    return len == 1 && !a[0];
}

/** c = this/b, this %= b */
num &div( num b, num &c ) {
    c.len = len - b.len;
    for (int i = c.len; i >= 0; i--) {
        int k = (1.0L * a[len - 1] * BASE + (len >= 2 ? a[len - 2] : 0)) / (1.0L * b[b.len - 1] * BASE + (b.len >= 2 ? b[b.len - 2] + 1 : 0));
        c[i] = 0;
        if (k > 0) {
            c[i] += k;
            forn(j, b.len)
                a[i + j] -= (1L)b[j] * k;
            forn(j, b.len)
                if (a[i + j] < 0) {
                    1L k = (-a[i + j] + BASE - 1) / BASE;
                    a[i + j] += k * BASE, a[i + j + 1] -= k;
                }
        }
        if (i)
            len--, a[len - 1] += a[len] * BASE, a[len] = 0;
        else if (cmp(a, b.a, b.len) >= 0) {
            c[0]++;
            forn(j, b.len)
                if ((a[j] -= b[j]) < 0)
                    a[j] += BASE, a[j + 1]--;
        }
    }
    if (c.len < 0)
        c[c.len = 0] = 0;
    forn(i, c.len)
        if (c[i] >= BASE)
            c[i + 1] += c[i] / BASE, c[i] %= BASE;
    c.len += (!c.len || c[c.len]);
    return cor();
}

num& operator += ( num &a, const num &b ) {
    while (a.len < b.len)
        a[a.len++] = 0;
    forn(i, b.len)
        a[i] += b[i];
    forn(i, a.len - 1)
        if (a[i] >= BASE)
            a[i] -= BASE, a[i + 1]++;
    return a.cor();
}

num& operator -= ( num &a, const num &b ) {
    while (a.len < b.len)
        a[a.len++] = 0;
    forn(i, b.len)
        a[i] -= b[i];
    forn(i, a.len - 1)
        if (a[i] < 0)
            a[i] += BASE, a[i + 1]--;
    assert(a[a.len - 1] >= 0); // a >= b
    return a.cor();
}

num& operator *= ( num &a, int k ) {
    if (k == 1)
        return a;
    if (k == 0) {
        a.len = 0;
        return a;
    }
    forn(i, a.len)
        a[i] *= k;
    forn(i, a.len - 1)
        if (a[i] >= BASE)
            a[i + 1] += a[i] / BASE, a[i] %= BASE;
    return a.cor();
}

num& operator /= ( num &a, int k ) {
    if (k == 1)
        return a;
    assert(k != 0);
    for (int i = a.len - 1; i > 0; i--)
        a[i - 1] += (1L)(a[i] % k) * BASE, a[i] /= k;
    a[0] /= k;
    return a.cor();
}

num& mul( const num &a, const num &b, num &x ) {
    assert(a.len + b.len - 1 <= NUM_LEN);
    memset(x.a, 0, sizeof(x[0]) * (a.len + b.len - 1));
    forn(i, a.len)
        forn(j, b.len)
            if ((x[i + j] += a[i] * b[j]) >= INF)
                x[i + j + 1] += ADD, x[i + j] -= INF;
    x.len = a.len + b.len - 1;
    forn(i, x.len - 1)
        if (x[i] >= BASE)
            x[i + 1] += x[i] / BASE, x[i] %= BASE;
    return x.cor();
}

bool operator == ( const num &a, const num &b ) { return a.comp(b) == 0; }
bool operator != ( const num &a, const num &b ) { return a.comp(b) != 0; }
bool operator < ( const num &a, const num &b ) { return a.comp(b) < 0; }
bool operator > ( const num &a, const num &b ) { return a.comp(b) > 0; }
bool operator <= ( const num &a, const num &b ) { return a.comp(b) <= 0; }
bool operator >= ( const num &a, const num &b ) { return a.comp(b) >= 0; }

num& add( const num &a, const num &b, num &c ) { c = a; c += b; return c; }
num& sub( const num &a, const num &b, num &c ) { c = a; c -= b; return c; }
num& mul( const num &a, int k, num &c ) { c = a; c *= k; return c; }
num& div( const num &a, int k, num &c ) { c = a; c /= k; return c; }

num& operator *= ( num &a, const num &b ) {
    static num tmp;
    mul(a, b, tmp);
    return a = tmp;
}

num operator ^ ( const num &a, int k ) {
    num res(1);
    forn(i, k)
        res *= a;
    return res;
}

num& gcd_binary( num &a, num &b ) {

```

```

int cnt = 0;
while (!a.zero() && !b.zero()) {
    while (!(b[0] & 1) && !(a[0] & 1))
        cnt++, a.div2(), b.div2();
    while (!(b[0] & 1))
        b.div2();
    while (!(a[0] & 1))
        a.div2();
    if (a.cmp(b) < 0)
        b -= a;
    else
        a -= b;
}
if (a.zero())
    std::swap(a, b);
while (cnt)
    a.mul2(), cnt--;
return a;
}

num& gcd( num &a, num &b ) {
    static num tmp;
    return b.zero() ? a : gcd(b, a.div(b, tmp));
}

```

## 6 FFT

```

int rev[MAX_N];

//typedef complex<dbl> Num;
struct Num {
    dbl x, y;
    Num() {}
    Num(dbl _x, dbl _y): x(_x), y(_y) {}
    inline dbl real() const { return x; }
    inline dbl imag() const { return y; }
    inline Num operator+(const Num &B) const { return Num(x +
        ↪ B.x, y + B.y); }
    inline Num operator-(const Num &B) const { return Num(x -
        ↪ B.x, y - B.y); }
    inline Num operator*(dbl k) const { return Num(x * k, y *
        ↪ k); }
    inline Num operator*(const Num &B) const { return Num(x *
        ↪ B.x - y * B.y, x * B.y + y * B.x); }
    inline void operator+=(const Num &B) { x += B.x, y += B.y; }
    inline void operator/=(dbl k) { x /= k, y /= k; }
    inline void operator*=(const Num &B) { *this = *this * B; }
};

Num rt[MAX_N];

inline Num sqr(const Num &x) { return x * x; }
inline Num conj(const Num &x) { return Num(x.real(),
    ↪ -x.imag()); }

inline int getN(int n) {
    int k = 1;
    while(k < n)
        k <<= 1;
    return k;
}

void fft(Num *a, int n) {
    assert(rev[1]); // don't forget to init
    int q = MAX_N / n;
    forn (i, n)
        if(i < rev[i] / q)
            swap(a[i], a[rev[i] / q]);
    for (int k = 1; k < n; k <<= 1)
        for (int i = 0; i < n; i += 2 * k)
            forn (j, k) {

```

```

                const Num z = a[i + j + k] * rt[j + k];
                a[i + j + k] = a[i + j] - z;
                a[i + j] += z;
            }
        }

void fftInv(Num *a, int n) {
    fft(a, n);
    reverse(a + 1, a + n);
    forn (i, n)
        a[i] /= n;
}

void doubleFft(Num *a, Num *fa, Num *fb, int n) { // only if
    ↪ you need it
    fft(a, n);
    const int n1 = n - 1;
    forn (i, n) {
        const Num &z0 = a[i], &z1 = a[(n - i) & n1];
        fa[i] = Num(z0.real() + z1.real(), z0.imag() - z1.imag())
            ↪ * 0.5;
        fb[i] = Num(z0.imag() + z1.imag(), z1.real() - z0.real())
            ↪ * 0.5;
    }
}

```

```

Num tmp[MAX_N];
template<class T>
void mult(T *a, T *b, T *r, int n) { // n = 2^k
    forn (i, n)
        tmp[i] = Num((dbl) a[i], (dbl) b[i]);
    fft(tmp, n);
    const int n1 = n - 1;
    const Num c = Num(0, -0.25 / n);
    fornr (i, n / 2 + 1) {
        const int j = (n - i) & n1;
        const Num z0 = sqr(tmp[i]), z1 = sqr(tmp[j]);
        tmp[i] = (z1 - conj(z0)) * c;
        tmp[j] = (z0 - conj(z1)) * c;
    }
    fft(tmp, n);
    forn (i, n)
        r[i] = (T) round(tmp[i].real());
}

void init() { // don't forget to init
    forn(i, MAX_N)
        rev[i] = (rev[i >> 1] >> 1) + ((i & 1) << (LOG - 1));

    rt[1] = Num(1, 0);
    for (int k = 1, p = 2; k < LOG; k++, p *= 2) {
        const Num x(cos(PI / p), sin(PI / p));
        forab (i, p / 2, p)
            rt[2 * i] = rt[i], rt[2 * i + 1] = rt[i] * x;
    }
}

```

## 7 FFT by mod and FFT with digits up to 10<sup>6</sup>

Num ta[MAX\_N], tb[MAX\_N], tf[MAX\_N], tg[MAX\_N];

```

const int HALF = 15;

void mult(int *a, int *b, int *r, int n, int mod) {
    int tw = (1 << HALF) - 1;
    forn (i, n) {
        int x = int(a[i] % mod);
        ta[i] = Num(x & tw, x >> HALF);
    }
    forn (i, n) {
        int x = int(b[i] % mod);

```

```

    tb[i] = Num(x & tw, x >> HALF);
}

fft(ta, n), fft(tb, n);
for (i, n) {
    int j = (n - i) & (n - 1);
    Num a1 = (ta[i] + conj(ta[j])) * Num(0.5, 0);
    Num a2 = (ta[i] - conj(ta[j])) * Num(0, -0.5);
    Num b1 = (tb[i] + conj(tb[j])) * Num(0.5 / n, 0);
    Num b2 = (tb[i] - conj(tb[j])) * Num(0, -0.5 / n);
    tf[j] = a1 * b1 + a2 * b2 * Num(0, 1);
    tg[j] = a1 * b2 + a2 * b1;
}

fft(tf, n), fft(tg, n);
for (i, n) {
    ll aa = ll(tf[i].x + 0.5);
    ll bb = ll(tg[i].x + 0.5);
    ll cc = ll(tf[i].y + 0.5);
    r[i] = int((aa + ((bb % mod) << HALF) + ((cc % mod) << (2
    ↪ * HALF))) % mod);
}
}

int tc[MAX_N], td[MAX_N];

const int MOD1 = 1.5e9, MOD2 = MOD1 + 1;
void multLL(int *a, int *b, ll *r, int n){
    mult(a, b, tc, n, MOD1), mult(a, b, td, n, MOD2);
    for(i, n)
        r[i] = tc[i] + (td[i] - tc[i] + (ll)MOD2) * MOD1 % MOD2 *
        ↪ MOD1;
}

```

### 3 Data Structures

#### 8 Centroid Decomposition

```

vi g[MAX_N];
int d[MAX_N], par[MAX_N], centroid;
//d par -

int find(int v, int p, int total) {
    int size = 1, ok = 1;
    for (int to : g[v])
        if (d[to] == -1 && to != p) {
            int s = find(to, v, total);
            if (s > total / 2) ok = 0;
            size += s;
        }
    if (ok && size > total / 2) centroid = v;
    return size;
}

void calcInComponent(int v, int p, int level) {
    // do something
    for (int to : g[v])
        if (d[to] == -1 && to != p)
            calcInComponent(to, v, level);
}

//fill(d, d + n, -1)
//decompose(0, -1, 0)
void decompose(int root, int parent, int level) {
    find(root, -1, find(root, -1, INF));
    int c = centroid;
    par[c] = parent, d[c] = level;
    calcInComponent(centroid, -1, level);
    for (int to : g[c])
        if (d[to] == -1)

```

```

        decompose(to, c, level + 1);
}

```

#### 9 Convex Hull Trick

```

struct Line {
    int k, b;
    Line() {}
    Line(int _k, int _b): k(_k), b(_b) {}
    ll get(int x) { return b + k * 1ll * x; }
    bool operator<(const Line &l) const { return k < l.k; } //
    ↪ >
};

//      ,      (a,b)      (a,c)
inline bool check(Line a, Line b, Line c) {
    return (a.b - b.b) * 1ll * (c.k - a.k) < (a.b - c.b) * 1ll *
    ↪ (b.k - a.k);
}

struct Convex {
    vector<Line> st;
    inline void add(Line l) {
        while (sz(st) >= 2 && !check(st[sz(st) - 2], st[sz(st) -
        ↪ 1], l))
            st.pop_back();
        st.pb(l);
    }
    int get(int x) {
        int l = 0, r = sz(st);
        while (r - l > 1) {
            int m = (l + r) / 2; //      >
            if (st[m - 1].get(x) < st[m].get(x))
                l = m;
            else
                r = m;
        }
        return l;
    }
    Convex() {}
    Convex(vector<Line> &lines) {
        st.clear();
        for (Line &l : lines)
            add(l);
    }
    Convex(Line line) { st.pb(line); }
    Convex(const Convex &a, const Convex &b) {
        vector<Line> lines;
        lines.resize(sz(a.st) + sz(b.st));
        merge(all(a.st), all(b.st), lines.begin());
        st.clear();
        for (Line &l : lines)
            add(l);
    }
};

```

#### 10 DSU

```

int pr[MAX_N];

int get(int v) {
    return v == pr[v] ? v : pr[v] = get(pr[v]);
}

bool unite(int v, int u) {
    v = get(v), u = get(u);
    if (v == u) return 0;
    pr[u] = v;
    return 1;
}

```

```
void init(int n) {
    for (i, n) pr[i] = i;
}
```

## 11 Fenwick Tree

```
int t[MAX_N];

int get(int ind) {
    int res = 0;
    for (; ind >= 0; ind &= (ind + 1), ind--)
        res += t[ind];
    return res;
}

void add(int ind, int n, int val) {
    for (; ind < n; ind |= (ind + 1))
        t[ind] += val;
}

int sum(int l, int r) { // [l, r)
    return get(r - 1) - get(l - 1);
}
```

## 12 Hash Table

```
using H = ll;
const int HT_SIZE = 1<<20, HT_AND = HT_SIZE - 1, HT_SIZE_ADD =
    HT_SIZE / 100;
H ht[HT_SIZE + HT_SIZE_ADD];
int data[HT_SIZE + HT_SIZE_ADD];

int get(const H &hash){
    int k = ((ll) hash) & HT_AND;
    while (ht[k] && ht[k] != hash) ++k;
    return k;
}

void insert(const H &hash, int x){
    int k = get(hash);
    if (!ht[k]) ht[k] = hash, data[k] = x;
}

bool count(const H &hash, int x){
    int k = get(hash);
    return ht[k] != 0;
}
```

## 13 Heavy Light Decomposition

```
vi g[MAX_N];
int size[MAX_N], comp[MAX_N], num[MAX_N], top[MAX_N],
    pr[MAX_N], tin[MAX_N], tout[MAX_N];
vi t[MAX_N], toPush[MAX_N], lst[MAX_N];
int curPath = 0, curTime = 0;

void pushST(int path, int v, int vl, int vr) {
    if (toPush[path][v] != -1) {
        if (vl != vr - 1)
            for (j, 2)
                toPush[path][2 * v + j] = toPush[path][v];
        else
            t[path][v] = toPush[path][v];
        toPush[path][v] = -1;
    }
}

int getST(int path, int v, int vl, int vr, int ind) {
    pushST(path, v, vl, vr);
    if (vl == vr - 1)
        return t[path][v];
}
```

```
int vm = (vl + vr) / 2;
if (ind >= vm)
    return getST(path, 2 * v + 1, vm, vr, ind);
return getST(path, 2 * v, vl, vm, ind);
}
```

```
void setST(int path, int v, int vl, int vr, int l, int r, int
    val) {
    if (vl >= l && vr <= r) {
        toPush[path][v] = val;
        pushST(path, v, vl, vr);
        return;
    }
    pushST(path, v, vl, vr);
    if (vl >= r || l >= vr)
        return;
    int vm = (vl + vr) / 2;
    setST(path, 2 * v, vl, vm, l, r, val);
    setST(path, 2 * v + 1, vm, vr, l, r, val);
    t[path][v] = min(t[path][2 * v], t[path][2 * v + 1]);
}
```

```
bool isUpper(int v, int u) {
    return tin[v] <= tin[u] && tout[v] >= tout[u];
}
```

```
int getHLD(int v) {
    return getST(comp[v], 1, 0, sz(t[comp[v]]) / 2, num[v]);
}
```

```
int setHLD(int v, int u, int val) {
    int ans = 0, w = 0;
    for (i, 2) {
        while (!isUpper(w = top[comp[v]], u))
            setST(comp[v], 1, 0, sz(t[comp[v]]) / 2, 0, num[v] + 1,
                val), v = pr[w];
        swap(v, u);
    }
    setST(comp[v], 1, 0, sz(t[comp[v]]) / 2, min(num[v],
        num[u]), max(num[v], num[u]) + 1, val);
    return ans;
}
```

```
void dfs(int v, int p) {
    tin[v] = curTime++;
    size[v] = 1;
    pr[v] = p;
    for (int u : g[v])
        if (u != p) {
            dfs(u, v);
            size[v] += size[u];
        }
    tout[v] = curTime++;
}
```

```
void build(int v) {
    if (v == 0 || size[v] * 2 < size[pr[v]])
        top[curPath] = v, comp[v] = curPath, num[v] = 0,
        curPath++;
    else
        comp[v] = comp[pr[v]], num[v] = num[pr[v]] + 1;
    lst[comp[v]].pb(v);
    for (int u : g[v])
        if (u != pr[v])
            build(u);
}
```

```
void initHLD() {
    dfs(0, 0);
    build(0);
}
```

```

    forn (i, curPath) {
        int curSize = 1;
        while (curSize < sz(lst[i]))
            curSize *= 2;
        t[i].resize(curSize * 2);
        toPush[i] = vi(curSize * 2, -1);
        //initialize t[i]
    }
}

```

## 14 Next Greater in Segment Tree

```

int t[4 * MAX_N], tSize = 1;

//                pos                x
int nextGreaterX(int v, int l, int r, int pos, int x) {
    if (r <= pos + 1 || t[v] <= x) return INF;
    if (v >= tSize) return v - tSize;
    int ans = nextGreaterX(2 * v, l, (l + r) / 2, pos, x);
    if (ans == INF)
        ans = nextGreaterX(2 * v + 1, (l + r) / 2, r, pos, x);
    return ans;
}

```

## 15 Sparse Table

```

int st[MAX_N][MAX_LOG];
int lg[MAX_N];

int get(int l, int r) { // [l, r)
    int curLog = lg[r - l];
    return min(st[l][curLog], st[r - (1 << curLog)][curLog]);
}

void initSparseTable(int *a, int n) {
    lg[1] = 0;
    forab (i, 2, n + 1) lg[i] = lg[i / 2] + 1;
    forn (i, n) st[i][0] = a[i];
    forn (j, lg[n])
        forn (i, n - (1 << (j + 1)) + 1)
            st[i][j + 1] = min(st[i][j], st[i + (1 << j)][j]);
}

```

## 16 Fenwick Tree 2D

```

ll a[4][MAX_N][MAX_N];
int n, m;

inline int f(int x) { return x & ~(x - 1); }

inline void add(int k, int x, int y, ll val) {
    for (; x <= n; x += f(x))
        for (int j = y; j <= m; j += f(j))
            a[k][x][j] += val;
}

inline ll get(int k, int x, int y) {
    ll s = 0;
    for (; x > 0; x -= f(x))
        for (int j = y; j > 0; j -= f(j))
            s += a[k][x][j];
    return s;
}

inline ll get(int x, int y) {
    return ll(x + 1) * (y + 1) * get(0, x, y) - (y + 1) * get(1,
        ↪ x, y)
        - (x + 1) * get(2, x, y) + get(3, x, y);
}

inline void add(int x, int y, ll val) {

```

```

    add(0, x, y, val);
    add(1, x, y, val * x);
    add(2, x, y, val * y);
    add(3, x, y, val * x * y);
}

inline ll get(int x_1, int y_1, int x_2, int y_2) {
    return get(x_2, y_2) - get(x_1 - 1, y_2) - get(x_2, y_1 - 1)
        ↪ + get(x_1 - 1, y_1 - 1);
}

// Adds val to corresponding rectangle
inline void add(int x_1, int y_1, int x_2, int y_2, ll val) {
    add(x_1, y_1, val);
    if (y_2 < m) add(x_1, y_2 + 1, -val);
    if (x_2 < n) add(x_2 + 1, y_1, -val);
    if (x_2 < n && y_2 < m) add(x_2 + 1, y_2 + 1, val);
}

```

# 4 Dynamic Programming

## 17 LIS

```

int longestIncreasingSubsequence(vi a) {
    int n = sz(a);
    vi d(n + 1, INF);
    d[0] = -INF;
    forn (i, n)
        *upper_bound(all(d), a[i]) = a[i];
    fornr (i, n + 1) if (d[i] != INF) return i;
    return 0;
}

```

## 18 DP tree

```

int dp[MAX_N][MAX_N], a[MAX_N];
vi g[MAX_N];

int dfs(int v, int n) {
    forn (i, n + 1)
        dp[v][i] = -INF;
    dp[v][1] = a[v];
    int curSz = 1;
    for (int to : g[v]) {
        int toSz = dfs(to, n);
        for (int i = curSz; i >= 1; i--)
            fornr (j, toSz + 1)
                dp[v][i + j] = max(dp[v][i + j], dp[v][i] +
                    ↪ dp[to][j]);
        curSz += toSz;
    }
    return curSz;
}

```

## 19 Masks tricks

```

int dp[(1 << MAX_MASK)][MAX_MASK];

void calcDP(int n) {
    forn(mask, 1 << n) {
        dp[mask][n] = 1;
        fornr(i, n) {
            dp[mask][i] = dp[mask][i + 1];
            if ((1 << i) & mask)
                dp[mask][i] += dp[mask ^ (1 << i)][i + 1];
        }
    }
}

```



## 5 Flows

### 20 Utilities

```
vi g[MAX_N];

// for directed unweighted graph
struct Edge {
    int v, u, c, f;
    Edge() {}
    Edge(int _v, int _u, int _c): v(_v), u(_u), c(_c), f(0) {}
};

vector<Edge> edges;

inline void addFlow(int e, int flow) {
    edges[e].f += flow, edges[e ^ 1].f -= flow;
}

inline void addEdge(int v, int u, int c) {
    g[v].pb(sz(edges)), edges.pb(Edge(v, u, c));
    g[u].pb(sz(edges)), edges.pb(Edge(u, v, 0)); // for
    ↪ undirected 0 should be c
}
```

### 21 Ford-Fulkerson

```
int used[MAX_N], pr[MAX_N];
int curTime = 1;

int dfs(int v, int can, int toPush, int t) {
    if (v == t) return can;
    used[v] = curTime;
    for (int edge : g[v]) {
        auto &e = edges[edge];
        if (used[e.u] != curTime && e.c - e.f >= toPush) {
            int flow = dfs(e.u, min(can, e.c - e.f), toPush, t);
            if (flow > 0) {
                addFlow(edge, flow), pr[e.u] = edge;
                return flow;
            }
        }
    }
    return 0;
}

int fordFulkerson(int s, int t) {
    int ansFlow = 0, flow = 0;
    // Without scaling
    while ((flow = dfs(s, INF, 1, t)) > 0)
        ansFlow += flow, curTime++;
    // With scaling
    fornr (i, INF_LOG)
        for (curTime++; (flow = dfs(s, INF, (1 << i), t)) > 0;
            ↪ curTime++)
            ansFlow += flow;
    return ansFlow;
}
```

### 22 Dinic

```
int pr[MAX_N], d[MAX_N], q[MAX_N], first[MAX_N];

int dfs(int v, int can, int toPush, int t) {
    if (v == t) return can;
    int sum = 0;
    for (; first[v] < (int) g[v].size(); first[v]++) {
        auto &e = edges[g[v][first[v]]];
        if (d[e.u] != d[v] + 1 || e.c - e.f < toPush) continue;
        int flow = dfs(e.u, min(can, e.c - e.f), toPush, t);
        addFlow(g[v][first[v]], flow);
    }
```

```
        can -= flow, sum += flow;
        if (!can)
            return sum;
    }
    return sum;
}

bool bfs(int n, int s, int t, int curPush) {
    forn (i, n) d[i] = INF, first[i] = 0;
    int head = 0, tail = 0;
    q[tail++] = s;
    d[s] = 0;
    while (tail - head > 0) {
        int v = q[head++];
        for (int edge : g[v]) {
            auto &e = edges[edge];
            if (d[e.u] > d[v] + 1 && e.c - e.f >= curPush)
                d[e.u] = d[v] + 1, q[tail++] = e.u;
        }
    }
    return d[t] != INF;
}
```

```
int dinic(int n, int s, int t) {
    int ansFlow = 0;
    // Without scaling
    while (bfs(n, s, t, 1))
        ansFlow += dfs(s, INF, 1, t);
    // With scaling
    fornr (j, INF_LOG)
        while (bfs(n, s, t, 1 << j))
            ansFlow += dfs(s, INF, 1 << j, t);
    return ansFlow;
}
```

### 23 Hungarian

```
const int INF = 1e9;
int a[MAX_N][MAX_N];

// min = sum of a[pa[i], i]
// you may optimize speed by about 15%, just change all vectors
↪ to static arrays
vi Hungarian(int n) {
    vi pa(n + 1, -1), row(n + 1, 0), col(n + 1, 0), la(n + 1);
    forn (k, n) {
        vi u(n + 1, 0), d(n + 1, INF);
        pa[n] = k;
        int l = n, x;
        while ((x = pa[l]) != -1) {
            u[l] = 1;
            int minn = INF, tmp, lo = 1;
            forn (j, n)
                if (!u[j]) {
                    if ((tmp = a[x][j] + row[x] + col[j]) < d[j])
                        d[j] = tmp, la[j] = lo;
                    if (d[j] < minn)
                        minn = d[j], l = j;
                }
            forn (j, n + 1)
                if (u[j])
                    col[j] += minn, row[pa[j]] -= minn;
                else
                    d[j] -= minn;
        }
        forn (j, n + 1)
            if (u[j])
                while (l != n)
                    pa[l] = pa[la[l]], l = la[l];
        return pa;
    }
}
```

## 24 Min Cost Max Flow

```

const int MAX_M = 1e4;
int pr[MAX_N], in[MAX_N], q[MAX_N * MAX_M], used[MAX_N],
    ↪ d[MAX_N], pot[MAX_N];
vi g[MAX_N];

struct Edge {
    int v, u, c, f, w;
    Edge() {}
    Edge(int _v, int _u, int _c, int _w): v(_v), u(_u), c(_c),
    ↪ f(0), w(_w) {}
};

vector<Edge> edges;

inline void addFlow(int e, int flow) {
    edges[e].f += flow, edges[e ^ 1].f -= flow;
}

inline void addEdge(int v, int u, int c, int w) {
    g[v].pb(sz(edges)), edges.pb(Edge(v, u, c, w));
    g[u].pb(sz(edges)), edges.pb(Edge(u, v, 0, -w));
}

int dijkstra(int n, int s, int t) {
    forn (i, n) used[i] = 0, d[i] = INF;
    d[s] = 0;
    while (1) {
        int v = -1;
        forn (i, n)
            if (!used[i] && (v == -1 || d[v] > d[i]))
                v = i;
        if (v == -1 || d[v] == INF) break;
        used[v] = 1;
        for (int edge : g[v]) {
            auto &e = edges[edge];
            int w = e.w + pot[v] - pot[e.u];
            if (e.c > e.f && d[e.u] > d[v] + w)
                d[e.u] = d[v] + w, pr[e.u] = edge;
        }
        if (d[t] == INF) return d[t];
        forn (i, n) pot[i] += d[i];
        return pot[t];
    }

int fordBellman(int n, int s, int t) {
    forn (i, n) d[i] = INF;
    int head = 0, tail = 0;
    d[s] = 0, q[tail++] = s, in[s] = 1;
    while (tail - head > 0) {
        int v = q[head++];
        in[v] = 0;
        for (int edge : g[v]) {
            auto &e = edges[edge];
            if (e.c > e.f && d[e.u] > d[v] + e.w) {
                d[e.u] = d[v] + e.w;
                pr[e.u] = edge;
                if (!in[e.u])
                    in[e.u] = 1, q[tail++] = e.u;
            }
        }
    }
    return d[t];
}

int minCostMaxFlow(int n, int s, int t) {
    int ansFlow = 0, ansCost = 0, dist;
    while ((dist = dijkstra(n, s, t)) != INF) {
        int curFlow = INF;
        for (int cur = t; cur != s; cur = edges[pr[cur]].v)

```

```

        curFlow = min(curFlow, edges[pr[cur]].c -
        ↪ edges[pr[cur]].f);
        for (int cur = t; cur != s; cur = edges[pr[cur]].v)
            addFlow(pr[cur], curFlow);
        ansFlow += curFlow;
        ansCost += curFlow * dist;
    }
    return ansCost;
}

```

## 6 Games

### 25 Retrograde Analysis

```

int win[MAX_N], lose[MAX_N], outDeg[MAX_N];
vi rg[MAX_N];

void retro(int n) {
    queue<int> q;
    forn (i, n)
        if (!outDeg[i])
            lose[i] = 1, q.push(i);
    while (!q.empty()) {
        int v = q.front();
        q.pop();
        for (int to : rg[v])
            if (lose[v]) {
                if (!win[to])
                    win[to] = 1, q.push(to);
            } else {
                outDeg[to]--;
                if (!outDeg[to])
                    lose[to] = 1, q.push(to);
            }
    }
}

```

## 7 Geometry

### 26 ClosestPoints (SweepLine)

```

#include "header.h"

const int N = 2e5;

struct Pnt {
    int x, y, i;
    bool operator <(const Pnt &p) const { return mp(y, i) <
    ↪ mp(p.y, p.i); }
};

ll d2 = 8e18, d = (ll) sqrt(d2) + 1;
Pnt p[N];

inline ll sqr(int x){
    return (LL)x * x;
}

inline void relax(const Pnt &a, const Pnt &b){
    ll tmp = sqr(a.x - b.x) + sqr(a.y - b.y);
    if (tmp < d2)
        d2 = tmp, d = (LL)(sqrt(d2) + 1 - 1e-9); // round up
}

inline bool xless(const Pnt &a, const Pnt &b){
    return a.x < b.x;
}

int main() {

```

```

int n;
scanf("%d", &n);
for(i, n)
    scanf("%d%d", &p[i].x, &p[i].y), p[i].i = i;
sort(p, p + n, xless);

set<Pnt> s;
int l = 0;
for(r, n){
    set<Pnt>::iterator it_r = s.lower_bound(p[r]), it_l =
    ↪ it_r;
    for (; it_r != s.end() && it_r->y - p[r].y < d; ++it_r)
        relax(*it_r, p[r]);
    while (it_l != s.begin() && p[r].y - (--it_l)->y < d)
        relax(*it_l, p[r]);
    s.insert(p[r]);
    while (l <= r && p[r].x - p[l].x >= d)
        s.erase(p[l++]);
}
printf("%.9f\n", sqrt(d2));
return 0;
}

```

## 27 ConvexHull

```

typedef vector<Pnt> vpnt;

inline bool byAngle(const Pnt &a, const Pnt &b) {
    dbl x = a % b;
    return eq(x, 0) ? a.len2() < b.len2() : x < 0;
}

vpnt convexHull(vpnt p) {
    int n = sz(p);
    assert(n > 0);
    swap(p[0], *min_element(all(p)));
    forab(i, 1, n)
        p[i] = p[i] - p[0];
    sort(p.begin() + 1, p.end(), byAngle);

    /*
    (1)
    (2)
    (1):
    int k = p.size() - 1;
    while(k > 0 && eq((p[k] - p.back()) % p.back(), 0))
        --k;
    reverse(pi.begin() + k, pi.end());*/

    int rn = 0;
    vpnt r(n);
    r[rn++] = p[0];
    forab(i, 1, n){
        Pnt q = p[i] + p[0];
        while(rn >= 2 && geq((r[rn - 1] - r[rn - 2]) % (q - r[rn -
        ↪ 2]), 0)) // (2) ge
            --rn;
        r[rn++] = q;
    }
    r.resize(rn);
    return r;
}

```

## 28 GeometryBase

```

#include<bits/stdc++.h>
using namespace std;

typedef long long ll;
typedef long double ld;
typedef double dbl;

const dbl EPS = 1e-9;

```

```

const int PREC = 20;
inline bool eq(dbl a, dbl b) { return abs(a-b)<=EPS; }
inline bool gr(dbl a, dbl b) { return a>b+EPS; }
inline bool geq(dbl a, dbl b) { return a>=b-EPS; }
inline bool ls(dbl a, dbl b) { return a<b-EPS; }
inline bool leq(dbl a, dbl b) { return a<=b+EPS; }

struct Pnt {
    dbl x,y;
    Pnt(): x(0), y(0) {}
    Pnt(dbl xx, dbl yy): x(xx), y(yy) {}

    inline Pnt operator +(const Pnt &p) const { return Pnt(x +
    ↪ p.x, y + p.y); }
    inline Pnt operator -(const Pnt &p) const { return Pnt(x -
    ↪ p.x, y - p.y); }
    inline dbl operator *(const Pnt &p) const { return x * p.x
    ↪ + y * p.y; } // ll
    inline dbl operator %(const Pnt &p) const { return x * p.y
    ↪ - y * p.x; } // ll

    inline Pnt operator *(dbl k) const { return Pnt(x * k, y *
    ↪ k); }
    inline Pnt operator /(dbl k) const { return Pnt(x / k, y /
    ↪ k); }
    inline Pnt operator -() const { return Pnt(-x, -y); }

    inline void operator +=(const Pnt &p) { x += p.x, y +=
    ↪ p.y; }
    inline void operator -=(const Pnt &p) { x -= p.x, y -=
    ↪ p.y; }
    inline void operator *=(dbl k) { x*=k, y*=k; }

    inline bool operator ==(const Pnt &p) { return
    ↪ abs(x-p.x)<=EPS && abs(y-p.y)<=EPS; }
    inline bool operator !=(const Pnt &p) { return
    ↪ abs(x-p.x)>EPS || abs(y-p.y)>EPS; }
    inline bool operator <(const Pnt &p) { return
    ↪ abs(x-p.x)<=EPS ? y<p.y-EPS : x<p.x; }

    inline dbl angle() const { return atan2(y, x); } // ld
    inline dbl len2() const { return x*x+y*y; } // ll
    inline dbl len() const { return sqrt(x*x+y*y); } // ll, ld
    inline Pnt getNorm() const {
        auto l = len();
        return Pnt(x/l, y/l);
    }
    inline void normalize() {
        auto l = len();
        x/=l, y/=l;
    }

    inline Pnt getRot90() const { //counter-clockwise
        return Pnt(-y, x);
    }
    inline Pnt getRot(dbl a) const { // ld
        dbl si = sin(a), co = cos(a);
        return Pnt(x*co - y*si, x*si + y*co);
    }

    inline void read() {
        int xx, yy;
        cin >> xx >> yy;
        x = xx, y = yy;
    }
    inline void write() const{
        cout << fixed << (double)x << (double)y;
    }
};

struct Line{

```

```

    dbl a, b, c;
    Line(): a(0), b(0), c(0) {}
    Line(dbl aa, dbl bb, dbl cc): a(aa), b(bb), c(cc) {}

    Line(const Pnt &A, const Pnt &p){ // it normalizes (a,b),
    ↪ important in d(), normalToP()
        Pnt n = (p-A).getRot90().getNorm();
        a = n.x, b = n.y, c = -(a * A.x + b * A.y);
    }

    inline dbl d(const Pnt &p) const { return a*p.x + b*p.y +
    ↪ c; }
    inline Pnt no() const {return Pnt(a, b);}
    inline Pnt normalToP(const Pnt &p) const { return Pnt(a,b)
    ↪ * (a*p.x + b*p.y + c); }

    inline void write() const{
        cout << fixed << (double)a << " " << (double)b << " " <<
    ↪ (double)c << '\n';
    }
};

```

## 29 GeometryInterTangent

```

void buildTangent(Pnt p1, dbl r1, Pnt p2, dbl r2, Line &l) {
    ↪ // r1, r2 = radius with sign
    Pnt p = p2 - p1;
    l.c = r1;
    dbl c2 = p.len2(), c1 = sqrt(c2 - sqr(r2));
    l.a = (-p.x * (r1 - r2) + p.y * c1) / c2;
    l.b = (-p.y * (r1 - r2) - p.x * c1) / c2;
    l.c -= l.no() * p1;
    assert(eq(l.d(p1), r1));
    assert(eq(l.d(p2), r2));
}

```

```

struct Circle {
    Pnt p;
    dbl r;
};

```

```
vector<Pnt> v; // to store intersection
```

```
// Intersection of two lines
```

```

int line_line(const Line &l, const Line &m){
    dbl z = m.a * l.b - l.a * m.b;
    dbl x = m.c * l.b - l.c * m.b;
    dbl y = m.c * l.a - l.c * m.a;
    if(fabs(z) > EPS){
        v.pb(Pnt(-x/z, y/z));
        return 1;
    }else if(fabs(x) > EPS || fabs(y) > EPS)
        return 0; // parallel lines
    else
        return 2; // same lines
}

```

```
// Intersection of Circle and line
```

```

void circle_line(const Circle &c, const Line &l){
    dbl d = l.d(c.p);
    if(fabs(d) > c.r + EPS)
        return;
    if(fabs(fabs(d) / c.r - 1) < EPS)
        v.pb(c.p - l.no() * d);
    else{
        dbl s = sqrt(fabs(sqr(c.r) - sqr(d)));
        v.pb(c.p - l.no() * d + l.no().getRot90() * s);
        v.pb(c.p - l.no() * d - l.no().getRot90() * s);
    }
}

```

```
// Intersection of two circles
```

```

void circle_circle(const Circle &a, const Circle &b){
    circle_line(a, Line((b.p - a.p) * 2, a.p.len2() -
    ↪ b.p.len2() + sqr(b.r) - sqr(a.r)));
}

```

```
// Squared distance between point p and segment [a..b]
```

```

dbl dist2(Pnt p, Pnt a, Pnt b){
    if ((p - a) * (b - a) < 0) return (p - a).len2();
    if ((p - b) * (a - b) < 0) return (p - b).len2();
    dbl d = fabs((p - a) % (b - a));
    return d * d / (b - a).len2();
}

```

## 30 GeometrySimple

```
int sign(dbl a) { return (a > EPS) - (a < -EPS); }
```

```
// Checks, if point is inside the segment
```

```

inline bool inSeg(const Pnt &p, const Pnt &a, const Pnt &b) {
    return eq((p - a) % (p - b), 0) && leq((p - a) * (p - b),
    ↪ 0);
}

```

```

// Checks, if two intervals (segments without ends) intersect
↪ AND do not lie on the same line

```

```

inline bool subIntr(const Pnt &a, const Pnt &b, const Pnt &c,
    ↪ const Pnt &d){
    return
        sign((b - a) % (c - a)) * sign((b - a) % (d - a))
        ↪ == -1 &&
        sign((d - c) % (a - c)) * sign((d - c) % (b - c))
        ↪ == -1;
}

```

```

// Checks, if two segments (ends are included) has an
↪ intersection

```

```

inline bool checkSegInter(const Pnt &a, const Pnt &b, const
    ↪ Pnt &c, const Pnt &d){
    return inSeg(c, a, b) || inSeg(d, a, b) || inSeg(a, c, d)
    ↪ || inSeg(b, c, d) || subIntr(a, b, c, d);
}

```

```
inline dbl area(vector<Pnt> p){
```

```

    dbl s = 0;
    int n = sz(p);
    p.pb(p[0]);
    forn(i, n)
        s += p[i + 1] % p[i];
    p.pop_back();
    return abs(s) / 2;
}

```

```
// Check if point p is inside polygon <n, q[]>
```

```

int containsSlow(Pnt p, Pnt *z, int n){
    int cnt = 0;
    forn(j, n){
        Pnt a = z[j], b = z[(j + 1) % n];
        if (inSeg(p, a, b))
            return -1; // border
        if (min(a.y, b.y) - EPS <= p.y && p.y < max(a.y, b.y)
            ↪ - EPS)
            cnt += (p.x < a.x + (p.y - a.y) * (b.x - a.x) /
            ↪ (b.y - a.y));
    }
    return cnt & 1; // 0 = outside, 1 = inside
}

```

```
//for convex polygon
```

```
//assume polygon is counterclockwise-ordered
bool containsFast(Pnt p, Pnt *z, int n) {
    Pnt o = z[0];
    if(gr((p - o) % (z[1] - o), 0) || ls((p - o) % (z[n - 1] - o), 0))
        return 0;
    int l = 0, r = n - 1;
    while(r - l > 1){
        int m = (l + r) / 2;
        if(gr((p - o) % (z[m] - o), 0))
            r = m;
        else
            l = m;
    }
    return leq((p - z[l]) % (z[r] - z[l]), 0);
}

// Checks, if point "i" is in the triangle "abc" IFF triangle
// in CCW order
inline int isInTr(int i, int a, int b, int c){
    return
        gr((p[b] - p[a]) % (p[i] - p[a]), 0) &&
        gr((p[c] - p[b]) % (p[i] - p[b]), 0) &&
        gr((p[a] - p[c]) % (p[i] - p[c]), 0);
}
```

## 31 Halfplanes Intersection

```
const int maxn = (int)4e5 + 9;
const dbl eps = 1e-12;

dbl sqr( dbl x ) { return x * x; }

struct pnt{
    LL operator * ( pnt p ) { return (LL)x * p.y - (LL)y * p.x;
    ↪ }
    LL operator ^ ( pnt p ) { return (LL)x * p.x + (LL)y * p.y;
    ↪ }
    pnt ort() { return pnt(-y, x); }
    dbl ang() { return atan2(y, x); }
    LL d2() { return x * x + y * y; }
};

pnt st, v, p[maxn];
int n, sp, ss[maxn], ind[maxn], no[maxn], cnt[maxn], k = 0,
    ↪ a[maxn], b[maxn];
dbl ang[maxn];

pnt Norm( int k ){ return (p[a[k]] - p[b[k]]).ort();}

void AddPlane( int i, int j ){
    a[k] = i, b[k] = j, ind[k] = k;
    ang[k] = Norm(k).ang();
    k++;
}

bool angLess( int i, int j ){ return ang[i] < ang[j];}

void Unique()
{
    int i = 0, k2 = 0;
    while (i < k)
    {
        int ma = ind[i], st = i;
        pnt no = Norm(ma);

        for (i++; i < k && fabs(ang[ind[st]] - ang[ind[i]]) < eps;
            ↪ i++)
            if ((no ^ p[a[ma]]) < (no ^ p[a[ind[i]]]))
                ma = ind[i];
        ind[k2++] = ma;
    }
}
```

```

    }
    k = k2;
}

dbl xx, yy, tmp;

#define BUILD(a1, b1, c1, i) \
    dbl a1 = Norm(i).x; \
    dbl b1 = Norm(i).y; \
    tmp = sqrt(a1 * a1 + b1 * b1); \
    a1 /= tmp, b1 /= tmp; \
    dbl c1 = -(a1 * p[a[i]].x + b1 * p[a[i]].y);

void FindPoint( int i, int j, dbl step = 0.0 ){
    BUILD(a1, b1, c1, i);
    BUILD(a2, b2, c2, j);

    xx = -(c1 * b2 - c2 * b1) / (a1 * b2 - a2 * b1);
    yy = (c1 * a2 - c2 * a1) / (a1 * b2 - a2 * b1);

    dbl no = sqrt(sqr(a1 + a2) + sqr(b1 + b2));
    xx += (a1 + a2) * step / no;
    yy += (b1 + b2) * step / no;
}

void TryShiftPoint( int i, int j, dbl step )
{
    FindPoint(i, j, step);

    forn(i, k){
        BUILD(a1, b1, c1, ind[i]);
        if (a1 * xx + b1 * yy + c1 < eps)
            return;
    }

    puts("Possible");
    printf("%.20lf %.20lf\n", (double)xx, (double)yy);
    exit(0);
}

void PushPlaneIntoStack( int i )
{
    while (sp >= 2 && ang[ind[i]] - ang[ss[sp - 2]] + eps < M_PI){
        FindPoint(i, ss[sp - 2]);

        BUILD(a1, b1, c1, ss[sp - 1]);
        if ((a1 * xx + b1 * yy + c1) < -eps)
            break;

        sp--;
    }
    ss[sp++] = i;
}

int main()
{
    scanf("%d", &n);
    forn(i, n)
        scanf("%d%d", &p[i].x, &p[i].y);
    p[n] = p[0];

    // Find set of planes
    forn(i, sp)
        AddPlane(max(ss[i], ss[i + 1]), min(ss[i], ss[i + 1]));
    forn(i, n - 1)
        AddPlane(i + 1, i);
    sort(ind, ind + k, angLess);

    int oldK = k;
    Unique();
}
```

```

forn(i, oldK)
  no[i] = i;
forn(i, k){
  int j = oldK + i, x = ind[i];
  ang[j] = ang[x] + 2 * M_PI;
  a[j] = a[x];
  b[j] = b[x];
  ind[i + k] = j, no[j] = x;
}

sp = 0;
forn(i, 2 * k)
  PushPlaneIntoStack(ind[i]);
forn(t, sp)
  if (++cnt[no[ss[t]]] > 1){
    TryShiftPoint(ss[t], ss[t - 1], 1e-5);
    break;
  }
return 0;
}

```

## 8 Graphs

### 32 2-SAT

```

// MAXVAR - 2 * vars
int cntVar = 0, val[MAXVAR], usedSat[MAXVAR], comp[MAXVAR];
vi topsortSat;

vi g[MAXVAR], rg[MAXVAR];

inline int newVar() {
  cntVar++;
  return (cntVar - 1) * 2;
}

inline int Not(int v) { return v ^ 1; }

inline void Implies(int v1, int v2) { g[v1].pb(v2),
  ⇔ rg[v2].pb(v1); }

inline void Or(int v1, int v2) { Implies(Not(v1), v2),
  ⇔ Implies(Not(v2), v1); }

inline void Nand(int v1, int v2) { Or(Not(v1), Not(v2)); }

inline void setTrue(int v) { Implies(Not(v), v); }

void dfs1(int v) {
  usedSat[v] = 1;
  for (int to : g[v])
    if (!usedSat[to]) dfs1(to);
  topsortSat.pb(v);
}

void dfs2(int v, int c) {
  comp[v] = c;
  for (int to : rg[v])
    if (!comp[to]) dfs2(to, c);
}

int getVal(int v) { return val[v]; }

// cntVar
bool solveSat() {
  for (i, 2 * cntVar) usedSat[i] = 0;
  for (i, 2 * cntVar)
    if (!usedSat[i]) dfs1(i);
  reverse(all(topsortSat));
  int c = 0;

```

```

for (int v : topsortSat)
  if (!comp[v]) dfs2(v, ++c);
forn(i, cntVar) {
  if (comp[2 * i] == comp[2 * i + 1]) return false;
  if (comp[2 * i] < comp[2 * i + 1]) val[2 * i + 1] = 1;
  else val[2 * i] = 1;
}
return true;
}

```

### 33 Bridges

```

int up[MAX_N], tIn[MAX_N], timer;
vector<vi> comps;
vi st;

struct Edge {
  int to, id;
  Edge(int _to, int _id) : to(_to), id(_id) {}
};

vector<Edge> g[MAX_N];

void newComp(int size = 0) {
  comps.emplace_back(); //
  while (sz(st) > size) {
    comps.back().pb(st.back());
    st.pop_back();
  }
}

void findBridges(int v, int parentEdge = -1) {
  if (up[v]) //
    return;
  up[v] = tIn[v] = ++timer;
  st.pb(v);
  for (Edge e : g[v]) {
    if (e.id == parentEdge)
      continue;
    int u = e.to;
    if (!tIn[u]) {
      int size = sz(st);
      findBridges(u, e.id);
      if (up[u] > tIn[v])
        newComp(size);
    }
    up[v] = min(up[v], up[u]);
  }
}

// find_bridges newComp()
void run(int n) {
  for (i, n)
    if (!up[i]) {
      findBridges(i);
      newComp();
    }
}

```

### 34 Cut Points

```

bool used[MAX_M];
int tIn[MAX_N], timer, isCut[MAX_N], color[MAX_M], compCnt;
vi st;

struct Edge {
  int to, id;
  Edge(int _to, int _id) : to(_to), id(_id) {}
};

vector<Edge> g[MAX_N];

```

```

int dfs(int v, int parent = -1) {
    tIn[v] = ++timer;
    int up = tIn[v], x = 0, y = (parent != -1);
    for (Edge p : g[v]) {
        int u = p.to, id = p.id;
        if (id != parent) {
            int t, size = sz(st);
            if (!used[id])
                used[id] = 1, st.push_back(id);
            if (!tIn[u]) { // not visited yet
                t = dfs(u, id);
                if (t >= tIn[v]) {
                    ++x, ++compCnt;
                    while (sz(st) != size) {
                        color[st.back()] = compCnt;
                        st.pop_back();
                    }
                }
            } else
                t = tIn[u];
            up = min(up, t);
        }
    }
    if (x + y >= 2)
        isCut[v] = 1; // v is cut vertex
    return up;
}

```

## 35 Eulerian Cycle

```

struct Edge {
    int to, used;
    Edge(): to(-1), used(0) {}
    Edge(int v): to(v), used(0) {}
};

vector<Edge> edges;
vi g[MAX_N], res, ptr;
// ptr

void dfs(int v) {
    for(; ptr[v] < sz(g[v]);) {
        int id = g[v][ptr[v]++];
        if (!edges[id].used) {
            edges[id].used = edges[id ^ 1].used = 1;
            dfs(edges[id].to);
            res.pb(id); //
        }
    }
    res.pb(v); // res
}

```

## 36 Euler Tour Tree

```

mt19937 rng(239);

struct Edge {
    int v, u;
    Edge(int _v, int _u): v(_v), u(_u) {}
};

struct Node {
    Node *l, *r, *p;
    Edge e;
    int y, size;
    Node(Edge _e): l(nullptr), r(nullptr), p(this), e(_e),
        y(rng()), size(1) {}
};

```

```

inline int getSize(Node* root) { return root ? root->size : 0;
}

```

```

inline void recalc(Node* root) { root->size = getSize(root->l)
+ getSize(root->r) + 1; }

```

```

set<pair<int, Node*>> edges[MAX_N];

```

```

Node* merge(Node *a, Node *b) {
    if (!a) return b;
    if (!b) return a;
    if (a->y < b->y) {
        a->r = merge(a->r, b);
        if (a->r) a->r->p = a;
        recalc(a);
        return a;
    }
    b->l = merge(a, b->l);
    if (b->l) b->l->p = b;
    recalc(b);
    return b;
}

```

```

void split(Node *root, Node *&a, Node *&b, int size) {
    if (!root) {
        a = b = nullptr;
        return;
    }
    int lSize = getSize(root->l);
    if (lSize >= size) {
        split(root->l, a, root->l, size);
        if (root->l) root->l->p = root;
        b = root, b->p = b;
    } else {
        split(root->r, root->r, b, size - lSize - 1);
        if (root->r) root->r->p = root;
        a = root, a->p = a;
        a->p = a;
    }
    recalc(root);
}

```

```

inline Node* rotate(Node* root, int k) {
    if (k == 0) return root;
    Node *l, *r;
    split(root, l, r, k);
    return merge(r, l);
}

```

```

inline pair<Node*, int> goUp(Node* root) {
    int pos = getSize(root->l);
    while (root->p != root)
        pos += (root->p->r == root ? getSize(root->p->l) + 1 : 0),
        root = root->p;
    return mp(root, pos);
}

```

```

inline Node* deleteFirst(Node* root) {
    Node* a;
    split(root, a, root, 1);
    edges[a->e.v].erase(mp(a->e.u, a));
    return root;
}

```

```

inline Node* getNode(int v, int u) {
    return edges[v].lower_bound(mp(u, nullptr))->snd;
}

```

```

inline void cut(int v, int u) {
    auto pV = goUp(getNode(v, u));
    auto pU = goUp(getNode(u, v));
}

```

```

    int l = min(pV.snd, pU.snd), r = max(pV.snd, pU.snd);
    Node *a, *b, *c;
    split(pV.fst, a, b, l);
    split(b, b, c, r - l);
    deleteFirst(b);
    merge(a, deleteFirst(c));
}

inline pair<Node*, int> getRoot(int v) {
    return !sz(edges[v]) ? mp(nullptr, 0) :
        ↳ goUp(edges[v].begin()->snd);
}

inline Node* makeRoot(int v) {
    auto root = getRoot(v);
    return rotate(root.fst, root.snd);
}

inline Node* makeEdge(int v, int u) {
    Node* e = new Node(Edge(v, u));
    edges[v].insert(mp(u, e));
    return e;
}

inline void link(int v, int u) {
    Node *vN = makeRoot(v), *uN = makeRoot(u);
    merge(merge(merge(vN, makeEdge(v, u)), uN), makeEdge(u, v));
}

```

## 37 Hamilton Cycle

```

//          -          n*2^n
vi g[MAX_MASK];
int adj[MAX_MASK], dp[1 << MAX_MASK];

vi hamiltonCycle(int n) {
    fill(dp, dp + (1 << n), 0);
    forn (v, n) {
        adj[v] = 0;
        for (int to : g[v])
            adj[v] |= (1 << to);
    }
    dp[1] = 1;
    forn (mask, (1 << n))
        forn(v, n)
            if (mask & (1 << v) && dp[mask ^ (1 << v)] & adj[v])
                dp[mask] |= (1 << v);
    vi ans;
    int mask = (1 << n) - 1, v;
    if (dp[mask] & adj[0]) {
        forab (i, 1, n)
            if ((1 << i) & (mask & adj[0]))
                v = i;
        ans.pb(v);
        mask ^= (1 << v);
        while(v) {
            forn(i, n)
                if ((dp[mask] & (1 << i)) && (adj[i] & (1 << v))) {
                    v = i;
                    break;
                }
            mask ^= (1 << v);
            ans.pb(v);
        }
    }
    return ans;
}

```

## 38 Karp with cycle

```

int d[MAX_N][MAX_N], p[MAX_N][MAX_N];
vi g[MAX_N], ans;

struct Edge {
    int a, b, w;
    Edge(int _a, int _b, int _w) : a(_a), b(_b), w(_w) {}
};

vector<Edge> edges;

void fordBellman(int s, int n) {
    forn (i, n + 1)
        forn (j, n + 1)
            d[i][j] = INF;
    d[0][s] = 0;
    forab (i, 1, n + 1)
        for (auto &e : edges)
            if (d[i - 1][e.a] < INF && d[i][e.b] > d[i - 1][e.a] +
                ↳ e.w)
                d[i][e.b] = d[i - 1][e.a] + e.w, p[i][e.b] = e.a;
}

ld karp(int n) {
    int s = n++;
    forn (i, n - 1)
        g[s].pb(sz(edges)), edges.pb(Edge(s, i, 0));
    fordBellman(s, n);
    ld ansValue = INF;
    int curV = -1, dist = -1;
    forn (v, n - 1)
        if (d[n][v] != INF) {
            ld curAns = -INF;
            int curPos = -1;
            forn(k, n)
                if (curAns <= (d[n][v] - d[k][v]) * (ld) (1) / (n -
                    ↳ k))
                    curAns = (d[n][v] - d[k][v]) * (ld) (1) / (n - k),
                    ↳ curPos = k;
            if (ansValue > curAns)
                ansValue = curAns, dist = curPos, curV = v;
        }
    if (curV == -1) return ansValue;
    for (int iter = n; iter != dist; iter--)
        ans.pb(curV), curV = p[iter][curV];
    reverse(all(ans));
    return ansValue;
}

```

## 39 Kuhn's algorithm

```

//          - n          ,          - m
//
int n, m, paired[2 * MAX_N], used[2 * MAX_N];
vi g[MAX_N];

bool dfs(int v) {
    if (used[v]) return false;
    used[v] = 1;
    for (int to : g[v])
        if (paired[to] == -1 || dfs(paired[to])) {
            paired[to] = v, paired[v] = to;
            return true;
        }
    return false;
}

int kuhn() {
    int ans = 0;
    forn (i, n + m) paired[i] = -1;
    for (int run = 1; run;) {

```



```

run = 0;
fill(used, used + n + m, 0);
for (i, n)
    if (!used[i] && paired[i] == -1 && dfs(i))
        ans++, run = 1;
}
return ans;
}

//
//
// Max      -- A+, B-
// Min      -- A-, B+

vi minCover, maxIndependent;

void dfsCoverIndependent(int v) {
    if (used[v]) return;
    used[v] = 1;
    for (int to : g[v])
        if (!used[to])
            used[to] = 1, dfsCoverIndependent(paired[to]);
}

//
void findCoverIndependent() {
    fill(used, used + n + m, 0);
    for (i, n)
        if (paired[i] == -1)
            dfsCoverIndependent(i);
    for (i, n)
        if (used[i]) maxIndependent.pb(i);
        else minCover.pb(i);
    forab (i, n, n + m)
        if (used[i]) minCover.pb(i);
        else maxIndependent.pb(i);
}

```

## 40 LCA

```

int tin[MAX_N], tout[MAX_N], up[MAX_N][MAX_LOG];
vi g[MAX_N];
int curTime = 0;

void dfs(int v, int p) {
    up[v][0] = p;
    for (i, MAX_LOG - 1)
        up[v][i + 1] = up[up[v][i]][i];
    tin[v] = curTime++;
    for (int u : g[v])
        if (u != p)
            dfs(u, v);
    tout[v] = curTime++;
}

int isUpper(int v, int u) {
    return tin[v] <= tin[u] && tout[v] >= tout[u];
}

int lca(int v, int u) {
    if (isUpper(u, v)) return u;
    for (i, MAX_LOG)
        if (!isUpper(up[u][i], v))
            u = up[u][i];
    return up[u][0];
}

void init() {
    dfs(0, 0);
}

```

## 41 LCA offline (Tarjan)

```

vi g[MAX_N], q[MAX_N];
int pr[MAX_N], ancestor[MAX_N], used[MAX_N];

int get(int v) {
    return v == pr[v] ? v : pr[v] = get(pr[v]);
}

void unite(int v, int u, int anc) {
    v = get(v), u = get(u);
    pr[u] = v, ancestor[v] = anc;
}

void dfs(int v) {
    used[v] = 1;
    for (int u : g[v])
        if (!used[u])
            dfs(u), unite(v, u, v);
    for (int u : q[v])
        if (used[u])
            ancestor[get(u)]; // handle answer somehow
}

void init(int n) {
    for (i, n) pr[i] = i, ancestor[i] = i;
    dfs(0);
}

```

## 9 Math

### 42 CRT (KTO)

```

vi crt(vi a, vi mod) {
    int n = sz(a);
    vi x(n);
    for (i, n) {
        x[i] = a[i];
        for (j, i) {
            x[i] = inverse(mod[j], mod[i]) * (x[i] - x[j]) % mod[i];
            if (x[i] < 0) x[i] += mod[i];
        }
    }
    return x;
}

```

### 43 Discrete Logarithm

```

// Returns x: a^x = b (mod mod) or -1, if no such x exists
int discreteLogarithm(int a, int b, int mod) {
    int sq = sqrt(mod);
    int sq2 = mod / sq + (mod % sq ? 1 : 0);
    vector<pii> powers(sq2);
    for (i, sq2)
        powers[i] = mp(power(a, (i + 1) * sq, mod), i + 1);
    sort(all(powers));
    for (i, sq + 1) {
        int cur = power(a, i, mod);
        cur = (cur * 1ll * b) % mod;
        auto it = lower_bound(all(powers), mp(cur, 0));
        if (it != powers.end() && it->fst == cur)
            return it->snd * sq - i;
    }
    return -1;
}

```

### 44 Discrete Root

```

// Returns x: x^k = a mod mod, mod is prime
int discreteRoot(int a, int k, int mod) {
    if (a == 0)

```

```

    return 0;
    int g = primitiveRoot(mod);
    int y = discreteLogarithm(power(g, k, mod), a, mod);
    return power(g, y, mod);
}

```

## 45 Eratosthenes

```

vi eratosthenes(int n) {
    vi minDiv(n + 1, 0);
    minDiv[1] = 1;
    forab (i, 2, n + 1)
        if (minDiv[i] == 0)
            for (int j = i; j <= n; j += i)
                if (minDiv[j] == 0) minDiv[j] = i;
    return minDiv;
}

vi eratosthenesLinear(int n) {
    vi minDiv(n + 1, 0), primes;
    minDiv[1] = 1;
    forab (i, 2, n + 1) {
        if (minDiv[i] == 0)
            minDiv[i] = i, primes.pb(i);
        for (int j = 0; j < sz(primes) && primes[j] <= minDiv[i]
            && i * primes[j] <= n; j++)
            minDiv[i * primes[j]] = primes[j];
    }
    return minDiv;
}

```

## 46 Factorial

```

// Returns pair (rem, deg), where rem = n! % mod,
// deg = k: mod^k | n!, mod is prime, 0(mod log mod)
pii fact(int n, int mod) {
    int rem = 1, deg = 0, nCopy = n;
    while (nCopy) nCopy /= mod, deg += nCopy;
    while (n > 1) {
        rem = (rem * ((n / mod) % 2 ? -1 : 1) + mod) % mod;
        for (int i = 2; i <= n % mod; i++)
            rem = (rem * 1ll * i) % mod;
        n /= mod;
    }
    return mp(rem % mod, deg);
}

```

## 47 Gauss

```

const double EPS = 1e-9;

int gauss(double **a, int n, int m) { // n is number of
    ⇨ equations, m is number of variables
    int row = 0, col = 0;
    vi par(m, -1);
    vector<double> ans(m, 0);
    for (col = 0; col < m && row < n; col++) {
        int best = row;
        for (int i = row; i < n; i++)
            if (abs(a[i][col]) > abs(a[best][col]))
                best = i;
        if (abs(a[best][col]) < EPS) continue;
        par[col] = row;
        for (i, m + 1) swap(a[row][i], a[best][i]);
        for (i, n)
            if (i != row) {
                double k = a[i][col] / a[row][col];
                for (int j = col; j <= m; j++)
                    a[i][j] -= k * a[row][j];
            }
        row++;
    }
}

```

```

}
int single = 1;
for (i, m)
    if (par[i] != -1) ans[i] = a[par[i]][m] / a[par[i]][i];
    else single = 0;
for (i, n) {
    double cur = 0;
    for (int j = 0; j < m; j++)
        cur += ans[j] * a[i][j];
    if (abs(cur - a[i][m]) > EPS)
        return 0;
}
if (!single)
    return 2;
return 1;
}

```

## 48 Gauss binary

```

const int MAX = 1024;

int gaussBinary(vector<bitset<MAX>> a, int n, int m) {
    int row = 0, col = 0;
    vi par(m, -1);
    for (col = 0; col < m && row < n; col++) {
        int best = row;
        for (int i = row; i < n; i++)
            if (a[i][col] > a[best][col])
                best = i;
        if (a[best][col] == 0)
            continue;
        par[col] = row;
        swap(a[row], a[best]);
        for (i, n)
            if (i != row && a[i][col])
                a[i] ^= a[row];
        row++;
    }
    vi ans(m, 0);
    for (i, m)
        if (par[i] != -1)
            ans[i] = a[par[i]][n] / a[par[i]][i];
    bool ok = 1;
    for (i, n) {
        int cur = 0;
        for (j, m) cur ^= (ans[j] & a[i][j]);
        if (cur != a[i][n]) ok = 0;
    }
    return ok;
}

```

## 49 Gcd

```

int gcd(int a, int b) {
    return b ? gcd(b, a % b) : a;
}

int gcd(int a, int b, int &x, int &y) {
    if (b == 0) {
        x = 1, y = 0;
        return a;
    }
    int g = gcd(b, a % b, x, y), newX = y;
    y = x - a / b * y;
    x = newX;
    return g;
}

void diophant(int a, int b, int c, int &x, int &y) {
    int g = gcd(a, b, x, y);
    if (c % g != 0) return;
}

```

```

    x *= c / g, y *= c / g;
    // next solutions: x += b / g, y -= a / g
}

int inverse(int a, int mod) { // Returns -1, if a and mod are
    ⇨ not coprime
    int x, y;
    int g = gcd(a, mod, x, y);
    return g == 1 ? (x % mod + mod) % mod : -1;
}

vi inverseForAll(int mod) {
    vi r(mod, 0);
    r[1] = 1;
    for (int i = 2; i < mod; i++)
        r[i] = (mod - r[mod % i]) * (mod / i) % mod;
    return r;
}

```

## 50 Gray

```

int gray(int n) {
    return n ^ (n >> 1);
}

int revGray(int n) {
    int k = 0;
    for (; n; n >>= 1) k ^= n;
    return k;
}

```

## 51 Miller-Rabin Test

```
vector<int> primes = {2, 3, 5, 7, 11, 13, 17, 19, 23};
```

```

bool isPrimeMillerRabin(ll n) {
    int k = 0;
    ll t = n - 1;
    while (t % 2 == 0) k++, t /= 2;
    for (auto p : primes) {
        ll g = __gcd(n, (ll) p);
        if (g > 1 && g < n) return 0;
        if (g == n) return 1;
        ll b = power(p, t, n), last = n - 1;
        bool was = 0;
        forn (i, k + 1) {
            if (b == 1 && last != n - 1)
                return 0;
            if (b == 1) {
                was = 1;
                break;
            }
        }
        last = b, b = mul(b, b, n);
    }
    if (!was) return 0;
    return 1;
}

```

## 52 Phi

```

int phi(int n) {
    int result = n;
    for (int i = 2; i * i <= n; i++)
        if (n % i == 0) {
            while (n % i == 0) n /= i;
            result -= result / i;
        }
    if (n > 1) result -= result / n;
    return result;
}

```

```

int inversePhi(int a, int mod) {
    return power(a, phi(mod) - 1, mod);
}

```

## 53 Pollard

```

inline void pollardFoo(ll& x, ll mod) {
    x = (mul(x, x, mod) + 1) % mod;
}

vector<pair<ll, int>> factorize(ll n) {
    if (n == 1) return {};
    if (isPrimeMillerRabin(n)) return {mp(n, 1)};
    if (n <= 100) {
        vector<pair<ll, int>> ans;
        for (int i = 2; i * i <= n; i++)
            if (n % i == 0) {
                int cnt = 0;
                while (n % i == 0) n /= i, cnt++;
                ans.pb(mp(i, cnt));
            }
        if (n != 1) ans.pb(mp(n, 1));
        sort(all(ans));
        return ans;
    }
    while (1) {
        ll a = rand() % n, b = a;
        while (1) {
            pollardFoo(a, n), pollardFoo(b, n), pollardFoo(b, n);
            ll g = __gcd(abs(a-b), n);
            if (g != 1) {
                if (g == n)
                    break;
                auto ans1 = factorize(g);
                auto ans2 = factorize(n / g);
                vector<pair<ll, int>> ans;
                ans1.insert(ans1.end(), all(ans2));
                sort(all(ans1));
                for (auto np : ans1)
                    if (sz(ans) == 0 || np.fst != ans.back().fst)
                        ans.pb(np);
                    else
                        ans.back().snd += np.snd;
                return ans;
            }
        }
    }
    assert(0);
}

```

## 54 Power And Mul

```

inline ll fix(ll a, ll mod) { // a in [0, 2 * mod)
    if (a >= mod) a -= mod;
    return a;
}

// Returns (a * b) % mod, 0 <= a < mod, 0 <= b < mod
ll mulSlow(ll a, ll b, ll mod) {
    if (!b) return 0;
    ll c = fix(mulSlow(a, b / 2, mod) * 2, mod);
    return b & 1 ? fix(c + a, mod) : c;
}

ll mul(ll a, ll b, ll mod) {
    ll q = (ld) a * b / mod;
    ll r = a * b - mod * q;
    while (r < 0) r += mod;
    while (r >= mod) r -= mod;
    return r;
}

```

```

}

int power(int a, int n, int mod) {
    if (!n) return 1;
    int b = power(a, n / 2, mod);
    b = (b * 111 * b) % mod;
    return n & 1 ? (a * 111 * b) % mod : b;
}

ll powerLL(ll a, ll n, ll mod) {
    if (!n) return 1;
    ll b = power(a, n / 2, mod);
    b = mul(b, b, mod);
    return n & 1 ? mul(a, b, mod) : b;
}

int powerFast(int a, int n, int mod) {
    int res = 1;
    while (n) {
        if (n & 1)
            res = (res * 111 * a) % mod;
        a = (a * 111 * a) % mod;
        n /= 2;
    }
    return res;
}

```

## 55 Primitive Root

```

int primitiveRoot(int mod) { // Returns -1 if no primitive
    ↪ root exists
    vi fact;
    int ph = phi(mod);
    int n = mod;
    for (int i = 2; i * i <= n; i++) {
        if (n % i == 0) {
            fact.pb(i);
            while (n % i == 0) n /= i;
        }
    }
    if (n > 1) fact.pb(n);
    forab (i, 2, mod + 1) {
        bool ok = 1;
        for (int j = 0; j < sz(fact) && ok; j++)
            ok &= power(i, ph / fact[j], mod) != 1;
        if (ok) return i;
    }
    return -1;
}

```

## 56 Simpson

```

double f(double x) { return x; }

double simpson(double a, double b, int iterNumber) {
    double res = 0, h = (b - a) / iterNumber;
    forn (i, iterNumber + 1)
        res += f(a + h * i) * ((i == 0) || (i == iterNumber) ? 1 :
            ↪ ((i & 1) == 0) ? 2 : 4);
    return res * h / 3;
}

```

## 10 Strings

### 57 Aho-Corasick

```

const int ALPHA = 26;
const int MAX_N = 1e5;

```

```

struct Node {
    int next[ALPHA], term; //
    int go[ALPHA], suf, p, pCh; //
    Node(): term(0), suf(-1), p(-1) {
        fill(next, next + ALPHA, -1);
        fill(go, go + ALPHA, -1);
    }
};

Node g[MAX_N];
int last;

void add(const string &s) {
    int now = 0;
    for (char x : s) {
        if (g[now].next[x - 'a'] == -1) {
            g[now].next[x - 'a'] = ++last;
            g[last].p = now, g[last].pCh = x;
        }
        now = g[now].next[x - 'a'];
    }
    g[now].term = 1;
}

```

```

int go(int v, int c);

int getLink(int v) {
    if (g[v].suf == -1) {
        if (!v || !g[v].p) g[v].suf = 0;
        else g[v].suf = go(getLink(g[v].p), g[v].pCh);
    }
    return g[v].suf;
}

int go(int v, int c) {
    if (g[v].go[c] == -1) {
        if (g[v].next[c] != -1) g[v].go[c] = g[v].next[c];
        else g[v].go[c] = !v ? 0 : go(getLink(v), c);
    }
    return g[v].go[c];
}

```

## 58 Prefix-function

```

vi prefix(const string &s) {
    int n = sz(s);
    vi pr(n);
    forab (i, 1, n + 1) {
        int j = pr[i - 1];
        while (j > 0 && s[i] != s[j]) j = pr[j - 1];
        if (s[i] == s[j]) j++;
        pr[i] = j;
    }
    return pr;
}

```

## 59 Z-function

```

vi z(const string& s) {
    int n = sz(s);
    vi z(n);
    for (int i = 1, l = 0, r = 0; i < n; i++) {
        if (i <= r) z[i] = min(r - i + 1, z[i - l]);
        while (i + z[i] < n && s[z[i]] == s[i + z[i]]) z[i]++;
        if (i + z[i] - 1 > r) l = i, r = i + z[i] - 1;
    }
    return z;
}

```

## 60 Hashes

```
const int P = 239017;

inline int add(int a, int b, int m) {
    a += b;
    return a >= m ? a - m : a;
}

inline int sub(int a, int b, int m) {
    a -= b;
    return a < 0 ? a + m : a;
}

const int MOD_X = 1e9 + 9, MOD_Y = 1e9 + 7;

// using H = unsigned long long;
struct H {
    int x, y;
    H(): x(0), y(0) {}
    H(int _x): x(_x), y(_x) {}
    H(int _x, int _y): x(_x), y(_y) {}
    inline H operator+(const H& h) const { return H(add(x, h.x,
        ↪ MOD_X), add(y, h.y, MOD_Y)); }
    inline H operator-(const H& h) const { return H(sub(x, h.x,
        ↪ MOD_X), sub(y, h.y, MOD_Y)); }
    inline H operator*(ll k) const { return H(int((x * k) %
        ↪ MOD_X), int((y * k) % MOD_Y)); }
    inline H operator*(const H& h) const { return H(int((ll(x) *
        ↪ h.x) % MOD_X), int((ll(y) * h.y) % MOD_Y)); }
    inline bool operator==(const H& h) const { return x == h.x
        ↪ && y == h.y; }
    inline bool operator!=(const H& h) const { return x != h.x
        ↪ || y != h.y; }
    inline bool operator<(const H& h) const { return x < h.x ||
        ↪ (x == h.x && y < h.y); }
    explicit inline operator ll() const { return ll(x) * MOD_Y +
        ↪ y + 1; } // > 0
};

H deg[MAX_N], h[MAX_N];

inline H get(int l, int r) { return h[r] - h[l] * deg[r - l];
    ↪ }

void init(const string& s) {
    int n = sz(s);
    deg[0] = 1;
    forn (i, n)
        h[i + 1] = h[i] * P + s[i], deg[i + 1] = deg[i] * P;
}
```

## 61 Manaker

```
void manaker(const string& s, int *z0, int *z1) {
    int n = sz(s);
    forn (t, 2) {
        int *z = t ? z1 : z0, l = -1, r = -1; // [l..r]
        forn (i, n - t) {
            int k = 0;
            if (r > i + t) {
                int j = l + (r - i - t);
                k = min(z[j], j - l);
            }
            while (i - k >= 0 && i + k + t < n && s[i - k] == s[i +
                ↪ k + t])
                k++;
            z[i] = k;
            if (k && i + k + t > r)
                l = i - k + 1, r = i + k + t - 1;
        }
    }
}
```

}

## 62 Palindromic Tree

```
const int ALPHA = 26;

struct Vertex {
    int suf, len, next[ALPHA];
    Vertex() { fill(next, next + ALPHA, 0); }
};

int vn, v;
Vertex t[MAX_N + 2];
int n, s[MAX_N];

int get(int i) { return i < 0 ? -1 : s[i]; }

void init() {
    t[0].len = -1, vn = 2, v = 0, n = 0;
}

void add(int ch) {
    s[n++] = ch;
    while (v != 0 && ch != get(n - t[v].len - 2))
        v = t[v].suf;
    int& r = t[v].next[ch];
    if (!r) {
        t[vn].len = t[v].len + 2;
        if (!v) t[vn].suf = 1;
        else {
            v = t[v].suf;
            while (v != 0 && ch != get(n - t[v].len - 2))
                v = t[v].suf;
            t[vn].suf = t[v].next[ch];
        }
        r = vn++;
    }
    v = r;
}
```

## 63 Suffix Array (+stable)

```
int sLen, num[MAX_N + 1];
char s[MAX_N + 1];
int p[MAX_N], col[MAX_N], inv[MAX_N], lcp[MAX_N];

inline int mod(int x) {
    return (x + sLen) % sLen;
}

void buildArray(int n) {
    sLen = n;
    int ma = max(n, 256);
    forn (i, n)
        col[i] = s[i], p[i] = i;

    for (int k2 = 1; k2 / 2 < n; k2 *= 2) {
        int k = k2 / 2;
        memset(num, 0, sizeof(num));
        forn (i, n) num[col[i] + 1]++;
        forn (i, ma) num[i + 1] += num[i];
        forn (i, n)
            inv[num[col[mod(p[i] - k)]]++ = mod(p[i] - k);
        int cc = 0;
        forn (i, n) {
            bool add = col[inv[i]] != col[inv[i - 1]];
            add |= col[mod(inv[i] + k)] != col[mod(inv[i - 1] + k)];
            if (i && add) cc++;
            num[inv[i]] = cc;
        }
        forn (i, n) p[i] = inv[i], col[i] = num[i];
    }
```

```

}

memset(num, 0, sizeof(num));
for (i, n) num[col[i] + 1]++;
for (i, ma) num[i + 1] += num[i];
for (i, n) inv[num[col[i]]++] = i;
for (i, n) p[i] = inv[i];
for (i, n) inv[p[i]] = i;
}

void buildLCP(int n) {
    int len = 0;
    for (ind, n){
        int i = inv[ind];
        len = max(0, len - 1);
        if (i != n - 1)
            while (len < n && s[mod(p[i] + len)] == s[mod(p[i + 1] +
                ↪ len)])
                len++;
        lcp[i] = len;
        if (i != n - 1 && p[i + 1] == n - 1) len = 0;
    }
}

```

## 64 Suffix Automaton

```

struct Vx {
    static const int AL = 26;
    int len, suf;
    int next[AL];
    Vx() {}
    Vx(int l, int s): len(l), suf(s) {}
};

struct SA {
    static const int MAX_LEN = 1e5 + 100, MAX_V = 2 * MAX_LEN;
    int last, vcnt;
    Vx v[MAX_V];

    SA() { vcnt = 1, last = newV(0, 0); } // root = vertex
    ↪ with number 1
    int newV(int len, int suf){
        v[vcnt] = Vx(len, suf);
        return vcnt++;
    }

    int add(char ch) {
        int p = last, c = ch - 'a';
        last = newV(v[last].len + 1, 0);
        while (p && !v[p].next[c]) // added p &&
            v[p].next[c] = last, p = v[p].suf;
        if (!p)
            v[last].suf = 1;
        else {
            int q = v[p].next[c];
            if (v[q].len == v[p].len + 1) v[last].suf = q;
            else {
                int r = newV(v[p].len + 1, v[q].suf);
                v[last].suf = v[q].suf = r;
                memcpy(v[r].next, v[q].next,
                    ↪ sizeof(v[r].next));
                while (p && v[p].next[c] == q)
                    v[p].next[c] = r, p = v[p].suf;
            }
        }
        return last;
    }
};

```

## 65 Suffix Tree

```

const int MAX_L=1e5+10;
char S[MAX_L];
int L;

struct Node;
struct Pos;
typedef Node *pNode;
typedef map<char,pNode> mapt;

struct Node{
    pNode P,link;
    int L,R;
    mapt next;

    Node():P(NULL),link(this),L(0),R(0){}
    Node(pNode P,int L,int R):P(P),link(NULL),L(L),R(R){}

    inline int elen() const{return R-L;}
    inline pNode add_edge(int L,int R){return next[S[L]]=new
        ↪ Node(this,L,R);}
};

struct Pos{
    pNode V;
    int up;
    Pos():V(NULL),up(0){}
    Pos(pNode V,int up):V(V),up(up){}

    pNode split_edge() const{
        if(!up)
            return V;
        int L=V->L, M=V->R-up;
        pNode P=V->P, n=new Node(P,L,M);
        P->next[S[L]]=n;
        n->next[S[M]]=V;
        V->P=n, V->L=M;
        return n;
    }

    Pos next_char(char c) const{
        if(up)
            return S[V->R-up]==c ? Pos(V,up-1) : Pos();
        else{
            mapt::iterator it=V->next.find(c);
            return it==V->next.end() ? Pos() :
                ↪ Pos(it->snd,it->snd->elen()-1);
        }
    }
};

Pos go_down(pNode V,int L,int R){
    if(L==R)
        return Pos(V,0);
    while(1){
        V=V->next[S[L]];
        L+=V->elen();
        if(L>=R)
            return Pos(V,L-R);
    }
}

inline pNode calc_link(pNode &V){
    if(!V->link)
        V->link=go_down(V->P->link,V->L+!V->P->P,V->R).split_edge();
    return V->link;
}

Pos add_char(Pos P,int k){
    while(1){
        Pos p=P.next_char(S[k]);
        if(p.V)

```

```

    return p;
    pNode n=P.split_edge();
    n->add_edge(k,MAX_L);
    if(!n->P)
        return Pos(n,0);
    P=Pos(calc_link(n),0);
}
}

pNode Root;
void make_tree(){
    Root=new Node();
    Pos P(Root,0);
    forn(i,L)
        P=add_char(P,i);
}

```

## 11 C++ Tricks

### 66 Fast allocation

```

const int MAX_MEM = 1e8;

int mpos = 0;
char mem[MAX_MEM];
inline void* operator new(size_t n) {
    char *res = mem + mpos;
    mpos += n;
    assert(mpos <= MAX_MEM);
    return (void*) res;
}
inline void operator delete(void*) {}

inline void* operator new[](size_t) { assert(0); }
inline void operator delete[](void*) { assert(0); }

```

### 67 Hash of pair

```

struct PairHasher {
    size_t operator()(const pair<int, int>& p) const { return
        ↪ p.fst * 239017 + p.snd; }
};

```

### 68 Ordered Set

```

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

using namespace __gnu_pbds;

typedef tree<int, null_type, less<int>, rb_tree_tag,
    ↪ tree_order_statistics_node_update> ordered_set;

void example() {
    ordered_set X;
    X.insert(1);
    cout << *X.find_by_order(1) << " " << X.order_of_key(1) <<
        ↪ "\n";
}

```

### 69 Hash Map

```

#include <ext/pb_ds/assoc_container.hpp>

using namespace __gnu_pbds;

struct chash { // To use most bits rather than just the lowest
    ↪ ones:
    const uint64_t C = 11(2e18 * PI) + 71; // large odd number
    const int RANDOM = 912387491;

```

```

    ll operator()(ll x) const { return __builtin_bswap64((x ^
        ↪ RANDOM) * C); }
};

template<class K, class V> using ht = gp_hash_table<K, V,
    ↪ chash>;

template<class K, class V> V get(ht<K, V>& u, K x) {
    return u.find(x) == end(u) ? 0 : u[x];
}

ht<ll, int> h({}, {}, {}, {}, {1<<20});

```

## 70 Fast I/O (short)

```

inline int readChar();
inline int readInt();
template <class T> inline void writeInt(T x);

inline int readChar() {
    int c = getchar();
    while (c <= 32)
        c = getchar();
    return c;
}

inline int readInt() {
    int s = 0, c = readChar(), x = 0;
    if (c == '-')
        s = 1, c = readChar();
    while ('0' <= c && c <= '9')
        x = x * 10 + c - '0', c = readChar();
    return s ? -x : x;
}

template <class T> inline void writeInt(T x) {
    if (x < 0)
        putchar('-'), x = -x;
    char s[24];
    int n = 0;
    while (x || !n)
        s[n++] = '0' + x % 10, x /= 10;
    while (n--)
        putchar(s[n]);
}

```

## 71 Fast I/O (long)

```

template <class T = int> inline T readInt();
inline double readDouble();
inline int readUInt();
inline int readChar();
inline void readWord(char *s);
inline bool readLine(char *s); // do not save '\n'
inline bool isEof();
inline int peekChar();
inline bool seekEof();

template <class T> inline void writeInt(T x, int len);
template <class T> inline void writeUInt(T x, int len);
template <class T> inline void writeInt(T x) { writeInt(x,
    ↪ -1); };
template <class T> inline void writeUInt(T x) { writeUInt(x,
    ↪ -1); };
inline void writeChar(int x);
inline void writeWord(const char *s);
inline void writeDouble(double x, int len = 0);
inline void flush();

const int BUF_SIZE = 4096;

char buf[BUF_SIZE];
int bufLen = 0, pos = 0;

```

```

inline bool isEof() {
    if (pos == bufLen) {
        pos = 0, bufLen = fread(buf, 1, BUF_SIZE, stdin);
        if (pos == bufLen)
            return 1;
    }
    return 0;
}

inline int getChar() {
    return isEof() ? -1 : buf[pos++];
}

inline int peekChar() {
    return isEof() ? -1 : buf[pos];
}

inline bool seekEof() {
    int c;
    while ((c = peekChar()) != -1 && c <= 32)
        pos++;
    return c == -1;
}

inline int readChar() {
    int c = getChar();
    while (c != -1 && c <= 32)
        c = getChar();
    return c;
}

inline int readUInt() {
    int c = readChar(), x = 0;
    while ('0' <= c && c <= '9')
        x = x * 10 + c - '0', c = getChar();
    return x;
}

template <class T>
inline T readInt() {
    int s = 1, c = readChar();
    T x = 0;
    if (c == '-')
        s = -1, c = getChar();
    while ('0' <= c && c <= '9')
        x = x * 10 + c - '0', c = getChar();
    return s == 1 ? x : -x;
}

inline double readDouble() {
    int s = 1, c = readChar();
    double x = 0;
    if (c == '-')
        s = -1, c = getChar();
    while ('0' <= c && c <= '9')
        x = x * 10 + c - '0', c = getChar();
    if (c == '.') {
        c = getChar();
        double coef = 1;
        while ('0' <= c && c <= '9')
            x += (c - '0') * (coef *= 1e-1), c = getChar();
    }
    return s == 1 ? x : -x;
}

inline void readWord(char *s) {
    int c = readChar();
    while (c > 32)
        *s++ = c, c = getChar();
    *s = 0;
}

```

```

}

inline bool readLine(char *s) {
    int c = getChar();
    while (c != '\n' && c != -1)
        *s++ = c, c = getChar();
    *s = 0;
    return c != -1;
}

int writePos = 0;
char writeBuf[BUF_SIZE];

inline void writeChar(int x) {
    if (writePos == BUF_SIZE)
        fwrite(writeBuf, 1, BUF_SIZE, stdout), writePos = 0;
    writeBuf[writePos++] = x;
}

inline void flush() {
    if (writePos)
        fwrite(writeBuf, 1, writePos, stdout), writePos = 0;
}

template <class T>
inline void writeInt(T x, int outputLen) {
    if (x < 0)
        writeChar('-'), x = -x;

    char s[24];
    int n = 0;
    while (x || !n)
        s[n++] = '0' + x % 10, x /= 10;
    while (n < outputLen)
        s[n++] = '0';
    while (n--)
        writeChar(s[n]);
}

template <class T>
inline void writeUInt(T x, int outputLen) {
    char s[24];
    int n = 0;
    while (x || !n)
        s[n++] = '0' + char(x % 10), x /= 10;
    while (n < outputLen)
        s[n++] = '0';
    while (n--)
        writeChar(s[n]);
}

inline void writeWord(const char *s) {
    while (*s)
        writeChar(*s++);
}

inline void writeDouble(double x, int outputLen) {
    if (x < 0)
        writeChar('-'), x = -x;
    int t = (int) x;
    writeUInt(t, x -= t);
    writeChar('.');
    for (int i = outputLen - 1; i > 0; i--) {
        x *= 10;
        t = std::min(9, (int) x);
        writeChar('0' + t), x -= t;
    }
    x *= 10;
    t = std::min(9, (int)(x + 0.5));
    writeChar('0' + t);
}

```



}

12 Notes

72 Работа с деревьями

Приемы для работы с деревьями:

- 1. Двоичные подъемы
- 2. Поддеревья как отрезки Эйлера обхода
- 3. Вертикальные пути в Эйлеровом обходе (на ребрах вниз  $+k$ , на ребрах вверх  $-k$ ).
- 4. Храним в вершине значение функции на пути от корня до нее, дальше LCA.
- 5. Спуск с DFS, поддерживаем ДО на пути до текущей вершины.
- 6. Heavy-light decomposition
- 7. Centroid decomposition

73 Маски

Считаем динамику по маскам за  $O(2^n \cdot n)$   $f[mask] = sum$  по  $submask$   $g[submask]$ .  $dp[mask][i]$  — значение динамики для маски  $mask$ , если младшие  $i$  бит в ней зафиксированы (то есть мы не можем удалять оттуда). Ответ в  $dp[mask][0]$ .  $dp[mask][len] = g[mask]$ . Если  $i$ -ый бит 0, то  $dp[mask][i] = dp[mask][i + 1]$ , иначе  $dp[mask][i] = dp[mask][i + 1] + dp[mask \setminus (1 \ll i)][i + 1]$ .

Старший бит: предподсчет.

Младший бит:  $x \& \sim (-x)$

Чтобы по степени двойки получить логарифм, можно воспользоваться тем, что все степени двойки имеют разный остаток по модулю 67.

```
for (int mask = 0; mask < (1 << n); mask++)
  ~Isubmask : for (int s = mask; s; s = (s - 1) & mask)
  ~Isupmask : for (int s = mask; s < (1 << n); s = (s + 1) |
    ~ mask)
```

74 Гранди

Теорема Шпрага-Гранди: берем тех всех значений функции Гранди по состояниям, в которые можем перейти из данного. Если сумма независимых игр, то значение функции Гранди равно хог значений функций Гранди по всем играм. Бывает полезно вывести первые  $n$  значений и поискать закономерность. Часто сводится к *хот* по чему-нибудь.

75 Потoki

Потоки:

Name	Asympthotic
Ford-Fulkerson	$O( f  \cdot E)$
Ford-Fulkerson with scaling	$O(\log  f  \cdot E^2)$
Edmonds-Karp	$O(V \cdot E^2)$
Dinic	$O(V^2 \cdot E)$
Dinic with scaling	$O(V \cdot E \cdot \log C)$
Dinic on bipartite graph	$O(E\sqrt{V})$
Dinic on unit network	$O(E\sqrt{E})$

L-R потоки: Есть граф с недостатками или избытками в каждой вершине. Создаем фиктивные исток и сток (из истока все ребра в избытки, из недостатков все ребра в сток). Теперь пусть у нас есть L-R граф, для каждого ребра  $e (v \rightarrow u)$  известны  $L_e$  и  $R_e$ . Добавим в  $v$  избыток  $L_e$ , в  $u$  недостаток  $L_e$ , а

пропускную способность сделаем  $R_e - L_e$ . Получили решение задачи о LR-циркуляции. Если у нас обычный граф с истоком и стоком, то добавляем бесконечное ребро из стока в сток и ищем циркуляцию. Таким образом нашли удовлетворяющий условиям LR-поток. Если хотим максимальный поток, то на остаточной сети запускаем поиск максимального потока. В новом графе в прямую сторону пропускная способность равна  $R_e - f_e$ , в обратную  $f_e - L_e$ .

MinCostCirculation: Пока есть цикл отрицательного веса, запускаем алгоритм Карпа и пускаем максимальный поток по найденному циклу.

76 ДП

Табличка с оптимизациями для динамики:

Name	Original recurrence Sufficient Condition	From To
CHT1	$dp[i] = \min_{j < i} dp[j] + b[j] \cdot a[i]$ $b[j] \geq b[j + 1] \parallel a[i] \leq a[i + 1]$	$O(n^2)$ $O(n)$
CHT2	$dp[i][j] = \min_{k < j} dp[i - 1][k] + b[k] \cdot a[j]$ $b[k] \geq b[k + 1] \parallel a[j] \leq a[j + 1]$	$O(kn^2)$ $O(kn)$
D&C	$dp[i][j] = \min_{k < j} dp[i - 1][k] + c[k][j]$ $p[i, j] \leq p[i, j + 1]$	$O(kn^2)$ $O(kn \log n)$
Knuth	$dp[i][j] = \min_{i < k < j} dp[i][k] + dp[k][j] + c[i][j]$ $p[i, j - 1] \leq p[i, j] \leq p[i + 1, j]$	$O(n^3)$ $O(n^2)$
IOI	$f_n(k)$ — best for fixed k $f_n$ — convex, add penalty $\lambda \cdot k$	$O(k^{(2)}n)$ $O(n \log C)$

77 Комбинаторика

Биномиальные коэффициенты:

Теорема Люка для биномиальных коэффициентов: Хотим посчитать  $C_n^k$ , разложим в  $p$ -ичной системе счисления,  $n = (n_0, n_1, \dots), k = (k_0, k_1, \dots)$ .  $ans = C_{n_0}^{k_0} \cdot C_{n_1}^{k_1} \cdot \dots$

Способы вычисления  $C_n^k$ :

- 1.  $C_n^k = C_{n-1}^k + C_{n-1}^{k-1}$   
precalc:  $O(n^2)$ , query:  $O(1)$ .
- 2.  $C_n^k = \frac{n!}{k!(n-k)!}$ , предподсчитываем факториалы  
precalc:  $O(n \log n)$ , query:  $O(\log n)$
- 3. Теорема Люка  
precalc:  $O(p \log p)$ , query:  $O(\log p)$ .
- 4.  $C_n^k = C_n^{k-1} \cdot \frac{n-k+1}{k}$
- 5.  $C_n^k = \frac{n!}{k!(n-k)!}$ , для каждого факториала считаем степень вхождения и остаток  
precalc:  $O(p \log p)$ , query:  $O(\log p)$ .

$$C_n^{\frac{n}{2}} = \frac{2^n}{\sqrt{\pi n}}$$