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目录

1 代数

1.1 FFT-wrz

```
typedef complex<double> comp;
int len;
comp w[N<<1], a[N<<1], b[N<<1], c[N<<1]; // 数组记得至少开两倍
void init()
{
    double pi = acos(-1.0);
    for(int i = 0; i < len; i++) w[i] = (comp){cos(2*pi*i/len), sin(2*pi*i/len)};
}
void FFT(comp *a, comp *w)
{
    for(int i = 0, j = 0; i < len; i++)
    {
        if(i<j) swap(a[i], a[j]);
        for(int l = len>>1; (j^=l)<l; l >>= 1);
    }
    for(int i = 2; i <= len; i <<= 1)
    {
        int m = i >> 1;
        for(int j = 0; j < len; j += i)
        {
            for(int k = 0; k < m; k++)
            {
                comp tmp = w[len/i*k] * a[j+k+m];
                a[j+k+m] = a[j+k] - tmp;
                a[j+k] = a[j+k] + tmp;
            }
        }
    }
}
void mul(comp *a, comp *b, comp *c, int l) // 多项式乘法, c = a * b , c的长度为l
{
    for(len = 1; len <= l; len <<= 1);
    init(); FFT(a, w); FFT(b, w);
    for(int i = 0; i < len; i++) c[i] = a[i] * b[i];
    reverse(c+1, c+len); FFT(c, w);
    for(int i = 0; i < len; i++) c[i].r /= len; // 转化为int等时应加0.5, 如int(c[i].r+0.5)
}
```

1.2 FWT

```
void FWT(int a[],int n)
{
    for (int d = 1; d < n; d <<= 1)
        for (int m = d << 1, i = 0; i < n; i += m)
            for (int j = 0; j < d; j++) {
                int x = a[i + j], y = a[i + j + d];

                a[i + j] = (x + y) % mod,
                a[i + j + d] = (x - y + mod) % mod;

                //xor: a[i + j] = x + y, a[i + j + d] = (x - y + mod) % mod;
                //and: a[i + j] = x + y;
                //or:  a[i + j + d] = x + y;
            }
}

void UFWT(int a[], int n)
{
    for (int d = 1; d < n; d <<= 1)
        for (int m = d << 1, i = 0; i < n; i += m)
            for(int j = 0; j < d; j++) {
                int x = a[i + j], y = a[i + j + d];

                a[i + j] = 1LL * (x + y) * rev % mod,
                a[i + j + d] = (1LL * (x - y) * rev % mod + mod) % mod;

                //xor: a[i + j] = (x + y) / 2, a[i + j + d] = (x - y) / 2;
                //and: a[i + j] = x - y;
                //or:  a[i + j + d] = y - x;
            }
}

void solve(int a[], int b[], int n)
{
    FWT(a, n);
    FWT(b, n);
    for (int i = 0; i < n; i++)
        a[i] = 1LL * a[i] * b[i] % mod;
    UFWT(a, n);
}
```

1.3 高精度-wrz

```
#include<cmath>
#include<cstdio>
#include<cstring>
#include<algorithm>
#define BASE 10000
#define L 20005
using namespace std;
int p;
char s[10*L];
struct bigint
{
    int num[L], len;
    bigint(int x = 0)
    {
        memset(num,0,sizeof(num));
        len = 1;
        num[0] = x;
    }
    bigint operator + (bigint b)
    {
        bigint c;
        c.len = max(b.len, len);
        for(int i = 0; i < c.len; i++)
        {
            c.num[i] += num[i] + b.num[i];
            c.num[i+1] = c.num[i] / BASE;
            c.num[i] %= BASE;
        }
        if(c.num[c.len])c.len++;
        return c;
    }
    bigint operator - (bigint b)
    {
        bigint c;
        c.len = max(len, b.len);
        for(int i = 0; i < c.len; i++)
        {
            c.num[i] += num[i] - b.num[i];
            if(c.num[i] < 0)
            {
                c.num[i] += BASE;
                c.num[i+1]--;
            }
        }
        while(!c.num[c.len-1] && c.len > 1)c.len--;
        return c;
    }
    void operator -= (int b)
    {
        num[0] -= b;
        for(int i = 0; i < len; i++)
        {
            num[i+1] += num[i] / BASE;
            num[i] %= BASE;
            if(num[i] < 0)num[i] += BASE, num[i+1]--;
        }
        while(!num[len-1] && len > 1) len--;
    }
    bigint operator * (bigint b)
    {
        bigint c;
        c.len = len + b.len;
        for(int i = 0; i < len; i++)
        {
            for(int j = 0; j < b.len; j++)
            {
                c.num[i+j] += num[i] * b.num[j];
                c.num[i+j+1] += c.num[i+j] / BASE;
                c.num[i+j] %= BASE;
            }
        }
        if(!c.num[c.len-1] && c.len > 1)c.len--;
        return c;
    }
    bigint operator * (int b)
    {
        bigint c;
        for(int i = 0; i < len; i++)
            c.num[i] = num[i] * b; // long long
        for(int i = 0; i < len; i++)
        {
            c.num[i+1] += c.num[i] / BASE;
            c.num[i] %= BASE;
        }
        c.len = len;
        while(c.num[c.len])c.len++;
        return c;
    }
    bool substract(bigint b, int pos)
    {
        if(len < b.len - pos)return false;
        else if(len == b.len-pos)
            for(int i = len-1; i>=0; i--)
                if(num[i] < b.num[i+pos])return false;
                else if(num[i] > b.num[i+pos])break;
        for(int i = 0; i < len; i++)
        {
            num[i] -= b.num[i+pos];
            if(num[i] < 0)
            {
                num[i] += BASE;
                num[i+1] --;
            }
        }
        while(!num[len-1] && len > 1)len--;
        return true;
    }
```

```
    // remember to change [BASE] to 10 !!!
    // [this] is the remainder
    bigint operator / (bigint b)
    {
        bigint c;
        if(len < b.len)return c;
        int k = len - b.len;
        c.len = k + 1;
        for(int i = len-1; i>=0; i--)
        {
            if(i>=k)b.num[i] = b.num[i-k];
            else b.num[i] = 0;
        }
        b.len = len;
        for(int i = 0; i <= k; i++)
            while(this->substract(b,i)) c.num[k-i]++;
        for(int i = 0; i < c.len; i++)
        {
            c.num[i+1] += c.num[i] / BASE;
            c.num[i] %= BASE;
        }
        while(!c.num[c.len-1] && c.len > 0) c.len--;
        return c;
    }

    // [this] is not the remainder
    bigint operator / (int b)
    {
        bigint c;
        int tmp = 0;
        for(int i = len-1; i>=0; i--)
        {
            tmp = tmp * BASE + num[i];
            c.num[i] = tmp / b;
            tmp %= b;
        }
        for(c.len = len; !c.num[c.len-1] && c.len > 1;
            c.len--);
        return c;
    }
    bool scan()
    {
        int n = -1;
        char ch = getchar();
        while(ch < '0' || ch > '9') if(ch == EOF)
            return false; else ch = getchar();
        while(ch >= '0' && ch <= '9') s[++n] = ch - '0
            ', ch = getchar();
        len = 0;
        for(int i = n; i >= 0; i-=4)
        {
            num[len] += s[i];
            if(i>=1)num[len] += s[i-1] * 10;
            if(i>=2)num[len] += s[i-2] * 100;
            if(i>=3)num[len] += s[i-3] * 1000;
            ++len;
        }
        return true;
    }
    void clr()
    {
        memset(num,0,sizeof(num));
    }
    void print()
    {
        printf("%d",num[len-1]);
        for(int i = len-2; i>=0; i--)
            printf("%04d",num[i]);
        printf("\n");
    }
};
```

1.4 线性基-gwx

```
ll solve()
{
    ll res = 0;
    memset(b, 0, sizeof(b));
    for(int i = 1; i <= tot; i++)
        for(int j = 60; j >= 0; j--)
            if((a[i] >> j) & 1)
            {
                if(!b[j])
                {
                    b[j] = a[i];
                    break;
                }
                a[i] ^= b[j];
            }
    for(int i = 60; i >= 0; i--)
        res = max(res, res ^ b[i]);
    return res;
}
```

1.5 单纯形

```
// max{c * x | Ax <= b, x >= 0}的解, 无解返回空的
    vector, 否则就是解. 答案在an中
template <int MAXN = 100, int MAXM = 100>
struct simplex {
    int n, m; double a[MAXM][MAXN], b[MAXM], c[MAXN];
    bool infeasible, unbounded;
    double v, an[MAXN + MAXM]; int q[MAXN + MAXM];
    void pivot (int l, int e) {
        std::swap (q[e], q[l + n]);
        double t = a[l][e]; a[l][e] = 1; b[l] /= t;
        for (int i = 0; i < n; ++i) a[l][i] /= t;
        for (int i = 0; i < m; ++i) if (i != l && std
            ::abs (a[i][e]) > EPS) {
            t = a[i][e]; a[i][e] = 0; b[i] -= t * b[l
                ];
            for (int j = 0; j < n; ++j) a[i][j] -= t *
                 a[l][j]; }
        if (std::abs (c[e]) > EPS) {
            t = c[e]; c[e] = 0; v += t * b[l];
            for (int j = 0; j < n; ++j) c[j] -= t * a[
                l][j]; } }
    bool pre () {
        for (int l, e; ; ) {
            l = e = -1;
            for (int i = 0; i < m; ++i) if (b[i] < -
                EPS && (!~l || rand () & 1)) l = i;
            if (!~l) return false;
            for (int i = 0; i < n; ++i) if (a[l][i] <
                -EPS && (!~e || rand () & 1)) e = i;
            if (!~e) return infeasible = true;
            pivot (l, e); } }
    double solve () {
        double p; std::fill (q, q + n + m, -1);
        for (int i = 0; i < n; ++i) q[i] = i;
        v = 0; infeasible = unbounded = false;
        if (pre ()) return 0;
        for (int l, e; ; pivot (l, e)) {
            l = e = -1; for (int i = 0; i < n; ++i) if
                 (c[i] > EPS) { e = i; break; }
            if (!~e) break; p = INF;
            for (int i = 0; i < m; ++i) if (a[i][e] >
                EPS && p > b[i] / a[i][e])
                p = b[i] / a[i][e], l = i;
            if (!~l) return unbounded = true, 0; }
        for (int i = n; i < n + m; ++i) if (~q[i]) an[
            q[i]] = b[i - n];
        return v; } };
```

1.6 NTT-gwx

```
const int G;
int n, m, inm;
int rev[maxn], a[maxn], b[maxn];    //maxn > 2 ^ k

ll power(ll b, int k)
{
    ll res = 1;
    for(; k; k >>= 1, b = b * b % mod)
        if(k & 1)
            res = res * b % mod;
    return res;
}

void ntt(ll*a, int f)
{
    for(int i = 0; i < m; i++)
        if(rev[i] < i)
            swap(a[i], a[rev[i]]);
    for(int l = 2, h = 1; l <= m; h = l, l <<= 1)
    {
        int ur;
        if(f == 1)
            ur = power(G, (mod - 1) / l);
        else
            ur = power(G, mod - 1 - (mod - 1) / l);
        for(int i = 0; i < m; i += l)
        {
            ll w = 1;
            for(int k = i; k < i + h; k++, w = w * ur
                % mod)
            {
                int x = a[k], y = a[k + h] * w % mod;
                a[k] = (x + y) % mod;
                a[k + h] = (x - y + mod) % mod;
            }
        }
    }
    if(f == -1)
        for(int i = 0; i < m; i++)
            a[i] = a[i] * inm % mod;
}

void multi()
{
    ntt(a, 1); ntt(b, 1);
    for(int i = 0; i < m; i++)
        a[i] = a[i] * b[i] % mod;
    ntt(a, -1);
}

void init()
{
    for(m = 1; m <= 2 * n; m <<= 1) ;
    for(int i = 1; i < m; i++)
    {
```

```
        rev[i] = rev[i - 1];
        for(int j = m >> 1; (rev[i] ^= j) < j; j >>= 1) ;
    }
}
```

2 计算几何

2.1 二维计算几何-wrz

```
#include<bits/stdc++.h>
using namespace std;
const double inf = 1e9;
const double eps = 1e-9;
const double pi = acos(-1.0);
bool le(double x, double y){return x < y - eps;} // x严格小于y
bool leq(double x, double y){return x < y + eps;} // x小于等于y
bool equ(double x, double y){return fabs(x - y) < eps;} // x等于y
double mysqrt(double x) {return x < eps ? 0 : sqrt(x);} // 开根号
double sqr(double x) {return x * x;} // 平方
struct point // 点或向量
{
    double x, y;
    double operator * (point that){return x*that.x + y*that.y;}
    double operator ^ (point that){return x*that.y - y*that.x;}
    point operator * (double t){return (point){x*t, y*t};}
    point operator / (double t){return (point){x/t, y/t};}
    point operator + (point that) {return (point){x + that.x, y + that.y};}
    point operator - (point that) {return (point){x - that.x, y - that.y};}
    double len(){return mysqrt(x*x+y*y);} // 到原点距离/向量长度
    point reset_len(double t) // 改变向量长度为t, t为正则方向不变, t为负则方向相反
    {double p = len();return (point){x*t/p, y*t/p};}
    point rot90() {return (point){-y, x};} // 逆时针旋转90度
    point rotate(double angle) // 使向量逆时针旋转angle弧度
    {double c = cos(angle), s = sin(angle);return (point){c * x  - s * y, s * x + c * y};}
};
struct line // 参数方程表示, p为线上一点, v为方向向量
{
    point p, v; // p为线上一点, v为方向向量
    double angle; // 半平面交用, 用atan2计算, 此时v的左侧为表示的半平面。注意有的函数声明一个新的line时没有初始化这个值!
    bool operator < (const line &that) const {return angle < that.angle;} // 半平面交用, 按与x轴夹角排序
};
struct circle{point c; double r;};
double distance(point a, point b) // a, b两点距离
{return mysqrt(sqr(a.x - b.x) + sqr(a.y - b.y));}
circle make_circle(point a, point b) // 以a, b两点为直径作圆
{double d = distance(a, b);return (circle){(a+b)/2, d/2};}
double point_to_line(point a, line b) // 点a到直线b距离
{return fabs((b.v ^ (a - b.p)) / b.v.len());}
point project_to_line(point a, line b) // 点a到直线b的垂足/投影
{return b.v.reset_len((a - b.p) * b.v / b.v.len()) + b.p;}
vector<point> circle_inter(circle a, circle b) // 圆a和圆b的交点, 需保证两圆不重合, 圆的半径必须大于0
{
    double d = distance(a.c, b.c);
    vector<point> ret;
    if(le(a.r + b.r, d) || le(a.r + d, b.r) || le(b.r + d, a.r)) return vector<point>(); // 相离或内含
    point r = (b.c - a.c).reset_len(1);
    double x = ((sqr(a.r) - sqr(b.r)) / d + d) / 2;
    double h = mysqrt(sqr(a.r) - sqr(x));
    if(equ(h, 0)) return vector<point>({a.c + r * x}); // 内切或外切
    else return vector<point>({a.c + r*x + r.rot90()*h, a.c + r*x - r.rot90()*h}); // 相交两点
}
vector<point> line_circle_inter(line a, circle b) // 直线a和圆b的交点
{
    double d = point_to_line(b.c, a);
    if(le(b.r, d)) return vector<point>(); // 不交
    double x = mysqrt(sqr(b.r) - sqr(d));
    point p = project_to_line(b.c, a);
    if(equ(x, 0)) return vector<point> ({p}); // 相切
    else return vector<point> ({p + a.v.reset_len(x), p - a.v.reset_len(x)}); // 相交两点
}
point line_inter(line a, line b) // 直线a和直线b的交点, 需保证两直线不平行
{double s1 = a.v ^ (b.p - a.p);double s2 = a.v ^ (b.p + b.v - a.p);return (b.p * s2 - (b.p + b.v) * s1) / (s2 - s1);}
vector<point> tangent(point p, circle a) // 过点p的圆a的切线的切点, 圆的半径必须大于0
{circle c = make_circle(p, a.c);return circle_inter(a, c);}
vector<line> intangent(circle a, circle b) // 圆a和圆b的内公切线
{
    point p = (b.c * a.r + a.c * b.r) / (a.r + b.r);
    vector<point> va = tangent(p, a), vb = tangent(p, b);
    vector<line> ret;
    if(va.size() == 2 && vb.size() == 2){ret.push_back((line){va[0], vb[0] - va[0]});ret.push_back((line){va[1], vb[1] - va[1]});}
    else if(va.size() == 1 && vb.size() == 1){ret.push_back((line){p, (a.c - b.c).rot90()});}
    return ret;
}
// 判断半平面交是否有解, 若有解需保证半平面交必须有界, 可以通过外加四个大半平面解决
// lcnt为半平面数量, l为需要做的所有半平面的数组, p为存交点的临时数组, h为时刻更新的合法的半平面数组, 下标均从1开始
bool HP(int lcnt, line *l, line *h, point *p)
{
    sort(l+1, l+1+lcnt);
    int head = 1, tail = 1;
    h[1] = l[1];
    for(int i = 2; i <= lcnt; i++)
    {
        line cur = l[i];
        for(; head < tail && le(cur.v ^ (p[tail-1]-cur.p), 0); tail--); // 先删队尾再删队头, 顺序不能换
        for(; head < tail && le(cur.v ^ (p[head]-cur.p), 0); head++);
        h[++tail] = cur;
        if(equ(h[tail].v ^ h[tail-1].v, 0)) // 平行
        {
            if(le(h[tail].v * h[tail-1].v, 0)) return false; // 方向相反的平行直线, 显然已经不可能围出有界半平面了
            tail--;
            if(le(h[tail+1].v ^ (h[tail].p - h[tail+1].p), 0)) h[tail] = h[tail+1];
        }
        if(head < tail) p[tail-1] = line_inter(h[tail-1], h[tail]);
    }
    for(; head < tail && le(h[head].v ^ (p[tail-1]-h[head].p), 0); tail--);
    return tail - head > 1;
}
double calc(double X){return 0;} // 计算给定X坐标上的覆盖的长度, 配合辛普森积分使用
// 自适应辛普森积分, 参数分别为(左端点x坐标, 中点x坐标, 右端点x坐标, 左端点答案, 中点答案, 右端点答案)
// 改变计算深度应调整eps
double simpson(double l, double mid, double r, double fl, double fm, double fr)
{
    double lmid = (l+mid)/2, rmid = (r+mid)/2, flm = calc(lmid), frm = calc(rmid);
    double ans = (r-l) * (fl + 4*fm + fr), ansl = (mid-l) * (fl + 4*flm + fm), ansr = (r-mid) * (fm + 4*frm + fr);
    if(fabs(ansl + ansr - ans) < eps) return ans / 6;
    else return simpson(l,lmid,mid,fl,flm,fm) + simpson(mid,rmid,r,fm,frm,fr);
}
int main(){}
```

2.2 basis

```
struct Point {
    DB x, y;
    Point rotate(DB ang) const {return Point(cos(ang) * x - sin(ang) * y, cos(ang) * y + sin(ang) * x);} // 逆时针旋转 ang 弧度
    Point turn90() const {return Point(-y, x);} // 逆时针旋转 90 度
    Point unit() const {return *this / len();}
};
DB dot(const Point& a, const Point& b) {return a.x * b.x + a.y * b.y;}
DB det(const Point& a, const Point& b) {return a.x * b.y - a.y * b.x;}
#define cross(p1,p2,p3) ((p2.x-p1.x)*(p3.y-p1.y)-(p3.x
```

```
    -p1.x)*(p2.y-p1.y))
#define crossOp(p1,p2,p3) sign(cross(p1,p2,p3))
bool isLL(const Line& l1, const Line& l2, Point& p) {
    // 直线与直线交点
    DB s1 = det(l2.b - l2.a, l1.a - l2.a),
       s2 = -det(l2.b - l2.a, l1.b - l2.a);
    if (!sign(s1 + s2)) return false;
    p = (l1.a * s2 + l1.b * s1) / (s1 + s2);
    return true;
}
bool onSeg(const Line& l, const Point& p) {  // 点在线段上
    return sign(det(p - l.a, l.b - l.a)) == 0 && sign(dot(p - l.a, p - l.b)) <= 0;}
Point projection(const Line & l, const Point& p) {
    return l.a + (l.b - l.a) * (dot(p - l.a, l.b - l.a) / (l.b - l.a).len2());}
DB disToLine(const Line& l, const Point& p) {  // 点到*直线*距离
    return fabs(det(p - l.a, l.b - l.a) / (l.b - l.a).len());}
DB disToSeg(const Line& l, const Point& p) {  // 点到线段距离
    return sign(dot(p - l.a, l.b - l.a)) * sign(dot(p - l.b, l.a - l.b)) == 1 ? disToLine(l, p) : std::min((p - l.a).len(), (p - l.b).len());}
// 圆与直线交点
bool isCL(Circle a, Line l, Point& p1, Point& p2) {
    DB x = dot(l.a - a.o, l.b - l.a),
       y = (l.b - l.a).len2(),
       d = x * x - y * ((l.a - a.o).len2() - a.r * a.r);
    if (sign(d) < 0) return false;
    Point p = l.a - ((l.b - l.a) * (x / y)), delta = (l.b - l.a) * (msqrt(d) / y);
    p1 = p + delta; p2 = p - delta;
    return true;
}
//圆与圆的交面积
DB areaCC(const Circle& c1, const Circle& c2) {
    DB d = (c1.o - c2.o).len();
    if (sign(d - (c1.r + c2.r)) >= 0) return 0;
    if (sign(d - std::abs(c1.r - c2.r)) <= 0) {
        DB r = std::min(c1.r, c2.r);
        return r * r * PI;  }
    DB x = (d * d + c1.r * c1.r - c2.r * c2.r) / (2 * d),
       t1 = acos(x / c1.r), t2 = acos((d - x) / c2.r);
    return c1.r * c1.r * t1 + c2.r * c2.r * t2 - d * c1.r * sin(t1);
}
// 圆与圆交点
bool isCC(Circle a, Circle b, P& p1, P& p2) {
    DB s1 = (a.o - b.o).len();
    if (sign(s1 - a.r - b.r) > 0 || sign(s1 - std::abs(a.r - b.r)) < 0) return false;
    DB s2 = (a.r * a.r - b.r * b.r) / s1;
    DB aa = (s1 + s2) * 0.5, bb = (s1 - s2) * 0.5;
    P o = (b.o - a.o) * (aa / (aa + bb)) + a.o;
    P delta = (b.o - a.o).unit().turn90() * msqrt(a.r * a.r - aa * aa);
    p1 = o + delta, p2 = o - delta;
    return true;
}
// 求点到圆的切点，按关于点的顺时针方向返回两个点
bool tanCP(const Circle &c, const Point &p0, Point &p1, Point &p2) {
    double x = (p0 - c.o).len2(), d = x - c.r * c.r;
    if (d < eps) return false; // 点在圆上认为没有切点
    Point p = (p0 - c.o) * (c.r * c.r / x);
    Point delta = ((p0 - c.o) * (-c.r * sqrt(d) / x)).turn90();
    p1 = c.o + p + delta;
    p2 = c.o + p - delta;
    return true;
}
// 求圆到圆的外共切线，按关于 c1.o 的顺时针方向返回两条线
vector<Line> extanCC(const Circle &c1, const Circle &c2) {
    vector<Line> ret;
    if (sign(c1.r - c2.r) == 0) {
        Point dir = c2.o - c1.o;
        dir = (dir * (c1.r / dir.len())).turn90();
        ret.push_back(Line(c1.o + dir, c2.o + dir));
        ret.push_back(Line(c1.o - dir, c2.o - dir));
    } else {
        Point p = (c1.o * -c2.r + c2.o * c1.r) / (c1.r - c2.r);
        Point p1, p2, q1, q2;
        if (tanCP(c1, p, p1, p2) && tanCP(c2, p, q1, q2)) {
            if (c1.r < c2.r) swap(p1, p2), swap(q1, q2);
            ret.push_back(Line(p1, q1));
            ret.push_back(Line(p2, q2));
        }
    }
    return ret;
}
// 求圆到圆的内共切线，按关于 c1.o 的顺时针方向返回两条线
std::vector<Line> intanCC(const Circle &c1, const Circle &c2) {
    std::vector<Line> ret;
    Point p = (c1.o * c2.r + c2.o * c1.r) / (c1.r + c2.r);
    Point p1, p2, q1, q2;
    if (tanCP(c1, p, p1, p2) && tanCP(c2, p, q1, q2)) { // 两圆相切认为没有切线
        ret.push_back(Line(p1, q1));
        ret.push_back(Line(p2, q2));
    }
    return ret;
}
bool contain(vector<Point> polygon, Point p) { // 判断点 p 是否被多边形包含，包括落在边界上
    int ret = 0, n = polygon.size();
    for(int i = 0; i < n; ++ i) {
        Point u = polygon[i], v = polygon[(i + 1) % n];
        if (onSeg(Line(u, v), p)) return true;  // Here I guess.
        if (sign(u.y - v.y) <= 0) swap(u, v);
        if (sign(p.y - u.y) > 0 || sign(p.y - v.y) <= 0) continue;
        ret += sign(det(p, v, u)) > 0;
    }
    return ret & 1;
}
// 用半平面 (q1,q2) 的逆时针方向去切凸多边形
std::vector<Point> convexCut(const std::vector<Point>& ps, Point q1, Point q2) {
    std::vector<Point> qs; int n = ps.size();
    for (int i = 0; i < n; ++i) {
        Point p1 = ps[i], p2 = ps[(i + 1) % n];
        int d1 = crossOp(q1,q2,p1), d2 = crossOp(q1,q2,p2);
        if (d1 >= 0) qs.push_back(p1);
        if (d1 * d2 < 0) qs.push_back(isSS(p1, p2, q1, q2));
    } return qs;
}
```

2.3 circles-intersections

```
struct Event {
    Point p; double ang; int delta;
    Event (Point p = Point(0, 0), double ang = 0, double delta = 0) : p(p), ang(ang), delta(delta) {}
};
bool operator < (const Event &a, const Event &b) {return a.ang < b.ang;}
void addEvent(const Circle &a, const Circle &b, vector<Event> &evt, int &cnt) {
    double d2 = (a.o - b.o).len2(),
           dRatio = ((a.r - b.r) * (a.r + b.r) / d2 + 1) / 2,
           pRatio = sqrt(-(d2 - sqr(a.r - b.r)) * (d2 - sqr(a.r + b.r)) / (d2 * d2 * 4));
    Point d = b.o - a.o, p = d.rotate(PI / 2),
          q0 = a.o + d * dRatio + p * pRatio,
          q1 = a.o + d * dRatio - p * pRatio;
    double ang0 = (q0 - a.o).ang(),
           ang1 = (q1 - a.o).ang();
    evt.push_back(Event(q1, ang1, 1));
    evt.push_back(Event(q0, ang0, -1));
    cnt += ang1 > ang0;
}
bool issame(const Circle &a, const Circle &b) { return sign((a.o - b.o).len()) == 0 && sign(a.r - b.r) == 0; }
bool overlap(const Circle &a, const Circle &b) {
    return sign(a.r - b.r - (a.o - b.o).len()) >= 0; }
bool intersect(const Circle &a, const Circle &b) {
    return sign((a.o - b.o).len() - a.r - b.r) < 0; }
Circle c[N];
double area[N];  // area[k] -> area of intersections >= k.
Point centroid[N];
bool keep[N];
void add(int cnt, DB a, Point c) {area[cnt] += a; centroid[cnt] = centroid[cnt] + c * a;}
void solve(int C) {
    for (int i = 1; i <= C; ++ i) {area[i] = 0; centroid[i] = Point(0, 0);}
    for (int i = 0; i < C; ++i) {
        int cnt = 1;
        vector<Event> evt;
        for (int j = 0; j < i; ++j) if (issame(c[i], c[j])) ++cnt;
        for (int j = 0; j < C; ++j) {
            if (j != i && !issame(c[i], c[j]) && overlap(c[j], c[i])){++cnt;}
        }
        for (int j = 0; j < C; ++j) {
            if (j != i && !overlap(c[j], c[i]) && !overlap(c[i], c[j]) && intersect(c[i],
```

```
                c[j])) {addEvent(c[i], c[j], evt, cnt
                );}}
        if (evt.size() == 0u) { add(cnt, PI * c[i].r *
             c[i].r, c[i].o);}
        else {
            sort(evt.begin(), evt.end());
            evt.push_back(evt.front());
            for (int j = 0; j + 1 < (int)evt.size();
                ++j) {
                cnt += evt[j].delta;
                add(cnt, det(evt[j].p, evt[j + 1].p) /
                     2, (evt[j].p + evt[j + 1].p) / 3)
                    ;
                double ang = evt[j + 1].ang - evt[j].
                    ang;
                if (ang < 0) { ang += PI * 2;}
                if (sign(ang) == 0) continue;
                add(cnt, ang * c[i].r * c[i].r / 2, c[
                    i].o +
                    Point(sin(ang1) - sin(ang0), -cos(
                        ang1) + cos(ang0)) * (2 / (3 *
                         ang) * c[i].r));
                add(cnt, -sin(ang) * c[i].r * c[i].r /
                     2, (c[i].o + evt[j].p + evt[j +
                    1].p) / 3);
            }
        }
    }
    for (int i = 1; i <= C; ++ i)if (sign(area[i])) {
        centroid[i] = centroid[i] / area[i];}
}
```

2.4 cirque-area-merge

```
//n^2*logn
struct point {
    point rotate(const double &ang) {return point(cos(
        ang) * x - sin(ang) * y, cos(ang) * y + sin(
        ang) * x);}
    double ang() {return atan2(y, x);}
};
struct Circle {
    point o; double r;
    int tp; // 正圆为1 反向圆为-1
    Circle (point o = point(0, 0), double r = 0, int
        tp = 0) : o(o), r(r), tp(tp) {}
};
struct Event {
    point p; double ang;    int delta;
    Event (point p = point(0, 0), double ang = 0,
        double delta = 0) : p(p), ang(ang), delta(
        delta) {}
};
bool operator < (const Event &a, const Event &b) {
    return a.ang < b.ang;}
void addEvent(const Circle &a, const Circle &b, vector
    <Event> &evt, int &cnt) {
    double d2 = (a.o - b.o).len2(),
        dRatio = ((a.r - b.r) * (a.r + b.r) / d2 + 1)
            / 2,
        pRatio = sqrt(-(d2 - sqr(a.r - b.r)) * (d2 -
            sqr(a.r + b.r))) / d2 / 2;
    point d = b.o - a.o, p = d.rotate(PI / 2),
        q0 = a.o + d * dRatio + p * pRatio,
        q1 = a.o + d * dRatio - p * pRatio;
    double ang0 = (q0 - a.o).ang(),
        ang1 = (q1 - a.o).ang();
    evt.push_back(Event(q1, ang1, b.tp));
    evt.push_back(Event(q0, ang0, -b.tp));
    cnt += (ang1 > ang0) * b.tp;
}
bool issame(const Circle &a, const Circle &b) {return
    sign((a.o - b.o).len()) == 0 && sign(a.r - b.r) ==
     0;}
bool overlap(const Circle &a, const Circle &b) {return
     sign(a.r - b.r - (a.o - b.o).len()) >= 0;}
bool intersect(const Circle &a, const Circle &b) {
    return sign((a.o - b.o).len() - a.r - b.r) < 0;}
int C;
Circle c[N];
double area[N];
void solve() { // area[1]..area[C]
    memset(area, 0, sizeof(double) * (C + 1));
    for (int i = 0; i < C; ++i) {
        int cnt = (c[i].tp > 0);
        vector<Event> evt;
        for (int j = 0; j < i; ++j) if (issame(c[i], c
            [j])) cnt += c[j].tp;
        for (int j = 0; j < C; ++j)
            if (j != i && !issame(c[i], c[j]) &&
                overlap(c[j], c[i])) cnt += c[j].tp;
        for (int j = 0; j < C; ++j)
            if (j != i && !overlap(c[j], c[i]) && !
                overlap(c[i], c[j]) && intersect(c[i],
                 c[j]))
                addEvent(c[i], c[j], evt, cnt);
        if (evt.size() == 0) area[cnt] += c[i].tp * PI
             * c[i].r * c[i].r;
        else {
            sort(evt.begin(), evt.end());
            evt.push_back(evt.front());
            for (int j = 0; j + 1 < (int)evt.size();
                ++j) {
                cnt += evt[j].delta;
                area[cnt] += c[i].tp * det(evt[j].p,
                    evt[j + 1].p) / 2;
                double ang = evt[j + 1].ang - evt[j].
                    ang;
                if (ang < 0) ang += PI * 2;
                area[cnt] += c[i].tp * (ang * c[i].r *
                     c[i].r / 2 - sin(ang) * c[i].r *
                    c[i].r / 2);
            }
        }
    }
}
```

2.5 凸包

```
// 凸包中的点按逆时针方向
struct Convex {
    int n;
    std::vector<Point> a, upper, lower;
    void make_shell(const std::vector<Point>& p,
            std::vector<Point>& shell) {  // p needs
                to be sorted.
        clear(shell); int n = p.size();
        for (int i = 0, j = 0; i < n; i++, j++) {
            for (; j >= 2 && sign(det(shell[j-1] -
                shell[j-2],
                            p[i] - shell[j-2])) <= 0;
                                --j) shell.pop_back();
            shell.push_back(p[i]);
        }
    }
    void make_convex() {
        std::sort(a.begin(), a.end());
        make_shell(a, lower);
        std::reverse(a.begin(), a.end());
        make_shell(a, upper);
        a = lower; a.pop_back();
        a.insert(a.end(), upper.begin(), upper.end());
        if ((int)a.size() >= 2) a.pop_back();
        n = a.size();
    }
    void init(const std::vector<Point>& _a) {clear(a);
         a = _a; n = a.size();make_convex();}
    void read(int _n) {  // Won't make convex.
        clear(a); n = _n; a.resize(n);
        for (int i = 0; i < n; i++) a[i].read();
    }
    std::pair<DB, int> get_tangent(
            const std::vector<Point>& convex, const
                Point& vec) {
        int l = 0, r = (int)convex.size() - 2;
        assert(r >= 0);
        for (; l + 1 < r; ) {
            int mid = (l + r) / 2;
            if (sign(det(convex[mid + 1] - convex[mid
                ], vec)) > 0)r = mid;
            else l = mid;
        }
        return std::max(std::make_pair(det(vec, convex
            [r]), r),
                std::make_pair(det(vec, convex[0]), 0)
                    );
    }
    int binary_search(Point u, Point v, int l, int r)
        {
        int s1 = sign(det(v - u, a[l % n] - u));
        for (; l + 1 < r; ) {
            int mid = (l + r) / 2;
            int smid = sign(det(v - u, a[mid % n] - u)
                );
            if (smid == s1) l = mid;
            else r = mid;
        }
        return l % n;
    }
    // 求凸包上和向量 vec 叉积最大的点，返回编号，共线
        的多个切点返回任意一个
    int get_tangent(Point vec) {
        std::pair<DB, int> ret = get_tangent(upper,
            vec);
        ret.second = (ret.second + (int)lower.size() -
             1) % n;
        ret = std::max(ret, get_tangent(lower, vec));
        return ret.second;
    }
    // 求凸包和直线 u, v 的交点，如果不相交返回 false
        ，如果有则是和 (i, next(i)) 的交点，交在点上不
        确定返回前后两条边其中之一
    bool get_intersection(Point u, Point v, int &i0,
        int &i1) {
        int p0 = get_tangent(u - v), p1 = get_tangent(
            v - u);
        if (sign(det(v - u, a[p0] - u)) * sign(det(v -
             u, a[p1] - u)) <= 0) {
            if (p0 > p1) std::swap(p0, p1);
            i0 = binary_search(u, v, p0, p1);
            i1 = binary_search(u, v, p1, p0 + n);
```

```
            return true;
        }
        else return false;
    }
};
```

2.6 三角形内心，外心，垂心

```
Point inCenter(const Point &A, const Point &B, const Point &C) { // 内心
    double a = (B - C).len(), b = (C - A).len(), c = (A - B).len(),
        s = fabs(det(B - A, C - A)),
        r = s / p;
    return (A * a + B * b + C * c) / (a + b + c);
}
Point circumCenter(const Point &a, const Point &b, const Point &c) { // 外心
    Point bb = b - a, cc = c - a;
    double db = bb.len2(), dc = cc.len2(), d = 2 * det(bb, cc);
    return a - Point(bb.y * dc - cc.y * db, cc.x * db - bb.x * dc) / d;
}
Point othroCenter(const Point &a, const Point &b, const Point &c) { // 垂心
    Point ba = b - a, ca = c - a, bc = b - c;
    double Y = ba.y * ca.y * bc.y,
           A = ca.x * ba.y - ba.x * ca.y,
           x0 = (Y + ca.x * ba.y * b.x - ba.x * ca.y * c.x) / A,
           y0 = -ba.x * (x0 - c.x) / ba.y + ca.y;
    return Point(x0, y0);
}
```

2.7 三维计算几何

```
// 三维绕轴旋转，大拇指指向 axis 向量方向，四指弯曲方向转 w 弧度
Point rotate(const Point& s, const Point& axis, DB w) {
    DB x = axis.x, y = axis.y, z = axis.z;
    DB s1 = x * x + y * y + z * z, ss1 = msqrt(s1),
       cosw = cos(w), sinw = sin(w);
    DB a[4][4];
    memset(a, 0, sizeof a);
    a[3][3] = 1;
    a[0][0] = ((y * y + z * z) * cosw + x * x) / s1;
    a[0][1] = x * y * (1 - cosw) / s1 + z * sinw / ss1;
    a[0][2] = x * z * (1 - cosw) / s1 - y * sinw / ss1;
    a[1][0] = x * y * (1 - cosw) / s1 - z * sinw / ss1;
    a[1][1] = ((x * x + z * z) * cosw + y * y) / s1;
    a[1][2] = y * z * (1 - cosw) / s1 + x * sinw / ss1;
    a[2][0] = x * z * (1 - cosw) / s1 + y * sinw / ss1;
    a[2][1] = y * z * (1 - cosw) / s1 - x * sinw / ss1;
    a[2][2] = ((x * x + y * y) * cos(w) + z * z) / s1;
    DB ans[4] = {0, 0, 0, 0}, c[4] = {s.x, s.y, s.z, 1};
    for (int i = 0; i < 4; ++ i)
        for (int j = 0; j < 4; ++ j)
            ans[i] += a[j][i] * c[j];
    return Point(ans[0], ans[1], ans[2]);
}
```

2.8 三维凸包

```
__inline P cross(const P& a, const P& b) { return P(a.y * b.z - a.z * b.y,  a.z * b.x - a.x * b.z,  a.x * b.y - a.y * b.x);}
__inline DB mix(const P& a, const P& b, const P& c) { return dot(cross(a, b), c);}
__inline DB volume(const P& a, const P& b, const P& c, const P& d) { return mix(b - a, c - a, d - a);}
struct Face {
    int a, b, c;
    __inline Face() {}
    __inline Face(int _a, int _b, int _c):a(_a), b(_b), c(_c) {}
    __inline DB area() const { return 0.5 * cross(p[b] - p[a], p[c] - p[a]).len();}
    __inline P normal() const { return cross(p[b] - p[a], p[c] - p[a]).unit();}
    __inline DB dis(const P& p0) const {return dot(normal(), p0 - p[a]);}
};
std::vector<Face> face, tmp;  // Should be O(n).
int mark[N][N], Time, n;
__inline void add(int v) {
    ++ Time;
    clear(tmp);
    for (int i = 0; i < (int)face.size(); ++ i) {
        int a = face[i].a, b = face[i].b, c = face[i].c;
        if (sign(volume(p[v], p[a], p[b], p[c])) > 0) {
            mark[a][b] = mark[b][a] = mark[a][c] = mark[c][a] = mark[b][c] = mark[c][b] = Time;}
        else {tmp.push_back(face[i]);}
    }
    clear(face); face = tmp;
    for (int i = 0; i < (int)tmp.size(); ++ i) {
        int a = face[i].a, b = face[i].b, c = face[i].c;
        if (mark[a][b] == Time) face.emplace_back(v, b, a);
        if (mark[b][c] == Time) face.emplace_back(v, c, b);
        if (mark[c][a] == Time) face.emplace_back(v, a, c);
        assert(face.size() < 500u);
    }
}
void reorder() {
    for (int i = 2; i < n; ++ i) {
        P tmp = cross(p[i] - p[0], p[i] - p[1]);
        if (sign(tmp.len())) {
            std::swap(p[i], p[2]);
            for (int j = 3; j < n; ++ j)
                if (sign(volume(p[0], p[1], p[2], p[j]))) {
                    std::swap(p[j], p[3]); return;
                }
        }
    }
}
void build_convex() {
    reorder(); clear(face);
    face.emplace_back(0, 1, 2);
    face.emplace_back(0, 2, 1);
    for (int i = 3; i < n; ++ i)add(i);
}
```

3 数据结构

3.1 KD 树-wrz

```
// 这里写的是询问三维空间中的一个长方体内有没有点
int D;
struct point
{
    int d[3];
    bool operator < (const point &that) const {return d[D] < that.d[D];}
}p[N];
struct node
{
    int d[2][3]; // 0 min 1 max
}t[N<<2];
void pushup(int x)
{
    for(int i = 0; i < 3; i++)
    {
        t[x].d[0][i] = min(t[x<<1].d[0][i], t[x<<1|1].d[0][i]);
        t[x].d[1][i] = max(t[x<<1].d[1][i], t[x<<1|1].d[1][i]);
    }
}
void build(int x, int l, int r, int d)
{
    if(l == r)
    {
        for(int i = 0; i < 3; i++)
            t[x].d[0][i] = t[x].d[1][i] = p[l].d[i];
        return;
    }
    D = d; int mid = (l+r) >> 1;
    nth_element(p+l, p+mid, p+r+1);
    (++d) %= 3;
    build(x<<1, l, mid, d);
    build(x<<1|1, mid+1, r, d);
    pushup(x);
}
int d[2][3];
bool query(int x, int l, int r)
{
    int in = 1, out = 0;
    for(int i = 0; i < 3; i++)
    {
        if(!(d[0][i] <= t[x].d[0][i] && t[x].d[1][i] <= d[1][i])) in = 0; // 包含
        if(d[1][i] < t[x].d[0][i] || t[x].d[1][i] < d[0][i]) out = 1; // 不交
    }
    if(in) return true; if(out) return false;
    int mid = (l+r) >> 1;
    return query(x<<1, l, mid) || query(x<<1|1, mid+1, r);
}
```

3.2 KD 树-gwx

```
struct Point
{
    double x, y;
    int id;
    Point operator - (const Point &a) const {
        return (Point){x - a.x, y - a.y, id};
    }
} b[maxn], c[maxn];
struct node
{
    Point p;
    int ch[2];
} a[maxn];
struct rev
{
    int id;
    double dis;
    bool operator < (const rev &a) const{
        int tmp = sign(dis - a.dis);
        if(tmp)
            return tmp < 0;
        return id < a.id;
    }
};
typedef pr priority_queue <rev>;
pr p0;

int build(int l, int r, int f)
{
    if(l > r)
        return 0;
    int x = (l + r) >> 1;
    if(f == 0)
        nth_element(a + l, a + x, a + r + 1, cmp0); //按x排序
    else
        nth_element(a + l, a + x, a + r + 1, Cmp1); //按y排序
    a[x].ch[0] = build(l, x - 1, f ^ 1);
    a[x].ch[1] = build(x + 1, r, f ^ 1);
    return x;
}
void update(pr &a, rev x)
{
    if(a.size() < K)
        a.push(x);
    else if(x < a.top())
    {
        a.pop();
        a.push(x);
    }
}
pr merge(pr a, pr b)
{
    int s1 = a.size(), s2 = b.size();
    if(s1 < s2)
    {
        while(!a.empty())
        {
            update(b, a.top());
            a.pop();
        }
        return b;
    }
    else
    {
        while(!b.empty())
        {
            update(a, b.top());
            b.pop();
        }
        return a;
    }
}
pr query(int u, Point x, int f)
{
    if(!u)
        return p0;//empty priority_queue
    int d = (dis(a[a[u].ch[0]].p, x) > dis(a[a[u].ch[1]].p, x));
    double dx;
    pr res = query(a[u].ch[d], x, f ^ 1);
    update(res, (rev){a[u].p.id, dis(a[u].p, x)});
    if(f == 0)
        dx = abs(x.x - a[u].p.x);
    else
        dx = abs(x.y - a[u].p.y);
    if(dx > res.top().dis)
        return res;
    res = merge(res, query(a[u].ch[d ^ 1], x, f ^ 1));
    return res;
}
pr solve(Point p)    //离p最近的K个点
{
    int root = build(1, tot, 0);
    return query(root, p, 0);
}
```

3.3 LCT-wrz

```
struct node
{
    node *ch[2], *fa;
    uint v, sum, k, b; int rev, siz;
}mem[N], *tot, *null, *pos[N];
void init()
{
    null = tot = mem;
    null->ch[0] = null->ch[1] = null->fa = null;
    null->v = null->sum = null->b = null->rev = null->siz = 0; null->k = 1;
    for(int i = 1; i <= n; i++) pos[i] = ++tot, *pos[i] = *null, pos[i]->v = pos[i]->sum = 1;
}
int type(node *x){return x->fa->ch[1]==x?1:0;}
int isroot(node *x){return x->fa->ch[type(x)] != x;}
void mswap(node *&x, node *&y){node *t = x; x = y; y = t;}
void pushup(node *x)
{
    x->sum = (x->v + x->ch[0]->sum + x->ch[1]->sum) % MOD;
    x->siz = (x->ch[0]->siz + x->ch[1]->siz + 1) % MOD;
}
void pushdown(node *x)
{
    if(x->rev)
    {
        x->rev = 0, x->ch[0]->rev ^= 1, x->ch[1]->rev ^= 1;
        mswap(x->ch[0]->ch[0], x->ch[0]->ch[1]);
        mswap(x->ch[1]->ch[0], x->ch[1]->ch[1]);
    }
    for(int i = 0; i <= 1; i++)
    {
        x->ch[i]->v = (x->k * x->ch[i]->v % MOD + x->b) % MOD;
        x->ch[i]->sum = (x->ch[i]->sum * x->k % MOD + x->b * x->ch[i]->siz % MOD) % MOD;
        (x->ch[i]->k *= x->k) %= MOD;
        (x->ch[i]->b *= x->k) %= MOD, (x->ch[i]->b += x->b) %= MOD;
    }
    x->k = 1;  x->b = 0;
}
void update(node *x){if(!isroot(x))update(x->fa); pushdown(x);}
void rotate(node *x)
{
    node *f = x->fa; int d = type(x);
    x->fa = f->fa, !isroot(f) ? x->fa->ch[type(f)] = x : 0;
    (f->ch[d] = x->ch[d^1]) != null ? f->ch[d]->fa = f : 0;
    f->fa = x, x->ch[d^1] = f; pushup(f);
}
void splay(node *x)
{
    update(x);
    for(; !isroot(x); )
    {
        if(isroot(x->fa)) rotate(x);
        else if(type(x) == type(x->fa)) rotate(x->fa), rotate(x);
        else rotate(x),rotate(x);
    }
    pushup(x);
}
void access(node *x)
{
    node *tmp = null;
    for(; x != null; )
    {
        splay(x);
        x->ch[1] = tmp;
        pushup(x);
        tmp = x;
        x = x->fa;
    }
}
void makeroot(node *x)
{
    access(x);
    splay(x);
    x->rev ^= 1;
    swap(x->ch[0], x->ch[1]);
}
void link(node *x, node *y)
{
    makeroot(x);
    x->fa = y;
}
void cut(node *x, node *y)
{
    makeroot(x); access(y);
    splay(y); y->ch[0] = x->fa = null;
    pushup(y);
}
```

3.4 左偏树-wrz

```
struct heap
{
    heap *ch[2];
    int dis, siz, v;
}mem[N*2], *h[N], *null, *tot;
heap* newheap()
{
    heap *p = ++tot;
    *p = *null;
    return p;
}
void init()
{
    null = tot = mem;
    null->ch[0] = null->ch[1] = null;
    null->v = null->dis = null->siz = 0;
    for(int i = 1; i <= n; i++) h[i] = null;
}
heap *merge(heap *x, heap *y) // big
{
    if(x == null) return y;
    if(y == null) return x;
    if(x->v < y->v) swap(x, y);
    x->ch[1] = merge(x->ch[1], y);
    if(x->ch[0]->dis < x->ch[1]->dis) swap(x->ch[0], x->ch[1]);
    x->dis = x->ch[1]->dis + 1;
    x->siz = x->ch[0]->siz + x->ch[1]->siz + 1;
    return x;
}
heap *pop(heap *x){return merge(x->ch[0], x->ch[1]);}
int main()
{
    init();
    heap *a = newheap(); a->siz = 1; a->v = 233;
    heap *b = newheap(); b->siz = 1; b->v = 233;
    heap *c = merge(a, b);
}
```

3.5 splay-wrz

```
struct node
{
    node *ch[2], *fa;
    ll key; int siz, tag;
}mem[N*20], *tot, *null, *root;
void init()
{
    root = null = tot = mem;
    null->ch[0] = null->ch[1] = null->fa = null;
    null->key = null->siz = null->tag = 0;
}
int type(node *x){return x->fa->ch[1]==x;}
node *newnode(ll key)
{
    node *p = ++tot; *p = *null;
    p->key = key; p->siz = 1;
    return p;
}
void pushup(node *x)
{
    x->siz = x->ch[0]->siz + x->ch[1]->siz + 1;
}
void rotate(node *x)
{
    node *f =  x->fa; int d = type(x);
    (x->fa = f->fa) != null ? x->fa->ch[type(f)] = x : 0;
    (f->ch[d] = x->ch[!d]) != null ? f->ch[d]->fa = f : 0;
    x->ch[!d] = f, f->fa = x, pushup(f);
}
void pushdown(node *x)
{
    if(x->tag)
    {
        int &tag = x->tag;
        if(x->ch[0] != null) x->ch[0]->key += tag, x->ch[0]->tag += tag;
        if(x->ch[1] != null) x->ch[1]->key += tag, x->ch[1]->tag += tag;
        tag = 0;
    }
}
void update(node *x)
{
    if(x==null) return;
    update(x->fa);
    pushdown(x);
}
void splay(node *x, node *top)
{
    update(x);
    for(;x->fa!=top;)
    {
        if(x->fa->fa == top) rotate(x);
        else if(type(x) == type(x->fa)) rotate(x->fa), rotate(x);
        else rotate(x), rotate(x);
    }
    if(top == null) root = x;
    pushup(x);
}
void insert(node *x, node *f, node *p, int d)
{
    if(x == null)
    {
        p->fa = f, f->ch[d] = p;
        return;
    }
    pushdown(x);
    if(p->key < x->key) insert(x->ch[0], x, p ,0);
    else insert(x->ch[1], x, p, 1);
    pushup(x);
}

void insert(node *p)
{
    if(root == null) root = p, p->fa = p->ch[0] = p->ch[1] = null;
    else insert(root, null, p, 0), splay(p, null);
}
node *findl(node *x){return x->ch[0]==null?x:findl(x->ch[0]);}
node *findr(node *x){return x->ch[1]==null?x:findr(x->ch[1]);}
void insertlr()
{
    insert(newnode(-INF));
    insert(newnode(INF));
}
void delet(node *p)
{
    splay(p, null);
    node *lp = findr(p->ch[0]), *rp = findl(p->ch[1]);
    if(lp == null && rp != null) root = p->ch[1], root->fa = null;
    else if(lp != null && rp == null) root = p->ch[0], root->fa = null;
    else if(lp == null && rp == null)root = null;
    else
    {
        splay(rp, null); splay(lp,rp);
        lp->ch[1] = null; splay(lp,null);
    }
}
node* findk(node *p, int k)
{
    for(; ; )
    {
        pushdown(p);
        if(p->ch[0]->siz >= k) p = p->ch[0];
        else if(p->ch[0]->siz + 1 == k) {splay(p, null); return p;}
        else k -= p->ch[0]->siz + 1, p = p->ch[1];
    }
}
node* findv(node *p, int v)
{
    node* ret = null;
    for(; p!=null; )
    {
        pushdown(p);
        if(p->key >= v) ret = p, p = p->ch[0];
        else p = p->ch[1];
    }
    splay(ret, null);
    return ret;
}
void addv(node *p, int v)
{
    if(p == null) return;
    p->key += v;
    p->tag += v;
}
```

3.6 treap-gwx

```
//srand()
struct node
{
    int pri, val, c, s;    //pri: random value; c: times of showing; s: size of subtree
    int ch[2];
    int cmp(int x) const {
        if(x == val) return -1;
        return x < val ? 0 : 1;
    }
} a[maxn];
void maintain(int u)  {
    a[u].s = a[u].c + a[a[u].ch[0]].s + a[a[u].ch[1]].s;
}
void rotate(int &u, int d)
{
    int tmp = a[u].ch[d ^ 1];
    a[u].ch[d ^ 1] = a[tmp].ch[d];
    a[tmp].ch[d] = u;
    maintain(u); maintain(tmp);
    u = tmp;
```

```
}
void insert(int &u, int val)
{
    if(!u)
    {
        u = ++cnt;
        a[cnt] = (node){rand(), val, 1, 1};
        return;
    }
    a[u].s++;
    int d = a[u].cmp(val);
    if(d == -1)  {a[u].c++; return;}
    insert(a[u].ch[d], val);
    if(a[a[u].ch[d]].pri > a[u].pri) rotate(u, d ^ 1);
}
int find(int u, int val, int comp, int &res)
{
    int d = a[u].cmp(val);
    if(!u) return -1;
    if(d == -1) return u;
    if(d == comp)
    {
        if(d) res = max(res, a[u].val);
        else res = min(res, a[u].val);
    }
    return find(a[u].ch[d], val, comp, res);
}
void remove(int &u)
{
    if(!a[u].ch[0]) u = a[u].ch[1];
    else if(!a[u].ch[1]) u = a[u].ch[0];
    else
    {
        int d = a[a[u].ch[0]].pri < a[a[u].ch[1]].pri
            ? 0 : 1;
        rotate(u, d); remove(a[u].ch[d]);
    }
}
void del(int &u, int val)
{
    if(find(root, val, -2, val) == -1) return;
    a[u].s--;
    int d = a[u].cmp(val);
    if(d == -1)
    {
        a[u].c--;
        if(!a[u].c) remove(u);
    }
    else del(a[u].ch[d], val);
}
int find_rank(int u, int val)
{
    int d = a[u].cmp(val);
    if(d == -1) return 1 + a[a[u].ch[0]].s;
    if(d == 0) return find_rank(a[u].ch[0], val);
    return a[u].s - a[a[u].ch[1]].s + find_rank(a[u].
        ch[1], val);
}
int find_kth(int u, int k)
{
    if(k <= a[a[u].ch[0]].s) return find_kth(a[u].ch
        [0], k);
    if(k > a[a[u].ch[0]].s + a[u].c) return find_kth(a
        [u].ch[1], k - a[a[u].ch[0]].s - a[u].c);
    return a[u].val;
}
int pre(int val)
{
    int ans = -inf;
    int pos = find(root, val, 1, ans);
    if(pos != -1 && a[pos].ch[0])
    {
        pos = a[pos].ch[0];
        while(a[pos].ch[1]) pos = a[pos].ch[1];
        ans = max(ans, a[pos].val);
    }
    return ans;
}
int post(int val)
{
    int ans = inf;
    int pos = find(root, val, 0, ans);
    if(pos != -1 && a[pos].ch[1])
    {
        pos = a[pos].ch[1];
        while(a[pos].ch[0]) pos = a[pos].ch[0];
        ans = min(ans, a[pos].val);
    }
    return ans;
}
```

3.7 可持久化平衡树

```
int Copy(int x){// 可持久化
    id++;sz[id]=sz[x];L[id]=L[x];R[id]=R[x];
    v[id]=v[x];return id;}
int merge(int x,int y){
    // 合并x 和y 两颗子树, 可持久化到z 中
    if(!x||!y)return x+y;int z;
    int o=rand()%(sz[x]+sz[y]);// 注意rand 上限
    if(o<sz[x])z=Copy(y),L[z]=merge(x,L[y]);
    else z=Copy(x),R[z]=merge(R[x],y);
    ps(z);return z;
}
void split(int x,int&y,int&z,int k){
    // 将x 分成y 和z 两颗子树, y 的大小为k
    y=z=0;if(!x)return;
    if(sz[L[x]]>=k)z=Copy(x),split(L[x],y,L[z],k),ps(z
        );
    else y=Copy(x),split(R[x],R[y],z,k-sz[L[x]]-1),ps(
        y);}
```

4 图论

4.1 树哈希

A[n] is the hash of the sub-tree with root n.
B[n] is the hash of the whole tree with root n.

```
template <int MAXN = 100000, int MAXM = 200000, long
    long MOD = 1000000000000000003ll>
struct tree_hash {
    static long long ra[MAXN];
    tree_hash () {
        std::mt19937_64 mt (time (0));
        std::uniform_int_distribution <long long> uid
            (0, MOD - 1);
        for (int i = 0; i < MAXN; ++i) ra[i] = uid (mt
            ); }
    struct node {
        std::vector <long long> s; int d1, d2; long
            long h1, h2;
        node () { d1 = d2 = 0; }
        void add (int d, long long v) {
            s.push_back (v);
            if (d > d1) d2 = d1, d1 = d; else if (d >
                d2) d2 = d; }
        long long hash () {
            h1 = h2 = 1; for (long long i : s) {
                h1 = mul_mod (h1, ra[d1] + i, MOD);
                h2 = mul_mod (h2, ra[d2] + i, MOD); }
                    return h1; }
    std::pair <int, long long> del (int d, long long v
        ) {
        if (d == d1) return { d2 + 1, mul_mod (h2,
            inverse (ra[d2] + v, MOD), MOD) };
        return { d1 + 1, mul_mod (h1, inverse (ra[d1]
            + v, MOD), MOD) }; } };
    std::pair <int, long long> u[MAXN]; node tree[MAXN
        ];
    long long A[MAXN], B[MAXN];
    void dfs1 (const edge_list <MAXN, MAXM> &e, int x,
         int p = -1) {
        tree[x] = node ();
        for (int i = e.begin[x]; ~i; i = e.next[i]) {
            int c = e.dest[i]; if (c != p) {
                dfs1 (e, c, x); tree[x].add (tree[c].
                    d1 + 1, tree[c].h1); } }
            A[x] = tree[x].hash (); }
    void dfs2 (const edge_list <MAXN, MAXM> &e, int x,
         int p = -1) {
        if (~p) tree[x].add (u[x].first, u[x].second);
        B[x] = tree[x].hash ();
    for (int i = e.begin[x]; ~i; i = e.next[i]) {
            int c = e.dest[i]; if (c != p) {
                u[c] = tree[x].del (tree[c].d1 + 1,
                    tree[c].h1);
                dfs2 (e, c, x); } } }
    void solve (const edge_list <MAXN, MAXM> &e, int
        root) {
        dfs1 (e, root); dfs2 (e, root); } };
template <int MAXN, int MAXM, long long MOD>
long long tree_hash <MAXN, MAXM, MOD>::ra[MAXN];
```

4.2 匹配

Tutte-Berge formula The theorem states that the size of a maximum matching of a graph $G = (V, E)$ equals

$$\frac{1}{2} \min_{U \subseteq V} \left(|U| - \operatorname{odd}(G - U) + |V| \right),$$

where $\operatorname{odd}(H)$ counts how many of the connected components of the graph H have an odd number of vertices.

Tutte theorem A graph, $G = (V, E)$, has a perfect matching if and only if for every subset U of V, the subgraph induced by $V - U$ has at most $|U|$ connected components with an odd number of vertices.

Hall's marriage theorem A family S of finite sets has a transversal if and only if S satisfies the marriage condition.

4.3 上下界网络流

```
有源汇上下界费用流:
    转换为求无源汇上下界最小费用可行循环流, 通过T→S连
        边, 流量上下界为(原总流量, INF)。

无源汇上下界最小费用可行循环流:
    在原基础上再新增一个超级源点 supS, supT, 构造只有
        上界的网络。
    对于原图的每一条边 (u, v) , 再新图中添加一条 supS→
        v 流量为 u, v 流量下界的边, 一条 u→supT 流量为
```

```
        u, v 流量下界的边, 一条 u→v 流量为 u, v 流量上界-流量下界的边。
    做从 supS→supT 的最小费用流, 限定到达 supT 的流量为满流 (即 supS 所有出边的流量和) 。此即为答案。
    HINT: 原图中所有未提及的边费用都应记为 0 。新图中的重新构造的边的费用等同原图中对应边的费用。


4.7 上下界网络流
B(u, v) 表示边 (u, v) 流量的下界,C(u, v) 表示边 (u, v) 流量的上界,F (u, v) 表示边 (u, v)
的流量。设 G(u, v) = F (u, v) - B(u, v),显然有
0   G(u, v)   C(u, v) - B(u, v)
4.7.1 无源汇的上下界可行流
建立超级源点 S * 和超级汇点 T * ,对于原图每条边 (u, v) 在新网络中连如下三条边: S * → v,
容量为 B(u, v);u → T * ,容量为 B(u, v);u → v,容量为 C(u, v) - B(u, v)。最后求新网络
的最大流,判断从超级源点 S * 出发的边是否都满流即可,边 (u, v) 的最终解中的实际流量为
G(u, v) + B(u, v)。
4.7.2 有源汇的上下界可行流
从汇点 T 到源点 S 连一条上界为 ∞,下界为 0 的边。按照无源汇的上下界可行流一样做
即可,流量即为 T → S 边上的流量。
4.7.3 有源汇的上下界最大流
1. 在有源汇的上下界可行流中,从汇点 T 到源点 S 的边改为连一条上界为 ∞,下届为 x 的
边。x 满足二分性质,找到最大的 x 使得新网络存在无源汇的上下界可行流即为原图的最大
流。
2. 从汇点 T 到源点 S 连一条上界为 ∞,下界为 0 的边,变成无源汇的网络。按照无源汇的
上下界可行流的方法,建立超级源点 S * 和超级汇点 T * ,求一遍 S * → T * 的最大流,再将
从汇点 T 到源点 S 的这条边拆掉,求一次 S → T 的最大流即可。
4.7.4 有源汇的上下界最小流
1. 在有源汇的上下界可行流中,从汇点 T 到源点 S 的边改为连一条上界为 x,下界为 0 的
边。x 满足二分性质,找到最小的 x 使得新网络存在无源汇的上下界可行流即为原图的最小
流。
712. 按照无源汇的上下界可行流的方法,建立超级源点 S * 与超级汇点 T * ,求一遍 S * → T * 的
最大流,但是注意这一次不加上汇点 T 到源点 S 的这条边,即不使之改为无源汇的网络去
求解。求完后,再加上那条汇点 T 到源点 S 上界 ∞ 的边。因为这条边下界为 0,所以
S * ,T * 无影响,再直接求一次 S * → T * 的最大流。若超级源点 S * 出发的边全部满流,则
T → S 边上的流量即为原图的最小流,否则无解。
```

4.4 矩阵树定理

```
C = 度数矩阵-邻接矩阵
无向图G的生成树个数 = C的任意n - 1阶主子式(对角线的乘积)
```

4.5 边双联通-gwx

```
//G[i]: 第i个边双联通分量中有哪些点
void tarjan(int u, int pa)
{
    d[u] = l[u] = ++timer;
    for(int i = tail[u]; i; i = e[i].next)
    {
        if(!d[e[i].v])
        {
            st[++top] = i;
            tarjan(e[i].v, u);
            l[u] = min(l[u], l[e[i].v]);
            if(l[e[i].v] >= d[u])
            {
                bcc++;
                while(true)
                {
                    int now = st[top--];
                    if(vst[e[now].u] != bcc)
                    {
                        vst[e[now].u] = bcc;
                        G[bcc].push_back(e[now].u);
                    }
                    if(vst[e[now].v] != bcc)
                    {
                        vst[e[now].v] = bcc;
                        G[bcc].push_back(e[now].v);
                    }
                    if(now == i) break;
                }
            }
        }
        else if(e[i].v != pa)
            l[u] = min(l[u], d[e[i].v]);
    }
}
```

4.6 带花树

```
vector<int> link[maxn];
int n,match[maxn],Queue[maxn],head,tail;
int pred[maxn],base[maxn],start,finish,newbase;
bool InQueue[maxn],InBlossom[maxn];
void push(int u){ Queue[tail++]=u;InQueue[u]=true; }
int pop(){ return Queue[head++]; }
int FindCommonAncestor(int u,int v){
    bool InPath[maxn];
    for(int i=0;i<n;i++) InPath[i]=0;
    while(true){ u=base[u];InPath[u]=true;if(u==start) break;u=pred[match[u]]; }
    while(true){ v=base[v];if(InPath[v]) break;v=pred[match[v]]; }
    return v;
}
void ResetTrace(int u){
    int v;
    while(base[u]!=newbase){
        v=match[u];
        InBlossom[base[u]]=InBlossom[base[v]]=true;
        u=pred[v];
        if(base[u]!=newbase) pred[u]=v;
    }
}
void BlossomContract(int u,int v){
    newbase=FindCommonAncestor(u,v);
    for (int i=0;i<n;i++)
    InBlossom[i]=0;
    ResetTrace(u);ResetTrace(v);
    if(base[u]!=newbase) pred[u]=v;
    if(base[v]!=newbase) pred[v]=u;
    for(int i=0;i<n;++i)
    if(InBlossom[base[i]]){
        base[i]=newbase;
        if(!InQueue[i]) push(i);
    }
}
bool FindAugmentingPath(int u){
    bool found=false;
    for(int i=0;i<n;++i) pred[i]=-1,base[i]=i;
    for (int i=0;i<n;i++) InQueue[i]=0;
    start=u;finish=-1; head=tail=0; push(start);
    while(head<tail){
        int u=pop();
        for(int i=link[u].size()-1;i>=0;i--){
            int v=link[u][i];
            if(base[u]!=base[v]&&match[u]!=v)
                if(v==start||(match[v]>=0&&pred[match[v]]>=0))
                    BlossomContract(u,v);
                else if(pred[v]==-1){
                    pred[v]=u;
                    if(match[v]>=0) push(match[v]);
                    else{ finish=v; return true; }
                }
        }
    }
    return found;
}
void AugmentPath(){
    int u=finish,v,w;
    while(u>=0){ v=pred[u];w=match[v];match[v]=u;match[u]=v;u=w; }
}
void FindMaxMatching(){
    for(int i=0;i<n;++i) match[i]=-1;
    for(int i=0;i<n;++i) if(match[i]==-1) if(FindAugmentingPath(i)) AugmentPath();
}
```

4.7 弦图

```
/*定义  我们称连接环中不相邻的两个点的边为弦. 一个无向图称为弦图, 当
图中任意长度都大于3 的环都至少有一个弦. 弦图的每一个诱导子图一定是
弦图.
单纯点  设N(v)表示与点v相邻的点集. 一个点称为单纯点当v+N(v)的
诱导子图为一个团. 引理: 任何一个弦图都至少有一个单纯点, 不是完全图
的弦图至少有两个不相邻的单纯点.
完美消除序列    一个序列v1, v2, ..., vn满足vi在vi, vi+1, ..., vn的诱导子
图中为一个单纯点. 一个无向图是弦图当且仅当它有一个完美消除序列.
最大势算法  最大势算法能判断一个图是否是弦图. 从n到1的顺序依次给
点标号 标号为i 的点出现在完美消除序列的第i个 . 设labeli表示第i个点
与多少个已标号的点相邻, 每次选择labeli最大的未标号的点进行标号.
```

```
然后判断这个序列是否为完美序列. 如果依次判断vi+1, ..., vn 中
所有与vi相邻的点是否构成一个团, 时间复杂度为O(nm). 考虑优化,
设vi+1, ..., vn中所有与vi 相邻的点依次为vj1,...,vjk. 只需判断vj1是否
与vj2,...,vjk相邻即可. 时间复杂度O(n + m).
弦图的染色  按照完美消除序列中的点倒着给图中的点贪心染尽可能最小
的颜色, 这样一定能用最少的颜色数给图中所有点染色. 弦图的团数=染色
数.
最大独立集  完美消除序列从前往后能选就选. 最大独立集=最小团覆盖.*/

template <int MAXN = 100000, int MAXM = 100000>
struct chordal_graph {
    int n; edge_list <MAXN, MAXM> e;
    int id[MAXN], seq[MAXN];
    void init () {
        struct point {
            int lab, u;
            point (int lab = 0, int u = 0) : lab (lab), u (u) {}
            bool operator < (const point &a) const { return lab < a.lab; } };
        std::fill (id, id + n, -1);
        static int label[MAXN]; std::fill (label, label + n, 0);
        std::priority_queue <point> q;
        for (int i = 0; i < n; ++i) q.push (point (0, i));
        for (int i = n - 1; i >= 0; --i) {
            for (; ~id[q.top ().u]; ) q.pop ();
            int u = q.top ().u; q.pop (); id[u] = i;
            for (int j = e.begin[u], v; ~j; j = e.next[j])
                if (v = e.dest[j], !~id[v]) ++label[v], q.push (point (label[v], v)); }
        for (int i = 0; i < n; ++i) seq[id[i]] = i; }
    bool is_chordal () {
        static int vis[MAXN], q[MAXN]; std::fill (vis, vis + n, -1);
        for (int i = n - 1; i >= 0; --i) {
            int u = seq[i], t = 0, v;
            for (int j = e.begin[u]; ~j; j = e.next[j])
                if (v = e.dest[j], id[v] > id[u]) q[t++] = v;
            if (!t) continue; int w = q[0];
            for (int j = 0; j < t; ++j) if (id[q[j]] < id[w]) w = q[j];
            for (int j = e.begin[w]; ~j; j = e.next[j]) vis[e.dest[j]] = i;
            for (int j = 0; j < t; ++j) if (q[j] != w && vis[q[j]] != i) return 0;
        }
        return 1; }
    int min_color () {
        int res = 0;
        static int vis[MAXN], c[MAXN];
        std::fill (vis, vis + n, -1);
        std::fill (c, c + n, n);
        for (int i = n - 1; i >= 0; --i) {
            int u = seq[i];
            for (int j = e.begin[u]; ~j; j = e.next[j]) vis[c[e.dest[j]]] = i;
            int k; for (k = 0; vis[k] == i; ++k);
            c[u] = k; res = std::max (res, k + 1);
        }
        return res; } };
```

4.8 支配树-gwx

```
/*
    用ins()加边
    build前设置n为点数, s为源点
    树中的i号点对应原图的id[i]号点
*/
struct Dominator_Tree {
    int n, s, cnt;
    int dfn[N], id[N], pa[N], semi[N], idom[N], p[N], mn[N];
    vector<int>e[N], dom[N], be[N];
    void ins(int x, int y) {e[x].push_back(y);}
    void dfs(int x) {
        dfn[x] = ++cnt; id[cnt] = x;
        for (int i : e[x]) {
            if (!dfn[i])dfs(i), pa[dfn[i]] = dfn[x];
            be[dfn[i]].push_back(dfn[x]);
        }
    }
    int get(int x) {
        if (p[x] != p[p[x]]) {
            if (semi[mn[x]] > semi[get(p[x])])mn[x] = get(p[x]);
            p[x] = p[p[x]];
        }
        return mn[x];
    }
    void LT() {
        for (int i = cnt; i > 1; i--) {
            for (int j : be[i])semi[i] = min(semi[i], semi[get(j)]);
            dom[semi[i]].push_back(i);
            int x = p[i] = pa[i];
            for (int j : dom[x])idom[j] = (semi[get(j)] < x ? get(j) : x);
            dom[x].clear();
        }
        for (int i = 2; i <= cnt; i++) {
            if (idom[i] != semi[i])idom[i] = idom[idom[i]];
            dom[id[idom[i]]].push_back(id[i]);
        }
    }
    void build() {
        for(int i = 1; i <= n; ++i)
            dfn[i] = 0, dom[i].clear(), be[i].clear(), p[i] = mn[i] = semi[i] = i;
        cnt = 0; dfs(s); LT();
    }
};
```

4.9 欧拉回路-wrz

```
#include<cstdio>
#define N 100005
#define M 200005
using namespace std;
int last[N], ecnt = 1, cnt, ans[M], in_deg[N], out_deg[N];
bool vis[M];
struct edge{int next,to;}e[M<<1];
void addedge(int a, int b)
{
    e[++ecnt] = (edge){last[a], b};
    last[a] = ecnt;
}
void dfs(int x)
{
    for(int &i = last[x]; i; i = e[i].next)
    {
        int y = e[i].to, j = i;
        if(!vis[j>>1])
        {
            vis[j>>1] = 1;
            dfs(y);
            ans[++cnt] = j;
        }
    }
}
int main()
{
    int t, n, m, a, b;
    scanf("%d%d%d",&t,&n,&m);
    for(int i = 1; i <= m; i++)
    {
        scanf("%d%d",&a,&b);
        addedge(a,b);
        if(t == 1)addedge(b,a), in_deg[a]++, in_deg[b]++;
        else ecnt++, in_deg[b]++, out_deg[a]++;
    }

    if(t == 1) // 无向
    {
        for(int i = 1; i <= n; i++)
            if((in_deg[i]+out_deg[i]) & 1)
                return !printf("NO\n");
    }
    else // 有向
    {
        for(int i = 1; i <= n; i++)
            if(in_deg[i] != out_deg[i])
                return !printf("NO\n");
    }
    dfs(a);
    if(cnt != m)
    {
        puts("NO");
    }
    else
    {
        puts("YES");
        for(int i = cnt; i; i--)
        {
            printf("%d␣",ans[i]&1?-(ans[i]>>1):(ans[i]>>1));
        }
    }
}
```

4.10 Hopcoft-Karp

```
// O(sqrt(n)m)
template <int MAXN = 100000, int MAXM = 100000>
struct hopcoft_karp {
    int mx[MAXN], my[MAXM], lv[MAXN];
```

```
    bool dfs (edge_list <MAXN, MAXM> &e, int x) {
        for (int i = e.begin[x]; ~i; i = e.next[i]) {
            int y = e.dest[i], w = my[y];
            if (!~w || (lv[x] + 1 == lv[w] && dfs (e,
                w))) {
                mx[x] = y; my[y] = x; return true; } }
        lv[x] = -1; return false; }
    int solve (edge_list <MAXN, MAXM> &e, int n, int m
        ) {
        std::fill (mx, mx + n, -1); std::fill (my, my
            + m, -1);
        for (int ans = 0; ; ) {
            std::vector <int> q;
            for (int i = 0; i < n; ++i)
                if (mx[i] == -1) {
                    lv[i] = 0; q.push_back (i);
                } else lv[i] = -1;
            for (int head = 0; head < (int) q.size();
                ++head) {
                int x = q[head];
                for (int i = e.begin[x]; ~i; i = e.
                    next[i]) {
                    int y = e.dest[i], w = my[y];
                    if (~w && lv[w] < 0) { lv[w] = lv[
                        x] + 1; q.push_back (w); } } }
            int d = 0; for (int i = 0; i < n; ++i) if
                (!~mx[i] && dfs (e, i)) ++d;
            if (d == 0) return ans; else ans += d; } }
                };
```

4.11 KM-truly-n3

```
struct KM {
    // Truly O(n^3)
    // 邻接矩阵，不能连的边设为 -INF，求最小权匹配时边
        权取负，但不能连的还是 -INF，使用时先对 1 -> n
        调用 hungary() ，再 get_ans() 求值
    int w[N][N];
    int lx[N], ly[N], match[N], way[N], slack[N];
    bool used[N];
    void init() {
        for (int i = 1; i <= n; i++) {
            match[i] = 0;
            lx[i] = 0;
            ly[i] = 0;
            way[i] = 0;
        }
    }
    void hungary(int x) {
        match[0] = x;
        int j0 = 0;
        for (int j = 0; j <= n; j++) {
            slack[j] = INF;
            used[j] = false;
        }

        do {
            used[j0] = true;
            int i0 = match[j0], delta = INF, j1 = 0;
            for (int j = 1; j <= n; j++) {
                if (used[j] == false) {
                    int cur = -w[i0][j] - lx[i0] - ly[
                        j];
                    if (cur < slack[j]) {
                        slack[j] = cur;
                        way[j] = j0;
                    }
                    if (slack[j] < delta) {
                        delta = slack[j];
                        j1 = j;
                    }
                }
            }
            for (int j = 0; j <= n; j++) {
                if (used[j]) {
                    lx[match[j]] += delta;
                    ly[j] -= delta;
                }
                else slack[j] -= delta;
            }
            j0 = j1;
        } while (match[j0] != 0);

        do {
            int j1 = way[j0];
            match[j0] = match[j1];
            j0 = j1;
        } while (j0);
    }

    int get_ans() {
        int sum = 0;
        for(int i = 1; i <= n; i++) {
            if (w[match[i]][i] == -INF) ; // 无解
            if (match[i] > 0) sum += w[match[i]][i];
        }
        return sum;
    }
} km;
```

4.12 k 短路 a 星-gwx

```
const int maxn = 1005;
int n, m;
int S, T, K;
int dist[maxn], cnt[maxn];
bool vst[maxn];
vector<pair<int, int>> G[maxn], H[maxn];    //正图&反
    图
struct node
{
    ll d;
    int id;
    node(){}
    node(ll d, int id): d(d), id(id) {}
    bool operator< (const node &other) const{
        return d + dist[id] > other.d + dist[other.id
            ];
    }
};

priority_queue <pair<ll, int>> q;
priority_queue <node> Q;

void init()
{
    for(int i = 1; i <= n; ++i)
        G[i].clear(), H[i].clear(), cnt[i] = 0;
}

void dijkstra(int S)
{
    memset(dist, 127, sizeof(dist));
    memset(vst, 0, sizeof(vst));
    while(!q.empty()) q.pop();
    dist[S] = 0;
    q.push(make_pair(0, S));
    for(int i = 1; i <= n; ++i)
    {
        if(q.empty()) break;
        while(vst[q.top().second]) q.pop();
        int u = q.top().second; q.pop();
        vst[u] = 1;
        for(auto i: H[u])
        {
            if(dist[i.first] > dist[u] + i.second)
            {
                dist[i.first] = dist[u] + i.second;
                q.push(make_pair(-dist[i.first], i.
                    first));
            }
        }
    }
}

int solve()
{
    while(!Q.empty()) Q.pop();
    Q.push(node(0, S));
    while(!Q.empty())
    {
        auto u = Q.top(); Q.pop();
        if(++cnt[u.id] > K) continue;
        if(u.d + dist[u.id] > ti) continue;
        if(u.id == T && cnt[T] == K)
            return u.d;
        for(auto i: G[u.id])
            Q.push(node(u.d + i.second, i.first));
    }
    return -1;
}
```

4.13 K 短路可并堆

```
//Kth Shortest Path via Persistable Mergeable Heap
//可持久化可并堆求k短路 O(SSSP+(m+k)\log n)
//By ysf
//通过题目：USACO Mar08 牛跑步（板子题）

//注意这是个多项式算法，在k比较大时很有优势，但k比较小
    时最好还是用A*
//DAG和有环的情况都可以，有重边或自环也无所谓，但不能
    有零环
//以下代码以Dijkstra+可持久化左偏树为例

const int maxn=1005,maxe=10005,maxm=maxe*30;//点数，边
    数，左偏树结点数

//需要用到的结构体定义
struct A{//用来求最短路
    int x,d;
    A(int x,int d):x(x),d(d){}
    bool operator<(const A &a)const{return d>a.d;}
};

struct node{//左偏树结点
    int w,i,d;//i：最后一条边的编号 d：左偏树附加信息
    node *lc,*rc;
    node(){}
    node(int w,int i):w(w),i(i),d(0){}
```

```
    void refresh(){d=rc->d+1;}
}null[maxm],*ptr=null,*root[maxn];

struct B{//维护答案用
    int x,w;//x是结点编号，w表示之前已经产生的权值
    node *rt;//这个答案对应的堆顶，注意可能不等于任何一个结点的堆
    B(int x,node *rt,int w):x(x),w(w),rt(rt){}
    bool operator<(const B &a)const{return w+rt->w>a.w+a.rt->w;}
};

//全局变量和数组定义
vector<int>G[maxn],W[maxn],id[maxn];//最开始要存反向图，然后把G清空作为儿子列表
bool vis[maxn],used[maxe];//used表示边是否在最短路树上
int u[maxe],v[maxe],w[maxe];//存下每条边，注意是有向边
int d[maxn],p[maxn];//p表示最短路树上每个点的父边
int n,m,k,s,t;//s,t分别表示起点和终点

//以下是主函数中较关键的部分
for(int i=0;i<=n;i++)root[i]=null;//一定要加上！！！
//(读入&建反向图)
Dijkstra();
//(清空G,W,id)
for(int i=1;i<=n;i++)
    if(p[i]){
        used[p[i]]=true;//在最短路树上
        G[v[p[i]]].push_back(i);
    }
for(int i=1;i<=m;i++){
    w[i]-=d[u[i]]-d[v[i]];//现在的w[i]表示这条边能使路径长度增加多少
    if(!used[i])
        root[u[i]]=merge(root[u[i]],newnode(w[i],i));
}
dfs(t);
priority_queue<B>heap;
heap.push(B(s,root[s],0));//初始状态是找贡献最小的边加进去
printf("%d\n",d[s]);//第1短路需要特判
while(--k){//其余k-1短路径用二叉堆维护
    if(heap.empty())printf("-1\n");
    else{
        int x=heap.top().x,w=heap.top().w;
        node *rt=heap.top().rt;
        heap.pop();
        printf("%d\n",d[s]+w+rt->w);
        if(rt->lc!=null||rt->rc!=null)
            heap.push(B(x,merge(rt->lc,rt->rc),w));//pop掉当前边，换成另一条贡献大一点的边
        if(root[v[rt->i]]!=null)
            heap.push(B(v[rt->i],root[v[rt->i]],w+rt->w));//保留当前边，往后面再接上另一条边
    }
}
//主函数到此结束

//Dijkstra预处理最短路 O(m\log n)
void Dijkstra(){
    memset(d,63,sizeof(d));
    d[t]=0;
    priority_queue<A>heap;
    heap.push(A(t,0));
    while(!heap.empty()){
        int x=heap.top().x;
        heap.pop();
        if(vis[x])continue;
        vis[x]=true;
        for(int i=0;i<(int)G[x].size();i++)
            if(!vis[G[x][i]]&&d[G[x][i]]>d[x]+W[x][i]){
                d[G[x][i]]=d[x]+W[x][i];
                p[G[x][i]]=id[x][i];
                heap.push(A(G[x][i],d[G[x][i]]));
            }
    }
}

//dfs求出每个点的堆 总计O(m\log n)
//需要调用merge，同时递归调用自身
void dfs(int x){
    root[x]=merge(root[x],root[v[p[x]]]);
    for(int i=0;i<(int)G[x].size();i++)
        dfs(G[x][i]);
}

//包装过的new node() O(1)
node *newnode(int w,int i){
    *++ptr=node(w,i);
    ptr->lc=ptr->rc=null;
    return ptr;
}

//带可持久化的左偏树合并 总计O(\log n)
//递归调用自身
node *merge(node *x,node *y){
    if(x==null)return y;
    if(y==null)return x;
    if(x->w>y->w)swap(x,y);
    node *z=newnode(x->w,x->i);
    z->lc=x->lc;
    z->rc=merge(x->rc,y);
    if(z->lc->d>z->rc->d)swap(z->lc,z->rc);
    z->refresh();
    return z;
}
```

4.14 最大团

```
/*
Int g[][]为图的邻接矩阵。
    MC(V)表示点集V的最大团
    令Si={vi, vi+1, ..., vn}, mc[i]表示MC(Si)
    倒着算mc[i]，那么显然MC(V)=mc[1]
    此外有mc[i]=mc[i+1] or mc[i]=mc[i+1]+1
*/
void init(){
    int i, j;
    for (i=1; i<=n; ++i) for (j=1; j<=n; ++j) scanf("%d", &g[i][j]);
}
void dfs(int size){
    int i, j, k;
    if (len[size]==0) {
        if (size>ans) {
            ans=size; found=true;
        }
        return;
    }
    for (k=0; k<len[size] && !found; ++k) {
        if (size+len[size]-k<=ans) break;
        i=list[size][k];
        if (size+mc[i]<=ans) break;
        for (j=k+1, len[size+1]=0; j<len[size]; ++j)
        if (g[i][list[size][j]]) list[size+1][len[size+1]++]=list[size][j];
        dfs(size+1);
    }
}
void work(){
    int i, j;
    mc[n]=ans=1;
    for (i=n-1; i; --i) {
        found=false;
        len[1]=0;
        for (j=i+1; j<=n; ++j) if (g[i][j]) list[1][len[1]++]=j;
        dfs(1);
        mc[i]=ans;
    }
}
```

4.15 SPFA 判负环-wrz

```
int inq[N], inqt[N], dis[N];
bool SPFA()
{
    queue<int> q;
    for(int i = 1; i <= n; i++) dis[i] = 0, q.push(i), inq[i] = 1; // 全部入队
    for(; !q.empty(); )
    {
        int x = q.front(); q.pop(); inq[x] = 0;
        for(int i = last[x]; i; i = e[i].next)
        {
            int y = e[i].to;
            if(dis[x] + e[i].val < dis[y])
            {
                dis[y] = dis[x] + e[i].val;
                if(!inq[y])
                {
                    if(++inqt[y] > n) return false; //入队n次即有负环
                    inq[y] = 1;
                    q.push(y);
                }
            }
        }
    }
    return true;
}
/*
    步骤:
    1.建好原图
    2.SPFA() // 若返回为true表示无负环，false表示有负环

    多次调用时记得清空inqt等数组
    有负环时理论复杂度是O(n^2)的
*/
```

4.16 斯坦纳树

```
//Nμ   , M±   , P¹  μ
const int inf = 0x3f3f3f3f;
```

```
int n, m, p, status, idx[P], f[1 << P][N];
priority_queue<pair<int, int> > q; //int top, h[N];
void dijkstra(int dis[]) {}
void Steiner_Tree() {
    for (int i = 1; i < status; i++) {
        while (!q.empty()) q.pop(); //top = 0;
        memset(vis, 0, sizeof(vis));
        for (int j = 1; j <= n; j++) {
            for (int k = i & (i - 1); k; (--k) &= i)
                f[i][j] = min(f[i][j], f[k][j] + f[i ^
                    k][j]);
            if (f[i][j] != inf)
                q.push(make_pair(-f[i][j], j)); //h[++
                    top] = j, vis[j] = 1;
        }
        dijkstra(f[i]); //SPFA(f[i]);
    }
}
int main() {
    scanf("%d%d%d", &n, &m, &p);
    status = 1 << p;
    tot = 0; memset(lst, 0, sizeof(lst));
    /*      ³
      ÿ¿   ³                ¸ Fp  I´ ¼
       ¿ª ¸      p 0  I
      Add(0, i, val[i]); Add(i, 0, val[i]);*/
    for (int i = 1; i <= p; i++) scanf("%d", &idx[i]);
    memset(f, 0x3f, sizeof(f));
    for (int i = 1; i <= n; i++) f[0][i] = 0;
    for (int i = 1; i <= p; i++) f[1 << (i - 1)][idx[i
        ]] = 0;
    Steiner_Tree();
    int ans = inf;
    for (int i = 1; i <= n; i++) ans = min(ans, f[
        status - 1][i]);
}
```

4.17 stoer-wagner 无向图最小割树

```
int cost[maxn][maxn],seq[maxn],len[maxn],n,m,pop,ans;
bool used[maxn];
void Init(){
    int i,j,a,b,c;
    for(i=0;i<n;i++) for(j=0;j<n;j++) cost[i][j]=0;
    for(i=0;i<m;i++){
        scanf("%d %d %d",&a,&b,&c); cost[a][b]+=c;
            cost[b][a]+=c;
    }
    pop=n; for(i=0;i<n;i++) seq[i]=i;
}
void Work(){
    ans=inf; int i,j,k,l,mm,sum,pk;
    while(pop > 1){
        for(i=1;i<pop;i++) used[seq[i]]=0; used[seq
            [0]]=1;
        for(i=1;i<pop;i++) len[seq[i]]=cost[seq[0]][
            seq[i]];
        pk=0; mm=-inf; k=-1;
        for(i=1;i<pop;i++) if(len[seq[i]] > mm){ mm=
            len[seq[i]]; k=i; }
        for(i=1;i<pop;i++){
            used[seq[l=k]]=1;
            if(i==pop-2) pk=k;
            if(i==pop-1) break;
            mm=-inf;
            for(j=1;j<pop;j++) if(!used[seq[j]])
                if((len[seq[j]]+=cost[seq[l]][seq[j]])
                    > mm)
                    mm=len[seq[j]], k=j;
        }
        sum=0;
        for(i=0;i<pop;i++) if(i != k) sum+=cost[seq[k
            ]][seq[i]];
        ans=min(ans,sum);
        for(i=0;i<pop;i++)
            cost[seq[k]][seq[i]]=cost[seq[i]][seq[k
                ]]+=cost[seq[pk]][seq[i]];
        seq[pk]=seq[--pop];
    }
    printf("%d\n",ans);
}
```

4.18 tarjan-gwx

```
//cut[i]: i是否为割点
//bridge[i]: e[i]是否为桥
void dfs(int u, int pa)
{
    d[u] = l[u] = ++timer;
    st.push(u); vst[u] = 1;
    int child = 0;
    for(int i = tail[u]; i; i = e[i].next)
        if(!d[e[i].v])
        {
            child++;
            dfs(e[i].v, u);
            l[u] = min(l[u], l[e[i].v]);
            if(l[e[i].v] >= d[u])
            {
                cut[u] = 1;
                if(l[e[i].v] > d[u])
                    bridge[i] = 1;
            }
        }
        else if(vst[e[i].v]) l[u] = min(l[u], d[e[i].v
            ]);
    if(!pa && child < 2) cut[u] = 0;
    if(l[u] == d[u])
    {
        int v; scc++;
        while(true)
        {
            v = st.top(); st.pop();
            id[v] = scc; vst[v] = 0; size[scc]++;
            if(u == v) break;
        }
    }
}
```

4.19 朱刘算法-gwx

```
//时间复杂度: O(nm)
int N, m;
int pre[maxn], in[maxn], f[maxn], id[maxn];
struct node {int u, v, w;} a[maxm * 2]; //边表

int find(int x)
{
    return f[x] == x ? x : f[x] = find(f[x]);
}

int mst()
{
    long long res = 0;
    int root = 1;
    int n = N;
    while(true)
    {
        for(int i = 1; i <= n; i++) in[i] = INT_MAX,
            pre[i] = 0;
        for(int i = 1; i <= m; i++)
            if(a[i].u != a[i].v  && in[a[i].v] > a[i].
                w)
                in[a[i].v] = a[i].w, pre[a[i].v] = a[i
                    ].u;
        for(int i = 1; i <= n; i++)
            if(in[i] == INT_MAX && i != root) return
                0;
        int cnt = 0;
        for(int i = 1; i <= n; i++) f[i] = i, id[i] =
            0;
        for(int i = 1; i <= n; i++)
        {
            if(i == root) continue;
            res += in[i];
            if(find(i) != find(pre[i])) f[f[i]] = f[
                pre[i]];
            else
            {
                cnt++;
                for(int j = i; j && !id[j]; j = pre[j
                    ])
                    id[j] = cnt;
            }
        }
        if(!cnt) break;
        for(int i = 1; i <= n; i++)
            if(!id[i]) id[i] = ++cnt;
        for(int i = 1; i <= m; i++)
        {
            if(id[a[i].u] != id[a[i].v]) a[i].w -= in[
                a[i].v];
            a[i].u = id[a[i].u];
            a[i].v = id[a[i].v];
        }
        n = cnt;
        root = id[root];
    }
    return res;
}
```

4.20 zkw 费用流

```
//稠密图、二分图中较快，稀疏图中不如SPFA
int flow, cost, price;

int dfs(int u, int f)
{
    if(u == t)
    {
        flow += f;
        cost += price * f;
        return f;
    }
    vst[u] = 1;
    int used = 0;
    for(int i = tail[u]; i; i = e[i].next)
        if(!vst[e[i].v] && e[i].c > 0 && e[i].w == 0)
        {
            int w = dfs(e[i].v, min(e[i].c, f - used))
                ;
```

```
            e[i].c -= w; e[i ^ 1].c += w; used += w;
            if(used == f) return f;
        }
    return used;
}
bool modlabel()
{
    int d = inf;
    for(int u = s; u <= t; u++)
        if(vst[u])
            for(int i = tail[u]; i; i = e[i].next)
                if(e[i].c > 0 && !vst[e[i].v]) d = min
                    (d, e[i].w);
    if(d == inf) return 0;
    for(int u = s; u <= t; u++)
        if(vst[u])
            for(int i = tail[u]; i; i = e[i].next)
                e[i].w -= d, e[i ^ 1].w += d;
    price += d;
    return 1;
}
void zkw()
{
    do
        do memset(vst, 0, sizeof(vst));
        while(dfs(s, inf) > 0);
    while(modlabel());
}
```

5 数论

5.1 杜教筛

```
// 用之前必须先init(); 如果n很大, 求和记得开long long;
    如果有取模, 求和记得改取模
#define N 1000005 // (10^9)^(2/3)
#define M 3333331 // hash siz
int prime[N], notprime[N], pcnt, mu[N], pre[N];
int hash[M], nocnt; struct node{int id, f, next;}no
    [1000000];
int F(int n) // calculate mu[1]+mu[2]+...+mu[n]
{
    if(n<N) return pre[n];
    int h = n%M; for(int i = hash[h]; i; i = no[i].
        next) if(no[i].id == n) return no[i].f;
    int ret = 1;
    for(int i = 2, j; i <= n; i = j + 1)
    {
        j = n/(n/i);
        ret -= F(n/i) * (j-i+1);
    }
    no[++nocnt] = (node){n, ret, hash[h]};
    hash[h] = nocnt;
    return ret;
}
void init()
{
    mu[1] = 1;
    for(int i = 2; i < N; i++)
    {
        if(!notprime[i]) prime[++pcnt] = i, mu[i] =
            -1;
        for(int j = 1; j <= pcnt && prime[j] * i < N;
            j++)
        {
            notprime[prime[j] * i] = 1;
            if(i % prime[j]) mu[prime[j] * i] = -mu[i
                ];
            else {mu[prime[j] * i] = 0; break;}
        }
    }
    for(int i = 1; i < N; i++) pre[i] = pre[i-1] + mu[
        i];
}
```

5.2 直线下整点

```
// $\sum_{i=0}^{n-1} \lfloor \frac{a+bi}{m}\rfloor$,
    $n,m,a,b>0$
LL solve(LL n,LL a,LL b,LL m){
    if(b==0) return n*(a/m);
    if(a>=m) return n*(a/m)+solve(n,a%m,b,m);
    if(b>=m) return (n-1)*n/2*(b/m)+solve(n,a,b%m,m);
    return solve((a+b*n)/m,(a+b*n)%m,m,b);
}
```

5.3 拉格朗日插值

```
// 用之前必须先init(); 如果所有的逆元都能预处理就是O(n
    )的, 否则是O(nlogn)的
#define MOD 1000000007
int inv[N], invf[N], f[N];
int fpow(int a, int b)
{
    int r = 1;
    for(; b; b >>= 1)
    {
        if(b & 1) r = 1ll*r*a%MOD;
        a = 1ll*a*a%MOD;
    }
    return r;
}
int la(int x, int k) // k次, 求f(x)
{
    int lim = k+2, ff = 1;
    for(int i = 1; i <= lim; i++)
        ff = 1ll * ff * (x-i) % MOD;
    for(int i = 1; i <= lim; i++)
        f[i] = (f[i-1] + fpow(i, k)) % MOD; // 预处理
            f(1),f(2),...,f(lim), 注意修改
    if(x <= lim) return f[x];
    int ret = 0;
    for(int i = 1; i <= lim; i++)
    {
        (ret += 1ll * f[i]
                * ff % MOD * (x-i < N ? inv[x-i] :
                    fpow(x-i, MOD-2)) % MOD // 复杂度
                * invf[i-1] % MOD * invf[lim-i] % MOD
                    * ((lim-i) % 2 ? MOD-1 : 1) % MOD
        ) %= MOD;
    }
    return ret;
}
void init()
{
    inv[1] = 1;
    for(int i = 2; i < N; i++) inv[i] = 1ll * (MOD -
        MOD / i) * inv[MOD % i] % MOD;
    invf[0] = 1;
    for(int i = 1; i < N; i++) invf[i] = 1ll * invf[i
        -1] * inv[i] % MOD;
}
```

5.4 线性回归

```
// O(m^2logn)
// Given a[0], a[1], ..., a[m - 1]
// a[n] = c[0] * a[n - m] + ... + c[m - 1] * a[n - 1]
// Solve for a[n] = v[0] * a[0] + v[1] * a[1] + ... +
    v[m - 1] * a[m - 1]
void linear_recurrence(long long n, int m, int a[],
    int c[], int p) {
    long long v[M] = {1 % p}, u[M << 1], msk = !!n;
    for(long long i(n); i > 1; i >>= 1) {
        msk <<= 1;
    }
    for(long long x(0); msk; msk >>= 1, x <<= 1) {
        fill_n(u, m << 1, 0);
        int b(!!(n & msk));
        x |= b;
        if(x < m) {
            u[x] = 1 % p;
        }else {
            for(int i(0); i < m; i++) {
                for(int j(0), t(i + b); j < m; j++, t
                    ++) {
                    u[t] = (u[t] + v[i] * v[j]) % p;
                }
            }
            for(int i((m << 1) - 1); i >= m; i--) {
                for(int j(0), t(i - m); j < m; j++, t
                    ++) {
                    u[t] = (u[t] + c[j] * u[i]) % p;
                }
            }
        }
        copy(u, u + m, v);
    }
    for(int i(m); i < 2 * m; i++) {
        a[i] = 0;
        for(int j(0); j < m; j++) {
            a[i] = (a[i] + (long long)c[j] * a[i + j -
                m]) % p;
        }
    }
    for(int j(0); j < m; j++) {
        b[j] = 0;
        for(int i(0); i < m; i++) {
            b[j] = (b[j] + v[i] * a[i + j]) % p;
        }
    }
    for(int j(0); j < m; j++) {
        a[j] = b[j];
    }
}
```

5.5 素数测试-gwx

```
ll multi(ll x, ll y, ll M) {
    ll res = 0;
    for(; y; y >>= 1, x = (x + x) % M)
        if(y & 1) res = (res + x) % M;
    return res;
}
ll power(ll x, ll y, ll p)
{
    ll res = 1;
    for(; y; y >>= 1, x = multi(x, x, p))
        if(y & 1) res = multi(res, x, p);
```

```
    return res;
}
int primetest(ll n, int base)
{
    ll n2 = n - 1, res;
    int s = 0;
    while(!(n2 & 1)) n2 >>= 1, s++;
    res = power(base, n2, n);
    if(res == 1 || res == n - 1) return 1;
    s--;
    while(s >= 0)
    {
        res = multi(res, res, n);
        if(res == n - 1) return 1;
        s--;
    }
    return 0;   // n is not a strong pseudo prime
}
int isprime(ll n)
{
    static ll testNum[] = {2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37};
    static ll lim[] = {4, 0, 1373653ll, 2532600l1l, 250000000001l, 215230289874711, 3474749660383ll, 3415500717283211l, 0, 0, 0, 0};
    if(n < 2 || n == 321503175111) return 0;
    for(int i = 0; i < 12; i++)
    {
        if(n < lim[i]) return 1;
        if(!primetest(n, testNum[i])) return 0;
    }
    return 1;
}
ll pollard(ll n)
{
    ll i, x, y, p;
    if(isprime(n)) return n;
    if(!(n & 1)) return 2;
    for(i = 1; i < 20; i++)
    {
        x = i, y = func(x, n), p = gcd(y - x, n);
        while(p == 1)
        {
            x = func(x, n);
            y = func(func(y, n), n);
            p = gcd((y - x + n) % n, n) % n;
        }
        if(p == 0 || p == n) continue;
        return p;
    }
}
```

5.6 原根-gwx

```
bool check_force(int g, int p)
{
    int cnt = 0, prod = g;
    for(int i = 1; i <= p - 1; ++i, prod = prod * g % p)
        if(prod == 1) if(++cnt > 1) return 0;
    return 1;
}
//d[]: prime divisor of (p - 1)
bool check_fast(int g, int p)
{
    for(int i = 1; i <= m; ++i)
        if(power(g, (p - 1) / d[i], p) == 1) return 0;
    return 1;
}
int primitive_root(int p)
{
    for(int i = 2; i < p; ++i) if(check(i, p)) return i;
}
```

5.7 勾股数

```
a=m^2-n^2, b=2mn, c=m^2+n^2
其中m和n中有一个是偶数，则(a, b, c)是素勾股数
```

5.8 Pell 方程

Find the smallest integer root of $x^2-ny^2=1$ when n is not a square number, with the solution set $x_{k+1}=x_0x_k+ny_0y_k, y_{k+1}=x_0y_k+y_0x_k$.

```
template <int MAXN = 100000>
struct pell {
    std::pair <long long, long long> solve (long long n) {
        static long long p[MAXN], q[MAXN], g[MAXN], h[MAXN], a[MAXN];
        p[1] = q[0] = h[1] = 1; p[0] = q[1] = g[1] = 0;
        a[2] = (long long) (floor (sqrtl (n) + 1e-7L));
        for (int i = 2; ; ++i) {
            g[i] = -g[i - 1] + a[i] * h[i - 1];
            h[i] = (n - g[i] * g[i]) / h[i - 1];
            a[i + 1] = (g[i] + a[2]) / h[i];
            p[i] = a[i] * p[i - 1] + p[i - 2];
            q[i] = a[i] * q[i - 1] + q[i - 2];
            if (p[i] * p[i] - n * q[i] * q[i] == 1)
                return { p[i], q[i] }; } } };
```

5.9 平方剩余

Solve $x^2\equiv n \mod p (0\le a<p)$ where p is prime in $O(\log p)$.

```
struct quadric {
    void multiply(long long &c, long long &d, long long a, long long b, long long w, long long p) {
        int cc = (a * c + b * d % p * w) % p;
        int dd = (a * d + b * c) % p; c = cc, d = dd; }
    bool solve(int n, int p, int &x) {
        if (n == 0) return x = 0, true; if (p == 2) return x = 1, true;
        if (power (n, p / 2, p) == p - 1) return false;
        long long c = 1, d = 0, b = 1, a, w;
        do { a = rand() % p; w = (a * a - n + p) % p;
            if (w == 0) return x = a, true;
        } while (power (w, p / 2, p) != p - 1);
        for (int times = (p + 1) / 2; times; times >>= 1) {
            if (times & 1) multiply (c, d, a, b, w, p);
            multiply (a, b, a, b, w, p); }
        return x = c, true; } };
```

5.10 博弈论

Nim For simplicity, we denote a_i as the number of stones in the i-th pile, $M_i(S)$ as removing stones with the amount chosen in the set S from the i-th pile, and $M_i=M_i[1,a_i]$. Without further explanation, it is assumed that the SG function of a game $SG=\bigoplus_{i=1}^{n}SG(a_i)$.

Nim $M=\bigcup_{i=1}^{n}M_i$.
Normal: $SG(n)=n$.
Misere: The same, opposite if all piles are 1's.

Nim (powers) Given k, $M=\bigcup_{i=1}^{n}M_i\{k^m|m\ge 0\}$.
Normal: If k is odd, $SG(n)=n\%2$. Otherwise,

$$SG(n)=\begin{cases}2 & n\%(k+1)=k\\ n\%(k+1)\%2 & \text{otherwise}.\end{cases}$$

Nim (no greater than half) $M=\bigcup_{i=1}^{n}M_i[1,\frac{a_i}{2}]$.
Normal: $SG(2n)=n, SG(2n+1)=SG(n)$.

Nim (always greater than half) $M=\bigcup_{i=1}^{n}M_i[\lceil\frac{a_i}{2}\rceil,a_i]$.
Normal: $SG(0)=0, SG(n)=\lfloor\log_2 n\rfloor+1$.

Nim (proper divisors) $M=\bigcup_{i=1}^{n}M_i\{x|x>1\wedge a_i\%x=0\}$.
Normal: $SG(1)=0, SG(n)=\max_x(n\%2^x=0)$.

Nim (divisors) $M=\bigcup_{i=1}^{n}M_i\{x|a_i\%x=0\}$.
Normal: $SG(0)=0, SG(n)=1+\max_x(n\%2^x=0)$.

Nim (fixed) Given a finite set S, $M=\bigcup_{i=1}^{n}M_i(S)$.
Normal: $SG_1(n)$ is eventually periodic.
Given a finite set S, $M=\bigcup_{i=1}^{n}M_i(S\cup a_i)$.
Normal: $SG_2(n)=SG_1(n)+1$.

Moore's Nim Given k, $M=\bigcup\{M_{x_1}\times M_{x_2}\cdots\times M_{x_l}|l\le k\wedge\forall i(x_i<x_{i+1})\}$.
Normal: Sum all $(a_i)_2$ in base $k+1$ without carry. Lose if the result is 0.
Misere: The same, except if all piles are 1's.

Staircase Nim One can take any number of objects from a_{i+1} to $a_i(i\ge 0)$.
Normal: Lose if $\bigoplus_{i=0}^{(n-1)/2}a_{2i+1}=0$.

Lasker's Nim $M=\bigcup_{i=1}^{n}M_i\cup S_i$. ($S_i$: Split a pile into two non-empty piles.)

$$\text{Normal: } SG(n)=\begin{cases}n & n\%4=1,2\\ n+1 & n\%4=3\\ n-1 & n\%4=0.\end{cases}$$

Kayles $M=\bigcup_{i=1}^{n}M_i[1,2]\cup MS_i[1,2]$. ($MS_i$: Split a pile into two non-empty piles after removing stones.)
Normal: Periodic from the 72-th item with period length 12.

Dawson's chess n stones in a line. One can take a stone if its neighbours are not taken.
Normal: Periodic from the 52-th item with period length 34.

Ferguson game Two boxes with m stones and n stones. One can empty any one box and move any positive number of stones from another box to this box each step.
Normal: Lose if both m and n are odd.

Fibonacci game n stones. The first player may take any positive number of stones during the first move, but not all of them. After that, each player may take any positive number of stones, but less than twice the number of stones taken during the last turn.
Normal: Win if n is not a fibonacci number.

Wythoff's game Two piles of stones. Players take turns removing stones from one or both piles; when removing stones from both piles, the numbers of stones removed from each pile must be equal.
Normal: Lose if $\lfloor\frac{\sqrt{5}+1}{2}|A-B|\rfloor=\min(A,B)$

Mock turtles n coins in a line. One can turn over any 1, 2, or 3 coins, but the rightmost coin turned must be from head to tail.
Normal: $SG(n)=2n+[\text{popcount}(n)\text{ is even}]$.

Ruler n coins in a line. One can turn over any consecutive coins, but the rightmost coin turned must be from head to tail.

Normal: $SG(n) = \text{lowbit}(n)$.

Hackenbush The game starts with the players drawing a ground line (conventionally, but not necessarily, a horizontal line at the bottom of the paper or other playing area) and several line segments such that each line segment is connected to the ground, either directly at an endpoint, or indirectly, via a chain of other segments connected by endpoints. Any number of segments may meet at a point and thus there may be multiple paths to ground.

On his turn, a player cuts (erases) any line segment of his choice. Every line segment no longer connected to the ground by any path falls (i.e., gets erased). According to the normal play convention of combinatorial game theory, the first player who is unable to move loses.

Played exclusively with vertical stacks of line segments, also referred to as bamboo stalks, the game directly becomes Nim and can be directly analyzed as such. Divergent segments, or trees, add an additional wrinkle to the game and require use of the colon principle stating that when branches come together at a vertex, one may replace the branches by a non-branching stalk of length equal to their nim sum. This principle changes the representation of the game to the more basic version of the bamboo stalks. The last possible set of graphs that can be made are convergent ones, also known as arbitrarily rooted graphs. By using the fusion principle, we can state that all vertices on any cycle may be fused together without changing the value of the graph. Therefore, any convergent graph can also be interpreted as a simple bamboo stalk graph. By combining all three types of graphs we can add complexity to the game, without ever changing the Nim sum of the game, thereby allowing the game to take the strategies of Nim.

Joseph cycle n players are numbered with $0, 1, 2, ..., n-1$. $f_{1,m} = 0, f_{n,m} = (f_{n-1,m} + m) \mod n$.

6 字符串

6.1 AC 自动机-wrz

```
struct ACAM
{
    ACAM *next[S], *fail;
    int ban;
}mem[N], *tot, *null, *root, *q[N];
ACAM *newACAM()
{
    ACAM *p = ++tot;
    *p = *null; return p;
}
void init()
{
    null = tot = mem;
    for(int i = 0; i < alpha; i++) null->next[i] = null;
    null->fail = null; null->ban = 0;
    root = newACAM();
}
void inser(char *s)
{
    ACAM *p = root;
    for(int i = 0; s[i]; i++)
    {
        int w = s[i] - 'a';
        if(p->next[w] == null) p->next[w] = newACAM();
        p = p->next[w];
    }
    p->ban = 1;
}
void build()
{
    root->fail = root; int head = 0, tail = 0;
    for(int i = 0; i < alpha; i++)
    {
        if(root->next[i] == null) root->next[i] = root;
        else root->next[i]->fail = root, q[tail++] = root->next[i];
    }
    for(; head < tail; head++)
    {
        ACAM *p = q[head];
        p->ban |= p->fail->ban;
        for(int i = 0; i < alpha; i++)
        {
            if(p->next[i] == null) p->next[i] = p->fail->next[i];
            else p->next[i]->fail = p->fail->next[i], q[tail++] = p->next[i];
        }
    }
}
```

6.2 扩展 KMP-gwx

```
void get_next()
{
    int a = 0, p = 0;
    nxt[0] = m;
    for(int i = 1; i < m; i++)
    {
        if(i >= p || i + nxt[i - a] >= p)
        {
            if(i >= p)  p = i;
            while(p < m && t[p] == t[p - i]) p++;
            nxt[i] = p - i;
            a = i;
        }
        else nxt[i] = nxt[i - a];
    }
}

void exkmp()
{
    int a = 0, p = 0;
    get_next();
    for(int i = 0; i < n; i++)
    {
        if(i >= p || i + nxt[i - a] >= p) // i >= p 的作用：举个典型例子，s 和 t 无一字符相同
        {
            if(i >= p) p = i;
            while(p < n && p - i < m && s[p] == t[p - i]) p++;
            ext[i] = p - i;
            a = i;
        }
        else ext[i] = nxt[i - a];
    }
}
```

6.3 马拉车-gwx

```
//maxn = 2 * n
void manacher(int n)
{
    int p = 0, r = 0;
    for(int i = 1; i <= n; i++)
    {
        if(i <= r) len[i] = min(len[2 * p - i], r - i + 1);
        else len[i] = 1;
        while(b[i + len[i]] == b[i - len[i]]) len[i]++;
        if(i + len[i] - 1 >= r)
            r = i + len[i] - 1, p = i;
    }
}

int main()
{
    scanf("%d\n%s", &n, a + 1);
    b[++tot] = '@'; b[++tot] = '#';
    for(int i = 1; i < n; i++)
        b[++tot] = a[i], b[++tot] = '#';
    b[++tot] = a[n];
    b[++tot] = '#'; b[++tot] = '$';
    manacher(tot);
}
```

6.4 最小表示-gwx

```
//不保证起始位置最靠前(?)
string find(int N, string s) {
    int i, j, k, l;
    for (i = 0, j = 1; j < N; ) {
        for (k = 0; k < N && s[i + k] == s[j + k]; k++);
        if (k >= N) break;
        if (s[i + k] > s[j + k]) j += k + 1;
        else l = i + k, i = j, j = max(l, j) + 1;
    }
    return s.substr(i, N);
}
```

6.5 回文树-wrz

```
char s[N], out[N];
struct PT
{
    PT *fail, *next[A];
    int len;
}mem[N], *tot, *null, *root1, *root0, *last;
PT *newPT()
{
    PT *p = ++tot;
    *p = *null; return p;
}
void init()
{
    null = tot = mem;
    null->fail = null;
    for(int i = 0; i < A; i++) null->next[i] = null;
    null->len = 0;
    root1 = newPT(); root1->fail = root1; root1->len = -1;
    root0 = newPT(); root0->fail = root1; last = root1;
}
int extend(int c, int i) // 返回这一次是否多了一个回文子串
{
    PT *p = last;
```

```
    for(; s[i-p->len-1] != c+'a'; p = p->fail);
    if(p->next[c] != null) {last = p->next[c]; return 0;}
    PT *np = p->next[c] = last = newPT(); np->len = p->len + 2;
    if(p->len == -1) np->fail = root0;
    else
    {
        for(p=p->fail; s[i-p->len-1] != c+'a'; p = p->fail);
        np->fail = p->next[c];
    }
    return 1;
}
void main()
{
    scanf("%s",s+1); init();
    for(int i = 1, ii = strlen(s+1); i <= ii; i++)
        out[i] = extend(s[i]-'a', i)?'1':'0';
    puts(out+1);
}
```

6.6 后缀数组-wrz

```
// 对都是数字的数组做SA时要保证数组中没有0，否则height等可能由于s[0]=s[n+1]=0出问题
// 多次使用要保证s[0]=s[n+1]=0
char s[N];
int n, t1[N], t2[N], sa[N], rank[N], sum[N], height[N], lef, rig; // 数组开两倍
void SA_build()
{
    int *x = t1, *y = t2, m = 30;
    for(int i = 1; i <= n; i++) sum[x[i] = s[i] - 'a' + 1]++;
    for(int i = 1; i <= m; i++) sum[i] += sum[i-1];
    for(int i = n; i >= 1; i--) sa[sum[x[i]]--] = i;
    for(int k = 1; k <= n; k <<= 1)
    {
        int p = 0;
        for(int i = n-k+1; i <= n; i++) y[++p] = i;
        for(int i = 1; i <= n; i++) if(sa[i] - k > 0)
            y[++p] = sa[i] - k;

        for(int i = 1; i <= m; i++) sum[i] = 0;
        for(int i = 1; i <= n; i++) sum[x[i]]++;
        for(int i = 1; i <= m; i++) sum[i] += sum[i-1];
        for(int i = n; i >= 1; i--) sa[sum[x[y[i]]]--] = y[i];

        swap(x, y);
        for(int i = 1; i <= n; i++)
            x[sa[i]] = x[sa[i-1]] + (y[sa[i]] == y[sa[i-1]] && y[sa[i]+k] == y[sa[i-1]+k] ? 0 : 1);
        m = x[sa[n]];
        if(m == n) break;
    }
    for(int i = 1; i <= n; i++) rank[sa[i]] = i;
    for(int i = 1, k = 0; i <= n; height[rank[i++]] = k?k--:k)
        for(; s[i+k] == s[sa[ran[i]-1]+k] && i+k <= n && sa[ran[i]-1]+k <= n; k++);
}
```

6.7 后缀数组 SAIS

```
// string is 0-based
// sa[] is 1-based
// s[n] < s[i] i = 0...n-1
namespace SA {
    int sa[MAXN], rk[MAXN], ht[MAXN], s[MAXN << 1], t[MAX << 1], p[MAXN], cnt[MAXN], cur[MAXN];
#define pushS(x) sa[cur[s[x]]--] = x
#define pushL(x) sa[cur[s[x]]++] = x
#define inducedSort(v) std::fill_n(sa, n, -1); std::fill_n(cnt, m, 0);\
    for (int i = 0; i < n; i++) cnt[s[i]]++;\
    for (int i = 1; i < m; i++) cnt[i] += cnt[i-1];\
    for (int i = 0; i < m; i++) cur[i] = cnt[i]-1;\
    for (int i = n1-1; ~i; i--) pushS(v[i]);\
    for (int i = 1; i < m; i++) cur[i] = cnt[i-1];\
    for (int i = 0; i < n; i++) if (sa[i] > 0 && t[sa[i]-1]) pushL(sa[i]-1);\
    for (int i = 0; i < m; i++) cur[i] = cnt[i]-1;\
    for (int i = n-1; ~i; i--) if (sa[i] > 0 && !t[sa[i]-1]) pushS(sa[i]-1)
    void sais(int n, int m, int *s, int *t, int *p) {
        int n1 = t[n-1] = 0, ch = rk[0] = -1, *s1 = s+n;
        for (int i = n-2; ~i; i--) t[i] = s[i] == s[i+1] ? t[i+1] : s[i] > s[i+1];
        for (int i = 1; i < n; i++) rk[i] = t[i-1] && !t[i] ? (p[n1] = i, n1++) : -1;
        inducedSort(p);
        for (int i = 0, x, y; i < n; i++) if (~(x = rk[sa[i]])) {
            if (ch < 1 || p[x+1] - p[x] != p[y+1] - p[y]) ch++;
            else for (int j = p[x], k = p[y]; j <= p[x+1]; j++, k++)
                if ((s[j]<<1|t[j]) != (s[k]<<1|t[k]))
                    {ch++; break;}
            s1[y = x] = ch; }
        if (ch+1 < n1) sais(n1, ch+1, s1, t+n, p+n1);
        else for (int i = 0; i < n1; i++) sa[s1[i]] = i;
        for (int i = 0; i < n1; i++) s1[i] = p[sa[i]];
        inducedSort(s1); }
    int mapCharToInt(int n, const T *str) {
        int m = *std::max_element(str, str+n);
        std::fill_n(rk, m+1, 0);
        for (int i = 0; i < n; i++) rk[str[i]] = 1;
        for (int i = 0; i < m; i++) rk[i+1] += rk[i];
        for (int i = 0; i < n; i++) s[i] = rk[str[i]] - 1;
        return rk[m]; }
    void suffixArray(int n, const T *str) {
        int m = mapCharToInt(++n, str);
        sais(n, m, s, t, p);
        for (int i = 0; i < n; i++) rk[sa[i]] = i;
        for (int i = 0, h = ht[0] = 0; i < n-1; i++) {
            int j = sa[rk[i]-1];
            while (i+h < n && j+h < n && s[i+h] == s[j+h]) h++;
            if (ht[rk[i]] = h) h--; } } };
```

6.8 后缀自动机-wrz

```
struct SAM
{
    SAM *next[A], *fail;
    int len, mi, mx;
}mem[N], *tot, *null, *root, *last, *q[N];
SAM *newSAM(int len)
{
    SAM *p = ++tot;
    *p = *null;
    p->len = p->mi = len;
    p->mx = 0;
    return p;
}
void init()
{
    null = tot = mem;
    for(int i = 0; i < A; i++) null->next[i] = null;
    null->fail = null;
    null->len = null->mi = null->mx = 0;
    root = last = newSAM(0);
}
void extend(int v)
{
    SAM *p = last, *np = newSAM(p->len + 1); last = np;
    for(; p->next[v] == null && p != null; p = p->fail) p->next[v] = np;
    if(p==null) np->fail = root;
    else
    {
        SAM *q = p->next[v];
        if(q->len == p->len+1) np->fail = q;
        else
        {
            SAM *nq = newSAM(p->len+1);
            memcpy(nq->next, q->next, sizeof(nq->next));
            nq->fail = q->fail;
            q->fail = np->fail = nq;
            for(; p->next[v] == q && p != null; p = p->fail) p->next[v] = nq;
        }
    }
}
```

6.9 ex 后缀自动机-wrz

```
struct sam
{
    sam *fail, *next[A];
    int len;
}mem[N<<1], *tot, *null, *root;
sam* newsam()
{
    *++tot = *null;
    return tot;
}
void init()
{
    null = tot = mem; null->fail = null; null->len = 0;
    for(int i = 0; i < A; i++) null->next[i] = null;
    root = newsam();
}
sam* extend(sam *p, int v)
{
    if(p->next[v] != null)
    {
        sam *q = p->next[v];
        if(p->len + 1 == q->len) return q;
        else
```

```
        {
            sam *nq = newsam(); *nq = *q; nq->len = p->len + 1;
            q->fail = nq;
            for(; p->next[v] == q && p != null; p = p->fail) p->next[v] = nq;
            return nq;
        }
    }
    else
    {
        sam *np = newsam(); np->len = p->len + 1;
        for(; p->next[v] == null && p != null; p = p->fail) p->next[v] = np;
        if(p == null) np->fail = root;
        else
        {
            sam *q = p->next[v];
            if(p->len + 1 == q->len) np->fail = q;
            else
            {
                sam *nq = newsam(); *nq = *q; nq->len = p->len + 1;
                np->fail = q->fail = nq;
                for(; p->next[v] == q && p != null; p = p->fail) p->next[v] = nq;
            }
        }
        return np;
    }
}
void build_tree()
{
    for(sam *i = tot; i != mem; i--)
        addedge(i->fail - mem, i - mem);
}
```

7 其他

7.1 蔡勒公式

```
int zeller(int y,int m,int d) {
    if (m<=2) y--,m+=12; int c=y/100; y%=100;
    int w=((c>>2)-(c<<1)+y+(y>>2)+(13*(m+1)/5)+d-1)%7;
    if (w<0) w+=7; return(w);
}
```

7.2 dancing-links

```
struct Node {
    Node *l, *r, *u, *d, *col;
    int size, line_no;
    Node() {
        size = 0; line_no = -1;
        l = r = u = d = col = NULL;
    }
} *root;
void cover(Node *c) {
    c->l->r = c->r; c->r->l = c->l;
    for (Node *u = c->d; u != c; u = u->d)
        for (Node *v = u->r; v != u; v = v->r) {
            v->d->u = v->u;
            v->u->d = v->d;
            -- v->col->size;
        }
}
void uncover(Node *c) {
    for (Node *u = c->u; u != c; u = u->u) {
        for (Node *v = u->l; v != u; v = v->l) {
            ++ v->col->size;
            v->u->d = v;
            v->d->u = v;
        }
    }
    c->l->r = c; c->r->l = c;
}
std::vector<int> answer;
bool search(int k) {
    if (root->r == root) return true;
    Node *r = NULL;
    for (Node *u = root->r; u != root; u = u->r)
        if (r == NULL || u->size < r->size)
            r = u;
    if (r == NULL || r->size == 0) return false;
    else {
        cover(r);
        bool succ = false;
        for (Node *u = r->d; u != r && !succ; u = u->d) {
            answer.push_back(u->line_no);
            for (Node *v = u->r; v != u; v = v->r)  // Cover row
                cover(v->col);
            succ |= search(k + 1);
            for (Node *v = u->l; v != u; v = v->l)
                uncover(v->col);
            if (!succ) answer.pop_back();
        }
        uncover(r);
        return succ;
    }
}
```

```
}
bool entry[CR][CC];
Node *who[CR][CC];
int cr, cc;
void construct() {
    root = new Node();
    Node *last = root;
    for (int i = 0; i < cc; ++ i) {
        Node *u = new Node();
        last->r = u; u->l = last;
        Node *v = u; u->line_no = i;
        last = u;
        for (int j = 0; j < cr; ++ j)
            if (entry[j][i]) {
                ++ u->size;
                Node *cur = new Node();
                who[j][i] = cur;
                cur->line_no = j;
                cur->col = u;
                cur->u = v; v->d = cur;
                v = cur;
            }
        v->d = u; u->u = v;
    }
    last->r = root; root->l = last;
    for (int j = 0; j < cr; ++ j) {
        Node *last = NULL;
        for (int i = cc - 1; i >= 0; -- i)
            if (entry[j][i]) {
                last = who[j][i];
                break;
            }
        for (int i = 0; i < cc; ++ i)
            if (entry[j][i]) {
                last->r = who[j][i];
                who[j][i]->l = last;
                last = who[j][i];
            }
    }
}
void destruct() {
    for (Node *u = root->r; u != root; ) {
        for (Node *v = u->d; v != u; ) {
            Node *nxt = v->d;
            delete(v);
            v = nxt;
        }
        Node *nxt = u->r;
        delete(u); u = nxt;
    }
    delete root;
}
```

7.3 枚举子集

```
for (int x = 1; x <= n; x++)
    for (int y  = x & (x - 1); y; (--y) &= x) {
        //y is a subset of x
    }
```

7.4 梅森旋转

```
#include <random>
int main() {
    std::mt19937 g(seed);  // std::mt19937_64
    std::cout << g() << std::endl;
}
```

7.5 大数乘法取模

```
// 需要保证 x 和 y 非负
long long mult(long long x, long long y, long long MODN) {
    long long t = (x * y - (long long)((long double)x / MODN * y + 1e-3) * MODN) % MODN;
    return t < 0 ? t + MODN : t;
}
```

8 提示

8.1 make 支持 c++11

```
export CXXFLAGS='-std=c++11 -Wall'
source .bashrc
```

8.2 Java

```
import java.util.*;
import java.math.*;
public class javaNote
{
    static BigInteger q[] = new BigInteger[5000000];
        // 定义数组的正确姿势，记得分配内存

    public static void main(String[] args)
    {

        long currentTime = System.currentTimeMillis();
            // 获取时间，单位是ms

```

```
        Scanner sc = new Scanner(System.in); // 定义输入
        int a = sc.nextInt(), b;
        System.out.println("integer=" + a); // 输出

        BigInteger x = new BigInteger("233"), y = new BigInteger("666");
        BigInteger.valueOf(1); // 将指定的表达式转化成BigInteger类型
        x.add(y); //x+y
        x.subtract(y); //x-y
        x.multiply(y); //x*y
        x.divide(y);

        x.pow(233); // x**233
        x.compareTo(y); // 比较x和y, x < y : -1, x = y : 0, x > y : 1

        BigDecimal n = new BigDecimal("233"), m = new BigDecimal("666");
        n.divide(m,a,RoundingMode.DOWN); //n/m并精确到小数点后第a位, a=0表示精确到个位, a为负数表示精确到小数点前-a+1位, 可能变成科学计数法
        /*
            取整方式
            RoundingMode.CEILING: 取右边最近的整数, 即向正无穷取整
            RoundingMode.FLOOR: 取左边最近的整数, 即向负无穷取整
            RoundingMode.DOWN: 向0取整
            RoundingMode.UP: 远离0取整
            RoundingMode.HALF_UP:上取整的四舍五入, >=0.5会进位, <0.5会舍去, 负数会先取绝对值再四舍五入再变回负数
            RoundingMode.HALF_DOWN:下取整的四舍五入, >0.5会进位, <=0.5会舍去, 负数原理同上
            RoundingMode.HALF_EVEN:分奇偶的四舍五入, >0.5会进位, <0.5会舍去, =0.5会向最近的偶数取整, 如2.5->2, (-2.5)->(-2)
        */

        Math.max(a, b);//取大
        Math.min(a, b);//取小
        Math.PI;//pi

        HashSet<BigInteger> hash = new HashSet<BigInteger>(); // hash table
        hash.contains(x); // hash table中是否有a, 有则返回true, 反之返回false
        hash.add(x); // 把x加进hash table
        hash.remove(x); // 从hash table中删去x

        Arrays.sort(arr, 1, n+1); // arr 是需要排序的数组, 后两个参数分别是排序的起始位置和结束位置+1, 还可以有第四个参数是比较函数
        // Arrays.sort(arr, a, b, cmp) = sort(arr+a, arr+b, cmp)
    }

    public static BigInteger sqrt (BigInteger x) {
    if (x.equals (BigInteger.ZERO) || x.equals (BigInteger.ONE)) return x;
    BigInteger d = BigInteger.ZERO.setBit (x.bitLength () / 2);
    BigInteger d2 = d;
    for (; ; ) {
        BigInteger y = d.add (x.divide (d)).shiftRight (1);
        if (y.equals (d) || y.equals (d2)) return d.min (d2);
        d2 = d; d = y; } }
}
```

8.3 cout 输出小数

```
std::cout << std::fixed << std::setprecision(5);
```

8.4 释放容器内存

```
template <typename T>
__inline void clear(T& container) {
    container.clear();  // 或者删除了一堆元素
    T(container).swap(container);
}
```

8.5 tuple

```
mytuple = std::make_tuple (10, 2.6, 'a');           // packing values into tuple
std::tie (myint, std::ignore, mychar) = mytuple;    // unpacking tuple into variables
std::get<I>(mytuple) = 20;
std::cout << std::get<I>(mytuple) << std::endl;     // get the Ith(const) element
```

8.6 读入优化 & 手开 O3

```
// getchar()读入优化 << 关同步cin << 此优化
// 用isdigit()会小幅变慢
// 返回 false 表示读到文件尾
#define _ __ __attribute__ ((optimize ("-O3")))
#define _ __ __inline __attribute__ ((__gnu_inline__, __always_inline__, __artificial__))
namespace Reader {
    const int L = (1 << 15) + 5;
    char buffer[L], *S, *T;
    __inline bool getchar(char &ch) {
        if (S == T) {
            T = (S = buffer) + fread(buffer, 1, L, stdin);
            if (S == T) {
                ch = EOF;
                return false;
            }
        }
        ch = *S++;
        return true;
    }
    __inline bool getint(int &x) {
        char ch; bool neg = 0;
        for (; getchar(ch) && (ch < '0' || ch > '9'); ) neg ^= ch == '-';
        if (ch == EOF) return false;
        x = ch - '0';
        for (; getchar(ch), ch >= '0' && ch <= '9'; )
            x = x * 10 + ch - '0';
        if (neg) x = -x;
        return true;
    }
}
```

8.7 手开栈

The following lines allow the program to use larger stack memory.

```
//C++
#pragma comment (linker, "/STACK:36777216")
//G++
int __size__ = 256 << 20;
char *__p__ = (char*) malloc(__size__) + __size__;
__asm__ ("movl %0, %%esp\n" :: "r"(__p__));
```

9 附录-数学公式

Binomial coefficients

$$\binom{n}{k} = (-1)^k \binom{k-n-1}{k}, \quad \sum_{k \le n} \binom{r+k}{k} = \binom{r+n+1}{n}$$

$$\sum_{k=0}^{n} \binom{k}{m} = \binom{n+1}{m+1}$$

$$\sqrt{1+z} = 1 + \sum_{k=1}^{\infty} \frac{(-1)^{k-1}}{k \times 2^{2k-1}} \binom{2k-2}{k-1} z^k$$

$$\sum_{k=0}^{r} \binom{r-k}{m} \binom{s+k}{n} = \binom{r+s+1}{m+n+1}$$

$$C_{n,m} = \binom{n+m}{m} - \binom{n+m}{m-1}, n \ge m$$

$$\binom{n}{k} \equiv [n \& k = k] \pmod 2$$

$$\binom{n_1 + \cdots + n_p}{m} = \sum_{k_1 + \cdots + k_p = m} \binom{n_1}{k_1} \cdots \binom{n_p}{k_p}$$

Fibonacci numbers

$$F(z) = \frac{z}{1 - z - z^2}$$

$$f_n = \frac{\phi^n - \hat{\phi}^n}{\sqrt{5}}, \phi = \frac{1+\sqrt{5}}{2}, \hat{\phi} = \frac{1-\sqrt{5}}{2}$$

$$\sum_{k=1}^{n} f_k = f_{n+2} - 1, \quad \sum_{k=1}^{n} f_k^2 = f_n f_{n+1}$$

$$\sum_{k=0}^{n} f_k f_{n-k} = \frac{1}{5}(n-1) f_n + \frac{2}{5} n f_{n-1}$$

$$\frac{f_{2n}}{f_n} = f_{n-1} + f_{n+1}$$

$$f_1 + 2f_2 + 3f_3 + \cdots + nf_n = n f_{n+2} - f_{n+3} + 2]$$

$$\gcd(f_m, f_n) = f_{\gcd(m,n)}$$

$$f_n^2 + (-1)^n = f_{n+1} f_{n-1}$$

$$f_{n+k} = f_n f_{k+1} + f_{n-1} f_k$$

$$f_{2n+1} = f_n^2 + f_{n+1}^2$$

$$(-1)^k f_{n-k} = f_n f_{k-1} - f_{n-1} f_k$$

$$\text{Modulo } f_n, f_{mn+r} \equiv \begin{cases} f_r, & m \bmod 4 = 0; \\ (-1)^{r+1} f_{n-r}, & m \bmod 4 = 1; \\ (-1)^n f_r, & m \bmod 4 = 2; \\ (-1)^{r+1+n} f_{n-r}, & m \bmod 4 = 3. \end{cases}$$

Period modulo a prime p is a factor of $2p+2$ or $p-1$.
Only exception: $G(5) = 20$.

Period modulo the power of a prime p^k: $G(p^k) = G(p)p^{k-1}$.

Period modulo $n = p_1^{k_1}...p_m^{k_m}$: $G(n) = lcm(G(p_1^{k_1}), ..., G(p_m^{k_m}))$.

Lucas numbers

$$L_0 = 2, L_1 = 1, L_n = L_{n-1} + L_{n-2} = (\frac{1+\sqrt{5}}{2})^n + \frac{1-\sqrt{5}}{2})^n$$

$$L(x) = \frac{2-x}{1-x-x^2}$$

Catlan numbers

$$c_1 = 1, c_n = \sum_{i=0}^{n-1} c_i c_{n-1-i} = c_{n-1}\frac{4n-2}{n+1} = \frac{\binom{2n}{n}}{n+1}$$
$$= \binom{2n}{n} - \binom{2n}{n-1}, c(x) = \frac{1-\sqrt{1-4x}}{2x}$$

Stirling cycle numbers Divide n elements into k non-empty cycles.

$$s(n,0) = 0, s(n,n) = 1, s(n+1,k) = s(n,k-1) - ns(n,k)$$

$$s(n,k) = (-1)^{n-k}\begin{bmatrix} n \\ k \end{bmatrix}$$

$$\begin{bmatrix} n+1 \\ k \end{bmatrix} = n\begin{bmatrix} n \\ k \end{bmatrix} + \begin{bmatrix} n \\ k-1 \end{bmatrix}, \begin{bmatrix} n+1 \\ 2 \end{bmatrix} = n!H_n$$

$$x^{\underline{n}} = x(x-1)...(x-n+1) = \sum_{k=0}^{n} \begin{bmatrix} n \\ k \end{bmatrix}(-1)^{n-k}x^k$$

$$x^{\overline{n}} = x(x+1)...(x+n-1) = \sum_{k=0}^{n} \begin{bmatrix} n \\ k \end{bmatrix}x^k$$

Stirling subset numbers Divide n elements into k non-empty subsets.

$$\begin{Bmatrix} n+1 \\ k \end{Bmatrix} = k\begin{Bmatrix} n \\ k \end{Bmatrix} + \begin{Bmatrix} n \\ k-1 \end{Bmatrix}$$

$$x^n = \sum_{k=0}^{n} \begin{Bmatrix} n \\ k \end{Bmatrix} x^{\underline{k}} = \sum_{k=0}^{n} \begin{Bmatrix} n \\ k \end{Bmatrix}(-1)^{n-k}x^{\overline{k}}$$

$$m!\begin{Bmatrix} n \\ m \end{Bmatrix} = \sum_{k=0}^{m} \binom{m}{k} k^n (-1)^{m-k}$$

$$\sum_{k=1}^{n} k^p = \sum_{k=0}^{p} \begin{Bmatrix} p \\ k \end{Bmatrix}(n+1)^{\underline{k}}$$

For a fixed k, generating functions :

$$\sum_{n=0}^{\infty} \begin{Bmatrix} n \\ k \end{Bmatrix} x^{n-k} = \prod_{r=1}^{k} \frac{1}{1-rx}$$

Motzkin numbers Draw non-intersecting chords between n points on a circle.

Pick n numbers $k_1, k_2, ..., k_n \in \{-1, 0, 1\}$ so that $\sum_i^a k_i (1 \le a \le n)$ is non-negative and the sum of all numbers is 0.

$$M_{n+1} = M_n + \sum_{i}^{n-1} M_i M_{n-1-i} = \frac{(2n+3)M_n + 3nM_{n-1}}{n+3}$$

$$M_n = \sum_{i=0}^{\lfloor \frac{n}{2} \rfloor} \binom{n}{2k} Catlan(k)$$

$$M(X) = \frac{1-x-\sqrt{1-2x-3x^2}}{2x^2}$$

Eulerian numbers Permutations of the numbers 1 to n in which exactly k elements are greater than the previous element.

$$\left\langle {n \atop k} \right\rangle = (k+1)\left\langle {n-1 \atop k} \right\rangle + (n-k)\left\langle {n-1 \atop k-1} \right\rangle$$

$$x^n = \sum_k \left\langle {n \atop k} \right\rangle \binom{x+k}{n}$$

$$\left\langle {n \atop m} \right\rangle = \sum_{k=0}^{m} \binom{n+1}{k}(m+1-k)^n(-1)^k$$

Harmonic numbers Sum of the reciprocals of the first n natural numbers.

$$\sum_{k=1}^{n} H_k = (n+1)H_n - n$$

$$\sum_{k=1}^{n} kH_k = \frac{n(n+1)}{2}H_n - \frac{n(n-1)}{4}$$

$$\sum_{k=1}^{n} \binom{k}{m} H_k = \binom{n+1}{m+1}(H_{n+1} - \frac{1}{m+1})$$

Pentagonal number theorem

$$\prod_{n=1}^{\infty}(1-x^n) = \sum_{n=-\infty}^{\infty}(-1)^k x^{k(3k-1)/2}$$

$$p(n) = p(n-1) + p(n-2) - p(n-5) - p(n-7) + \cdots$$
$$f(n,k) = p(n) - p(n-k) - p(n-2k) + p(n-5k) + p(n-7k) - \cdots$$

Bell numbers Divide a set that has exactly n elements.

$$B_n = \sum_{k=1}^{n} \begin{Bmatrix} n \\ k \end{Bmatrix}, \quad B_{n+1} = \sum_{k=0}^{n} \binom{n}{k} B_k$$

$$B_{p^m+n} \equiv mB_n + B_{n+1} \pmod{p}$$

$$B(x) = \sum_{n=0}^{\infty} \frac{B_n}{n!}x^n = \mathrm{e}^{\mathrm{e}^x - 1}$$

Bernoulli numbers

$$B_n = 1 - \sum_{k=0}^{n-1} \binom{n}{k} \frac{B_k}{n-k+1}$$

$$G(x) = \sum_{k=0}^{\infty} \frac{B_k}{k!}x^k = \frac{1}{\sum_{k=0}^{\infty} \frac{x^k}{(k+1)!}}$$

$$\sum_{k=1}^{n} k^m = \frac{1}{m+1}\sum_{k=0}^{m} \binom{m+1}{k} B_k n^{m-k+1}$$

Sum of powers

$$\sum_{i=1}^{n} i^2 = \frac{n(n+1)(2n+1)}{6}, \quad \sum_{i=1}^{n} i^3 = (\frac{n(n+1)}{2})^2$$

$$\sum_{i=1}^{n} i^4 = \frac{n(n+1)(2n+1)(3n^2+3n-1)}{30}$$

$$\sum_{i=1}^{n} i^5 = \frac{n^2(n+1)^2(2n^2+2n-1)}{12}$$

Sum of squares Denote $r_k(n)$ the ways to form n with k squares. If :

$$n = 2^{a_0} p_1^{2a_1} \cdots p_r^{2a_r} q_1 b_1 \cdots q_s b_s$$

where $p_i \equiv 3 \mod 4$, $q_i \equiv 1 \mod 4$, then

$$r_2(n) = \begin{cases} 0 & \text{if any } a_i \text{ is a half-integer} \\ 4\prod_1^r (b_i+1) & \text{if all } a_i \text{ are integers} \end{cases}$$

$r_3(n) > 0$ when and only when n is not $4^a(8b+7)$.

Derangement

$$D_1 = 0, D_2 = 1, D_n = n!(\frac{1}{0!} - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + ... + \frac{(-1)^n}{n!})$$

$$D_n = (n-1)(D_{n-1} + D_{n-2})$$

Tetrahedron volume If U, V, W, u, v, w are lengths of edges of the tetrahedron (first three form a triangle; u opposite to U and so on)

$$V = \frac{\sqrt{4u^2v^2w^2 - \sum_{cyc} u^2(v^2+w^2-U^2)^2 + \prod_{cyc}(v^2+w^2-U^2)}}{12}$$

Type	Width	Range
`signed char`	1	127
`unsigned char`	1	255
`short`	2	32 767
`unsigned short`	2	65 535
`int`	4	2 147 483 647
`unsigned int`	4	4 294 967 295
`long long`	8	9 223 372 036 854 775 807
`unsigned long long`	8	18 446 744 073 709 551 615
`float`	4	+/- 3.4e +/- 38 (7 digits)
`double`	8	+/- 1.7e +/- 308 (15 digits)
`__float128`	16	+/- 1.1e +/- 4932 (31 digits)