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```
#pragma GCC optimize("O3,unroll-loops")
#pragma GCC target("avx2,bmi,bmi2,lzcnt,popcnt")
#include <bits/stdc++.h>
using namespace std;
ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
```

```
set nu rnu ts=4 sw=4 bs=2 ai hls cin mouse=a
color default
sy on
inoremap {<CR> {<CR>}<C-o>0
inoremap jk <Esc>
nnoremap J 5j
nnoremap K 5k
nnoremap run :w<bar>!g++ -std=c++14 -DLOCAL -Wfatal-
errors -o test "%" && echo "done." && time ./test<
CR>
```

```
#include <sys/resource.h>
void increase_stack_size() {
    const rlim_t ks = 64*1024*1024;
    struct rlimit rl;
    int res=getrlimit(RLIMIT_STACK, &rl);
    if(res==0){
        if(rl.rlim_cur<ks){
            rl.rlim_cur=ks;
            res=setrlimit(RLIMIT_STACK, &rl);
        } } }
```

```
編譯參數: -std=c++14 -Wall -Wshadow (-fsanitize=
undefined)

mt19937 gen(chrono::steady_clock::now().
    time_since_epoch().count());
int randint(int lb, int ub)
{ return uniform_int_distribution<int>(lb, ub)(gen); }
```

```
#define SECs ((double)clock() / CLOCKS_PER_SEC)
double startTime;
bool TIME() { // 比最大可執行時間小一點
    return SECs - startTime > 0.8;
}
int main() {
    startTime = SECs;
}
```

```
struct KeyHasher {
    size_t operator()(const Key& k) const {
        return k.first + k.second * 100000;
    } };
typedef unordered_map<Key,int,KeyHasher> map_t;
// builtin function 可以代的值為int32
__builtin_popcountll // 二進位有幾個1
```

```
__builtin_clzll // 左起第一個1之前0的個數
__builtin_parityll // 1的個數的奇偶性
__builtin_mul_overflow(a,b,&h) // a*b是否溢位
```

## 1.5 check

```
for ((i=0;;i++))
do
    echo "$i"
    python3 gen.py > input
    ./ac < input > ac.out
    ./wa < input > wa.out
    diff ac.out wa.out || break
done
```

## 1.6 python-related

```
parser:
int(eval(num.replace("/", "///")))

from fractions import Fraction
from decimal import Decimal, getcontext, ROUND_HALF_UP,
    ROUND_CEILING, ROUND_FLOOR
getcontext().prec = 250 # set precision
getcontext().rounding = ROUND_HALF_UP

itwo = Decimal(0.5)
two = Decimal(2)

format(x, '0.10f') # set precision

N = 200
def angle(cosT):
    """given cos(theta) in decimal return theta"""
    for i in range(N):
        cosT = ((cosT + 1) / two) ** itwo
        sinT = (1 - cosT * cosT) ** itwo
        return sinT * (2 ** N)
    pi = angle(Decimal(-1))

    """round to 2 decimal places"""
    sum = Decimal(input())
    sum.quantize(Decimal('.00'), ROUND_HALF_UP)

    """Fraction"""
    x = Fraction(1, 3) # 1/3
    x.as_integer_ratio() # (1, 3)

    """input list of integers"""
    arr = list(map(int, input().split()))
```

## 2 flow

### 2.1 ISAP $O(V^3)$

```
struct Maxflow {
    static const int MAXV = 20010;
    static const int INF = 1000000;
    struct Edge {
        int v, c, r;
        Edge(int _v, int _c, int _r):
            v(_v), c(_c), r(_r) {}
    };
    int s, t;
    vector<Edge> G[MAXV*2];
    int iter[MAXV*2], d[MAXV*2], gap[MAXV*2], tot;
    void init(int x) {
        tot = x+2;
        s = x+1, t = x+2;
        for(int i = 0; i <= tot; i++) {
            G[i].clear();
            iter[i] = d[i] = gap[i] = 0;
        }
    }
    void addEdge(int u, int v, int c) {
```

```
G[u].push_back(Edge(v, c, SZ(G[v])));
G[v].push_back(Edge(u, 0, SZ(G[u]) - 1));
}
int dfs(int p, int flow) {
    if(p == t) return flow;
    for(int &i = iter[p]; i < SZ(G[p]); i++) {
        Edge &e = G[p][i];
        if(e.c > 0 && d[p] == d[e.v]+1) {
            int f = dfs(e.v, min(flow, e.c));
            if(f) {
                e.c -= f;
                G[e.v][e.r].c += f;
                return f;
            }
        }
    }
    if(--gap[d[p]] == 0) d[s] = tot;
    else {
        d[p]++;
        iter[p] = 0;
        ++gap[d[p]];
    }
    return 0;
}
int solve() {
    int res = 0;
    gap[0] = tot;
    for(res = 0; d[s] < tot; res += dfs(s, INF));
    return res;
}
void reset() {
    for(int i=0;i<=tot;i++) {
        iter[i]=d[i]=gap[i]=0;
    }
}
} } flow;
```

### 2.2 MinCostFlow

```
struct zkwflow{
    static const int maxN=10000;
    struct Edge{ int v,f,re; ll w;};
    int n,s,t,ptr[maxN]; bool vis[maxN]; ll dis[maxN];
    vector<Edge> E[maxN];
    void init(int _n,int _s,int _t){
        n=_n,s=_s,t=_t;
        for(int i=0;i<n;i++) E[i].clear();
    }
    void addEdge(int u,int v,int f,ll w){
        E[u].push_back({v,f,(int)E[v].size(),w});
        E[v].push_back({u,0,(int)E[u].size()-1,-w});
    }
    bool SPFA(){
        fill_n(dis,n,LLONG_MAX); fill_n(vis,n,false);
        queue<int> q; q.push(s); dis[s]=0;
        while (!q.empty()){
            int u=q.front(); q.pop(); vis[u]=false;
            for(auto &it:E[u]){
                if(it.f>0&&dis[it.v]>dis[u]+it.w){
                    dis[it.v]=dis[u]+it.w;
                    if(!vis[it.v]){
                        vis[it.v]=true; q.push(it.v);
                    }
                }
            }
            return dis[t]!=LLONG_MAX;
        }
    }
    int DFS(int u,int nf){
        if(u==t) return nf;
        int res=0; vis[u]=true;
        for(int &i=ptr[u];i<(int)E[u].size();i++){
            auto &it=E[u][i];
            if(it.f>0&&dis[it.v]==dis[u]+it.w&&!vis[it.v]){
                int tf=DFS(it.v,min(nf,it.f));
                res+=tf,nf-=tf,it.f-=tf;
                E[it.v][it.re].f+=tf;
                if(nf==0){ vis[u]=false; break; }
            }
        }
        return res;
    }
    pair<int,ll> flow(){
        int flow=0; ll cost=0;
        while (SPFA()){
            fill_n(ptr,n,0);
            int f=DFS(s,INT_MAX);
```

```

    flow+=f; cost+=dis[t]*f;
}
return{ flow,cost };
} // reset: do nothing
} flow;

```

### 2.3 Dinic $O(V^2E)$

```

#define SZ(x) (int)x.size()
#define PB push_back
struct Dinic{
    struct Edge{ int v,f,re; };
    int n,s,t,level[MXN];
    vector<Edge> E[MXN];
    void init(int _n, int _s, int _t){
        n = _n; s = _s; t = _t;
        for (int i=0; i<n; i++) E[i].clear();
    }
    void add_edge(int u, int v, int f){
        E[u].PB({v,f,SZ(E[v])});
        E[v].PB({u,0,SZ(E[u])-1});
    }
    bool BFS(){
        for (int i=0; i<n; i++) level[i] = -1;
        queue<int> que;
        que.push(s);
        level[s] = 0;
        while (!que.empty()){
            int u = que.front(); que.pop();
            for (auto it : E[u]){
                if (it.f > 0 && level[it.v] == -1){
                    level[it.v] = level[u]+1;
                    que.push(it.v);
                }
            }
        }
        return level[t] != -1;
    }
    int DFS(int u, int nf){
        if (u == t) return nf;
        int res = 0;
        for (auto &it : E[u]){
            if (it.f > 0 && level[it.v] == level[u]+1){
                int tf = DFS(it.v, min(nf,it.f));
                res += tf; nf -= tf; it.f -= tf;
                E[it.v][it.re].f += tf;
                if (nf == 0) return res;
            }
        }
        if (!res) level[u] = -1;
        return res;
    }
    int flow(int res=0){
        while (BFS())
            res += DFS(s,2147483647);
        return res;
    }
} }flow;

```

### 2.4 Kuhn Munkres 最大完美二分匹配 $O(n^3)$

```

struct KM{ // max weight, for min negate the weights
    int n, mx[MXN], my[MXN], pa[MXN];
    ll g[MXN][MXN], lx[MXN], ly[MXN], sy[MXN];
    bool vx[MXN], vy[MXN];
    void init(int _n) { // 1-based
        n = _n;
        for(int i=1; i<=n; i++) fill(g[i], g[i]+n+1, 0);
    }
    void addEdge(int x, int y, ll w) {g[x][y] = w;}
    void augment(int y) {
        for(int x, z; y; y = z){
            x=pa[y], z=mx[x], my[y]=x, mx[x]=y;
        }
    }
    void bfs(int st) {
        for(int i=1; i<=n; ++i) sy[i]=INF, vx[i]=vy[i]=0;
        queue<int> q; q.push(st);
        for(;;) {
            while(q.size()) {
                int x=q.front(); q.pop(); vx[x]=1;
                for(int y=1; y<=n; ++y) if(!vy[y]){
                    ll t = lx[x]+ly[y]-g[x][y];

```

```

                    if(t==0){
                        pa[y]=x;
                        if(!my[y]){augment(y);return;}
                        vy[y]=1, q.push(my[y]);
                    }else if(sy[y]>t) pa[y]=x,sy[y]=t;
                }
            }
            ll cut = INF;
            for(int y=1; y<=n; ++y)
                if(!vy[y]&&cut>sy[y]) cut=sy[y];
            for(int j=1; j<=n; ++j){
                if(vx[j]) lx[j] -= cut;
                if(vy[j]) ly[j] += cut;
                else sy[j] -= cut;
            }
            for(int y=1; y<=n; ++y) if(!vy[y]&&sy[y]==0){
                if(!my[y]){augment(y);return;}
                vy[y]=1, q.push(my[y]);
            }
        }
    }
    ll solve(){
        fill(mx, mx+n+1, 0); fill(my, my+n+1, 0);
        fill(ly, ly+n+1, 0); fill(lx, lx+n+1, -INF);
        for(int x=1; x<=n; ++x) for(int y=1; y<=n; ++y)
            lx[x] = max(lx[x], g[x][y]);
        for(int x=1; x<=n; ++x) bfs(x);
        ll ans = 0;
        for(int y=1; y<=n; ++y) ans += g[my[y]][y];
        return ans;
    }
} }graph;

```

### 2.5 SW min-cut (不限 S-T 的 min-cut) $O(V^3)$

```

// global min cut
struct SW{ //  $O(V^3)$ 
    int n,vst[MXN],del[MXN];
    int edge[MXN][MXN],wei[MXN];
    void init(int _n){
        n = _n; FZ(edge); FZ(del);
    }
    void addEdge(int u, int v, int w){
        edge[u][v] += w; edge[v][u] += w;
    }
    void search(int &s, int &t){
        FZ(vst); FZ(wei);
        s = t = -1;
        while (true){
            int mx=-1, cur=0;
            for (int i=0; i<n; i++){
                if (!del[i] && !vst[i] && mx<wei[i])
                    cur = i, mx = wei[i];
            }
            if (mx == -1) break;
            vst[cur] = 1;
            s = t; t = cur;
            for (int i=0; i<n; i++){
                if (!vst[i] && !del[i]) wei[i] += edge[cur][i];
            }
        }
    }
    int solve(){
        int res = 2147483647;
        for (int i=0,x,y; i<n-1; i++){
            search(x,y);
            res = min(res,wei[y]);
            del[y] = 1;
            for (int j=0; j<n; j++)
                edge[x][j] = (edge[j][x] += edge[y][j]);
        }
        return res;
    }
} }graph;

```

### 2.6 Max flow with lower/upper bound

```

// flow use ISAP
// Max flow with lower/upper bound on edges
// source = 1, sink = n
int in[ N ], out[ N ];
int l[ M ], r[ M ], a[ M ], b[ M ]; //0-base, a下界, b
上界
int solve(){

```

```

flow.init( n );    //n為點的數量,m為邊的數量,點是1-
    base
for( int i = 0 ; i < m ; i ++ ){
    in[ r[ i ] ] += a[ i ];
    out[ l[ i ] ] += a[ i ];
    flow.addEdge( l[ i ] , r[ i ] , b[ i ] - a[ i ] );
    // flow from l[i] to r[i] must in [a[i], b[i]]
}
int nd = 0;
for( int i = 1 ; i <= n ; i ++ ){
    if( in[ i ] < out[ i ] ){
        flow.addEdge( i , flow.t , out[ i ] - in[ i ] );
        nd += out[ i ] - in[ i ];
    }
    if( out[ i ] < in[ i ] )
        flow.addEdge( flow.s , i , in[ i ] - out[ i ] );
}
// original sink to source
flow.addEdge( n , 1 , INF );
if( flow.maxflow() != nd )
    return -1; // no solution
int ans = flow.G[ 1 ].back().c; // source to sink
flow.G[ 1 ].back().c = flow.G[ n ].back().c = 0;
// take out super source and super sink
for( size_t i = 0 ; i < flow.G[ flow.s ].size() ; i
    ++ ){
    flow.G[ flow.s ][ i ].c = 0;
    Edge &e = flow.G[ flow.s ][ i ];
    flow.G[ e.v ][ e.r ].c = 0;
}
for( size_t i = 0 ; i < flow.G[ flow.t ].size() ; i
    ++ ){
    flow.G[ flow.t ][ i ].c = 0;
    Edge &e = flow.G[ flow.t ][ i ];
    flow.G[ e.v ][ e.r ].c = 0;
}
flow.addEdge( flow.s , 1 , INF );
flow.addEdge( n , flow.t , INF );
flow.reset();
return ans + flow.maxflow();
}

```

## 2.7 Flow Method

Maximize  $c^T x$  subject to  $Ax \leq b$ ,  $x \geq 0$ ;  
 with the corresponding symmetric dual problem,  
 Minimize  $b^T y$  subject to  $A^T y \geq c$ ,  $y \geq 0$ .

Maximize  $c^T x$  subject to  $Ax \leq b$ ;  
 with the corresponding asymmetric dual problem,  
 Minimize  $b^T y$  subject to  $A^T y = c$ ,  $y \geq 0$ .

Minimum vertex cover on bipartite graph =  
 Maximum matching on bipartite graph

Minimum edge cover on bipartite graph =  
 vertex number - Minimum vertex cover(Maximum matching)

Independent set on bipartite graph =  
 vertex number - Minimum vertex cover(Maximum matching)

找出最小點覆蓋。做完dinic之後。從源點dfs只走還有流量的邊。左邊沒被走到的點跟右邊被走到的點就是答案。其他點為最大獨立集

Maximum density subgraph  $(\sum W_e + \sum W_v) / |V|$

Binary search on answer:

For a fixed D, construct a Max flow model as follow:

Let S be Sum of all weight( or inf)

1. from source to each node with cap = S

2. For each  $(u,v,w)$  in E,  $(u \rightarrow v, cap=w)$ ,  $(v \rightarrow u, cap=w)$

3. For each node v, from v to sink with cap =  $S + 2 * D$   
 $- deg[v] - 2 * (W \text{ of } v)$

where  $deg[v] = \sum \text{weight of edge associated with } v$

If  $\text{maxflow} < S * |V|$ , D is an answer.

Requiring subgraph: all vertex can be reached from  
 source with  
 edge whose cap  $> 0$ .

## 3 Math

### 3.1 FFT

```

// const int MAXN = 262144;
// (must be 2^k)
// before any usage, run pre_fft() first
typedef long double ld;
typedef complex<ld> cplx; //real() ,imag()
const ld PI = acos(-1);
const cplx I(0, 1);
cplx omega[MAXN+1];
void pre_fft(){
    for(int i=0; i<=MAXN; i++)
        omega[i] = exp(i * 2 * PI / MAXN * I);
}
// n must be 2^k
void fft(int n, cplx a[], bool inv=false){
    int basic = MAXN / n;
    int theta = basic;
    for (int m = n; m >= 2; m >= 1) {
        int mh = m >> 1;
        for (int i = 0; i < mh; i++) {
            cplx w = omega[inv ? MAXN-(i*theta*MAXN)
                : i*theta*MAXN];
            for (int j = i; j < n; j += m) {
                int k = j + mh;
                cplx x = a[j] - a[k];
                a[j] += a[k];
                a[k] = w * x;
            }
            theta = (theta * 2) % MAXN;
        }
    }
    int i = 0;
    for (int j = 1; j < n - 1; j++) {
        for (int k = n >> 1; k > (i ^= k); k >= 1);
        if (j < i) swap(a[i], a[j]);
    }
    if(inv) for (i = 0; i < n; i++) a[i] /= n;
}
cplx arr[MAXN+1];
inline void mul(int _n, ll a[], int _m, ll b[], ll ans[]){
    int n=1, sum=_n+_m-1;
    while(n<sum)
        n<<=1;
    for(int i=0; i<n; i++) {
        double x=(i<_n?a[i]:0), y=(i<_m?b[i]:0);
        arr[i]=complex<double>(x+y, x-y);
    }
    fft(n, arr);
    for(int i=0; i<n; i++)
        arr[i]=arr[i]*arr[i];
    fft(n, arr, true);
    for(int i=0; i<sum; i++)
        ans[i]=(long long int)(arr[i].real()/4+0.5);
}

```

### 3.2 $O(1)$ mul

```

LL mul(LL x, LL y, LL mod){
    LL ret=x*y-(LL)((long double)x/mod*y)*mod;
    // LL ret=x*y-(LL)((long double)x*y/mod+0.5)*mod;
    return ret<0?ret+mod:ret;
}

```

### 3.3 Faulhaber $(\sum_{i=1}^n i^p)$

```

/* faulhaber' s formula -
 * cal power sum formula of all p=1~k in  $O(k^2)$  */
#define MAXK 2500
const int mod = 1000000007;
int b[MAXK]; // bernoulli number
int inv[MAXK+1]; // inverse
int cm[MAXK+1][MAXK+1]; // combinatorics
int co[MAXK][MAXK+2]; // coefficient of  $x^j$  when  $p=i$ 

```

```

inline int getinv(int x) {
    int a=x,b=mod,a0=1,a1=0,b0=0,b1=1;
    while(b) {
        int q,t;
        q=a/b; t=b; b=a-b*q; a=t;
        t=b0; b0=a0-b0*q; a0=t;
        t=b1; b1=a1-b1*q; a1=t;
    }
    return a0<0?a0+mod:a0;
}
inline void pre() {
    /* combinational */
    for(int i=0;i<=MAXK;i++) {
        cm[i][0]=cm[i][i]=1;
        for(int j=1;j<i;j++)
            cm[i][j]=add(cm[i-1][j-1],cm[i-1][j]);
    }
    /* inverse */
    for(int i=1;i<=MAXK;i++) inv[i]=getinv(i);
    /* bernoulli */
    b[0]=1; b[1]=getinv(2); // with b[1] = 1/2
    for(int i=2;i<MAXK;i++) {
        if(i&1) { b[i]=0; continue; }
        b[i]=1;
        for(int j=0;j<i;j++)
            b[i]=sub(b[i],
                mul(cm[i][j],mul(b[j], inv[i-j+1])));
    }
    /* faulhaber */
    // sigma_x=1~n {x^p} =
    // 1/(p+1) * sigma_j=0~p {C(p+1,j)*Bj*n^(p-j+1)}
    for(int i=1;i<MAXK;i++) {
        co[i][0]=0;
        for(int j=0;j<=i;j++)
            co[i][i-j+1]=mul(inv[i+1], mul(cm[i+1][j], b[j]));
    }
}
/* sample usage: return f(n,p) = sigma_x=1~n (x^p) */
inline int solve(int n,int p) {
    int sol=0,m=n;
    for(int i=1;i<=p+1;i++) {
        sol=add(sol,mul(co[p][i],m));
        m = mul(m, n);
    }
    return sol;
}

```

### 3.4 Chinese Remainder

```

LL x[N],m[N];
LL CRT(LL x1, LL m1, LL x2, LL m2) {
    LL g = __gcd(m1, m2);
    if((x2 - x1) % g) return -1; // no sol
    m1 /= g; m2 /= g;
    pair<LL,LL> p = gcd(m1, m2);
    LL lcm = m1 * m2 * g;
    LL res = p.first * (x2 - x1) * m1 + x1;
    return (res % lcm + lcm) % lcm;
}
LL solve(int n){ // n>=2, be careful with no solution
    LL res=CRT(x[0],m[0],x[1],m[1]),p=m[0]/__gcd(m[0],m[1])*m[1];
    for(int i=2;i<n;i++){
        res=CRT(res,p,x[i],m[i]);
        p=p/__gcd(p,m[i])*m[i];
    }
    return res;
}

```

### 3.5 Miller Rabin

```

// n < 4,759,123,141      3 : 2, 7, 61
// n < 1,122,004,669,633  4 : 2, 13, 23, 1662803
// n < 3,474,749,660,383  6 : pirmes <= 13
// n < 2^64               7 :
// 2, 325, 9375, 28178, 450775, 9780504, 1795265022
// Make sure testing integer is in range [2, n-2] if

```

```

// you want to use magic.
LL magic[]={}
bool witness(LL a,LL n,LL u,int t){
    if(!a) return 0;
    LL x=myspow(a,u,n);
    for(int i=0;i<t;i++) {
        LL nx=mul(x,x,n);
        if(nx==1&&x!=1&&x!=n-1) return 1;
        x=nx;
    }
    return x!=1;
}
bool miller_rabin(LL n) {
    int s=(magic number size)
    // iterate s times of witness on n
    if(n<2) return 0;
    if(!(n&1)) return n == 2;
    ll u=n-1; int t=0;
    // n-1 = u*2^t
    while(!(u&1)) u>>=1, t++;
    while(s--){
        LL a=magic[s]%n;
        if(witness(a,n,u,t)) return 0;
    }
    return 1;
}

```

### 3.6 Pollard Rho

```

// does not work when n is prime O(n^(1/4))
LL f(LL x, LL mod){ return add(mul(x,x,mod),1,mod); }
LL pollard_rho(LL n) {
    if(!(n&1)) return 2;
    while(true){
        LL y=2, x=rand()%(n-1)+1, res=1;
        for(int sz=2; res==1; sz*=2) {
            for(int i=0; i<sz && res<=1; i++) {
                x = f(x, n);
                res = __gcd(abs(x-y), n);
            }
            y = x;
        }
        if (res!=0 && res!=n) return res;
    }
}

```

### 3.7 Josephus Problem

```

int josephus(int n, int m){ //n人每m次
    int ans = 0;
    for (int i=1; i<=n; ++i)
        ans = (ans + m) % i;
    return ans;
}

```

### 3.8 Matrix

```

//矩陣乘法
for(int i = 0; i < n; i++){
    for(int j = 0; j < n; j++){
        for(int k = 0; k < n; k++){
            ret[i][j] += a[i][k] * b[k][j];
        }
    }
}
//矩陣快速幂
int base[2][2] = { {1, 1}, {1, 0} };
int ans[2][2] = { {1, 0}, {0, 1} };
};

```

```

int mypow(int y){
    while(y){
        if (y&1) { ans = mul(ans, base); } //實作矩陣乘法
        base = mul(base, base); //實作矩陣乘法
        y >>= 1;
    }
}

```

```

    }
    return ans[0][0];
}

```

### 3.9 Gaussian Elimination

```

const int GAUSS_MOD = 100000007LL;
struct GAUSS{
    int n;
    vector<vector<int>> v;
    int ppow(int a , int k){
        if(k == 0) return 1;
        if(k % 2 == 0) return ppow(a * a % GAUSS_MOD , k >> 1);
        if(k % 2 == 1) return ppow(a * a % GAUSS_MOD , k >> 1) * a % GAUSS_MOD;
    }
    vector<int> solve(){
        vector<int> ans(n);
        REP(now , 0 , n){
            REP(i , now , n) if(v[now][now] == 0 && v[i][now] != 0)
                swap(v[i] , v[now]); // det = -det;
            if(v[now][now] == 0) return ans;
            int inv = ppow(v[now][now] , GAUSS_MOD - 2);
            REP(i , 0 , n) if(i != now){
                int tmp = v[i][now] * inv % GAUSS_MOD;
                REP(j , now , n + 1) (v[i][j] += GAUSS_MOD - tmp * v[now][j] % GAUSS_MOD) %= GAUSS_MOD;
            }
            REP(i , 0 , n) ans[i] = v[i][n + 1] * ppow(v[i][i] , GAUSS_MOD - 2) % GAUSS_MOD;
        }
        return ans;
    }
    // gs.v.clear() , gs.v.resize(n , vector<int>(n + 1 , 0));
} gs;

```

### 3.10 Inverse Matrix

```

int GAUSS_MOD;
struct GAUSS{
    int n;
    vector<vector<int>> v;
    vector<vector<int>> rev;
    int mul(int x,int y,int mod){
        int ret=x*y-(int)((Long double)x/mod*y)*mod;
        return ret<0?ret+mod:ret;
    }
    int ppow(int a , int b){//res=(a^b)%m
        int res=1, k=a;
        while(b){
            if((b&1)) res=mul(res,k,GAUSS_MOD)%GAUSS_MOD;
            k=mul(k,k,GAUSS_MOD)%GAUSS_MOD;
            b>>=1;
        }
        return res%GAUSS_MOD;
    }
    bool solve(){
        for(int now = 0; now < n; now++){
            int ch;
            for(ch = now; ch < n && !v[ch][now]; ch++);
            if(ch >= n) return 0;
            for(int i = now; i < n; i++) if(v[now][now] == 0 && v[i][now] != 0){
                swap(v[i] , v[now]); // det = -det;
                swap(rev[i] , rev[now]);
            }
            if(v[now][now] == 0) return 0;
            int inv = ppow(v[now][now] , GAUSS_MOD - 2);
            for(int i = 0; i < n; i++) if(i != now){
                int tmp = v[i][now] * inv % GAUSS_MOD;
                for(int j = 0; j < n; j++) {
                    (v[i][j] += GAUSS_MOD - tmp * v[now][j] % GAUSS_MOD) %= GAUSS_MOD;
                    (rev[i][j] += GAUSS_MOD - tmp * rev[now][j] % GAUSS_MOD) %= GAUSS_MOD;
                }
            }
        }
    }
}

```

```

    }
    }
    return 1;
}} gs;

signed main(){
    int n, p; //n*n matrix, MOD=p
    cin>>n>>p; //if(!n && !p) return 0;
    GAUSS_MOD = p; gs.n = n;
    gs.v.clear() , gs.v.resize(n + 1, vector<int>(n + 2 , 0));
    gs.rev.clear() , gs.rev.resize(n + 1, vector<int>(n + 2 , 0));
    for(int i = 0; i < n; i++){
        for(int j = 0; j < n; j++){
            cin>>gs.v[i][j];
            if(i == j) gs.rev[i][j] = 1;
        }
    }
    if(!gs.solve()) cout << "singular\n";
    else{
        for(int i = 0; i < n; i++){
            int inv = gs.ppow(gs.v[i][i] , p - 2);
            for(int j = 0; j < n; j++){
                cout << (gs.rev[i][j] * inv % p) << " ";
                cout<<"\n";
            }
        }
        cout << "\n";
    }
}

```

### 3.11 模反元素

```

long long inv(long long a,long long m){
    long long x,y;
    long long d=exgcd(a,m,x,y);
    if(d==1) return (x+m)%m;
    else return -1; //-1為無解
}

```

### 3.12 ax+by=gcd

```

PII gcd(int a , int b){
    if(b == 0) return {1, 0};
    PII q = gcd(b , a % b);
    return {q.second, q.first - q.second * (a / b)};
}

int exgcd(int a,int b,long long &x,long long &y) {
    if(b == 0){x=1,y=0;return a;}
    int now=exgcd(b,a%b,y,x);
    y-=a/b*x;
    return now;
}

```

### 3.13 Discrete sqrt

```

void calch(LL &t, LL &h, const LL p) {
    LL tmp=p-1; for(t=0;(tmp&1)==0;tmp/=2) t++; h=tmp;
}
// solve equation x^2 mod p = a
bool solve(LL a, LL p, LL &x, LL &y) {
    if(p == 2) { x = y = 1; return true; }
    int p2 = p / 2, tmp = mypow(a, p2, p);
    if (tmp == p - 1) return false;
    if ((p + 1) % 4 == 0) {
        x=mypow(a,(p+1)/4,p); y=p-x; return true;
    } else {
        LL t, h, b, pb; calch(t, h, p);
        if (t >= 2) {
            do {b = rand() % (p - 2) + 2;
                while (mypow(b, p / 2, p) != p - 1);
                pb = mypow(b, h, p);
            } int s = mypow(a, h / 2, p);
            for (int step = 2; step <= t; step++) {

```



```

    int ss = (((LL)(s * s) % p) * a) % p;
    for(int i=0;i<t-step;i++) ss=mul(ss,ss,p);
    if (ss + 1 == p) s = (s * pb) % p;
    pb = ((LL)pb * pb) % p;
    } x = ((LL)s * a) % p; y = p - x;
} return true;
}

```

### 3.14 Prefix Inverse

```

void solve( int m ){
    inv[ 1 ] = 1;
    for( int i = 2 ; i < m ; i ++ )
        inv[ i ] = ((LL)(m - m / i) * inv[m % i]) % m;
}

```

### 3.15 Roots of Polynomial 找多項式的根

```

const double eps = 1e-12;
const double inf = 1e+12;
double a[ 10 ], x[ 10 ]; // a[0..n](coef) must be
    filled
int n; // degree of polynomial must be filled
int sign( double x ){return (x < -eps)?(-1):(x>eps);}
double f(double a[], int n, double x){
    double tmp=1,sum=0;
    for(int i=0;i<=n;i++)
        { sum=sum+a[i]*tmp; tmp=tmp*x; }
    return sum;
}
double binary(double l,double r,double a[],int n){
    int sl=sign(f(a,n,l)),sr=sign(f(a,n,r));
    if(sl==0) return l; if(sr==0) return r;
    if(sl*sr>0) return inf;
    while(r-l>eps){
        double mid=(l+r)/2;
        int ss=sign(f(a,n,mid));
        if(ss==0) return mid;
        if(ss*sl>0) l=mid; else r=mid;
    }
    return l;
}
void solve(int n,double a[],double x[],int &nx){
    if(n==1){ x[1]=-a[0]/a[1]; nx=1; return; }
    double da[10], dx[10]; int ndx;
    for(int i=n;i>=1;i--) da[i-1]=a[i]*i;
    solve(n-1,da,dx,ndx);
    nx=0;
    if(ndx==0){
        double tmp=binary(-inf,inf,a,n);
        if (tmp<inf) x[++nx]=tmp;
        return;
    }
    double tmp;
    tmp=binary(-inf,dx[1],a,n);
    if(tmp<inf) x[++nx]=tmp;
    for(int i=1;i<=ndx-1;i++){
        tmp=binary(dx[i],dx[i+1],a,n);
        if(tmp<inf) x[++nx]=tmp;
    }
    tmp=binary(dx[ndx],inf,a,n);
    if(tmp<inf) x[++nx]=tmp;
} // roots are stored in x[1..nx]

```

### 3.16 Combination thearom

```

const ll mod = 1e9 + 7;
ll fac[(int)2e6 + 1], inv[(int)2e6 + 1];
ll getinv(ll a){ return qpow(a, mod-2); }
void init(int n){
    fac[0] = 1;
    for(int i = 1; i <= n; i++){
        fac[i] = fac[i-1] * i % mod;
    }
    inv[n] = getinv(fac[n]);
    for(int i = n-1; i >= 0; i--){

```

```

        inv[i] = inv[i + 1] * (i + 1) % mod;
    }
}
ll C(int n, int m){
    if(m > n) return 0;
    return fac[n] * inv[m] % mod * inv[n-m] % mod;
}

```

### 3.17 Primes

```

/* 12721, 13331, 14341, 75577, 123457, 222557, 556679
 * 999983, 1097774749, 1076767633, 100102021, 999997771
 * 1001010013, 1000512343, 987654361, 999991231
 * 999888733, 98789101, 987777733, 999991921, 1010101333
 * 1010102101, 10000000000039, 1000000000000037
 * 2305843009213693951, 4611686018427387847
 * 9223372036854775783, 18446744073709551557 */
int mu[ N ], p_tbl[ N ];
vector<int> primes;
void sieve() {
    mu[ 1 ] = p_tbl[ 1 ] = 1;
    for( int i = 2 ; i < N ; i ++ ){
        if( !p_tbl[ i ] ){
            p_tbl[ i ] = i;
            primes.push_back( i );
            mu[ i ] = -1;
        }
        for( int p : primes ){
            int x = i * p;
            if( x >= M ) break;
            p_tbl[ x ] = p;
            mu[ x ] = -mu[ i ];
            if( i % p == 0 ){
                mu[ x ] = 0;
                break;
            }
        }
    }
}
vector<int> factor( int x ){
    vector<int> fac{ 1 };
    while( x > 1 ){
        int fn = SZ(fac), p = p_tbl[ x ], pos = 0;
        while( x % p == 0 ){
            x /= p;
            for( int i = 0 ; i < fn ; i ++ )
                fac.PB( fac[ pos ++ ] * p );
        }
    }
    return fac;
}

```

### 3.18 Phi

```

ll phi(ll n){ // 計算小於n的數中與n互質的有幾個
    ll res = n, a=n;
    for(ll i=2;i*i<=a;i++){ // O(sqrt(n))
        if(a%i==0){
            res = res/i*(i-1);
            while(a%i==0) a/=i;
        }
    }
    if(a>1) res=res/a*(a-1);
    return res;
}

```

### 3.19 Result

- Lucas' Theorem :  
For  $n, m \in \mathbb{Z}^*$  and prime  $P$ ,  $C(m, n) \bmod P = \prod_i C(m_i, n_i)$  where  $m_i$  is the  $i$ -th digit of  $m$  in base  $P$ .
- Stirling approximation :  
$$n! \approx \sqrt{2\pi n} \left(\frac{n}{e}\right)^n e^{\frac{1}{12n}}$$
- Stirling Numbers(permutation  $|P| = n$  with  $k$  cycles):  
 $S(n, k) = \text{coefficient of } x^k \text{ in } \prod_{i=0}^{n-1} (x + i)$
- Stirling Numbers(Partition  $n$  elements into  $k$  non-empty set):  
$$S(n, k) = \frac{1}{k!} \sum_{j=0}^k (-1)^{k-j} \binom{k}{j} j^n$$

- Pick's Theorem :  $A = i + b/2 - 1$   
在二維座標平面中畫上網格，對於任何簡單多邊形  
 $A$ : 面積、 $i$ : 內部的格點數、 $b$ : 邊上的格點數
- Catalan number :  $C_n = \frac{1}{n+1} \binom{2n}{n}$   
 $C_n^{n+m} - C_{n+1}^{n+m} = (m+n)! \frac{n-m+1}{n+1}$  for  $n \geq m$   
 $C_n = \frac{1}{n+1} \binom{2n}{n} = \frac{(2n)!}{(n+1)!n!}$   
 $C_0 = 1$  and  $C_{n+1} = 2 \binom{2n+1}{n+2} C_n$   
 $C_0 = 1$  and  $C_{n+1} = \sum_{i=0}^n C_i C_{n-i}$  for  $n \geq 0$
- Euler Characteristic:  
planar graph:  $V - E + F - C = 1$   
convex polyhedron:  $V - E + F = 2$   
 $V, E, F, C$ : number of vertices, edges, faces(regions), and components
- Kirchhoff's theorem :  
 $A_{ii} = \deg(i), A_{ij} = (i, j) \in E ? -1 : 0$ , Deleting any one row, one column, and cal the  $\det(A)$
- Polya's theorem ( $c$  is number of color,  $m$  is the number of cycle size):  
 $(\sum_{i=1}^m c^{\gcd(i,m)})/m$
- Burnside lemma:  
 $|X/G| = \frac{1}{|G|} \sum_{g \in G} |X^g|$
- 錯排公式: ( $n$  個人中，每個人皆不再原來位置的組合數):  
 $dp[0] = 1; dp[1] = 0;$   
 $dp[i] = (i-1) * (dp[i-1] + dp[i-2]);$
- Bell 數 (有  $n$  個人，把他們拆組的方法總數) :  
 $B_0 = 1$   
 $B_n = \sum_{k=0}^n s(n, k)$  (second - stirling)  
 $B_{n+1} = \sum_{k=0}^n \binom{n}{k} B_k$
- Wilson's theorem :  
 $(p-1)! \equiv -1 \pmod{p}$
- Fermat's little theorem :  
 $a^p \equiv a \pmod{p}$
- Euler's totient function:  
 $A^B \pmod{p} = \text{pow}(A, \text{pow}(B, C, p-1)) \pmod{p}$
- 歐拉函數降冪公式:  
 $A^B \pmod{C} = A^{B \pmod{\phi(C)} + \phi(C)} \pmod{C}$
- 用歐拉函數求模反元素:  
如果  $a$  和  $n$  互質，則  $a$  對  $n$  的模反元素  
 $a^{-1} \equiv a^{\phi(n)-1} \pmod{n}$
- 6 的倍數:  
 $(a-1)^3 + (a+1)^3 + (-a)^3 + (-a)^3 = 6a$
- 上高斯 (向上取整):  
 $\lceil \frac{a}{b} \rceil = \frac{a+b-1}{b}$

## 4 Geometry

### 4.1 definition

```
typedef long double ld;
const ld eps = 1e-8;
int dcmp(ld x) {
    if(abs(x) < eps) return 0;
    else return x < 0 ? -1 : 1;
}
struct Pt {
    ld x, y;
    Pt(ld _x=0, ld _y=0):x(_x), y(_y) {}
    Pt operator+(const Pt &a) const {
        return Pt(x+a.x, y+a.y);
    }
    Pt operator-(const Pt &a) const {
        return Pt(x-a.x, y-a.y);
    }
    Pt operator*(const ld &a) const {
        return Pt(x*a, y*a);
    }
    Pt operator/(const ld &a) const {
        return Pt(x/a, y/a);
    }
    ld operator*(const Pt &a) const {
        return x*a.x + y*a.y;
    }
    ld operator^(const Pt &a) const {
        return x*a.y - y*a.x;
    }
    bool operator<(const Pt &a) const {
        return x < a.x || (x == a.x && y < a.y);
    }
};
```

```
//return dcmp(x-a.x) < 0 || (dcmp(x-a.x) == 0 &&
    dcmp(y-a.y) < 0); }
bool operator==(const Pt &a) const {
    return dcmp(x-a.x) == 0 && dcmp(y-a.y) == 0;
}
ld norm2(const Pt &a) {
    return a*a;
}
ld norm(const Pt &a) {
    return sqrt(norm2(a));
}
Pt perp(const Pt &a) {
    return Pt(-a.y, a.x);
}
Pt rotate(const Pt &a, ld ang) {
    return Pt(a.x*cos(ang)-a.y*sin(ang), a.x*sin(ang)+a.y*cos(ang));
}
struct Line {
    Pt s, e, v; // start, end, end-start
    ld ang;
    Line(Pt _s=Pt(0, 0), Pt _e=Pt(0, 0)):s(_s), e(_e) { v
        = e-s; ang = atan2(v.y, v.x); }
    bool operator<(const Line &L) const {
        return ang < L.ang;
    }
};
struct Circle {
    Pt o; ld r;
    Circle(Pt _o=Pt(0, 0), ld _r=0):o(_o), r(_r) {}
};
```

### 4.2 Intersection of 2 lines

```
Pt LLIntersect(Line a, Line b) {
    Pt p1 = a.s, p2 = a.e, q1 = b.s, q2 = b.e;
    ld f1 = (p2-p1)^(q1-p1), f2 = (p2-p1)^(p1-q2), f;
    if(dcmp(f=f1+f2) == 0)
        return dcmp(f1)?Pt(NAN,NAN):Pt(INFINITY,INFINITY);
    return q1*(f2/f) + q2*(f1/f);
}
```

### 4.3 halfPlaneIntersection

```
// O(nlogn)
// 傳入 vector<Line>
// (半平面為點 st 往 ed 的逆時針方向)
// 回傳值為形成的凸多邊形的頂點 vector

// 對於點或線的解，將 '>' 改為 '>='
bool onleft(Line L, Pt p) { return dcmp(L.v ^ (p - L.s))
    > 0; }

// 假設線段是有交點的
vector<Pt> HPI(vector<Line> &L) {
    sort(L.begin(), L.end()); // 按角度排序
    int n = L.size(), fir, las;
    Pt *p = new Pt[n];
    Line *q = new Line[n];
    q[fir = las = 0] = L[0];
    for (int i = 1; i < n; i++) {
        while (fir < las && !onleft(L[i], p[las - 1])) las--;
        while (fir < las && !onleft(L[i], p[fir])) fir++;
        q[++las] = L[i];
        if (dcmp(q[las].v ^ q[las - 1].v) == 0) {
            las--;
            if (onleft(q[las], L[i].s)) q[las] = L[i];
        }
        if (fir < las)
            p[las - 1] = LLIntersect(q[las - 1], q[las]);
    }
    while (fir < las && !onleft(q[fir], p[las - 1])) las--;
    if (las - fir <= 1) return {};
    p[las] = LLIntersect(q[las], q[fir]);
    int m = 0;
    vector<Pt> ans(las - fir + 1);
    for (int i = fir; i <= las; i++) ans[m++] = p[i];
    return ans;
}
```



## 4.4 Convex Hull

```
double cross(Pt o, Pt a, Pt b){
    return (a-o) ^ (b-o);
}
vector<Pt> convex_hull(vector<Pt> pt){
    sort(pt.begin(), pt.end());
    int top=0;
    vector<Pt> stk(2*pt.size());
    for (int i=0; i<(int)pt.size(); i++){
        while (top >= 2 && cross(stk[top-2], stk[top-1], pt[i])
            <= 0) // 如果想要有點共線的點 · 把 <= 改成 <
            top--;
        stk[top++] = pt[i];
    }
    for (int i=pt.size()-2, t=top+1; i>=0; i--){
        while (top >= t && cross(stk[top-2], stk[top-1], pt[i])
            <= 0)
            top--;
        stk[top++] = pt[i];
    }
    stk.resize(top-1);
    return stk;
}
```

## 4.5 Convex Hull trick

```
/* Given a convexhull, answer queries in O(lgN)
CH should not contain identical points, the area should
be > 0, min pair(x, y) should be listed first */
double det( const Pt& p1 , const Pt& p2 )
{ return p1.X * p2.Y - p1.Y * p2.X; }
struct Conv{
    int n;
    vector<Pt> a;
    vector<Pt> upper, lower;
    Conv(vector<Pt> _a) : a(_a){
        n = a.size();
        int ptr = 0;
        for(int i=1; i<n; ++i) if (a[ptr] < a[i]) ptr = i;
        for(int i=0; i<=ptr; ++i) lower.push_back(a[i]);
        for(int i=ptr; i<n; ++i) upper.push_back(a[i]);
        upper.push_back(a[0]);
    }
    int sign( LL x ){ // fixed when changed to double
        return x < 0 ? -1 : x > 0; }
    pair<LL, int> get_tang(vector<Pt> &conv, Pt vec){
        int l = 0, r = (int)conv.size() - 2;
        for( ; l + 1 < r; ){
            int mid = (l + r) / 2;
            if(sign(det(conv[mid+1]-conv[mid], vec))>0)r=mid;
            else l = mid;
        }
        return max(make_pair(det(vec, conv[r]), r),
            make_pair(det(vec, conv[0]), 0));
    }
    void upd_tang(const Pt &p, int id, int &i0, int &i1){
        if(det(a[i0] - p, a[id] - p) > 0) i0 = id;
        if(det(a[i1] - p, a[id] - p) < 0) i1 = id;
    }
    void bi_search(int l, int r, Pt p, int &i0, int &i1){
        if(l == r) return;
        upd_tang(p, l % n, i0, i1);
        int sl=sign(det(a[l % n] - p, a[(l + 1) % n] - p));
        for( ; l + 1 < r; ){
            int mid = (l + r) / 2;
            int smid=sign(det(a[mid%n]-p, a[(mid+1)%n]-p));
            if (smid == sl) l = mid;
            else r = mid;
        }
        upd_tang(p, r % n, i0, i1);
    }
    int bi_search(Pt u, Pt v, int l, int r) {
        int sl = 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 == sl) l = mid;
            else r = mid;
        }
    }
}
```

```

    }
    return l % n;
}
// 1. whether a given point is inside the CH
bool contain(Pt p) {
    if (p.X < lower[0].X || p.X > lower.back().X)
        return 0;
    int id = lower_bound(lower.begin(), lower.end(), Pt
        (p.X, -INF)) - lower.begin();
    if (lower[id].X == p.X) {
        if (lower[id].Y > p.Y) return 0;
    }else if(det(lower[id-1]-p, lower[id]-p)<0)return 0;
    id = lower_bound(upper.begin(), upper.end(), Pt(p.X
        , INF), greater<Pt>()) - upper.begin();
    if (upper[id].X == p.X) {
        if (upper[id].Y < p.Y) return 0;
    }else if(det(upper[id-1]-p, upper[id]-p)<0)return 0;
    return 1;
}
// 2. Find 2 tang pts on CH of a given outside point
// return true with i0, i1 as index of tangent points
// return false if inside CH
bool get_tang(Pt p, int &i0, int &i1) {
    if (contain(p)) return false;
    i0 = i1 = 0;
    int id = lower_bound(lower.begin(), lower.end(), p)
        - lower.begin();
    bi_search(0, id, p, i0, i1);
    bi_search(id, (int)lower.size(), p, i0, i1);
    id = lower_bound(upper.begin(), upper.end(), p,
        greater<Pt>()) - upper.begin();
    bi_search((int)lower.size() - 1, (int)lower.size()
        - 1 + id, p, i0, i1);
    bi_search((int)lower.size() - 1 + id, (int)lower.
        size() - 1 + (int)upper.size(), p, i0, i1);
    return true;
}
// 3. Find tangent points of a given vector
// ret the idx of vertex has max cross value with vec
int get_tang(Pt vec){
    pair<LL, int> ret = get_tang(upper, vec);
    ret.second = (ret.second+(int)lower.size()-1)%n;
    ret = max(ret, get_tang(lower, vec));
    return ret.second;
}
// 4. Find intersection point of a given line
// return 1 and intersection is on edge (i, next(i))
// return 0 if no strictly intersection
bool get_intersection(Pt u, Pt v, int &i0, int &i1){
    int p0 = get_tang(u - v), p1 = get_tang(v - u);
    if(sign(det(v-u, a[p0]-u))*sign(det(v-u, a[p1]-u))<0){
        if (p0 > p1) swap(p0, p1);
        i0 = bi_search(u, v, p0, p1);
        i1 = bi_search(u, v, p1, p0 + n);
        return 1;
    }
    return 0;
}
}
}
```

## 4.6 Intersection of 2 segments

```
int ori( const Pt& o , const Pt& a , const Pt& b ){
    LL ret = ( a - o ) ^ ( b - o );
    return (ret > 0) - (ret < 0);
}
// p1 == p2 || q1 == q2 need to be handled
bool banana( const Pt& p1 , const Pt& p2 ,
    const Pt& q1 , const Pt& q2 ){
    if( ( ( p2 - p1 ) ^ ( q2 - q1 ) ) == 0 ){ // parallel
        if( ori( p1 , p2 , q1 ) ) return false;
        return ( ( p1 - q1 ) * ( p2 - q1 ) ) <= 0 ||
            ( ( p1 - q2 ) * ( p2 - q2 ) ) <= 0 ||
            ( ( q1 - p1 ) * ( q2 - p1 ) ) <= 0 ||
            ( ( q1 - p2 ) * ( q2 - p2 ) ) <= 0;
    }
    return (ori( p1, p2, q1 ) * ori( p1, p2, q2 )<=0) &&
        (ori( q1, q2, p1 ) * ori( q1, q2, p2 )<=0);
}
```

## 4.7 Point In Polygon

```
int ptInPoly(vector<Pt> ps,Pt p){
    int c=0;
    for(int i=0;i<ps.size();i++){
        int a=i,b=(i+1)%ps.size(); Line l(ps[a],ps[b]);
        Pt q=l.s+l.v*((l.v*(p-l.s))/norm2(l.v)); // project
        if(norm(p-q)<eps&&onseg(q,l)) return 1; // boundary
        if(dcmp(ps[a].y-ps[b].y)==0&&dcmp(ps[a].y-p.y)==0)
            continue;
        if(ps[a].y>ps[b].y) swap(a,b);
        if((ps[a].y<=p.y&&p.y<ps[b].y)&&p.x<=ps[a].x+(ps[b].x-
            ps[a].x)/(ps[b].y-ps[a].y)*(p.y-ps[a].y)) ++c;
    }
    return (c&1)*2; // 0: outside, 1: boundary, 2: inside
} // check whether a point is in a polygon
```

## 4.8 Tangent line of two circles

```
vector<Line> go( const Cir& c1 , const Cir& c2 , int
    sign1 ){
    // sign1 = 1 for outer tang, -1 for inter tang
    vector<Line> ret;
    double d_sq = norm2( c1.0 - c2.0 );
    if( d_sq < eps ) return ret;
    double d = sqrt( d_sq );
    Pt v = ( c2.0 - c1.0 ) / d;
    double c = ( c1.R - sign1 * c2.R ) / d;
    if( c * c > 1 ) return ret;
    double h = sqrt( max( 0.0 , 1.0 - c * c ) );
    for( int sign2 = 1 ; sign2 >= -1 ; sign2 -= 2 ){
        Pt n = { v.X * c - sign2 * h * v.Y ,
            v.Y * c + sign2 * h * v.X };
        Pt p1 = c1.0 + n * c1.R;
        Pt p2 = c2.0 + n * ( c2.R * sign1 );
        if( fabs( p1.X - p2.X ) < eps and
            fabs( p1.Y - p2.Y ) < eps )
            p2 = p1 + perp( c2.0 - c1.0 );
        ret.push_back( { p1 , p2 } );
    }
    return ret;
}
```

## 4.9 Minimum distance of two convex

```
double TwoConvexHullMinDis(Pt P[],Pt Q[],int n,int m){
    int mn=0,mx=0; double tmp,ans=1e9;
    for(int i=0;i<n;++i) if(P[i].y<P[mn].y) mn=i;
    for(int i=0;i<m;++i) if(Q[i].y>Q[mx].y) mx=i;
    P[n]=P[0]; Q[m]=Q[0];
    for( int i=0;i<n;++i) {
        while((tmp=((Q[mx+1]-P[mn+1])^(P[mn]-P[mn+1]))>((Q[
            mx]-P[mn+1])^(P[mn]-P[mn+1])))) mx=(mx+1)%m;
        if(tmp<0) // pt to segment distance
            ans=min(ans,dis(Line(P[mn],P[mn+1]),Q[mx]));
        else // segment to segment distance
            ans=min(ans,dis(Line(P[mn],P[mn+1]),Line(Q[mx],Q[
                mx+1])));
        mn=(mn+1)%n;
    }
    return ans;
}
```

## 4.10 Area of Rectangles

```
struct AreaofRectangles{
#define cl(x) (x<1)
#define cr(x) (x<11)
    ll n, id, sid;
    pair<ll,ll> tree[MXN<<3]; // count, area
    vector<ll> ind;
    tuple<ll,ll,ll,ll> scan[MXN<<1];
    void pull(int i, int l, int r){
        if(tree[i].first) tree[i].second = ind[r+1] -
            ind[l];
    }
```

```
    else if(l != r){
        int mid = (l+r)>>1;
        tree[i].second = tree[cl(i)].second + tree[
            cr(i)].second;
    }
    else tree[i].second = 0;
}
void upd(int i, int l, int r, int ql, int qr, int v
    ){
    if(ql <= l && r <= qr){
        tree[i].first += v;
        pull(i, l, r); return;
    }
    int mid = (l+r) >> 1;
    if(ql <= mid) upd(cl(i), l, mid, ql, qr, v);
    if(qr > mid) upd(cr(i), mid+1, r, ql, qr, v);
    pull(i, l, r);
}
void init(int _n){
    n = _n; id = sid = 0;
    ind.clear(); ind.resize(n<<1);
    fill(tree, tree+(n<<2), make_pair(0, 0));
}
void addRectangle(int lx, int ly, int rx, int ry){
    ind[id++] = lx; ind[id++] = rx;
    scan[sid++] = make_tuple(ly, 1, lx, rx);
    scan[sid++] = make_tuple(ry, -1, lx, rx);
}
ll solve(){
    sort(ind.begin(), ind.end());
    ind.resize(unique(ind.begin(), ind.end()) - ind
        .begin());
    sort(scan, scan + sid);
    ll area = 0, pre = get<0>(scan[0]);
    for(int i = 0; i < sid; i++){
        auto [x, v, l, r] = scan[i];
        area += tree[l].second * (x-pre);
        upd(1, 0, ind.size()-1, lower_bound(ind.
            begin(), ind.end(), l)-ind.begin(),
            lower_bound(ind.begin(), ind.end(), r)-
            ind.begin()-1, v);
        pre = x;
    }
    return area;
}
} rect;
```

## 4.11 Min dist on Cuboid

```
typedef LL T;
T r;
void turn(T i, T j, T x, T y, T z,
    T x0, T y0, T L, T W, T H) {
    if (z==0) { T R = x*x+y*y; if (R<r) r=R; return; }
    if(i>=0 && i<2) turn(i+1, j, x0+L+z, y, x0+L-x,
        x0+L, y0, H, W, L);
    if(j>=0 && j<2) turn(i, j+1, x, y0+W+z, y0+W-y,
        x0, y0+W, L, H, W);
    if(i<=0 && i>-2) turn(i-1, j, x0-z, y, x-x0,
        x0-H, y0, H, W, L);
    if(j<=0 && j>-2) turn(i, j-1, x, y0-z, y-y0,
        x0, y0-H, L, H, W);
}
T solve(T L, T W, T H,
    T x1, T y1, T z1, T x2, T y2, T z2){
    if( z1!=0 && z1!=H ){
        if( y1==0 || y1==W )
            swap(y1,z1), swap(y2,z2), swap(W,H);
        else swap(x1,z1), swap(x2,z2), swap(L,H);
    }
    if (z1==H) z1=0, z2=H-z2;
    r=INF; turn(0,0,x2-x1,y2-y1,z2,-x1,-y1,L,W,H);
    return r;
}
```

## 4.12 Heart of Triangle

```
Pt inCenter( Pt &A, Pt &B, Pt &C) { // 內心
    double a = norm(B-C), b = norm(C-A), c = norm(A-B);
```

```

return (A * a + B * b + C * c) / (a + b + c);
}
Pt circumCenter( Pt &a, Pt &b, Pt &c) { // 外心
Pt bb = b - a, cc = c - a;
double db=norm2(bb), dc=norm2(cc), d=2*(bb ^ cc);
return a-Pt(bb.Y*dc-cc.Y*db, cc.X*db-bb.X*dc) / d;
}
Pt othroCenter( Pt &a, Pt &b, Pt &c) { // 垂心
Pt 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 Pt(x0, y0);
}

```

## 5 Graph

### 5.1 DSU 並查集 & MST

```

struct DSU { // 並查集
vector<int> fa, sz;
DSU(int n = 0) : fa(n), sz(n, 1) {
iota(fa.begin(), fa.end(), 0);
}
int Find(int x) { // 路徑壓縮
while (x != fa[x])
x = fa[x] = fa[fa[x]];
return x;
}
bool Merge(int x, int y) { // 合併
x = Find(x), y = Find(y);
if (x == y) return false; // 是否為連通
if (sz[x] > sz[y]) swap(x, y);
fa[x] = y;
sz[y] += sz[x];
return true;
}
};

```

### 5.2 Lowest Common Ancestor $O(\lg n)$

```

struct LCA {
int n, ti, lgN;
int anc[MXN + 5][__lg(MXN) + 1] = {0};
int MaxLength[MXN][__lg(MXN) + 1] = {0};
int time_in[MXN] = {0};
int time_out[MXN] = {0};
LCA(int _n, int f):n(_n), ti(0), lgN(__lg(n)) {
dfs(f, f, 0);
build();
}
void dfs(int now, int f, int len_to_father) { // dfs
for anc, time, Lenth
ti++;
anc[now][0] = f;
time_in[now] = ti;
MaxLength[now][0] = len_to_father;
for (auto i : graph[now]) {
if (i.first == f) continue;
dfs(i.first, now, i.second);
}
time_out[now] = ti;
}
void build() { // build anc[], MaxLength[]
for (int i = 1; i <= lgN; ++i) {
for (int u = 1; u <= n; ++u) {
anc[u][i] = anc[anc[u][i-1]][i-1];
MaxLength[u][i] = max(MaxLength[u][i-1],
MaxLength[anc[u][i-1]][i-1]);
// dis[u][i] += dis[anc[u][i-1]][i-1];
// + dis[u][i-1];
}
}
}
bool isAncestor(int x, int y) {

```

```

return time_in[x] <= time_in[y] && time_out[x] >=
time_out[y];
}
int getLCA(int u, int v) {
if (isAncestor(u, v)) return u;
if (isAncestor(v, u)) return v;
for (int i = lgN; i >= 0; --i) {
if (!isAncestor(anc[u][i], v)) {
u = anc[u][i];
}
}
return anc[u][0];
}
int getMAX(int u, int v) { // 獲得路徑上最大邊權
int lca = getLCA(u, v);
int maxx = -1;
for (int i = lgN; i >= 0; --i) {
// u to lca
if (!isAncestor(anc[u][i], lca)) {
maxx = max(maxx, MaxLength[u][i]);
u = anc[u][i];
}
}
// v to lca
if (!isAncestor(anc[v][i], lca)) {
maxx = max(maxx, MaxLength[v][i]);
v = anc[v][i];
}
}
if (u != lca) maxx = max(maxx, MaxLength[u][0]);
if (v != lca) maxx = max(maxx, MaxLength[v][0]);
return maxx;
}
};

```

### 5.3 Hamiltonian path $O(n^2 2^n)$

```

//dp[i][j] = 目前在j節點走過{i}節點的最短路徑
for(int i=1 ; i < (1 << n) ; i++) {
for(int j = 1 ; j < n ; j++) {
if(!((1 << j) & i)&&(i&1)) {
for( int k = 0 ; k < n ; k++) {
if(j == k) continue;
if( (1<<k)&i ) dp[j][i|(1<<j)] =
min(dp[j][i|(1<<j)], dp[k][i]+dis[k][j]);
}
}
}
}
}
}

```

### 5.4 MaximumClique 最大團

```

#define N 111
struct MaxClique { // 0-base
typedef bitset<N> Int;
Int linkto[N], v[N];
int n;
void init(int _n){
n = _n;
for(int i = 0 ; i < n ; i++){
linkto[i].reset(); v[i].reset();
}
}
void addEdge(int a, int b)
{ v[a][b] = v[b][a] = 1; }
int popcount(const Int& val)
{ return val.count(); }
int lowbit(const Int& val)
{ return val._Find_first(); }
int ans, stk[N];
int id[N], di[N], deg[N];
Int cans;
void maxclique(int elem_num, Int candi){
if(elem_num > ans){
ans = elem_num; cans.reset();
for(int i = 0 ; i < elem_num ; i++){
cans[id[stk[i]]] = 1;
}
}
int potential = elem_num + popcount(candi);

```

```

if(potential <= ans) return;
int pivot = lowbit(candi);
Int smaller_candi = candi & (~linkto[pivot]);
while(smaller_candi.count() && potential > ans){
    int next = lowbit(smaller_candi);
    candi[next] = !candi[next];
    smaller_candi[next] = !smaller_candi[next];
    potential--;
    if(next == pivot || (smaller_candi & linkto[next
    ]).count()){
        stk[elem_num] = next;
        maxclique(elem_num + 1, candi & linkto[next]);
    } }
int solve(){
    for(int i = 0 ; i < n ; i++){
        id[i] = i; deg[i] = v[i].count();
    }
    sort(id , id + n , [&](int id1, int id2){
        return deg[id1] > deg[id2]; });
    for(int i = 0 ; i < n ; i++) di[id[i]] = i;
    for(int i = 0 ; i < n ; i++)
        for(int j = 0 ; j < n ; j++)
            if(v[i][j]) linkto[di[i]][di[j]] = 1;
    Int cand; cand.reset();
    for(int i = 0 ; i < n ; i++) cand[i] = 1;
    ans = 1;
    cans.reset(); cans[0] = 1;
    maxclique(0, cand);
    return ans;
} } solver;

```

## 5.5 MaximalClique 極大團

```

#define N 80
struct MaxClique{ // 0-base
    typedef bitset<N> Int;
    Int lnk[N] , v[N];
    int n;
    void init(int _n){
        n = _n;
        for(int i = 0 ; i < n ; i++){
            lnk[i].reset(); v[i].reset();
        }
    }
    void addEdge(int a , int b)
    { v[a][b] = v[b][a] = 1; }
    int ans , stk[N] , id[N] , di[N] , deg[N];
    Int cans;
    void dfs(int elem_num, Int candi, Int ex){
        if(candi.none() && ex.none()){
            cans.reset();
            for(int i = 0 ; i < elem_num ; i++)
                cans[id[stk[i]]] = 1;
            ans = elem_num; // cans is a maximal clique
            return;
        }
        int pivot = (candi.ex).Find_first();
        Int smaller_candi = candi & (~lnk[pivot]);
        while(smaller_candi.count()){
            int nxt = smaller_candi.Find_first();
            candi[nxt] = smaller_candi[nxt] = 0;
            ex[nxt] = 1;
            stk[elem_num] = nxt;
            dfs(elem_num+1, candi & lnk[nxt], ex & lnk[nxt]);
        }
    }
    int solve(){
        for(int i = 0 ; i < n ; i++){
            id[i] = i; deg[i] = v[i].count();
        }
        sort(id , id + n , [&](int id1, int id2){
            return deg[id1] > deg[id2]; });
        for(int i = 0 ; i < n ; i++) di[id[i]] = i;
        for(int i = 0 ; i < n ; i++)
            for(int j = 0 ; j < n ; j++)
                if(v[i][j]) lnk[di[i]][di[j]] = 1;
        ans = 1; cans.reset(); cans[0] = 1;
        dfs(0, Int(string(n, '1')), 0);
        return ans;
    }
} } solver;

```

## 5.6 BCC based on vertex 點雙聯通分量

```

#define PB push_back
#define REP(i, n) for(int i = 0; i < n; i++)
struct BccVertex {
    int n, nScc, step, dfn[MXN], low[MXN];
    vector<int> E[MXN], sccv[MXN];
    int top, stk[MXN];
    void init(int _n) { // 初始化n點
        n = _n; nScc = step = 0;
        for (int i=0; i<n; i++) E[i].clear();
    }
    void addEdge(int u, int v) // 無向邊
    { E[u].PB(v); E[v].PB(u); }
    void DFS(int u, int f) {
        dfn[u] = low[u] = step++;
        stk[top++] = u;
        for (auto v:E[u]) {
            if (v == f) continue;
            if (dfn[v] == -1) {
                DFS(v, u);
                low[u] = min(low[u], low[v]);
                if (low[v] >= dfn[u]) {
                    int z;
                    sccv[nScc].clear();
                    do {
                        z = stk[--top];
                        sccv[nScc].PB(z);
                    } while (z != v);
                    sccv[nScc++].PB(u);
                }
            }
            else
                low[u] = min(low[u], dfn[v]);
        }
    }
    vector<vector<int>> solve() { // 回傳(size=2 橋, size
        >2 點雙連通分量)
        vector<vector<int>> res;
        for (int i=0; i<n; i++)
            dfn[i] = low[i] = -1;
        for (int i=0; i<n; i++)
            if (dfn[i] == -1) {
                top = 0;
                DFS(i, i);
            }
        REP(i, nScc) res.PB(sccv[i]);
        return res;
    }
} graph;

```

## 5.7 Strongly Connected Component 強連通分量

```

#define PB push_back
#define FZ(x) memset(x, 0, sizeof(x)) //fill zero
struct Scc{
    int n, nScc, vst[MXN], bln[MXN];
    vector<int> E[MXN], rE[MXN], vec;
    void init(int _n){
        n = _n;
        for (int i=0; i<MXN; i++)
            E[i].clear(), rE[i].clear();
    }
    void addEdge(int u, int v){
        E[u].PB(v); rE[v].PB(u);
    }
    void DFS(int u){
        vst[u]=1;
        for (auto v : E[u]) if (!vst[v]) DFS(v);
        vec.PB(u);
    }
    void rDFS(int u){
        vst[u] = 1; bln[u] = nScc;
        for (auto v : rE[u]) if (!vst[v]) rDFS(v);
    }
    void solve(){
        nScc = 0;
        vec.clear();
        FZ(vst);
        for (int i=0; i<n; i++)

```

## 5.8 Maximum General graph Matching

### 5.9 Min Mean Cycle

```
// returns inf if no cycle, mmc otherwise
double mmc=inf;
int st = -1;
bellman_ford();
for(int i=0; i<n; i++) {
    double avg=-inf;
    for(int k=0; k<n; k++) {
        if(d[n][i]<inf-eps) avg=max(avg,(d[n][i]-d[k][i])/(n-k));
        else avg=max(avg,inf);
    }
    if (avg < mmc) tie(mmc, st) = tie(avg, i);
}
fill(vst,0); edgeID.clear(); cycle.clear(); rho.clear();
for (int i=n; !vst[st]; st=prv[i--][st]) {
    vst[st]++;
    edgeID.PB(prve[i][st]);
    rho.PB(st);
}
while (vst[st] != 2) {
    if(rho.empty()) return inf;
    int v = rho.back(); rho.pop_back();
    cycle.PB(v);
    vst[v]++;
}
reverse(ALL(edgeID));
edgeID.resize(SZ(cycle));
return mmc;
} }mmc;
```

### 5.10 Directed Graph Min Cost Cycle

```

// works in O(N M)
#define INF 1000000000000000LL
#define N 5010
#define M 200010
struct edge{
    int to; LL w;
    edge(int a=0, LL b=0): to(a), w(b){}
};
struct node{
    LL d; int u, next;
    node(LL a=0, int b=0, int c=0): d(a), u(b), next(c){}
}b[M];
struct DirectedGraphMinCycle{
    vector<edge> g[N], grev[N];
    LL dp[N][N], p[N], d[N], mu;
    bool inq[N];
    int n, bn, bsz, hd[N];
    void b_insert(LL d, int u){
        int i = d/mu;
        if(i >= bn) return;
        b[++bsz] = node(d, u, hd[i]);
        hd[i] = bsz;
    }
    void init( int _n ){
        n = _n;
        for( int i = 1 ; i <= n ; i ++ )
            g[ i ].clear();
    }
    void addEdge( int ai , int bi , LL ci )
    { g[ai].push_back(edge(bi,ci)); }
    LL solve(){
        fill(dp[0], dp[0]+n+1, 0);
        for(int i=1; i<=n; i++){
            fill(dp[i]+1, dp[i]+n+1, INF);
            for(int j=1; j<=n; j++) if(dp[i-1][j] < INF){
                for(int k=0; k<(int)g[j].size(); k++){
                    dp[i][g[j][k].to] = min(dp[i][g[j][k].to],
                                                dp[i-1][j]+g[j][k].w);
                }
            }
        }
        mu=INF; LL bunbo=1;
        for(int i=1; i<=n; i++) if(dp[n][i] < INF){
            LL a=-INF, b=1;
            for(int j=0; j<=n-1; j++) if(dp[j][i] < INF){
                if(a*(n-j) < b*(dp[n][i]-dp[j][i])){
                    a = dp[n][i]-dp[j][i];
                    b = n-j;
                }
            }
        }
    }
};

```



```

    if(mu*b > bunbo*a)
        mu = a, bunbo = b;
}
if(mu < 0) return -1; // negative cycle
if(mu == INF) return INF; // no cycle
if(mu == 0) return 0;
for(int i=1; i<=n; i++){
    for(int j=0; j<(int)g[i].size(); j++){
        g[i][j].w *= bunbo;
    }
    memset(p, 0, sizeof(p));
    queue<int> q;
    for(int i=1; i<=n; i++){
        q.push(i);
        inq[i] = true;
    }
    while(!q.empty()){
        int i=q.front(); q.pop(); inq[i]=false;
        for(int j=0; j<(int)g[i].size(); j++){
            if(p[g[i][j].to] > p[i]+g[i][j].w-mu){
                p[g[i][j].to] = p[i]+g[i][j].w-mu;
                if(!inq[g[i][j].to]){
                    q.push(g[i][j].to);
                    inq[g[i][j].to] = true;
                }
            }
        }
    }
    for(int i=1; i<=n; i++) grev[i].clear();
    for(int i=1; i<=n; i++){
        for(int j=0; j<(int)g[i].size(); j++){
            g[i][j].w += p[i]-p[g[i][j].to];
            grev[g[i][j].to].push_back(edge(i, g[i][j].w));
        }
    }
    LL mldc = n*mu;
    for(int i=1; i<=n; i++){
        bn=mldc/mu, bsz=0;
        memset(hd, 0, sizeof(hd));
        fill(d+i+1, d+n+1, INF);
        b_insert(d[i]=0, i);
        for(int j=0; j<=bn-1; j++) for(int k=hd[j]; k; k=
            b[k].next){
            int u = b[k].u;
            LL du = b[k].d;
            if(du > d[u]) continue;
            for(int l=0; l<(int)g[u].size(); l++) if(g[u][l]
                .to > i){
                if(d[g[u][l].to] > du + g[u][l].w){
                    d[g[u][l].to] = du + g[u][l].w;
                    b_insert(d[g[u][l].to], g[u][l].to);
                }
            }
        }
        for(int j=0; j<(int)grev[i].size(); j++) if(grev[i]
            [j].to > i)
            mldc=min(mldc,d[grev[i][j].to] + grev[i][j].w);
    }
    return mldc / bunbo;
} }graph;

```

## 5.11 K-th Shortest Path

```

// time: O(|E| \lg |E| + |V| \lg |V| + K)
// memory: O(|E| \lg |E| + |V|)
struct KSP{ // 1-base
    struct nd{
        int u, v; ll d;
        nd(int ui = 0, int vi = 0, ll di = INF)
        { u = ui; v = vi; d = di; }
    };
    struct heap{
        nd* edge; int dep; heap* chd[4];
    };
    static int cmp(heap* a, heap* b)
    { return a->edge->d > b->edge->d; }
    struct node{
        int v; ll d; heap* H; nd* E;
        node(ll _d, int _v, nd* _E)
        { d = _d; v = _v; E = _E; }
        node(heap* _H, ll _d)
        { H = _H; d = _d; }
        friend bool operator<(node a, node b)
        { return a.d > b.d; }
    };
    int n, k, s, t;

```

```

    ll dst[ N ];
    nd *nxt[ N ];
    vector<nd*> g[ N ], rg[ N ];
    heap *nullNd, *head[ N ];
    void init( int _n , int _k , int _s , int _t ){
        n = _n; k = _k; s = _s; t = _t;
        for( int i = 1 ; i <= n ; i ++ ){
            g[ i ].clear(); rg[ i ].clear();
            nxt[ i ] = NULL; head[ i ] = NULL;
            dst[ i ] = -1;
        }
    }
    void addEdge( int ui , int vi , ll di ){
        nd* e = new nd(ui, vi, di);
        g[ ui ].push_back( e );
        rg[ vi ].push_back( e );
    }
    queue<int> dfsQ;
    void dijkstra(){
        while(dfsQ.size()) dfsQ.pop();
        priority_queue<node> Q;
        Q.push(node(0, t, NULL));
        while (!Q.empty()){
            node p = Q.top(); Q.pop();
            if(dst[p.v] != -1) continue;
            dst[ p.v ] = p.d;
            nxt[ p.v ] = p.E;
            dfsQ.push( p.v );
            for(auto e: rg[ p.v ])
                Q.push(node(p.d + e->d, e->u, e));
        }
    }
    heap* merge(heap* curNd, heap* newNd){
        if(curNd == nullNd) return newNd;
        heap* root = new heap;
        memcpy(root, curNd, sizeof(heap));
        if(newNd->edge->d < curNd->edge->d){
            root->edge = newNd->edge;
            root->chd[2] = newNd->chd[2];
            root->chd[3] = newNd->chd[3];
            newNd->edge = curNd->edge;
            newNd->chd[2] = curNd->chd[2];
            newNd->chd[3] = curNd->chd[3];
        }
        if(root->chd[0]->dep < root->chd[1]->dep)
            root->chd[0] = merge(root->chd[0], newNd);
        else
            root->chd[1] = merge(root->chd[1], newNd);
        root->dep = max(root->chd[0]->dep, root->chd[1]->
            dep) + 1;
        return root;
    }
    vector<heap*> V;
    void build(){
        nullNd = new heap;
        nullNd->dep = 0;
        nullNd->edge = new nd;
        fill(nullNd->chd, nullNd->chd+4, nullNd);
        while(not dfsQ.empty()){
            int u = dfsQ.front(); dfsQ.pop();
            if(!nxt[ u ]) head[ u ] = nullNd;
            else head[ u ] = head[nxt[ u ]->v];
            V.clear();
            for( auto&& e : g[ u ] ){
                int v = e->v;
                if( dst[ v ] == -1 ) continue;
                e->d += dst[ v ] - dst[ u ];
                if( nxt[ u ] != e ){
                    heap* p = new heap;
                    fill(p->chd, p->chd+4, nullNd);
                    p->dep = 1;
                    p->edge = e;
                    V.push_back(p);
                }
            }
            if(V.empty()) continue;
            make_heap(V.begin(), V.end(), cmp);
#define L(X) ((X<<1)+1)
#define R(X) ((X<<1)+2)
            for( size_t i = 0 ; i < V.size() ; i ++ ){
                if(L(i) < V.size()) V[i]->chd[2] = V[L(i)];
                else V[i]->chd[2]=nullNd;
                if(R(i) < V.size()) V[i]->chd[3] = V[R(i)];
                else V[i]->chd[3]=nullNd;
            }

```



```

    head[u] = merge(head[u], V.front());
} }
vector<ll> ans;
void first_K(){
    ans.clear();
    priority_queue<node> Q;
    if( dst[ s ] == -1 ) return;
    ans.push_back( dst[ s ] );
    if( head[s] != nullNd )
        Q.push(node(head[s], dst[s]+head[s]->edge->d));
    for( int _ = 1 ; _ < k and not Q.empty() ; _ ++ ){
        node p = Q.top(), q; Q.pop();
        ans.push_back( p.d );
        if(head[ p.H->edge->v ] != nullNd){
            q.H = head[ p.H->edge->v ];
            q.d = p.d + q.H->edge->d;
            Q.push(q);
        }
        for( int i = 0 ; i < 4 ; i ++ )
            if( p.H->chd[ i ] != nullNd ){
                q.H = p.H->chd[ i ];
                q.d = p.d - p.H->edge->d + p.H->chd[ i ]->
                    edge->d;
                Q.push( q );
            }
    }
    void solve(){ // ans[i] stores the i-th shortest path
        dijkstra();
        build();
        first_K(); // ans.size() might less than k
    }
} solver;

```

## 5.12 Floryd Warshall

```

for( int k=0 ; k < n ; k++ )
    for( int i=0 ; i < n ; i++ )
        for( int j=0 ; j < n ; j++ )
            if( dis[i][j] > dis[i][k]+dis[k][j] && dis[i][k]
                ] < INF && dis[k][j] < INF )
                dis[i][j]=dis[i][k]+dis[k][j];
for( int i=0 ; i < n ; i++ )
    for( int j=0 ; j < n ; j++ )
        for( int k=0 ; k < n && dis[i][j] != negINF ; k++ )
            if( dis[k][k] < 0 && dis[i][k] != INF && dis[k]
                ][j] != INF )
                dis[i][j]=negINF;

```

## 5.13 SPFA

```

#define MXN 200005
struct SPFA{
    int n;
    LL inq[MXN], len[MXN];
    vector<LL> dis;
    vector<pair<int, LL>> edge[MXN];
    void init(int _n){
        n = _n;
        dis.clear(); dis.resize(n, 1e18);
        for(int i = 0; i < n; i++){
            edge[i].clear();
            inq[i] = len[i] = 0;
        }
    }
    void addEdge(int u, int v, LL w){
        edge[u].push_back({v, w});
    }
    vector<LL> solve(int st = 0){
        deque<int> dq; //return {-1} if has negative cycle
        dq.push_back(st); //otherwise return dis from st
        inq[st] = 1; dis[st] = 0;
        while(!dq.empty()){
            int u = dq.front(); dq.pop_front();
            inq[u] = 0;
            for(auto [to, d] : edge[u]){
                if(dis[to] > d+dis[u]){
                    dis[to] = d+dis[u];
                    len[to] = len[u]+1;
                    if(len[to] > n) return {-1};
                    if(inq[to]) continue;

```

```

                (!dq.empty()&&dis[dq.front()] > dis[to]?
                    dq.push_front(to) : dq.push_back(to));
                inq[to] = 1;
            } }
            return dis;
        } } spfa;

```

## 5.14 Tree Hash

```

//限定root = 1
//從 dfs(1,1) 開始
int subtree_sz[MXN];
vector<int> edge[MXN];

int dfs(int u, int f) {
    vector<pair<int, int>> h;
    subtree_sz[u] = 1;
    for (int child : edge[u]) {
        if (child == f) continue;
        int tmp = dfs(child, u);
        h.push_back(make_pair(tmp, subtree_sz[child]));
        subtree_sz[u] += subtree_sz[child];
    }
    sort(h.begin(), h.end());
    int ret = subtree_sz[u];
    for (auto v : h) {
        ret = ((ret * p) % MOD + v.first) % MOD;
        ret = ret * v.second % MOD;
    }
    return ret;
}

```

## 5.15 HeavyLightDecomposition

```

// 詢問,修改複雜度  $O(\log^2 n)$ 
// 1-base

int sz[MXN], dep[MXN], son[MXN], fa[MXN];

// 第一次 dfs
// 找重兒子 需要紀錄當前節點的子樹大小(sz)、深度(dep)、
// 重兒子(son)、父節點(fa)
// 沒有子節點 son[x] = 0
void dfs_sz(int x, int f, int d) { //當前節點 x · 父節
    點 f · 深度 d
    sz[x] = 1; dep[x] = d; fa[x] = f;
    for(int i : edge[x]) {
        if(i == f) continue;
        dfs_sz(i, x, d+1);
        sz[x] += sz[i];
        if(sz[son[x]] < sz[i]) son[x] = i;
    }
}

// 第二次 dfs
int top[MXN]; // 每個節點所在的鏈的頂端節點
int dfn[MXN]; // 節點編號,編號為在線段樹上的位置
int rnk[MXN]; // 編號為哪個節點
int bottom[MXN]; // 維護每個節點的子樹中最大 dfn 編號
int cnt = 0;
int dfs_hld(int x, int f){
    top[x] = (son[fa[x]] == x ? top[fa[x]] : x);
    rnk[cnt] = x;
    bottom[x] = dfn[x] = cnt++;
    if(son[x]) bottom[x] = max(bottom[x], dfs_hld(
        son[x], x)); // 更新子樹最大編號
    for(int i : edge[x]){
        if(i == f || i == son[x]) continue;
        bottom[x] = max(bottom[x], dfs_hld(i, x)); //
            更新子樹最大編號
    }
    return bottom[x];
}

// 求出 lca
// 不斷跳鏈 · 直到 u,v 跳到同一條鏈上為止
// 每次跳鏈選所在的鏈頂端深度較深的一端往上跳

```

```

int getLca(int u, int v) {
    while(top[u] != top[v]){
        if(dep[top[u]] > dep[top[v]])
            u = fa[top[u]];
        else
            v = fa[top[v]];
    }
    return dep[u] > dep[v] ? v : u;
}

// 路徑權重總和
int query(int u, int v) {
    int ret = 0;
    while(top[u] != top[v]){
        if (dep[top[u]] > dep[top[v]]){
            ret += segtree.query(dfn[top[u]], dfn[u]);
            u = fa[top[u]];
        }
        else{
            ret += segtree.query(dfn[top[v]], dfn[v]);
            v = fa[top[v]];
        }
    }
    // 最後到同一條鏈上
    ret += segtree.query(min(dfn[u], dfn[v]), max(dfn[u], dfn[v]));
    return ret;
}

```

## 5.16 差分約束

約束條件  $V_j - V_i \leq W$  addEdge( $V_i, V_j, W$ ) and run bellman-ford or spfa

# 6 String

## 6.1 PalTree $O(n)$

```

// state[i]代表第i個字元為結尾的最長回文編號
// len[s]是對應的回文長度
// num[s]是有幾個回文後綴
// cnt[s]是這個回文子字串在整個字串中的出現次數
// fail[s]是他長度次長的回文後綴 · aba的fail是a
const int MXN = 1000010;
struct PalT{
    int nxt[MXN][26], fail[MXN], len[MXN];
    int tot, lst, n, state[MXN], cnt[MXN], num[MXN];
    int diff[MXN], sfail[MXN], fac[MXN], dp[MXN];
    char s[MXN] = {"-1"};
    int newNode(int l, int f){
        len[tot] = l, fail[tot] = f, cnt[tot] = num[tot] = 0;
        memset(nxt[tot], 0, sizeof(nxt[tot]));
        diff[tot] = (l > 0 ? l - len[f] : 0);
        sfail[tot] = (l > 0 && diff[tot] == diff[f] ? sfail[f] : f);
        return tot++;
    }
    int getfail(int x){
        while(s[n - len[x] - 1] != s[n]) x = fail[x];
        return x;
    }
    int getmin(int v){
        dp[v] = fac[n - len[saile[v]] - diff[v]];
        if(diff[v] == diff[fail[v]])
            dp[v] = min(dp[v], dp[fail[v]]);
        return dp[v] + 1;
    }
    int push(){
        int c = s[n] - 'a', np = getfail(lst);
        if(! (lst == nxt[np][c])){
            lst = newNode(len[np] + 2, getfail(fail[np][c]));
            nxt[np][c] = lst; num[lst] = num[fail[lst]] + 1;
        }
        fac[n] = n;
        for(int v = lst; len[v] > 0; v = sfail[v])
            fac[n] = min(fac[n], getmin(v));
        return ++cnt[lst], lst;
    }
    void init(const char *_s){

```

```

        tot = lst = n = 0;
        newNode(0, 1), newNode(-1, 1);
        for(; _s[n];) s[n+1] = _s[n], ++n, state[n-1] = push();
        for(int i = tot - 1; i > 1; i--) cnt[fail[i]] += cnt[i];
    }
}palT;

```

## 6.2 Longest Increasing Subsequence

```

vector<int> getLIS(vector<int> a){
    vector<int> lis;
    for(int i : a){
        if(lis.empty() || lis.back() < i)    lis.push_back(i);
        else    *lower_bound(lis.begin(), lis.end(), i) = i;
    }
    return lis;
}

```

## 6.3 Longest Common Subsequence $O(n \lg n)$

```

int LCS(string& s1, string& s2) {
    vector<int> p[128]; // 假設字元範圍為 0 ~ 127
    for (int i = 0; i < s2.size(); ++i) p[s2[i]].push_back(i);
    vector<int> v;
    v.push_back(-1);

    for (int i = 0; i < s1.size(); ++i)
        for (int j = p[s1[i]].size() - 1; j >= 0; --j) {
            int n = p[s1[i]][j];

            if (n > v.back())
                v.push_back(n);
            else
                *lower_bound(v.begin(), v.end(), n) = n;
        }
    return v.size() - 1;
};

```

## 6.4 KMP

```

/* len-failure[k]:
在k結尾的情況下，這個子字串可以由開頭
長度為(len-failure[k])的部分重複出現來表達

failure[k]為次長相同前綴後綴
如果我們不只想求最多，而且以0-base做為考量
· 那可能的長度由大到小會是
failure[k]、failure[failuer[k]-1]
· failure[failure[failuer[k]-1]-1]..
直到有值為0為止 */
int failure[MXN];
vector<int> KMP(string& t, string& p) {
    vector<int> ret;
    if(p.size() > t.size()) return ret;
    for(int i = 1, j = failure[0] = -1; i < p.size(); i++) {
        while(j >= 0 && p[j + 1] != p[i]) j = failure[j];
        if(p[j + 1] == p[i]) j++;
        failure[i] = j;
    }
    for(int i = 0, j = -1; i < t.size(); i++) {
        while (j >= 0 && p[j + 1] != t[i]) j = failure[j];
        if(p[j + 1] == t[i]) j++;
        if(j == p.size() - 1) {
            ret.push_back(i - p.size() + 1);
            j = failure[j];
        }
    }
    return ret;
}

```

## 6.5 SAIS $O(n)$

```

/** SA · 將字串的所有後綴排序後的數組 */
/* SA[i] 儲存排序後第 i 小的後綴從哪裡開始 */
/** H[i] 為第 i 小的字串跟第 i-1 小的 LCP */
/** 註: LCP(Longest Common Prefix) */
/** ex: S = "babd", SA[0] = 1("abd") */
/** SA[1] = 0("babd"), SA[2] = 2("bd") */
/** H[0] = 0, H[1] = 0, H[2] = 1("b") */
/* 傳入參數: ip 陣列放字串 · len 為字串長度 */
/* 需保證 ip[len] 為 0, 且字串裡的元素不為 0 */
const int N = 300010;
struct SA {
#define REP(i,n) for (int i=0; i<int(n); i++)
#define REP1(i,a,b) for (int i=a; i<=int(b); i++)
    bool _t[N*2];
    int _s[N*2], _sa[N*2], _c[N*2], x[N], _p[N], _q[N*2],
        hei[N], r[N];
    int operator [] (int i){ return _sa[i]; }
    void build(int *s, int n, int m){
        memcpy(_s, s, sizeof(int) * n);
        sais(_s, _sa, _p, _q, _t, _c, n, m);
        mkhei(n);
    }
    void mkhei(int n){
        REP(i,n) r[_sa[i]] = i;
        hei[0] = 0;
        REP(i,n) if(r[i]) {
            int ans = i>0 ? max(hei[r[i-1]] - 1, 0) : 0;
            while(_s[i+ans] == _s[_sa[r[i]-1]+ans]) ans++;
            hei[r[i]] = ans;
        }
    }
    void sais(int *s, int *sa, int *p, int *q, bool *t,
        int *c, int n, int z){
        bool uniq = t[n-1] = true, neq;
        int nn = 0, nmzx = -1, *nsa = sa + n, *ns = s + n,
            lst = -1;
#define MS0(x,n) memset((x),0,n*sizeof(*(x)))
#define MAGIC(XD) MS0(sa, n); \
        memcpy(x, c, sizeof(int) * z); \
        XD; \
        memcpy(x + 1, c, sizeof(int) * (z - 1)); \
        REP(i,n) if(sa[i] && !t[sa[i]-1]) sa[x[sa[i]-1]]++ = sa[i]-1; \
        memcpy(x, c, sizeof(int) * z); \
        for(int i = n - 1; i >= 0; i--) if(sa[i] && t[sa[i]-1]) sa[--x[sa[i]-1]] = sa[i]-1;
        MS0(c, z);
        REP(i,n) uniq &= ++c[s[i]] < 2;
        REP(i,z-1) c[i+1] += c[i];
        if (uniq) { REP(i,n) sa[--c[s[i]]] = i; return; }
        for(int i = n - 2; i >= 0; i--) t[i] = (s[i]==s[i+1] ? t[i+1] : s[i]<s[i+1]);
        MAGIC(REP1(i,1,n-1) if(t[i] && !t[i-1]) sa[--x[s[i]]]=p[q[i]=nn++]=i);
        REP(i, n) if (sa[i] && t[sa[i]] && !t[sa[i]-1]) {
            neq=lst<0||memcmp(s+sa[i],s+lst,(p[q[sa[i]]+1]-sa[i])*sizeof(int));
            ns[q[lst=sa[i]]]=nmzx+=neq;
        }
        sais(ns, nsa, p + nn, q + n, t + n, c + z, nn, nmzx + 1);
        MAGIC(for(int i = nn - 1; i >= 0; i--) sa[--x[p[nsa[i]]]] = p[nsa[i]]);
    }
}sa;
int H[ N ], SA[ N ];
void suffix_array(int* ip, int len) {
    // should padding a zero in the back
    // ip is int array, len is array length
    // ip[0..n-1] != 0, and ip[len] = 0
    ip[len++] = 0;
    sa.build(ip, len, 128);
    for (int i=0; i<len; i++) {
        H[i] = sa.hei[i + 1];
        SA[i] = sa._sa[i + 1];
    }
    // resulting height, sa array \in [0,len)
}

```

## 6.6 Z Value $O(n)$

```

//z[i] = lcp(s[1...n-1],s[i...n-1])
int z[MAXN];
void Z_value(const string& s) {
    int i, j, left, right, len = s.size();
    left=right=0; z[0]=len;
    for(i=1;i<len;i++) {
        j=max(min(z[i-left],right-i),0);
        for(;i+j<len&&s[i+j]==s[j];j++);
        z[i]=j;
        if(i+z[i]>right) {
            right=i+z[i];
            left=i;
        }
    }
}

```

## 6.7 Manacher Algorithm $O(n)$

```

// 求以每個字元為中心的最長回文半徑
// 頭尾以及每個字元間都加入一個
// 沒出現過的字元 · 這邊以 '@' 為例
// s 為傳入的字串 · len 為字串長度
// z 為儲存答案的陣列 (有包含 '@' 要小心)
// ex: s = "abaac" -> "@a@b@a@a@c@"
// z = [12141232121]
void z_value_pal(char *s,int len,int *z){
    len=(len<<1)+1;
    for(int i=len-1;i>=0;i--)
        s[i]=i&1?s[i>>1]:'@';
    z[0]=1;
    for(int i=1,l=0,r=0;i<len;i++){
        z[i]=i<r?min(z[l+l-i],r-i):1;
        while(i-z[i]>=0&&i+z[i]<len&&s[i-z[i]]==s[i+z[i]])
            ++z[i];
        if(i+z[i]>r) l=i,r=i+z[i];
    }
}

```

## 6.8 Smallest Rotation

```

//rotate(begin(s),begin(s)+minRotation(s),end(s))
int minRotation(string s) {
    int a = 0, N = s.size(); s += s;
    rep(b,0,N) rep(k,0,N) {
        if(a+k == b || s[a+k] < s[b+k])
            {b += max(0, k-1); break;}
        if(s[a+k] > s[b+k]) {a = b; break;}
    } return a;
}

```

## 6.9 Cyclic LCS

```

#define L 0
#define LU 1
#define U 2
const int mov[3][2]={0,-1, -1,-1, -1,0};
int al,bl;
char a[MAXL*2],b[MAXL*2]; // 0-indexed
int dp[MAXL*2][MAXL];
char pred[MAXL*2][MAXL];
inline int lcs_length(int r) {
    int i=r+al,j=bl,l=0;
    while(i>r) {
        char dir=pred[i][j];
        if(dir==LU) l++;
        i+=mov[dir][0];
        j+=mov[dir][1];
    }
    return l;
}
inline void reroot(int r) { // r = new base row
    int i=r,j=1;
    while(j<=bl&&pred[i][j]!=LU) j++;
    if(j>bl) return;
    pred[i][j]=L;
    while(i<2*al&&j<=bl) {

```

```

    if(pred[i+1][j]==U) {
        i++;
        pred[i][j]=L;
    } else if(j<bl&&pred[i+1][j+1]==LU) {
        i++;
        j++;
        pred[i][j]=L;
    } else {
        j++;
    }
} } }
int cyclic_lcs() {
    // a, b, al, bl should be properly filled
    // note: a WILL be altered in process
    // -- concatenated after itself
    char tmp[MAXL];
    if(al>bl) {
        swap(al,bl);
        strcpy(tmp,a);
        strcpy(a,b);
        strcpy(b,tmp);
    }
    strcpy(tmp,a);
    strcat(a,tmp);
    // basic lcs
    for(int i=0;i<=2*al;i++) {
        dp[i][0]=0;
        pred[i][0]=U;
    }
    for(int j=0;j<=bl;j++) {
        dp[0][j]=0;
        pred[0][j]=L;
    }
    for(int i=1;i<=2*al;i++) {
        for(int j=1;j<=bl;j++) {
            if(a[i-1]==b[j-1]) dp[i][j]=dp[i-1][j-1]+1;
            else dp[i][j]=max(dp[i-1][j],dp[i][j-1]);
            if(dp[i][j-1]==dp[i][j]) pred[i][j]=L;
            else if(a[i-1]==b[j-1]) pred[i][j]=LU;
            else pred[i][j]=U;
        }
    }
    // do cyclic lcs
    int clcs=0;
    for(int i=0;i<al;i++) {
        clcs=max(clcs,lcs_length(i));
        reroot(i+1);
    }
    // recover a
    a[al]='\0';
    return clcs;
}

```

## 6.10 Hash

```

//字串雜湊前的idx是0-base · 雜湊後為1-base
//即區間為 [0,n-1] -> [1,n]
//若要取得區間[L,R]的值則
//H[R] - H[L-1] * p^(R-L+1)
//cmp為比較從i開始長度為len的字串和
//(h[i+len-1] - h[i-1] * qpow(p, len) % modl + modl)
//從j開始長度為len的字串是否相同
#define x first
#define y second
pair<int,int> Hash[MNX];
void build(const string& s){
    pair<int,int> val = make_pair(0,0);
    Hash[0]=val;
    for(int i=1;i<=s.size();i++){
        val.x = (val.x * P1 + s[i-1]) % MOD;
        val.y = (val.y * P2 + s[i-1]) % MOD;
        Hash[i] = val;
    }
}
bool cmp( int i, int j, int len ) {
    return ((Hash[i+len-1].x-Hash[i-1].x*qpow(P1,len)%
        MOD+MOD)%MOD == (Hash[j+len-1].x-Hash[j-1].x*
        qpow(P1,len)%MOD+MOD)%MOD)
    && ((Hash[i+len-1].y-Hash[i-1].y*qpow(P2,len)%MOD+
        MOD)%MOD == (Hash[j+len-1].y-Hash[j-1].y*qpow(
        P2,len)%MOD+MOD)%MOD);
}

```

```

}

```

## 7 Data Structure

### 7.1 Segment tree

```

// !!!注意build()時初始化用的陣列也是1-base
// !!!query(0, 0) 會報錯
#define cl(x) (x*2)
#define cr(x) (x*2+1)

struct segmentTree {
    int n;
    vector<int> seg, tag, cov;
    segmentTree(int _n): n(_n) {
        seg = tag = cov = vector<int>(n * 4, 0);
    }
    void push(int i, int L, int R) {
        if(cov[i]) {
            seg[i] = cov[i] * (R - L + 1);
            if(L < R) {
                cov[cl(i)] = cov[cr(i)] = cov[i];
                tag[cl(i)] = tag[cr(i)] = 0;
            }
            cov[i] = 0;
        }
        if(tag[i]) {
            seg[i] += tag[i] * (R - L + 1);
            if(L < R) {
                tag[cl(i)] += tag[i];
                tag[cr(i)] += tag[i];
            }
            tag[i] = 0;
        }
    }
    void pull(int i, int L, int R) {
        if(L >= R) return;
        int mid = L + R >> 1;
        push(cl(i), L, mid);
        push(cr(i), mid + 1, R);
        seg[i] = seg[cl(i)] + seg[cr(i)];
    }
    void build(vector<int>& arr, int i = 1, int L = 1,
        int R = -1) {
        if(R == -1) R = n;
        if(L == R) return void(seg[i] = arr[L]);
        int mid = L + R >> 1;
        build(arr, cl(i), L, mid);
        build(arr, cr(i), mid + 1, R);
        pull(i, L, R);
    }
    int query(int rL, int rR, int i = 1, int L = 1, int
        R = -1) {
        if(R == -1) R = n;
        push(i, L, R);
        if(rL <= L && R <= rR) return seg[i];
        int mid = L + R >> 1, ret = 0;
        if(rL <= mid) ret += query(rL, rR, cl(i), L,
            mid);
        if(mid < rR) ret += query(rL, rR, cr(i), mid +
            1, R);
        return ret;
    }
    void update(int rL, int rR, int val, int i = 1, int
        L = 1, int R = -1) {
        if(R == -1) R = n;
        push(i, L, R);
        if(rL <= L && R <= rR) return void(tag[i] = val);
        int mid = L + R >> 1;
        if(rL <= mid) update(rL, rR, val, cl(i), L, mid);
        if(mid < rR) update(rL, rR, val, cr(i), mid +
            1, R);
        pull(i, L, R);
    }
    void cover(int rL, int rR, int val, int i = 1, int
        L = 1, int R = -1) {

```

```

    if(R == -1) R = n;
    push(i, L, R);
    if(rL <= L && R <= rR) return void(cov[i] = val);
    int mid = L + R >> 1;
    if(rL <= mid) cover(rL, rR, val, cl(i), L, mid);
    if(mid < rR) cover(rL, rR, val, cr(i), mid + 1, R);
    pull(i, L, R);
}
};
/* Test Case:
4
1 2 3 4
5
2 1 3
1 1 3 1
2 1 3
1 1 4 1
2 1 4
*/

```

## 7.2 持久化 SMT

```

struct node{
    node *l, *r;
    int val;
};

vector<node*> ver;
int arr[MXN] = {0};

//0-base
struct SegmentTree{
    int n;
    node *root;
    void build(int _n){
        n = _n;
        root = build(0, n-1);
    }
    node* build(int L, int R){
        node *x = new node();
        if(L == R){ x->val = arr[L]; return x; }
        int mid = (L+R)/2;
        x->l = build(L, mid);
        x->r = build(mid + 1, R);
        x->val = x->l->val + x->r->val;
        return x;
    }
    int query(node *ro, int L, int R){return query(ro, 0, n-1, L, R);}
    int query(int L, int R){return query(root, 0, n-1, L, R);}
    int query(node *x, int L, int R, int recL, int recR){
        if(recL <= L && R <= recR) return x->val;
        int mid = (L+R)/2, res = 0;
        if(recL <= mid) res += query(x->l, L, mid, recL, recR);
        if(mid < recR) res += query(x->r, mid+1, R, recL, recR);
        return res;
    }
    void update(int pos, int v){update(root, 0, n-1, pos, v);}
    void update(node *x, int L, int R, int pos, int v){
        if(L == R){ x->val = v; arr[L] = v; return; }
        int mid = (L+R)/2;
        if(pos <= mid) update(x->l, L, mid, pos, v);
        else update(x->r, mid+1, R, pos, v);
        x->val = x->l->val + x->r->val;
    }
    node *update_ver(node *pre, int l, int r, int pos, int v){
        int v){
            node *x = new node(); //當前位置建立新節點
            if(l == r){
                x->val = v;
                return x;
            }
            int mid = (l+r)>>1;

```

```

        if(pos <= mid){ //更新左邊
            x->l = update_ver(pre->l, l, mid, pos, v); //左邊節點連向新節點
            x->r = pre->r; //右邊連到原本的右邊
        }
        else{ //更新右邊
            x->l = pre->l; //左邊連到原本的左邊
            x->r = update_ver(pre->r, mid+1, r, pos, v); //右邊節點連向新節點
        }
        x->val = x->l->val + x->r->val;
        return x;
    }
} seg;

void add_ver(int x, int v){ //修改位置 x 的值为 v
    ver.push_back(seg.update_ver(ver.back(), 0, seg.n-1, x, v));
}

```

## 7.3 Trie

```

struct trie{
    trie *nxt[26];
    int cnt; //紀錄有多少個字串以此節點結尾
    int sz; //有多少字串的前綴包括此節點
    trie():cnt(0),sz(0){
        memset(nxt,0,sizeof(nxt));
    }
};

trie *root = new trie(); //創建新的字典樹

void insert(string& s){
    trie *now = root; //每次從根結點出發
    for(auto i:s){
        now->sz++;
        if(now->nxt[i-'a'] == NULL){
            now->nxt[i-'a'] = new trie();
        }
        now = now->nxt[i-'a']; //走到下一個字母
    }
    now->cnt++; now->sz++;
}

int query_prefix(string& s){ //查詢有多少前綴為 s
    trie *now = root; //每次從根結點出發
    for(auto i:s){
        if(now->nxt[i-'a'] == NULL){
            return 0;
        }
        now = now->nxt[i-'a'];
    }
    return now->sz;
}

int query_count(string& s){ //查詢字串 s 出現次數
    trie *now = root; //每次從根結點出發
    for(auto i:s){
        if(now->nxt[i-'a'] == NULL){
            return 0;
        }
        now = now->nxt[i-'a'];
    }
    return now->cnt;
}

```

## 7.4 Treap (interval reverse)

```

//拆出[a,b]區間就如同下面所展示先使用splitByTh()拆出
//左右,再把左區間拆成l, m最後merge()回去
//反轉區間時又記得使用^=可以直接反轉01

//treap拆區間時從後面拆是因為這樣[a,b]的關係
//不用重新考慮·要是先拆前面b的位置會變成b-a+1
//0-base
//splitByTh(root,a-1,l,m);
//splitByTh(m,b-a+1,m,r);

```

```

mt19937 gen(chrono::steady_clock::now().
    time_since_epoch().count());
struct Treap {
    int key, pri, sz, tag, sum;
    Treap *L, *R;
    Treap( int val ) {
        sum=key=val, pri=gen(), sz=1, tag=0;
        L=R=NULL;
    };
};
int Size( Treap *a ) { return !a?0:a->sz;}
void pull( Treap *a ) {
    a->sz=Size(a->L)+Size(a->R)+1;
    a->sum=a->key;
    if( a->L ) a->sum+=a->L->sum;
    if( a->R ) a->sum+=a->R->sum;
}
void push( Treap *a ) {
    if( a && a->tag ) {
        swap(a->L, a->R);
        if( a->L ) a->L->tag^=1;
        if( a->R ) a->R->tag^=1;
        a->tag=0;
    }
}
Treap *merge(Treap *a, Treap *b) {
    if( !a || !b ) return a?a:b;
    push(a), push(b);
    if( a->pri > b->pri ) {
        a->R=merge(a->R, b);
        pull(a); return a;
    }
    b->L=merge(a, b->L);
    pull(b); return b;
}
void print(Treap *a) {
    if( !a ) return;
    push(a);
    print(a->L);
    cout.put(a->key);
    print(a->R);
}
Treap *buildTreap( int n, string& str ) {
    Treap *root=NULL;
    for( int i=0 ; i < n ; i++ )
        root=merge(root, new Treap(str[i]));
    return root;
}
void splitbyk( Treap *x, int k, Treap *&a, Treap *&b )
{
    if(!x) a=b=NULL;
    else if( x->key <= k ) {
        a=x;
        splitbyk(x->R, k, a->R, b);
        pull(a);
    }
    else {
        b=x;
        splitbyk(x->L, k, a, b->L);
        pull(b);
    }
}
void splitByTh( Treap *x, int k, Treap *&a, Treap *&b )
{
    if( !x ) { a=b=NULL; return; }
    push(x);
    if( Size(x->L)+1 <= k ) {
        a=x;
        splitByTh(x->R, k-Size(x->L)-1, a->R, b);
        pull(a);
    }
    else {
        b=x;
        splitByTh(x->L, k, a, b->L);
        pull(b);
    }
}
signed main() {
    string str;
    int n, m;
    cin>>n>>m>>str;
    Treap *root;
    root=buildTreap(n, str);

```

```

for( int i=0 ; i < m ; i++ ) {
    int a, b;
    cin>>a>>b;
    Treap *l, *m, *r;
    splitByTh(root, b, l, r);
    splitByTh(l, a-1, l, m);
    m->tag^=1;
    root=merge(l, merge(m, r));
}
print(root);
}

```

## 7.5 Treap (interval erase)

```

//區間移除使用bitset維護區間值
mt19937 gen(chrono::steady_clock::now().
    time_since_epoch().count());
struct Treap {
    char key;
    int pri, sz;
    bitset<128> tag;
    Treap *L, *R;
    Treap( char val ) {
        key=val, pri=gen(), sz=1;
        L=R=NULL;
        tag.set(key);
    };
};
int Size( Treap *a ) { return !a?0:a->sz;}
void pull( Treap *a ) {
    if( !a ) return;
    a->sz=Size(a->L)+Size(a->R)+1;
    a->tag=a->tag.reset();
    a->tag=a->tag.set(a->key);
    if( a->L ) a->tag|=a->L->tag;
    if( a->R ) a->tag|=a->R->tag;
}
Treap *merge( Treap *a, Treap *b ) {
    if( !a || !b ) return a?a:b;
    if( a->pri > b->pri ) {
        a->R=merge(a->R, b);
        pull(a);
        return a;
    }
    b->L=merge(a, b->L);
    pull(b);
    return b;
}
Treap *buildTreap( int n, string& str ) {
    Treap *root=NULL;
    for( int i=0 ; i < n ; i++ )
        root=merge(root, new Treap(str[i]));
    return root;
}
void print( Treap *a ) {
    if( !a ) return;
    print(a->L);
    cout.put(a->key);
    print(a->R);
}
void splitByTh( Treap *x, int k, Treap *&a, Treap *&b )
{
    if( !x ) { a=b=NULL; return; }
    if( Size(x->L)+1 <= k ) {
        a=x;
        splitByTh(x->R, k-Size(x->L)-1, a->R, b);
        pull(a);
    }
    else {
        b=x;
        splitByTh(x->L, k, a, b->L);
        pull(b);
    }
}
void erase( Treap *&x, char ch ) {
    if( !x || !x->tag.test(ch) ) return;
    erase(x->L, ch);
    erase(x->R, ch);
    if( x->key == ch ) {
        Treap *l=x->L, *r=x->R;
        x=NULL;
    }
}

```



```

    x=merge(l,r);
}
pull(x);
}
signed main() {
    string str;
    int n, m;
    cin>>n>>m>>str;
    Treap *root;
    root=buildTreap(n,str);
    for( int i=0 ; i < m ; i++ ) {
        char c;
        int a, b;
        cin>>a>>b>>c;
        Treap *l, *m, *r;
        if( !root || !root->tag.test(c) ) continue;
        splitByTh(root,b,l,r);
        splitByTh(l,a-1,l,m);
        if( m || !m->tag.test(c) ) erase(m,c);
        root=merge(l,merge(m,r));
    }
    print(root);
}

```

## 7.6 Link-Cut Tree

```

struct Splay {
    static Splay nil, mem[MEM], *pmem;
    Splay *ch[2], *f;
    int val, rev, size;
    Splay (int _val=-1) : val(_val), rev(0), size(1)
    { f = ch[0] = ch[1] = &nil; }
    bool isr()
    { return f->ch[0] != this && f->ch[1] != this; }
    int dir()
    { return f->ch[0] == this ? 0 : 1; }
    void setCh(Splay *c, int d){
        ch[d] = c;
        if (c != &nil) c->f = this;
        pull();
    }
    void push(){
        if( !rev ) return;
        swap(ch[0], ch[1]);
        if (ch[0] != &nil) ch[0]->rev ^= 1;
        if (ch[1] != &nil) ch[1]->rev ^= 1;
        rev=0;
    }
    void pull(){
        size = ch[0]->size + ch[1]->size + 1;
        if (ch[0] != &nil) ch[0]->f = this;
        if (ch[1] != &nil) ch[1]->f = this;
    }
} Splay::nil, Splay::mem[MEM], *Splay::pmem = Splay::
mem;
Splay *nil = &Splay::nil;
void rotate(Splay *x){
    Splay *p = x->f;
    int d = x->dir();
    if (!p->isr()) p->f->setCh(x, p->dir());
    else x->f = p->f;
    p->setCh(x->ch[!d], d);
    x->setCh(p, !d);
    p->pull(); x->pull();
}
vector<Splay*> splayVec;
void splay(Splay *x){
    splayVec.clear();
    for (Splay *q=x;; q=q->f){
        splayVec.push_back(q);
        if (q->isr()) break;
    }
    reverse(begin(splayVec), end(splayVec));
    for (auto it : splayVec) it->push();
    while (!x->isr()) {
        if (x->f->isr()) rotate(x);
        else if (x->dir()==x->f->dir())
            rotate(x->f), rotate(x);
        else rotate(x), rotate(x);
    }
}

```

```

}
int id(Splay *x) { return x - Splay::mem + 1; }
Splay* access(Splay *x){
    Splay *q = nil;
    for (;x!=nil;x=x->f){
        splay(x);
        x->setCh(q, 1);
        q = x;
    }
    return q;
}
void chroot(Splay *x){
    access(x);
    splay(x);
    x->rev ^= 1;
    x->push(); x->pull();
}
void link(Splay *x, Splay *y){
    access(x);
    splay(x);
    chroot(y);
    x->setCh(y, 1);
}
void cut_p(Splay *y) {
    access(y);
    splay(y);
    y->push();
    y->ch[0] = y->ch[0]->f = nil;
}
void cut(Splay *x, Splay *y){
    chroot(x);
    cut_p(y);
}
Splay* get_root(Splay *x) {
    access(x);
    splay(x);
    for(; x->ch[0] != nil; x = x->ch[0])
        x->push();
    splay(x);
    return x;
}
bool conn(Splay *x, Splay *y) {
    x = get_root(x);
    y = get_root(y);
    return x == y;
}
Splay* lca(Splay *x, Splay *y) {
    access(x);
    access(y);
    splay(x);
    if (x->f == nil) return x;
    else return x->f;
}
}

```

## 7.7 BIT

```

#define lowbit(x) (x&-x)
struct BIT {
    int n;
    vector<int> bit;
    BIT(int _n:n(_n), bit(n + 1) {}
    void update(int x, int val) {
        for(; x <= n; x += lowbit(x)) bit[x] += val;
    }
    void update(int L, int R, int val) {
        update(L, val), update(R + 1, -val);
    }
    int query(int x) {
        int res = 0;
        for(; x; x -= lowbit(x)) res += bit[x];
        return res;
    }
    int query(int L, int R) {
        return query(R) - query(L - 1);
    }
};

```

## 7.8 Black Magic

```

#include <bits/extc++.h>
using namespace __gnu_pbds;
typedef tree<int,null_type,less<int>,rb_tree_tag,
tree_order_statistics_node_update> set_t;
tree<int,null_type,less_equal<int>,rb_tree_tag,
tree_order_statistics_node_update> mt_t;
#include <ext/pb_ds/assoc_container.hpp>
typedef cc_hash_table<int,int> umap_t;
// gp_hash_table<int, int>
typedef priority_queue<int> heap;
#include<ext/rope>
using namespace __gnu_cxx;
int main(){
    // Insert some entries into s.
    set_t s; s.insert(12); s.insert(505);
    // The order of the keys should be: 12, 505.
    assert(*s.find_by_order(0) == 12);
    assert(*s.find_by_order(3) == 505);
    // The order of the keys should be: 12, 505.
    assert(s.order_of_key(12) == 0);
    assert(s.order_of_key(505) == 1);
    // Erase an entry.
    s.erase(12);
    // The order of the keys should be: 505.
    assert(*s.find_by_order(0) == 505);
    // The order of the keys should be: 505.
    assert(s.order_of_key(505) == 0);
    // if we want to delete less_equal tag tree
    mt_t.erase(mt_t.find_by_order(mt_t.order_of_key(val))
    );

    heap h1 , h2; h1.join( h2 );

    rope<char> r[ 2 ];
    r[ 1 ] = r[ 0 ]; // persistenet
    string t = "abc";
    r[ 1 ].insert( 0 , t.c_str() );
    r[ 1 ].erase( 1 , 1 );
    cout << r[ 1 ].substr( 0 , 2 );
}

```

## 8 Others

### 8.1 SOS dp

```

for(int i = 0; i<(1<<N); ++i)
    F[i] = A[i];
for(int i = 0; i < N; ++i) for(int mask = 0; mask < (1<<N); ++mask){
    if(mask & (1<<i))
        F[mask] += F[mask^(1<<i)];
}

```

### 8.2 De Bruijn sequence

```

// return cyclic array of length k^n such that every
// array of length n using 0~k-1 appears as a subarray.
vector<int> DeBruijn(int k,int n){
    if(k==1) return {0};
    vector<int> aux(k*n),res;
    function<void(int,int)> f=[&](int t,int p)->void{
        if(t>n){ if(n%p==0)
            for(int i=1;i<=p;++i) res.push_back(aux[i]);
        }else{
            aux[t]=aux[t-p]; f(t+1,p);
            for(aux[t]=aux[t-p]+1;aux[t]<k;++aux[t]) f(t+1,t)
        }
    };
    f(1,1); return res;
}

```

### 8.3 CDQ 分治

```

//cdq分治使用的結構u, v, w為排序物的三個維度
//ans記錄了有幾項三維都小於等於自己
//cnt記錄了相同物有幾個。在使用cdq之前必先去重。
//並且將相同元素紀錄至cnt中。可使用map來做到這步
//cdq使用的BIT就是普通求和的BIT。大小就開維度的
//值域範圍。若值域大於2e6則要先進行離散化
struct triple {int u, v, w, ans, cnt;};
BIT *bt;
void cdq(int L, int R, vector<triple>& arr) {
    if(R - L <= 1) return;
    int mid = L + R >> 1;
    vector<triple> temp;
    cdq(L, mid, arr), cdq(mid, R, arr);
    for(int i = L, j = mid; i < mid || j < R; ) {
        for(; i < mid && (j >= R || arr[i].v <= arr[j].v);
            i++) {
            bt->update(arr[i].w, arr[i].cnt);
            temp.push_back(arr[i]);
        }
        if(j < R) {
            arr[j].ans += bt->query(arr[j].w);
            temp.push_back(arr[j]);
            j++;
        }
    }
    for(int i = L; i < mid; i++)
        bt->update(arr[i].w, -arr[i].cnt);
    copy(temp.begin(), temp.end(), arr.begin() + L);
}
signed main()
{
    // n 個數 k 值域範圍
    int n, k;
    cin >> n >> k;
    map<tuple<int, int, int>, int> mp;
    vector<int> res(n, 0);
    vector<triple> arr;
    bt = new BIT(k + 1);
    for(int i = 0; i < n; i++) {
        int x, y, z;
        cin >> x >> y >> z;
        mp[{x, y, z}]++;
    }
    for(auto t : mp)
        arr.push_back({get<0>(t.first), get<1>(t.first),
            get<2>(t.first), 0, t.second});
    cdq(0, arr.size(), arr);
    for(auto &[x,y,z,a,b] : arr) res[a + b - 1] += b;
    for(int i : res) cout << i << '\n';
}

```

### 8.4 3D LIS

```

#define lowbit(x) (x&-x)
const int MAXN=1e5+5;
struct BIT {
    int n;
    vector<int> bit;
    BIT( int _n ):n(_n), bit(_n+1,0) {}
    int query( int x ) {
        int res=0;
        for(; x > 0 ; x-=lowbit(x) ) res=max(res,bit[x]);
        return res;
    }
    void update( int x, int val ) {
        for(; x <= n ; x+=lowbit(x) ) {
            if( val < 0 ) bit[x]=0;
            else bit[x]=max(bit[x],val);
        }
    }
}bt(MAXN);
struct triple {
    int u, v, w, ans, cnt;
    bool operator<( triple b ) { return u<b.u; }
};
bool cmp( triple a, triple b ) {return a.v<b.v;}
void cdq( int L, int R, vector<triple>& arr ) {
    if( R-L <= 1 ) return;
    int mid=L+R>>1;

```

```

cdq(L,mid,arr);
sort(arr.begin()+L,arr.begin()+mid,cmp);
sort(arr.begin()+mid,arr.begin()+R,cmp);
for( int i=L, j=mid ; i < mid || j < R ; ) {
    for( ; i < mid && ( j >= R || arr[i].v < arr[j].v )
        ; i++ ) bt.update(arr[i].w,arr[i].ans);
    if( j < R ) {
        arr[j].ans=max(bt.query(arr[j].w-1)+1,arr[j].ans);
        j++;
    }
}
for( int i=L ; i < mid ; i++ ) bt.update(arr[i].w,-1);
sort(arr.begin()+L,arr.begin()+R);
cdq(mid,R,arr);
}
signed main()
{
    ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0);
    ;
    int n, res=0;
    cin>>n;
    vector<int> ls;
    vector<triple> arr;
    for( int i=0 ; i < n ; i++ ) {
        int a, b;
        cin>>a>>b;
        arr.push_back({i,a,b,1,1}); //{第一維,第二維,第三維,
            答案,數量}
        ls.push_back(b);
    }
    sort(ls.begin(),ls.end());
    ls.resize(unique(ls.begin(),ls.end())-ls.begin());
    for( auto &t : arr ) t.w=lower_bound(ls.begin(),ls.
        end(),t.w)-ls.begin()+1;
    n=arr.size();
    cdq(0,n,arr);
    for( int i=0 ; i < n ; i++ ) res=max(res,arr[i].ans);
    cout<<res<<"\n";
}

```

## 8.5 Ternary Search

```

while(L <= R) {
    int ml = L + (R - L) / 3, mr = R - (R - L) / 3;
    if(L == R) return L;
    else if( checker(ml) < checker(mr) ) L = ml + 1;
    else R = mr - 1;
}

```

## 8.6 Max Subrectangle

```

const int N = 1e5+5;
int n, a[N],l[N], r[N];
long long ans;
int main() {
    while (cin>>n) {
        ans = 0;
        for (int i = 1; i <= n; i++) cin>>a[i], l[i] = r[i]
            = i;
        for (int i = 1; i <= n; i++)
            while (l[i] > 1 && a[i] <= a[l[i] - 1]) l[i] = l[
                l[i] - 1];
        for (int i = n; i >= 1; i--)
            while (r[i] < n && a[i] <= a[r[i] + 1]) r[i] = r[
                r[i] + 1];
        for (int i = 1; i <= n; i++)
            ans = max(ans, (long long)(r[i] - l[i] + 1) * a[i
                ]);
        cout<<ans<<"\n";
    }
}

```

## 8.7 Maximal Rectangle

```

const int MXN = 300;
int maximalRectangle(vector<vector<char>>& matrix) {
    int a[MXN][], l[MXN][], r[MXN][];
    int n = matrix.size(), m = matrix[0].size(), ans =
        0;
    for(int i = 1; i <= n; i++) {
        for(int j = 1; j <= m; j++) l[j] = r[j] = j;
        char c;
        for(int j = 1; j <= m; j++) { //對每一個直行做
            統計·若是上一個a[j]也是1則會變成2
            c = matrix[i - 1][j - 1];
            if (c == '1') a[j]++;
            else if (c == '0') a[j] = 0;
        }
        for(int j = 1; j <= m; j++) while(l[j] != 1 &&
            a[l[j] - 1] >= a[j]) l[j] = l[l[j] - 1];
        for(int j = m; j >= 1; j--) while(r[j] != m &&
            a[r[j] + 1] >= a[j]) r[j] = r[r[j] + 1];
        for(int j = 1; j <= m; j++) ans = max(ans, (r[j
            ] - l[j] + 1) * a[j]);
    }
    return ans;
}

```

## 8.8 p-Median

```

for(int i = 1; i <= n; i++) {
    for(int j = i; j <= n; j++) {
        dis[i][j] = 0;
        for(int k = i; k <= j; k++) dis[i][j] += abs(arr[k]
            - arr[i + j >> 1]);
        if(i == 1) dp[i][j] = dis[i][j];
    }
}
for(int i = 2; i <= p; i++) {
    for(int j = i; j <= n; j++) {
        dp[i][j] = INF;
        for(int k = i; k <= j; k++) {
            if(dp[i][j] > dp[i - 1][k - 1] + dis[k][j]) {
                dp[i][j] = dp[i - 1][k - 1] + dis[k][j];
                fa[i][j] = k - 1;
            }
        }
    }
}
}

```

## 8.9 Tree Knapsack

```

int dfs(int u) {
    int p = 1;
    dp[u][1] = s[u];
    for (int v : edge[u]) {
        int siz = dfs(v);
        for (int i = min(p, m + 1); i; i--)
            for (int j = 1; j <= siz && i + j <= m + 1; j++)
                dp[u][i + j] = max(dp[u][i + j], dp[u][i] + dp[
                    v][j]);
        p += siz;
    }
    return p;
}

```

## 8.10 AC-Automaton

```

// 1-based
// n is the number of patterns
struct Automaton {
    static const int MXN = 1e6;
    int n, cnt, vis[MXN], rev[MXN], indeg[MXN], ans[MXN]
        [];
    queue<int> q;
    struct trie_node {
        vector<int> son;
        int fail, flag, ans;
        trie_node(): son(27), fail(0), flag(0) {}
    };
};

```

```
} trie[MXN];
void init(int _n) {
    n = _n, cnt = 1;
    for (int i = 1; i <= n; i++) vis[i] = 0;
}
// insert a string s with number num
// num is the index of the pattern
void insert(string s, int num) {
    int u = 1, len = s.size();
    for (int i = 0; i < len; i++) {
        int v = s[i] - 'a';
        if (!trie[u].son[v]) trie[u].son[v] = ++cnt;
        u = trie[u].son[v];
    }
    if (!trie[u].flag) trie[u].flag = num;
    rev[num] = trie[u].flag;
}
void getfail() {
    for (int i = 0; i < 26; i++) trie[0].son[i] = 1;
    q.push(1);
    trie[1].fail = 0;
    while (q.size()) {
        int u = q.front(); q.pop();
        int Fail = trie[u].fail;
        for (int i = 0; i < 26; i++) {
            int v = trie[u].son[i];
            if (!v) {
                trie[u].son[i] = trie[Fail].son[i];
                continue;
            }
            trie[v].fail = trie[Fail].son[i];
            indeg[trie[Fail].son[i]]++;
            q.push(v);
        }
    }
}
void topu() {
    for (int i = 1; i <= cnt; i++)
        if (!indeg[i]) q.push(i);
    while (q.size()) {
        int fr = q.front(); q.pop();
        vis[trie[fr].flag] = trie[fr].ans;
        int u = trie[fr].fail;
        trie[u].ans += trie[fr].ans;
        if (!--indeg[u]) q.push(u);
    }
}
void query(string &s) {
    int u = 1, len = s.size();
    for (int i = 0; i < len; i++) u = trie[u].son[s[i] - 'a'], trie[u].ans++;
}
void solve(string &s) {
    getfail();
    query(s);
    topu();
    for (int i = 1; i <= n; i++) ans[i] = vis[rev[i]];
}
} AC;
```

