Contents

1 Basic

1.1 /.vimrc

```
set nu ai si cin ts=4 sw=4 sts=4 expandtab

nmap #2 :! gedit %<.in %<*.in &<CR>
nmap #4 :! date > %<.pt; cat -n % > %<.pt; lpr %<.pt <CR>
nmap #9 :! clear ; g++ -std=c++11 -O2 -D AC -o %<.out % ; for i in %<*.in; do echo $i; ./%<.out < $i; echo ""; done <CR>
nmap #0 :! clear ; g++ -std=c++11 -O2 -D AC -o %<.out % ; ./%<.out <CR>
nmap <C-I> :! read -p "CASE:" CASE; gedit %<_$CASE.in <CR>
```

1.2 default code

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

int main(){
#ifndef AC
  freopen("","r",stdin);
#endif
  ios_base::sync_with_stdio(0);
  cin.tie(false);
}
```

1.3 debug list

```
模板要記得 init
priority_queue 要清空
把邊界條件都加入測資
邊界條件 (過程溢位, 題目數據範圍), 會不會爆 long long
是否讀錯題目, 想不到時可以自己讀一次題目
環狀or凸包問題一定要每種都算n次
比較容易有問題的地方換人寫
注意公式有沒有推錯或抄錯
精度誤差 sqrt(大大的東西) + EPS
測試 %lld or %I64d
喇分 random_suffle 隨機演算法
用long long int記得要算MLE
```

2 Geometry

2.1 2D Point Template

```
typedef double Double;
struct Point {
  Double x,y;

  bool operator < (const Point &b)const{
    //return tie(x,y) < tie(b.x,b.y);
    //return atan2(y,x) < atan2(b.y,b.x);
    assert(0 && "choose compare");
  }
  Point operator + (const Point &b)const{
    return (Point){x+b.x,y+b.y};
  }
  Point operator - (const Point &b)const{
    return (Point){x-b.x,y-b.y};
  }
  Point operator * (const Double &d)const{
    return Point(d*x,d*y);
  }
  Double operator * (const Point &b)const{
    return x*b.x + y*b.y;
  }
  Double operator % (const Point &b)const{
    return x*b.y - y*b.x;
  }
  friend Double abs2(const Point &p){
    return p.x*p.x + p.y*p.y;
  }
  friend Double abs(const Point &p){
    return sqrt( abs2(p) );
  }
};
typedef Point Vector;
```

```
struct Line{
  Point P; Vector v;
  bool operator < (const Line &b)const{
    return atan2(v.y,v.x) < atan2(b.v.y,b.v.x);
  }
};
```

2.2 外心 Circumcentre

```
#include "2Dpoint.cpp"

Point circumcentre(Point &p0, Point &p1, Point &p2){
  Point a = p1-p0;
  Point b = p2-p0;
  Double c1 = abs2(a)*0.5;
  Double c2 = abs2(b)*0.5;
  Double d = a % b;
  Double x = p0.x + ( c1*b.y - c2*a.y ) / d;
  Double y = p0.y + ( c2*a.x - c1*b.x ) / d;
  return {x,y};
}
```

2.3 Convex Hull

```
#include "2Dpoint.cpp"

// retunr H, 第一個點會在 H 出現兩次
void ConvexHull(vector<Point> &P, vector<Point> &H){
    int n = P.size(), m=0;
    sort(P.begin(),P.end());
    H.clear();

    for (int i=0; i<n; i++){
        while (m>=2 && (P[i]-H[m-2]) % (H[m-1]-H[m-2])
            <0)H.pop_back(), m--;
        H.push_back(P[i]), m++;
    }

    for (int i=n-2; i>=0; i--){
        while (m>=2 && (P[i]-H[m-2]) % (H[m-1]-H[m-2])
            <0)H.pop_back(), m--;
        H.push_back(P[i]), m++;
    }
}
```

2.4 半平面交

```
bool OnLeft(const Line& L,const Point& p){
  return Cross(L.v,p-L.P)>0;
}
Point GetIntersection(Line a,Line b){
  Vector u = a.P-b.P;
  Double t = Cross(b.v,u)/Cross(a.v,b.v);
  return a.P + a.v*t;
}
int HalfplaneIntersection(Line* L,int n,Point* poly){
  sort(L,L+n);

  int first,last;
  Point *p = new Point[n];
  Line *q = new Line[n];
  q[first=last=0] = L[0];
  for(int i=1;i<n;i++){
    while(first < last && !OnLeft(L[i],p[last-1])) last
        --;
    while(first < last && !OnLeft(L[i],p[first])) first
        ++;
    q[++last]=L[i];
    if(fabs(Cross(q[last].v,q[last-1].v))<EPS){
      last--;
      if(OnLeft(q[last],L[i].P)) q[last]=L[i];
    }
    if(first < last) p[last-1]=GetIntersection(q[last
        -1],q[last]);
  }
  while(first<last && !OnLeft(q[first],p[last-1])) last
      --;
  if(last-first<=1) return 0;
  p[last]=GetIntersection(q[last],q[first]);

  int m=0;
  for(int i=first;i<=last;i++) poly[m++]=p[i];
  return m;
}
```

2.5 圓交

```
vector<Double> interCircle(Double o1, Double r1, Double
     o2, Double r2) {
  Double d2 = abs2(o1 - o2);
  Double d = sqrt(d2);
  if (d < fabs(r1-r2) || r1+r2 < d) return {};
  Double u = 0.5*(o1+o2) + ((r2*r2-r1*r1)/(2.0*d2))*(o1
      -o2);
  Double A = sqrt((r1+r2+d) * (r1-r2+d) * (r1+r2-d) *
      (-r1+r2+d));
  Double v = A / (2.0*d2) * Double(o1.S-o2.S, -o1.F+o2.
      F);
  return {u+v, u-v};
}
```

2.6 線段交

```
Point interPnt(Point p1, Point p2, Point q1, Point q2,
    bool &res){
  Double f1 = cross(p2, q1, p1);
  Double f2 = -cross(p2, q2, p1);
  Double f = (f1 + f2);

  if(fabs(f) < EPS) {
    res = false;
    return {};
    }

  res = true;
  return (f2 / f) * q1 + (f1 / f) * q2;
}
```

2.7 Smallest Covering Circle

```
#include "circumcentre.cpp"
pair<Point,Double> SmallestCircle(int n, Point _p[]){
  Point *p = new Point[n];
  memcpy(p,_p,sizeof(Point)*n);
  random_shuffle(p,p+n);

  Double r2=0;
  Point cen;
  for (int i=0; i<n; i++){
    if ( abs2(cen-p[i]) <= r2)continue;
    cen = p[i], r2=0;
    for (int j=0; j<i; j++){
      if ( abs2(cen-p[j]) <= r2)continue;
      cen = (p[i]+p[j])*0.5;
      r2 = abs2(cen-p[i]);
      for (int k=0; k<j; k++){
        if ( abs2(cen-p[k]) <= r2)continue;
        cen = circumcentre(p[i],p[j],p[k]);
        r2 = abs2(cen-p[k]);
      }
    }
  }

  delete[] p;
  return {cen,r2};
}
// auto res = SmallestCircle(,);
```

3 Mathmatics

3.1 ax+by=gcd(a,b)

```
typedef pair<int, int> pii;
pii extgcd(int a, int b){
  if(b == 0) return make_pair(1, 0);
  else{
    int p = a / b;
    pii q = extgcd(b, a % b);
    return make_pair(q.second, q.first - q.second * p);
  }
}
```

3.2 BigInt

```
struct Bigint{
  static const int LEN = 60;
  static const int BIGMOD = 10000;
  int s;
  int vl, v[LEN];
  //  vector<int> v;
  Bigint() : s(1) { vl = 0; }
  Bigint(long long a) {
    s = 1; vl = 0;
    if (a < 0) { s = -1; a = -a; }
    while (a) {
      push_back(a % BIGMOD);
      a /= BIGMOD;
    }
  }
  Bigint(string str) {
    s = 1; vl = 0;
    int stPos = 0, num = 0;
    if (!str.empty() && str[0] == '-') {
      stPos = 1;
      s = -1;
    }
    for (int i=SZ(str)-1, q=1; i>=stPos; i--) {
      num += (str[i] - '0') * q;
      if ((q *= 10) >= BIGMOD) {
        push_back(num);
        num = 0; q = 1;
      }
    }
    if (num) push_back(num);
  }
  int len() const { return vl; /* return SZ(v); */ }
  bool empty() const { return len() == 0; }
  void push_back(int x) { v[vl++] = x; /* v.PB(x); */ }
  void pop_back() { vl--; /* v.pop_back(); */ }
  int back() const { return v[vl-1]; /* return v.back()
      ; */ }
  void n() { while (!empty() && !back()) pop_back(); }
  void resize(int nl) {
    vl = nl; fill(v, v+vl, 0);
    //    v.resize(nl); // fill(ALL(v), 0);
  }
  void print() const {
    if (empty()) { putchar('0'); return; }
    if (s == -1) putchar('-');
    printf("%d", back());
    for (int i=len()-2; i>=0; i--) printf("%.4d",v[i]);
  }
```

```
friend std::ostream& operator << (std::ostream& out,
    const Bigint &a) {
  if (a.empty()) { out << "0"; return out; }
  if (a.s == -1) out << "-";
  out << a.back();
  for (int i=a.len()-2; i>=0; i--) {
    char str[10];
    snprintf(str, 5, "%.4d", a.v[i]);
    out << str;
  }
  return out;
}
int cp3(const Bigint &b)const {
  if (s != b.s) return s > b.s ? 1 : -1;
  if (s == -1) return -(-*this).cp3(-b);
  if (len() != b.len()) return len()>b.len()?1:-1;
  for (int i=len()-1; i>=0; i--)
    if (v[i]!=b.v[i]) return v[i]>b.v[i]?1:-1;
  return 0;
}
bool operator < (const Bigint &b)const{ return cp3(b)
    ==-1; }
bool operator <= (const Bigint &b)const{ return cp3(b
    )<=0; }
bool operator >= (const Bigint &b)const{ return cp3(b
    )>=0; }
bool operator == (const Bigint &b)const{ return cp3(b
    )==0; }
bool operator != (const Bigint &b)const{ return cp3(b
    )!=0; }
bool operator > (const Bigint &b)const{ return cp3(b)
    ==1; }
Bigint operator - () const {
  Bigint r = (*this);
  r.s = -r.s;
  return r;
}
Bigint operator + (const Bigint &b) const {
  if (s == -1) return -(-(*this)+(-b));
  if (b.s == -1) return (*this)-(-b);
  Bigint r;
  int nl = max(len(), b.len());
  r.resize(nl + 1);
  for (int i=0; i<nl; i++) {
    if (i < len()) r.v[i] += v[i];
    if (i < b.len()) r.v[i] += b.v[i];
    if(r.v[i] >= BIGMOD) {
      r.v[i+1] += r.v[i] / BIGMOD;
      r.v[i] %= BIGMOD;
    }
  }
  r.n();
  return r;
}
Bigint operator - (const Bigint &b) const {
  if (s == -1) return -(-(*this)-(-b));
  if (b.s == -1) return (*this)+(-b);
  if ((*this) < b) return -(b-(*this));
  Bigint r;
  r.resize(len());
  for (int i=0; i<len(); i++) {
    r.v[i] += v[i];
    if (i < b.len()) r.v[i] -= b.v[i];
    if (r.v[i] < 0) {
      r.v[i] += BIGMOD;
      r.v[i+1]--;
    }
  }
  r.n();
  return r;
}
Bigint operator * (const Bigint &b) {
  Bigint r;
  r.resize(len() + b.len() + 1);
  r.s = s * b.s;
  for (int i=0; i<len(); i++) {
    for (int j=0; j<b.len(); j++) {
        r.v[i+j] += v[i] * b.v[j];
        if(r.v[i+j] >= BIGMOD) {
          r.v[i+j+1] += r.v[i+j] / BIGMOD;
          r.v[i+j] %= BIGMOD;
        }
      }
    }
    r.n();
    return r;
  }
  Bigint operator / (const Bigint &b) {
    Bigint r;
    r.resize(max(1, len()-b.len()+1));
    int oriS = s;
    Bigint b2 = b; // b2 = abs(b)
    s = b2.s = r.s = 1;
    for (int i=r.len()-1; i>=0; i--) {
      int d=0, u=BIGMOD-1;
      while(d<u) {
        int m = (d+u+1)>>1;
        r.v[i] = m;
        if((r*b2) > (*this)) u = m-1;
        else d = m;
      }
      r.v[i] = d;
    }
    s = oriS;
    r.s = s * b.s;
    r.n();
    return r;
  }
  Bigint operator % (const Bigint &b) {
    return (*this)-(*this)/b*b;
  }
};
```

3.3 FFT

```
const double pi = atan(1.0)*4;
struct Complex {
  double x,y;
  Complex(double _x=0,double _y=0)
    :x(_x),y(_y) {}
  Complex operator + (Complex &tt) { return Complex(x
    +tt.x,y+tt.y); }
  Complex operator - (Complex &tt) { return Complex(x
    -tt.x,y-tt.y); }
  Complex operator * (Complex &tt) { return Complex(x
    *tt.x-y*tt.y,x*tt.y+y*tt.x); }
};
void fft(Complex *a, int n, int rev) {
  // n是大于等于相乘的两个数组长度的2的幂次
  // 从0开始表示长度，对a进行操作
  // rev==1进行DFT，==-1进行IDFT
  for (int i = 1,j = 0; i < n; ++ i) {
    for (int k = n>>1; k > (j^=k); k >>= 1);
    if (i<j) std::swap(a[i],a[j]);
  }
  for (int m = 2; m <= n; m <<= 1) {
    Complex wm(cos(2*pi*rev/m),sin(2*pi*rev/m));
    for (int i = 0; i < n; i += m) {
      Complex w(1.0,0.0);
      for (int j = i; j < i+m/2; ++ j) {
        Complex t = w*a[j+m/2];
        a[j+m/2] = a[j] - t;
        a[j] = a[j] + t;
        w = w * wm;
      }
    }
  }
  if (rev==-1) {
    for (int i = 0; i < n; ++ i) a[i].x /= n,a[i].y
      /= n;
  }
}
```

3.4 FWHT

```
// FWHT template

const int MAXN = 1<<20;

void FWHT(int a[], int l=0, int r=MAXN-1){
  if (l==r)return;

  int mid = (l+r)>>1+1, n = r-l+1;
  FWHT(a,l,mid-1);
  FWHT(a,mid,r);

  for (int i=0; i<(n>>1); i++){
    int a1=a[l+i], a2=a[mid+i];
    a[l+i] = a1+a2;
    a[mid+i] = a1-a2;
  }
}
```

3.5 GaussElimination

```
// by bcw_codebook

const int MAXN = 300;
const double EPS = 1e-8;

int n;
double A[MAXN][MAXN];

void Gauss() {
  for(int i = 0; i < n; i++) {
    bool ok = 0;
    for(int j = i; j < n; j++) {
      if(fabs(A[j][i]) > EPS) {
        swap(A[j], A[i]);
        ok = 1;
        break;
      }
    }
    if(!ok) continue;

    double fs = A[i][i];
    for(int j = i+1; j < n; j++) {
      double r = A[j][i] / fs;
      for(int k = i; k < n; k++) {
        A[j][k] -= A[i][k] * r;
      }
    }
  }
}
```

3.6 Inverse

```
int inverse[100000];
void invTable(int b, int p) {
  inverse[1] = 1;
  for( int i = 2; i <= b; i++ ) {
    inverse[i] = (long long)inverse[p%i] * (p-p/i) % p;
  }
}

int inv(int b, int p) {
  return b == 1 ? 1 : ((long long)inv(p % b, p) * (p-p/
    b) % p);
}
```

3.7 LinearPrime

```
const int MAXP = 100; //max prime
vector<int> P;  // primes
void build_prime(){
  static bitset<MAXP> ok;
  int np=0;
  for (int i=2; i<MAXP; i++){
    if (ok[i]==0)P.push_back(i), np++;
    for (int j=0; j<np && i*P[j]<MAXP; j++){
      ok[ i*P[j] ] = 1;
      if ( i%P[j]==0 )break;
    }
  }
}
```

3.8 Pollard’ s rho

```
// from PEC
// does not work when n is prime
Int f(Int x, Int mod){
  return add(mul(x, x, mod), 1, mod);
}
Int pollard_rho(Int n) {
  if ( !(n & 1) ) return 2;
  while (true) {
    Int 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;
  }
}
```

3.9 數論基本工具

```
Int POW(Int a, Int n, Int mod){
  Int re=1;
  while (n>0){
    if (n&1LL) re = re*a%mod;
    a = a*a%mod;
    n>>=1;
  }
  return re;
}

Int C(Int n, Int m){
  if (m<0 || m>n)return 0;
  return J[n] * inv(J[m]*J[n-m]%MOD) %MOD;
}
```

3.10 Mobius

```
void mobius() {
    fill(isPrime, isPrime + MAXN, 1);
    mu[1] = 1, num = 0;
    for (int i = 2; i < MAXN; ++i) {
        if (isPrime[i]) primes[num++] = i, mu[i] = -1;
        static int d;
        for (int j = 0; j < num && (d = i * primes[j])
            < MAXN; ++j) {
            isPrime[d] = false;
            if (i % primes[j] == 0) {
                mu[d] = 0; break;
            } else mu[d] = -mu[i];
        }
    }
}
```

3.11 Simplex

```
// Two-phase simplex algorithm for solving linear
    programs of the form
//
//     maximize     c^T x
//     subject to   Ax <= b
//                  x >= 0
//
// INPUT: A -- an m x n matrix
//        b -- an m-dimensional vector
//        c -- an n-dimensional vector
//        x -- a vector where the optimal solution will
     be stored
//
// OUTPUT: value of the optimal solution (infinity if
    unbounded
//         above, nan if infeasible)
//
// To use this code, create an LPSolver object with A,
    b, and c as
// arguments.  Then, call Solve(x).

#include <iostream>
#include <iomanip>
#include <vector>
#include <cmath>
#include <limits>

using namespace std;

typedef long double DOUBLE;
typedef vector<DOUBLE> VD;
typedef vector<VD> VVD;
typedef vector<int> VI;

const DOUBLE EPS = 1e-9;

struct LPSolver {
  int m, n;
  VI B, N;
  VVD D;

  LPSolver(const VVD &A, const VD &b, const VD &c) :
    m(b.size()), n(c.size()), N(n + 1), B(m), D(m + 2,
        VD(n + 2)) {
    for (int i = 0; i < m; i++) for (int j = 0; j < n;
        j++) D[i][j] = A[i][j];
    for (int i = 0; i < m; i++) { B[i] = n + i; D[i][n]
         = -1; D[i][n + 1] = b[i]; }
    for (int j = 0; j < n; j++) { N[j] = j; D[m][j] = -
        c[j]; }
    N[n] = -1; D[m + 1][n] = 1;
  }

  void Pivot(int r, int s) {
    double inv = 1.0 / D[r][s];
    for (int i = 0; i < m + 2; i++) if (i != r)
      for (int j = 0; j < n + 2; j++) if (j != s)
        D[i][j] -= D[r][j] * D[i][s] * inv;
    for (int j = 0; j < n + 2; j++) if (j != s) D[r][j]
         *= inv;
    for (int i = 0; i < m + 2; i++) if (i != r) D[i][s]
         *= -inv;
    D[r][s] = inv;
    swap(B[r], N[s]);
  }

  bool Simplex(int phase) {
    int x = phase == 1 ? m + 1 : m;
    while (true) {
      int s = -1;
      for (int j = 0; j <= n; j++) {
        if (phase == 2 && N[j] == -1) continue;
        if (s == -1 || D[x][j] < D[x][s] || D[x][j] ==
            D[x][s] && N[j] < N[s]) s = j;
      }
      if (D[x][s] > -EPS) return true;
      int r = -1;
      for (int i = 0; i < m; i++) {
        if (D[i][s] < EPS) continue;
        if (r == -1 || D[i][n + 1] / D[i][s] < D[r][n +
             1] / D[r][s] ||
          (D[i][n + 1] / D[i][s]) == (D[r][n + 1] / D[r
              ][s]) && B[i] < B[r]) r = i;
      }
      if (r == -1) return false;
      Pivot(r, s);
    }
  }

  DOUBLE Solve(VD &x) {
    int r = 0;
    for (int i = 1; i < m; i++) if (D[i][n + 1] < D[r][
        n + 1]) r = i;
    if (D[r][n + 1] < -EPS) {
      Pivot(r, n);
      if (!Simplex(1) || D[m + 1][n + 1] < -EPS) return
           -numeric_limits<DOUBLE>::infinity();
      for (int i = 0; i < m; i++) if (B[i] == -1) {
        int s = -1;
        for (int j = 0; j <= n; j++)
          if (s == -1 || D[i][j] < D[i][s] || D[i][j]
              == D[i][s] && N[j] < N[s]) s = j;
        Pivot(i, s);
      }
    }
    if (!Simplex(2)) return numeric_limits<DOUBLE>::
        infinity();
    x = VD(n);
    for (int i = 0; i < m; i++) if (B[i] < n) x[B[i]] =
         D[i][n + 1];
    return D[m][n + 1];
  }
};

int main() {

  const int m = 4;
  const int n = 3;
  DOUBLE _A[m][n] = {
    { 6, -1, 0 },
    { -1, -5, 0 },
    { 1, 5, 1 },
    { -1, -5, -1 }
  };
  DOUBLE _b[m] = { 10, -4, 5, -5 };
  DOUBLE _c[n] = { 1, -1, 0 };

  VVD A(m);
  VD b(_b, _b + m);
  VD c(_c, _c + n);
  for (int i = 0; i < m; i++) A[i] = VD(_A[i], _A[i] +
      n);

  LPSolver solver(A, b, c);
  VD x;
  DOUBLE value = solver.Solve(x);

  cerr << "VALUE: " << value << endl; // VALUE: 1.29032
  cerr << "SOLUTION:"; // SOLUTION: 1.74194 0.451613 1
  for (size_t i = 0; i < x.size(); i++) cerr << " " <<
      x[i];
  cerr << endl;
  return 0;
}
```

3.12 SG

```
Anti Nim (取走最後一個石子者敗)
先手必勝 if and only if
1. 「所有」堆的石子數都為 1 且遊戲的 SG 值為 0。
2. 「有些」堆的石子數大於 1 且遊戲的 SG 值不為 0。

------------------------------------------------------
Anti-SG (決策集合為空的遊戲者贏)

定義 SG 值為 0 時，遊戲結束，
則先手必勝 if and only if
1. 遊戲中沒有單一遊戲的 SG 函數大於 1 且遊戲的 SG 函數
    為 0。
2. 遊戲中某個單一遊戲的 SG 函數大於 1 且遊戲的 SG 函數
    不為 0。

------------------------------------------------------
Sprague-Grundy

1. 雙人、回合制
2. 資訊完全公開
3. 無隨機因素
4. 可在有限步內結束
5. 沒有和局
6. 雙方可採取的行動相同

SG(S) 的值為 0：後手(P)必勝
不為 0：先手(N)必勝

int mex(set S) {
  // find the min number >= 0 that not in the S
  // e.g. S = {0, 1, 3, 4} mex(S) = 2
}

state = []
int SG(A) {
  if (A not in state) {
    S = sub_states(A)
    if( len(S) > 1 ) state[A] = reduce(operator.xor, [
        SG(B) for B in S])
    else state[A] = mex(set(SG(B) for B in next_states(
        A)))
  }
  return state[A]
}
```

3.13 Theorem

```
/*
Lucas's Theorem
  For non-negative integer n,m and prime P,
  C(m,n) mod P = C(m/M,n/M) * C(m%M,n%M) mod P
  = mult_i ( C(m_i,n_i) )
  where m_i is the i-th digit of m in base P.
------------------------------------------------------
Pick's Theorem
  A = i + b/2 - 1
------------------------------------------------------
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)
------------------------------------------------------
Nth Catalan recursive function:
C_0 = 1, C_{n+1} = C_n * 2(2n + 1)/(n+2)
------------------------------------------------------
Mobius Formula
u(n) = 1        , if n = 1
       (-1)^m   , 若 n 無平方數因數，且 n = p1*p2*p3
           *...*pk
       0        , 若 n 有大於 1 的平方數因數
- Property
1. (積性函數) u(a)u(b) = u(ab)
2. ∑_{d|n} u(d) = [n == 1]
------------------------------------------------------
Mobius Inversion Formula
```

```
if      f(n) = ∑_{d|n} g(d)
then    g(n) = ∑_{d|n} u(n/d)f(d)
             = ∑_{d|n} u(d)f(n/d)
- Application
the number/power of gcd(i, j) = k
- Trick
分塊, O(sqrt(n))
-------------------------------------------------------
Chinese Remainder Theorem (m_i 兩兩互質)

  x = a_1 (mod m_1)
  x = a_2 (mod m_2)
  ....
  x = a_i (mod m_i)

construct a solution:

  Let M = m_1 * m_2 * m_3 * ... * m_n
  Let M_i = M / m_i

  t_i = 1 / M_i
  t_i * M_i = 1 (mod m_i)

  solution x = a_1 * t_1 * M_1 + a_2 * t_2 * M_2 + ...
      + a_n * t_n * M_n + k * M
  = k*M + ∑ a_i * t_i * M_i, k is positive integer.

  under mod M, there is one solution x = ∑ a_i * t_i *
      M_i
-------------------------------------------------------
Burnside's lemma
|G| * |X/G|  = sum( |X^g| ) where g in G
總方法數: 每一種旋轉下不動點的個數總和 除以 旋轉的方法
    數
*/
```

4 Graph

4.1 BCC

```
邊雙連通

任意兩點間至少有兩條不重疊的路徑連接，找法：
1. 標記出所有的橋
2. 對全圖進行 DFS，不走橋，每一次 DFS 就是一個新的邊雙
    連通

// from BCW

struct BccEdge {
  static const int MXN = 100005;
  struct Edge { int v,eid; };
  int n,m,step,par[MXN],dfn[MXN],low[MXN];
  vector<Edge> E[MXN];
  DisjointSet djs;
  void init(int _n) {
    n = _n; m = 0;
    for (int i=0; i<n; i++) E[i].clear();
    djs.init(n);
  }
  void add_edge(int u, int v) {
    E[u].PB({v, m});
    E[v].PB({u, m});
    m++;
  }
  void DFS(int u, int f, int f_eid) {
    par[u] = f;
    dfn[u] = low[u] = step++;
    for (auto it:E[u]) {
      if (it.eid == f_eid) continue;
      int v = it.v;
      if (dfn[v] == -1) {
        DFS(v, u, it.eid);
        low[u] = min(low[u], low[v]);
      } else {
        low[u] = min(low[u], dfn[v]);
      }
    }
  }
  void solve() {
    step = 0;
    memset(dfn, -1, sizeof(int)*n);
    for (int i=0; i<n; i++) {
      if (dfn[i] == -1) DFS(i, i, -1);
    }
    djs.init(n);
    for (int i=0; i<n; i++) {
      if (low[i] < dfn[i]) djs.uni(i, par[i]);
    }
  }
}graph;
```

4.2 Dijkstra

```
typedef struct Edge{
    int v; long long len;
    bool operator > (const Edge &b)const { return len>b
        .len; }
} State;

const long long INF = 1LL<<60;

void Dijkstra(int n, vector<Edge> G[], long long d[],
    int s, int t=-1){
    static priority_queue<State, vector<State>, greater
        <State> > pq;
    while ( pq.size() )pq.pop();
    for (int i=1; i<=n; i++)d[i]=INF;
    d[s]=0; pq.push( (State){s,d[s]} );
    while ( pq.size() ){
        auto x = pq.top(); pq.pop();
        int u = x.v;
        if (d[u]<x.len)continue;
        if (u==t)return;
        for (auto &e:G[u]){
            if (d[e.v] > d[u]+e.len){
                d[e.v] = d[u]+e.len;
                pq.push( (State) {e.v,d[e.v]} );
            }
        }
    }
}
```

4.3 Theorm - Domination

```
Maximum Independent Set
General: [NPC] maximum clique of complement of G
Tree: [P] Greedy
Bipartite Graph: [P] Maximum Cardinality Bipartite
    Matching
-------------------------------------------------------
Minimum Dominating Set
General: [NPC]
Tree: [P] DP
Bipartite Graph: [NPC]
-------------------------------------------------------
Minimum Vertex Cover
General: [NPC] (?)maximum clique of complement of G
Tree: [P] Greedy, from leaf to root
Bipartite Graph: [P] Maximum Cardinality Bipartite
    Matching
-------------------------------------------------------
Minimum Edge Cover
General: [P] V - Maximum Matching
Bipartite Graph: [P] Greedy, strategy: cover small
    degree node first.
(Min/Max)Weighted: [P]: Minimum/Minimum Weight Matching
```

4.4 Strongly Connected Component(SCC)

4.5 DominatorTree

```
// PEC VER

// idom[n] is the unique node that strictly dominates n but does
// not strictly dominate any other node that strictly dominates n.
// idom[n] = 0 if n is entry or the entry cannot reach n.
struct DominatorTree{
  static const int MAXN = 200010;
  int n,s;
  vector<int> g[MAXN],pred[MAXN];
  vector<int> cov[MAXN];
  int dfn[MAXN],nfd[MAXN],ts;
  int par[MAXN];
  int sdom[MAXN],idom[MAXN];
  int mom[MAXN],mn[MAXN];

  inline bool cmp(int u,int v) { return dfn[u] < dfn[v]; }

  int eval(int u) {
    if(mom[u] == u) return u;
    int res = eval(mom[u]);
    if(cmp(sdom[mn[mom[u]]],sdom[mn[u]]))
      mn[u] = mn[mom[u]];
    return mom[u] = res;
  }

  void init(int _n, int _s) {
    n = _n;
    s = _s;
    REP1(i,1,n) {
      g[i].clear();
      pred[i].clear();
      idom[i] = 0;
    }
  }
  void add_edge(int u, int v) {
    g[u].push_back(v);
    pred[v].push_back(u);
  }
  void DFS(int u) {
    ts++;
    dfn[u] = ts;
    nfd[ts] = u;
    for(int v:g[u]) if(dfn[v] == 0) {
      par[v] = u;
      DFS(v);
    }
  }
  void build() {
    ts = 0;
    REP1(i,1,n) {
      dfn[i] = nfd[i] = 0;
      cov[i].clear();
      mom[i] = mn[i] = sdom[i] = i;
    }
    DFS(s);
    for (int i=ts; i>=2; i--) {
      int u = nfd[i];
      if(u == 0) continue ;
      for(int v:pred[u]) if(dfn[v]) {
        eval(v);
        if(cmp(sdom[mn[v]],sdom[u])) sdom[u] = sdom[mn[v]];
      }
      cov[sdom[u]].push_back(u);
      mom[u] = par[u];
      for(int w:cov[par[u]]) {
        eval(w);
        if(cmp(sdom[mn[w]],par[u])) idom[w] = mn[w];
        else idom[w] = par[u];
      }
      cov[par[u]].clear();
    }
    REP1(i,2,ts) {
      int u = nfd[i];
      if(u == 0) continue ;
      if(idom[u] != sdom[u]) idom[u] = idom[idom[u]];
    }
  }
}dom;
```

```
#define MXN 100005
#define PB push_back
#define FZ(s) memset(s,0,sizeof(s))

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 add_edge(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++)
    if (!vst[i]) DFS(i);
  reverse(vec.begin(),vec.end());
  FZ(vst);
  for (auto v : vec){
    if (!vst[v]){
      rDFS(v);
      nScc++;
    }
  }
}
};
```

4.6 Manhattan MST

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

const int MAXN = 100005;
const int OFFSET = 2000; // y-x may < 0, offset it, if y-x too large, please write a unique function
const int INF = 0xFFFFFFF;
int n;
int x[MAXN], y[MAXN], p[MAXN];

typedef pair<int, int> pii;
pii bit[MAXN]; // [ val, pos ]

struct P {
    int x, y, id;
    bool operator<(const P&b ) const {
        if ( x == b.x ) return y > b.y;
        else return x > b.x;
    }
};
vector<P> op;

struct E {
    int x, y, cost;
    bool operator<(const E&b ) const {
        return cost < b.cost;
    }
};
vector<E> edges;

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

void update(int i, int v, int p) {
    while ( i ) {
        if ( bit[i].first > v ) bit[i] = {v, p};
        i -= i & (-i);
    }
}

pii query(int i) {
    pii res = {INF, INF};
    while ( i < MAXN ) {
        if ( bit[i].first < res.first ) res = {bit[i].
            first, bit[i].second};
        i += i & (-i);
    }
    return res;
}

void input() {
    cin >> n;
    for ( int i = 0 ; i < n ; i++ ) cin >> x[i] >> y[i
        ], op.push_back((P) {x[i], y[i], i});
}

void mst() {
    for ( int i = 0 ; i < MAXN ; i++ ) p[i] = i;
    int res = 0;
    sort(edges.begin(), edges.end());
    for ( auto e : edges ) {
        int x = find(e.x), y = find(e.y);
        if ( x != y ) {
            p[x] = y;
            res += e.cost;
        }
    }
    cout << res << endl;
}

void construct() {
    sort(op.begin(), op.end());
    for ( int i = 0 ; i < n ; i++ ) {
        pii q = query(op[i].y - op[i].x + OFFSET);
        update(op[i].y - op[i].x + OFFSET, op[i].x + op
            [i].y, op[i].id);
        if ( q.first == INF ) continue;
        edges.push_back((E) {op[i].id, q.second, abs(x[
            op[i].id]-x[q.second]) + abs(y[op[i].id]-y[
            q.second]) });
    }
}

void solve() {

    // [45 ~ 90 deg]
    for ( int i = 0 ; i < MAXN ; i++ ) bit[i] = {INF,
        INF};
    construct();

    // [0 ~ 45 deg]
    for ( int i = 0 ; i < MAXN ; i++ ) bit[i] = {INF,
        INF};
    for ( int i = 0 ; i < n ; i++ ) swap(op[i].x, op[i
        ].y);
    construct();
    for ( int i = 0 ; i < n ; i++ ) swap(op[i].x, op[i
        ].y);

    // [-90 ~ -45 deg]
    for ( int i = 0 ; i < MAXN ; i++ ) bit[i] = {INF,
        INF};
    for ( int i = 0 ; i < n ; i++ ) op[i].y *= -1;
    construct();

    // [-45 ~ 0 deg]
    for ( int i = 0 ; i < MAXN ; i++ ) bit[i] = {INF,
        INF};
    for ( int i = 0 ; i < n ; i++ ) swap(op[i].x, op[i
        ].y);
    construct();

    // mst
    mst();

}

int main () {
    input();
    solve();
    return 0;
}
```

4.7 Hungarian

```
// Maximum Cardinality Bipartite Matching

struct Graph {
    static const int MAXN = 5005;
    vector<int> G[MAXN];
    int n;
    int match[MAXN]; // Matching Result
    int vis[MAXN];

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

    bool dfs(int u) {
        for ( auto v:G[u] ) {
            if (!vis[v]) {
                vis[v] = true;
                if (match[v] == -1 || dfs(match[v])) {
                    match[v] = u;
                    match[u] = v;
                    return true;
                }
            }
        }
        return false;
    }

    int solve() {
        int res = 0;
        memset(match, -1, sizeof(match));
        for (int i = 0; i < n; i++) {
            if (match[i] == -1) {
                memset(vis, 0, sizeof(vis));
                if (dfs(i)) res += 1;
            }
        }
        return res;
    }
} graph;
```

4.8 KM

```
Detect non-perfect-matching:
1. set all edge[i][j] as INF
2. if solve() >= INF, it is not perfectmatching.
-------------------------------------------------------
// Maximum Weight Perfect Bipartite Matching
// allow negative weight!

typedef long long Int;
struct KM {
    static const int MAXN = 1050;
    static const int INF = 1LL<<60;
    int n, match[MAXN], vx[MAXN], vy[MAXN];
    Int edge[MAXN][MAXN], lx[MAXN], ly[MAXN], slack[
        MAXN];
    void init(int _n){
        n = _n;
        for ( int i = 0 ; i < n ; i++ )
            for ( int j = 0; j < n ; j++ )
                edge[i][j] = 0;
    }
    void add_edge(int x, int y, Int w){
        edge[x][y] = w;
    }
    bool DFS(int x){
        vx[x] = 1;
        for ( int y = 0 ; y < n ; y++ ) {
            if ( vy[y] ) continue;
            if ( lx[x] + ly[y] > edge[x][y] ) {
                slack[y] = min(slack[y], lx[x] + ly[y]
                    - edge[x][y]);
            } else {
                vy[y] = 1;
                if ( match[y] == -1 || DFS(match[y]) ){
                    match[y] = x;
                    return true;
                }
            }
        }
        return false;
    }
    Int solve() {
        fill(match, match + n, -1);
        fill(lx, lx + n, -INF);
        fill(ly, ly + n, 0);
        for ( int i = 0; i < n; i++ )
            for ( int j = 0; j < n; j++ )
                lx[i] = max(lx[i], edge[i][j]);
        for ( int i = 0 ; i < n; i++ ) {
            fill(slack, slack + n, INF);
            while (true){
                fill(vx, vx + n, 0);
                fill(vy, vy + n, 0);
                if ( DFS(i) ) break;
                Int d = INF;
                for ( int j = 0 ; j < n ; j++ )
                    if ( !vy[j] ) d = min(d, slack[j]);
                for ( int j = 0 ; j < n ; j++ ) {
                    if (vx[j]) lx[j] -= d;
                    if (vy[j]) ly[j] += d;
                    else slack[j] -= d;
                }
            }
        }
        Int res = 0;
        for ( int i = 0 ; i < n ; i++ ) {
            res += edge[ match[i] ][i];
        }
        return res;
    }
} graph;
```

4.9 Theorm - Matching

```
最大匹配 + 最小邊覆蓋 = V
最大獨立集 + 最小點覆蓋 = V
最大匹配 = 最小點覆蓋
最小路徑覆蓋數 = V - 最大匹配數
```

4.10 Maximum General Matching

```
// Maximum Cardinality Matching

struct Graph {
  vector<int> G[MAXN];
  int pa[MAXN], match[MAXN], st[MAXN], S[MAXN], vis[
      MAXN];
  int t, n;

  void init(int _n) {
    n = _n;
    for ( int i = 1 ; i <= n ; i++ ) G[i].clear();
  }
  void add_edge(int u, int v) {
    G[u].push_back(v);
    G[v].push_back(u);
  }
  int lca(int u, int v){
    for ( ++t ; ; swap(u, v) ) {
      if ( u == 0 ) continue;
      if ( vis[u] == t ) return u;
      vis[u] = t;
      u = st[ pa[ match[u] ] ];
    }
  }
  void flower(int u, int v, int l, queue<int> &q) {
    while ( st[u] != l ) {
      pa[u] = v;
      if ( S[ v = match[u] ] == 1 ) {
        q.push(v);
        S[v] = 0;
      }
      st[u] = st[v] = l;
      u = pa[v];
    }
  }
  bool bfs(int u){
    for ( int i = 1 ; i <= n ; i++ ) st[i] = i;
    memset(S, -1, sizeof(S));
    queue<int>q;
    q.push(u);
    S[u] = 0;
    while ( !q.empty() ) {
      u = q.front(); q.pop();
      for ( int i = 0 ; i < (int)G[u].size(); i++) {
        int v = G[u][i];
        if ( S[v] == -1 ) {
          pa[v] = u;
          S[v] = 1;
          if ( !match[v] ) {
            for ( int lst ; u ; v = lst, u = pa[v] ) {
              lst = match[u];
              match[u] = v;
              match[v] = u;
            }
            return 1;
          }
          q.push(match[v]);
          S[ match[v] ] = 0;
        } else if ( !S[v] && st[v] != st[u] ) {
          int l = lca(st[v], st[u]);
          flower(v, u, l, q);
          flower(u, v, l, q);
        }
      }
    }
    return 0;
  }
  int solve(){
```

```
  memset(pa, 0, sizeof(pa));
  memset(match, 0, sizeof(match));
  int ans = 0;
  for ( int i = 1 ; i <= n ; i++ )
   if ( !match[i] && bfs(i) ) ans++;
  return ans;
 }
} graph;
```

4.11 Minimum General Weighted Matching

```
// Minimum Weight Perfect Matching (Perfect Match)

struct Graph {
  static const int MAXN = 105;
  int n, e[MAXN][MAXN];
  int match[MAXN], d[MAXN], onstk[MAXN];
  vector<int> stk;
  void init(int _n) {
    n = _n;
    for( int i = 0 ; i < n ; i ++ )
      for( int j = 0 ; j < n ; j ++ )
        e[i][j] = 0;
  }
  void add_edge(int u, int v, int w) {
    e[u][v] = e[v][u] = w;
  }
  bool SPFA(int u){
    if (onstk[u]) return true;
    stk.push_back(u);
    onstk[u] = 1;
    for ( int v = 0 ; v < n ; v++ ) {
      if (u != v && match[u] != v && !onstk[v] )
        {
        int m = match[v];
        if ( d[m] > d[u] - e[v][m] + e[u][v] )
          {
          d[m] = d[u] - e[v][m] + e[u][v];
          onstk[v] = 1;
          stk.push_back(v);
          if (SPFA(m)) return true;
          stk.pop_back();
          onstk[v] = 0;
        }
      }
    }
    onstk[u] = 0;
    stk.pop_back();
    return false;
  }
  int solve() {
    for ( int i = 0 ; i < n ; i += 2 ) {
      match[i] = i+1;
      match[i+1] = i;
    }
    while (true){
      int found = 0;
      for ( int i = 0 ; i < n ; i++ )
        onstk[ i ] = d[ i ] = 0;
      for ( int i = 0 ; i < n ; i++ ) {
        stk.clear();
        if ( !onstk[i] && SPFA(i) ) {
          found = 1;
          while ( stk.size() >= 2 ) {
            int u = stk.back(); stk.
              pop_back();
            int v = stk.back(); stk.
              pop_back();
            match[u] = v;
            match[v] = u;
          }
        }
      }
      if (!found) break;
    }
    int ret = 0;
    for ( int i = 0 ; i < n ; i++ )
      ret += e[i][match[i]];
    ret /= 2;
    return ret;
  }
} graph;
```

4.12 Maximum Clique

```
const int MAXN = 105;
int best;
int m ,n;
int num[MAXN];
// int x[MAXN];
int path[MAXN];
int g[MAXN][MAXN];

bool dfs( int *adj, int total, int cnt ){
  int i, j, k;
  int t[MAXN];
  if( total == 0 ){
    if( best < cnt ){
      // for( i = 0; i < cnt; i++) path[i] = x[i
        ];
      best = cnt; return true;
    }
    return false;
  }
  for( i = 0; i < total; i++){
    if( cnt+(total-i) <= best ) return false;
    if( cnt+num[adj[i]] <= best ) return false;
    // x[cnt] = adj[i];
    for( k = 0, j = i+1; j < total; j++ )
      if( g[ adj[i] ][ adj[j] ] )
        t[ k++ ] = adj[j];
        if( dfs( t, k, cnt+1 ) ) return true;
  } return false;
}
int MaximumClique(){
  int i, j, k;
  int adj[MAXN];
  if( n <= 0 ) return 0;
  best = 0;
  for( i = n-1; i >= 0; i-- ){
    // x[0] = i;
    for( k = 0, j = i+1; j < n; j++ )
      if( g[i][j] ) adj[k++] = j;
    dfs( adj, k, 1 );
    num[i] = best;
  }
  return best;
}
```

4.13 Steiner Tree

```
// Minimum Steiner Tree
// O(V 3^T + V^2 2^T)
struct SteinerTree{
#define V 33
#define T 8
#define INF 1023456789
 int n , dst[V][V] , dp[1 << T][V] , tdst[V];
 void init( int _n ){
  n = _n;
  for( int i = 0 ; i < n ; i ++ ){
   for( int j = 0 ; j < n ; j ++ )
    dst[ i ][ j ] = INF;
   dst[ i ][ i ] = 0;
  }
 }
 void add_edge( int ui , int vi , int wi ){
  dst[ ui ][ vi ] = min( dst[ ui ][ vi ] , wi );
  dst[ vi ][ ui ] = min( dst[ vi ][ ui ] , wi );
  }
  void shortest_path(){
    for( int k = 0 ; k < n ; k ++ )
      for( int i = 0 ; i < n ; i ++ )
        for( int j = 0 ; j < n ; j ++ )
          dst[ i ][ j ] = min( dst[ i ][ j ],
                dst[ i ][ k ] + dst[ k ][ j ] );
  }
  int solve( const vector<int>& ter ){
    int t = (int)ter.size();
    for( int i = 0 ; i < ( 1 << t ) ; i ++ )
      for( int j = 0 ; j < n ; j ++ )
        dp[ i ][ j ] = INF;
    for( int i = 0 ; i < n ; i ++ )
      dp[ 0 ][ i ] = 0;
    for( int msk = 1 ; msk < ( 1 << t ) ; msk ++ ){
      if( msk == ( msk & (-msk) ) ){
        int who = __lg( msk );
        for( int i = 0 ; i < n ; i ++ )
          dp[ msk ][ i ] = dst[ ter[ who ] ][ i ];
        continue;
      }
      for( int i = 0 ; i < n ; i ++ )
        for( int submsk = ( msk - 1 ) & msk ; submsk ;
                 submsk = ( submsk - 1 ) & msk )
            dp[ msk ][ i ] = min( dp[ msk ][ i ],
                            dp[ submsk ][ i ] +
                            dp[ msk ^ submsk ][ i ] );
      for( int i = 0 ; i < n ; i ++ ){
        tdst[ i ] = INF;
        for( int j = 0 ; j < n ; j ++ )
          tdst[ i ] = min( tdst[ i ],
                     dp[ msk ][ j ] + dst[ j ][ i ] );
      }
      for( int i = 0 ; i < n ; i ++ )
        dp[ msk ][ i ] = tdst[ i ];
    }
    int ans = INF;
    for( int i = 0 ; i < n ; i ++ )
      ans = min( ans , dp[ ( 1 << t ) - 1 ][ i ] );
    return ans;
  }
} solver;
```

4.14 最小平均環

```
// from BCW

/* minimum mean cycle */
const int MAXE = 1805;
const int MAXN = 35;
const double inf = 1029384756;
const double eps = 1e-6;
struct Edge {
  int v,u;
  double c;
};
int n,m,prv[MAXN][MAXN], prve[MAXN][MAXN], vst[MAXN];
Edge e[MAXE];
vector<int> edgeID, cycle, rho;
double d[MAXN][MAXN];
inline void bellman_ford() {
  for(int i=0; i<n; i++) d[0][i]=0;
  for(int i=0; i<n; i++) {
    fill(d[i+1], d[i+1]+n, inf);
    for(int j=0; j<m; j++) {
      int v = e[j].v, u = e[j].u;
      if(d[i][v]<inf && d[i+1][u]>d[i][v]+e[j].c) {
        d[i+1][u] = d[i][v]+e[j].c;
        prv[i+1][u] = v;
        prve[i+1][u] = j;
      }
    }
  }
}
double karp_mmc() {
  // 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);
  }
  for(int i=0; i<n; i++) vst[i] = 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) {
    int v = rho.back(); rho.pop_back();
    cycle.PB(v);
    vst[v]++;
  }
  reverse(ALL(edgeID));
  edgeID.resize(SZ(cycle));
  return mmc;
}
```

4.15 SchreierSims

```
// time: O(n^2 lg^3 |G| + t n lg |G|)
// mem : O(n^2 lg |G| + tn)
// t : number of generator
namespace SchreierSimsAlgorithm{
  typedef vector<int> Permu;
  Permu inv( const Permu& p ){
    Permu ret( p.size() );
    for( int i = 0; i < int(p.size()); i ++ )
      ret[ p[ i ] ] = i;
    return ret;
  }
  Permu operator*( const Permu& a, const Permu& b ){
    Permu ret( a.size() );
    for( int i = 0 ; i < (int)a.size(); i ++ )
      ret[ i ] = b[ a[ i ] ];
    return ret;
  }
  typedef vector<Permu> Bucket;
  typedef vector<int> Table;
  typedef pair<int,int> pii;
  int n, m;
  vector<Bucket> bkts, bktsInv;
  vector<Table> lookup;
  int fastFilter( const Permu &g, bool addToG = 1 ){
    n = bkts.size();
    Permu p;
    for( int i = 0 ; i < n ; i ++ ){
      int res = lookup[ i ][ p[ i ] ];
      if( res == -1 ){
        if( addToG ){
          bkts[ i ].push_back( p );
          bktsInv[ i ].push_back( inv( p ) );
          lookup[ i ][ p[i] ] = (int)bkts[i].size()-1;
        }
        return i;
      }
      p = p * bktsInv[i][res];
    }
    return -1;
  }
  long long calcTotalSize(){
    long long ret = 1;
    for( int i = 0 ; i < n ; i ++ )
      ret *= bkts[i].size();
    return ret;
  }
  bool inGroup( const Permu &g ){
    return fastFilter( g, false ) == -1;
  }
  void solve( const Bucket &gen, int _n ){
    n = _n, m = gen.size(); // m perm[0..n-1]s
    {//clear all
      bkts.clear();
      bktsInv.clear();
      lookup.clear();
    }
    for(int i = 0 ; i < n ; i ++ ){
      lookup[i].resize(n);
      fill(lookup[i].begin(), lookup[i].end(), -1);
    }
    Permu id( n );
    for(int i = 0 ; i < n ; i ++ ) id[i] = i;
    for(int i = 0 ; i < n ; i ++ ){
      bkts[i].push_back(id);
      bktsInv[i].push_back(id);
      lookup[i][i] = 0;
    }
    for(int i = 0 ; i < m ; i ++)
      fastFilter( gen[i] );
    queue< pair<pii,pii> > toUpd;
    for(int i = 0; i < n; i ++)
      for(int j = i; j < n; j ++)
        for(int k = 0; k < (int)bkts[i].size(); k ++)
          for(int l = 0; l < (int)bkts[j].size(); l ++)
            toUpd.push( {pii(i,k), pii(j,l)} );
    while( !toUpd.empty() ){
      pii a = toUpd.front().first;
      pii b = toUpd.front().second;
      toUpd.pop();
      int res = fastFilter(bkts[a.first][a.second] *
                           bkts[b.first][b.second]);
      if(res == -1) continue;
      pii newPair(res, (int)bkts[res].size() - 1);
      for(int i = 0; i < n; i ++)
        for(int j = 0; j < (int)bkts[i].size(); ++j){
          if(i <= res)
            toUpd.push(make_pair(pii(i , j), newPair));
          if(res <= i)
            toUpd.push(make_pair(newPair, pii(i, j)));
        }
    }
  }
}
```

4.16 Tarjan

```
割點
點 u 為割點 if and only if 滿足 1. or 2.
1. u 爲樹根，且 u 有多於一個子樹。
2. u 不爲樹根，且滿足存在 (u,v) 爲樹枝邊 (或稱父子邊，
    即 u 爲 v 在搜索樹中的父親)，使得 DFN(u) <= Low(v)
    。

-------------------------------------------------------
橋
一條無向邊 (u,v) 是橋 if and only if (u,v) 爲樹枝邊，且
    滿足 DFN(u) < Low(v)。
```

```
// 0 base
struct TarjanSCC{
  static const int MAXN = 1000006;
  int n, dfn[MAXN], low[MAXN], scc[MAXN], scn, count;
  vector<int> G[MAXN];
  stack<int> stk;
  bool ins[MAXN];

  void tarjan(int u){
    dfn[u] = low[u] = ++count;
    stk.push(u);
    ins[u] = true;

    for(auto v:G[u]){
      if(!dfn[v]){
        tarjan(v);
        low[u] = min(low[u], low[v]);
      }else if(ins[v]){
        low[u] = min(low[u], dfn[v]);
      }
    }

    if(dfn[u] == low[u]){
      int v;
      do {
      v = stk.top();
      stk.pop();
      scc[v] = scn;
      ins[v] = false;
      } while(v != u);
      scn++;
    }
  }

  void getSCC(){
    memset(dfn,0,sizeof(dfn));
    memset(low,0,sizeof(low));
    memset(ins,0,sizeof(ins));
    memset(scc,0,sizeof(scc));
    count = scn = 0;
    for(int i = 0 ; i < n ; i++ ){
      if(!dfn[i]) tarjan(i);
    }
  }

}SCC;
```

4.17 2-SAT

```
const int MAXN = 2020;

struct TwoSAT{
    static const int MAXv = 2*MAXN;
    vector<int> GO[MAXv],BK[MAXv],stk;
    bool vis[MAXv];
    int SC[MAXv];

    void imply(int u,int v){ // u imply v
        GO[u].push_back(v);
        BK[v].push_back(u);
    }
    int dfs(int u,vector<int>*G,int sc){
        vis[u]=1, SC[u]=sc;
        for (int v:G[u])if (!vis[v])
            dfs(v,G,sc);
        if (G==GO)stk.push_back(u);
    }
    int scc(int n=MAXv){
        memset(vis,0,sizeof(vis));
        for (int i=0; i<n; i++)if (!vis[i])
            dfs(i,GO,-1);
        memset(vis,0,sizeof(vis));
        int sc=0;
        while (!stk.empty()){
            if (!vis[stk.back()])
                dfs(stk.back(),BK,sc++);
            stk.pop_back();
        }
    }
}SAT;

int main(){
    SAT.scc(2*n);
    bool ok=1;
    for (int i=0; i<n; i++){
        if (SAT.SC[2*i]==SAT.SC[2*i+1])ok=0;
    }
    if (ok){
        for (int i=0; i<n; i++){
            if (SAT.SC[2*i]>SAT.SC[2*i+1]){
                cout << i << endl;
            }
        }
    }
    else puts("NO");
}
```

5 Data Structure

5.1 Sparse Table

```
const int MAXN = 200005;
const int lgN = 20;

struct SP{ //sparse table
  int Sp[MAXN][lgN];
  function<int(int,int)> opt;
  void build(int n, int *a){ // 0 base
    for (int i=0 ;i<n; i++) Sp[i][0]=a[i];

    for (int h=1; h<lgN; h++){
      int len = 1<<(h-1), i=0;
      for (; i+len<n; i++)
        Sp[i][h] = opt( Sp[i][h-1] , Sp[i+len][h-1] );
      for (; i<n; i++)
        Sp[i][h] = Sp[i][h-1];
    }
  }
  int query(int l, int r){
    int h = __lg(r-l+1);
    int len = 1<<h;
    return opt( Sp[l][h] , Sp[r-len+1][h] );
  }
};
```

5.2 Segment Tree

```
int n,m,i,a,b,c;
int ans[MAXN<<2],add[MAXN<<2],inp[MAXN<<2];

inline int ls(const int&p){
    return p<<1;
}

inline int rs(const int&p){
    return p<<1|1;
}

inline int Max(const int&x,const int&y){
    return x>y?x:y;
}

inline void push_up(const int&p,const int&tag){
    ans[p]=Max(ans[ls(p)],ans[rs(p)])+tag;
}

void build(const int l=1,const int r=n,const int p=1){
    if(l==r){
        get(ans[p]);
        inp[l]=ans[p];
        return;
    }
    int mid=(l+r)>>1;
    build(l, mid, ls(p));
    build(mid+1,r,rs(p));
    push_up(p,0);
}
```

```
inline void update(const int&x,const int&y,const int&k,
    const int&l=1,const int&r=n,const int&p=1){
    if(l>=x&&r<=y){
        add[p]+=k;
        ans[p]+=k;
        return;
    }
    int mid=(l+r)>>1;
    if(x<=mid){
        update(x,y,k,l, mid, ls(p));
    }
    if(y>mid){
        update(x,y,k,mid+1,r,rs(p));
    }
    push_up(p,add[p]);
}

inline int query(const int &x,const int &y,const int &
    tag=0,const int &l=1,const int &r=n,const int &p=1)
    {
    if(l>=x&&r<=y){
        return ans[p]+tag;
    }
    int mx=-1;
    int mid=(l+r)>>1;
    if(x<=mid){
        mx=Max(mx,query(x,y,tag+add[p],l, mid, ls(p)));
    }
    if(y>mid){
        mx=Max(mx,query(x,y,tag+add[p],mid+1,r,rs(p)));
    }
    return mx;
}
```

6 String

6.1 KMP

```
template<typename T>
void build_KMP(int n, T *s, int *f){ // 1 base
  f[0]=-1, f[1]=0;
  for (int i=2; i<=n; i++){
    int w = f[i-1];
    while (w>=0 && s[w+1]!=s[i])w = f[w];
    f[i]=w+1;
  }
}

template<typename T>
int KMP(int n, T *a, int m, T *b){
  build_KMP(m,b,f);
  int ans=0;

  for (int i=1, w=0; i<=n; i++){
    while ( w>=0 && b[w+1]!=a[i] )w = f[w];
    w++;
    if (w==m){
      ans++;
      w=f[w];
    }
  }
  return ans;
}
```

7 Dark Code

7.1 輸入優化

```
#include <stdio.h>

char getc(){
  static const int bufsize = 1<<16;
  static char B[bufsize], *S=B, *T=B;
  return (S==T&&(T=(S=B)+fread(B,1,bufsize,stdin),S==T)
      ?0:*S++);
}

template <class T>
bool input(T& a){
  a=(T)0;
  register char p;
  while ((p = getc()) < '-')
    if (p==0 || p==EOF) return false;
  if (p == '-')
    while ((p = getc()) >= '0') a = a*10 - (p^'0');
  else {
    a = p ^ '0';
    while ((p = getc()) >= '0') a = a*10 + (p^'0');
  }
  return true;
}

template <class T, class... U>
bool input(T& a, U&... b){
  if (!input(a)) return false;
  return input(b...);
}
```

7.2 PBDS

```
#include<ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
#include <ext/pb_ds/detail/standard_policies.hpp>
typedef tree<int,null_type,less<int>,rb_tree_tag,
    tree_order_statistics_node_update> ordered_set;
```

8 Search

8.1 LIS

```
int LIS(vector<int>& s)
{
    if (s.size() == 0) return 0;

    vector<int> v;
    v.push_back(s[0]);

    for (int i = 1; i < s.size(); ++i)
    {
        int n = s[i];

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

    return v.size();
}
```

8.2 Merge sort

```
void merge(int *vec, int start, int end)
{
    if (start >= end) return;
    int mid = start + ((end - start) >> 1);
    merge(vec, start, mid);
    merge(vec, mid + 1, end);
    for (int i = start; i <= mid; i++)
    {
        //ans += distance(lower_bound(vec + mid + 1,
            vec + end + 1, vec[i] + lower),
        //                upper_bound(vec + mid + 1,
            vec + end + 1, vec[i] + upper));
        //Do some cool stuffs
    }
    inplace_merge(vec + start, vec + mid + 1, vec + end
         + 1);
}
```

9 Others

9.1 數位統計

```
int dfs(int pos, int state1, int state2 ....., bool
    limit, bool zero) {
    if ( pos == -1 ) return 是否符合條件;
    int &ret = dp[pos][state1][state2][....];
    if ( ret != -1 && !limit ) return ret;
    int ans = 0;
    int upper = limit ? digit[pos] : 9;
    for ( int i = 0 ; i <= upper ; i++ ) {
        ans += dfs(pos - 1, new_state1, new_state2,
            limit & ( i == upper), ( i == 0) && zero);
    }
    if ( !limit ) ret = ans;
    return ans;
}

int solve(int n) {
    int it = 0;
    for ( ; n ; n /= 10 ) digit[it++] = n % 10;
    return dfs(it - 1, 0, 0, 1, 1);
}
```

9.2 1D/1D dp 優化

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

int t, n, L;
int p;
char s[MAXN][35];
ll sum[MAXN] = {0};
long double dp[MAXN] = {0};
int prevd[MAXN] = {0};

long double pw(long double a, int n) {
    if ( n == 1 ) return a;
    long double b = pw(a, n/2);
    if ( n & 1 ) return b*b*a;
    else return b*b;
}
long double f(int i, int j) {
//    cout << (sum[i] - sum[j]+i-j-1-L) << endl;
    return pw(abs(sum[i] - sum[j]+i-j-1-L), p) + dp[j];
}
struct INV {
    int L, R, pos;
};
INV stk[MAXN*10];
int top = 1, bot = 1;
void update(int i) {
    while ( top > bot && i < stk[top].L && f(stk[top].L
        , i) < f(stk[top].L, stk[top].pos) ) {
        stk[top - 1].R = stk[top].R;
        top--;
    }
    int lo = stk[top].L, hi = stk[top].R, mid, pos =
        stk[top].pos;
    //if ( i >= lo ) lo = i + 1;
    while ( lo != hi ) {
        mid = lo + (hi - lo) / 2;
        if ( f(mid, i) < f(mid, pos) ) hi = mid;
        else lo = mid + 1;
    }
    if ( hi < stk[top].R ) {
        stk[top + 1] = (INV) { hi, stk[top].R, i };
        stk[top++].R = hi;
    }
}

int main() {
    cin >> t;
    while ( t-- ) {
        cin >> n >> L >> p;
        dp[0] = sum[0] = 0;
        for ( int i = 1 ; i <= n ; i++ ) {
            cin >> s[i];
            sum[i] = sum[i-1] + strlen(s[i]);
            dp[i] = numeric_limits<long double>::max();
        }
        stk[top] = (INV) {1, n + 1, 0};
        for ( int i = 1 ; i <= n ; i++ ) {
            if ( i >= stk[bot].R ) bot++;
            dp[i] = f(i, stk[bot].pos);
            update(i);
//              cout << (ll) f(i, stk[bot].pos) << endl;
        }
        if ( dp[n] > 1e18 ) {
            cout << "Too hard to arrange" << endl;
        } else {
            vector<PI> as;
            cout << (ll)dp[n] << endl;
        }
    }
    return 0;
}
```

9.3 Theorm - DP optimization

```
Monotonicity & 1D/1D DP & 2D/1D DP
-------------------------------------------------------
Definition xD/yD
1D/1D DP[j] = min(0≤i<j) { DP[i] + w(i, j) }; DP[0] = k
2D/1D DP[i][j] = min(i<k≤j) { DP[i][k - 1] + DP[k][j] }
     + w(i, j); DP[i][i] = 0
-------------------------------------------------------
Monotonicity
       c       d
  -----------------
a | w(a, c) w(a, d)
b | w(b, c) w(b, d)

Monge Condition
Concave(凹四邊形不等式): w(a, c) + w(b, d) >= w(a, d) +
     w(b, c)
Convex (凸四邊形不等式): w(a, c) + w(b, d) <= w(a, d) +
     w(b, c)

Totally Monotone
Concave(凹單調): w(a, c) <= w(b, d) -----> w(a, d) <= w
    (b, c)
Convex (凸單調): w(a, c) >= w(b, d) -----> w(a, d) >= w
    (b, c)
-------------------------------------------------------
1D/1D DP O(n^2) -> O(nlgn)
**CONSIDER THE TRANSITION POINT**
Solve 1D/1D Concave by Stack
Solve 1D/1D Convex by Deque
-------------------------------------------------------
2D/1D Convex DP (Totally Monotone) O(n^3) -> O(n^2)
h(i, j − 1) ≤ h(i, j) ≤ h(i + 1, j)
```

9.4 Mo’s algorithm

```
int l = 0, r = 0, nowAns = 0, BLOCK_SIZE, n, m;
int ans[];
struct QUE{
    int l, r, id;
    friend bool operator < (QUE a, QUE b){
        if(a.l / BLOCK_SIZE != b.l / BLOCK_SIZE)
            return a.l / BLOCK_SIZE < b.l / BLOCK_SIZE;
        return a.r < b.r;
    }
}querys[];

inline void move(int pos, int sign) {
    // update nowAns
}

void solve() {
    BLOCK_SIZE = int(ceil(pow(n, 0.5)));
    sort(querys, querys + m);
    for (int i = 0; i < m; ++i) {
        const QUE &q = querys[i];
        while (l > q.l) move(--l, 1);
        while (r < q.r) move(r++, 1);
        while (l < q.l) move(l++, -1);
        while (r > q.r) move(--r, -1);
        ans[q.id] = nowAns;
    }
}
```

10 Persistence