Team Notebook

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December 14, 2018

Contents

1 Data Structures and Matrices

1.1 Fenwick Tree

```
#define LSOne(S) (S & (-S))
vector<int> fen;
void ft_create(int n) { fen.assign(n + 1, 0); }
// initially n + 1 zeroes
int ft_rsq(int b)
{ // returns RSQ(1, b)
 int sum = 0;
 for (; b; b -= LSOne(b)) sum += fen[b];
 return sum;
}
int ft_rsq(int a, int b)
{ // returns RSQ(a, b)
 return ft_rsq(b) - (a == 1 ? 0 : ft_rsq(a - 1));
}
// adjusts value of the k-th element by v (v can be +ve/inc
     or -ve/dec).
void ft_adjust(int k, int v)
{
 for (; k < (int)fen.size(); k += LSOne(k)) fen[k] += v;
}
```

1.2 Matrix and Matrix Power

```
const int MN = 111;
const int mod = 10000;

struct matrix {
  int r, c;
  int m[MN][MN];

  matrix (int _r, int _c) : r (_r), c (_c) {
    memset(m, 0, sizeof m);
  }

  void print() {
    for (int i = 0; i < r; ++i) {
      for (int j = 0; j < c; ++j)
        cout << m[i][j] << " ";
      cout << endl;
    }
  }

  int x[MN][MN];
  matrix & operator *= (const matrix &o) {
    memset(x, 0, sizeof x);
    for (int i = 0; i < r; ++i)
      for (int k = 0; k < c; ++k)
        if (m[i][k] != 0)
          for (int j = 0; j < c; ++j) {
            x[i][j] = (x[i][j] + ((m[i][k] * o.m[k][j]) % mod
                 ) ) % mod;
          }
    memcpy(m, x, sizeof(m));
    return *this;
  }
};

void matrix_pow(matrix b, long long e, matrix &res) {
  memset(res.m, 0, sizeof res.m);
  for (int i = 0; i < b.r; ++i)
    res.m[i][i] = 1;

  if (e == 0) return;
  while (true) {
    if (e & 1) res *= b;
    if ((e >>= 1) == 0) break;
    b *= b;
  }
}
```

1.3 Ranged Fenwick Tree

```
//not tested
#define LSOne(S) (S & (-S))
vector<ll> fen[2];
void ft_create(int n) { fen[0].assign(n + 1, 0), fen[1].
     assign(n + 1, 0); }
ll ft_rsq(int b, bool bl)
{
 ll sum = 0;
 for (; b; b -= LSOne(b)) sum += fen[bl][b];
 return sum;
}
void ft_adjust(ll k, ll v, bool bl)
{
 for (; k <= (int)fen[bl].size(); k += LSOne(k)) fen[bl][k]
     += v;
}
void range_adjust(ll l, ll r, ll v)
{
 ft_adjust(l, v, 0), ft_adjust(r+1, -v, 0);
 ft_adjust(l, v*(l-1), 1), ft_adjust(r+1, -v*r, 1);
}
ll range_rsq(ll l, ll r)
{
 ll x=0, a, b;
 if(l)
 {
  a=ft_rsq(l-1, 0), b=ft_rsq(l-1, 1);
  x=(l-1)*a-b;
 }
 a=ft_rsq(r, 0), b=ft_rsq(r, 1);
 ll y=r*a-b;
 return y-x;
}
```

1.4 Sparse Table

```
int n, arr[MAXN], table[MAXN][20], table2[MAXN][20];
int Log[MAXN];
vector<int> tmp, best;
int GCD(int a, int b)
{
 if(b==0) return a;
 return GCD(b, a%b);
}
void init(int n)
{
 int mx=0, l=0, r=n+1, lim=2, lg=0;
 Rep(i, MAXN)
 {
  if(i==lim)
  {
   lg++;
   lim*=2;
  }
  Log[i]=lg;
 }
 Rep(i, n) table[i][0]=table2[i][0]=arr[i];
 For(i, 1, Log[n]+1) for(int j=0; j+(1<<i)-1< n; j++)
 {
  table[j][i]=GCD(table[j][i-1], table[j+(1<<(i-1))][i-1]);
  table2[j][i]=min(table2[j][i-1], table2[j+(1<<(i-1))][i
       -1]);
 }
}
int get_gcd(int l, int r)
{
 int lg=Log[r-l+1];
 return GCD(table[l][lg], table[r-(1<<lg)+1][lg]);
}
```

2 Dynamic Programming

2.1 Knuth Optimization

```
for (int s = 0; s<=k; s++)                    //s - length(size)
     of substring
    for (int L = 0; L+s<=k; L++) {              //L - left point
      int R = L + s;                            //R - right point
      if (s < 2) {
        res[L][R] = 0;                          //DP base -
            nothing to break
        mid[L][R] = l;                          //mid is equal to
             left border
        continue;
      }
      int mleft = mid[L][R-1];                  //Knuth's trick:
          getting bounds on M
      int mright = mid[L+1][R];
      res[L][R] = 10000000000000000000LL;
      for (int M = mleft; M<=mright; M++) { //iterating for M
           in the bounds only
        int64 tres = res[L][M] + res[M][R] + (x[R]-x[L]);
        if (res[L][R] > tres) {                 //relax current
            solution
          res[L][R] = tres;
          mid[L][R] = M;
        }
      }
    }
  int64 answer = res[0][k];
```

3 Games

3.1 Declare Winner

```
void declareWinner(int whoseTurn, int piles[], int Grundy[],
      int n) {
    int xorValue = Grundy[piles[0]];
    for (int i=1; i<=n-1; i++)
        xorValue = xorValue ^ Grundy[piles[i]];
    if (xorValue != 0) {
        if (whoseTurn == PLAYER1)
            printf("Player 1 will win\n");
        else
            printf("Player 2 will win\n");
    }
    else {
        if (whoseTurn == PLAYER1)
            printf("Player 2 will win\n");
        else
            printf("Player 1 will win\n");
    }
    return;
}
```

3.2 Grundy

```
// A function to Compute Grundy Number of 'n'
// Only this function varies according to the game
int calculateGrundy(int n) {
    if (n == 0)
        return (0);
    unordered_set<int> Set; // A Hash Table
    for (int i=0; i<=n-1; i++)
            Set.insert(calculateGrundy(i));
    return (calculateMex(Set));
}
```

3.3 Mex

```
int calculateMex(unordered_set<int> Set) {
    int Mex = 0;
    while (Set.find(Mex) != Set.end())
        Mex++;
    return (Mex);
}
```

4 Geometry

4.1 3D Rotation

```
//From "You Know Izad?" team cheat sheet
Where c = cos (theta), s = sin(theta), t = 1-cos(theta), and
      <X,Y,Z> is the unit vector representing the arbitary
     axis
1. Left handed about arbitrary axis:
 tX^2+c  tXY-sZ  tXZ+sY 0
 tXY+sZ  tY^2+c  tYZ-sX 0
 tXZ-sY  tYZ+sX  tZ^2+c 0
 0   0   0 1
2. Right handed about arbitrary axis:
 tX^2+c  tXY+sZ  tXZ-sY 0
 tXY-sZ  tY^2+c  tYZ+sX 0
 tXZ+sY  tYZ-sX  tZ^2+c 0
 0   0   0 1

3. About X Axis
 1 0 0 0
 0 c -s 0
 0 s c 0
 0 0 0 1


4. About Y Axis
 c 0 s 0
 0 1 0 0
 -s 0 c 0
 0 0 0 1

5. About Z Axis
 c -s 0 0
 s c 0 0
 0 0 1 0
 0 0 0 1
```

4.2 Angle Bisector

```
// angle bisector
int bcenter( PT p1, PT p2, PT p3, PT& r ){
 if( triarea( p1, p2, p3 ) < EPS ) return -1;
 double s1, s2, s3;
 s1 = dist( p2, p3 );
 s2 = dist( p1, p3 );
 s3 = dist( p1, p2 );
 double rt = s2/(s2+s3);
 PT a1,a2;
 a1 = p2*rt+p3*(1.0-rt);
 rt = s1/(s1+s3);
 a2 = p1*rt+p3*(1.0-rt);
 intersection( a1,p1, a2,p2, r );
 return 0;
}
```

4.3 Circle Circle Intersection

```
// rotate a point CCW or CW around the origin
PT RotateCCW90(PT p) { return PT(-p.y,p.x); }
```

```
PT RotateCW90(PT p)  { return PT(p.y,-p.x); }
PT RotateCCW(PT p, double t) {
  return PT(p.x*cos(t)-p.y*sin(t), p.x*sin(t)+p.y*cos(t));
}

// compute intersection of circle centered at a with radius
    r
// with circle centered at b with radius R
vector<PT> CircleCircleIntersection(PT a, PT b, double r,
    double R) {
  vector<PT> ret;
  double d = sqrt(dist2(a, b));
  if (d > r + R || d + min(r, R) < max(r, R)) return ret;
  double x = (d * d - R * R + r * r) / (2 * d);
  double y = sqrt(r * r - x * x);
  PT v = (b - a) / d;
  ret.push_back(a + v * x + RotateCCW90(v) * y);
  if (y > 0)
    ret.push_back(a + v * x - RotateCCW90(v) * y);
  return ret;
}
```

4.4 Circle Line Intersection

```
// compute intersection of line through points a and b with
// circle centered at c with radius r > 0
vector<PT> CircleLineIntersection(PT a, PT b, PT c, double r
    ) {
  vector<PT> ret;
  b = b-a;
  a = a-c;
  double A = dot(b, b);
  double B = dot(a, b);
  double C = dot(a, a) - r*r;
  double D = B*B - A*C;
  if (D < -EPS) return ret;
  ret.push_back(c+a+b*(-B+sqrt(D+EPS))/A);
  if (D > EPS)
    ret.push_back(c+a+b*(-B-sqrt(D))/A);
  return ret;
}
```

4.5 Circle from Three Points

```
Point center_from(double bx, double by, double cx, double cy
    ) {
  double B=bx*bx+by*by, C=cx*cx+cy*cy, D=bx*cy-by*cx;
  return Point((cy*B-by*C)/(2*D), (bx*C-cx*B)/(2*D));
}

Point circle_from(Point A, Point B, Point C) {
  Point I = center_from(B.X-A.X, B.Y-A.Y, C.X-A.X, C.Y-A.Y);
  return Point(I.X + A.X, I.Y + A.Y);
}
```

4.6 Closest Pair of Points

```
struct point {
  double x, y;
  int id;
  point() {}
  point (double a, double b) : x(a), y(b) {}
};

double dist(const point &o, const point &p) {
  double a = p.x - o.x, b = p.y - o.y;
  return sqrt(a * a + b * b);
}

double cp(vector<point> &p, vector<point> &x, vector<point>
    &y) {
  if (p.size() < 4) {
    double best = 1e100;
    for (int i = 0; i < p.size(); ++i)
      for (int j = i + 1; j < p.size(); ++j)
        best = min(best, dist(p[i], p[j]));
    return best;
  }

  int ls = (p.size() + 1) >> 1;
  double l = (p[ls - 1].x + p[ls].x) * 0.5;
  vector<point> xl(ls), xr(p.size() - ls);
  unordered_set<int> left;
  for (int i = 0; i < ls; ++i) {
    xl[i] = x[i];
    left.insert(x[i].id);
  }
  for (int i = ls; i < p.size(); ++i) {
    xr[i - ls] = x[i];
  }

  vector<point> yl, yr;
  vector<point> pl, pr;
  yl.reserve(ls); yr.reserve(p.size() - ls);
  pl.reserve(ls); pr.reserve(p.size() - ls);
  for (int i = 0; i < p.size(); ++i) {
    if (left.count(y[i].id))
      yl.push_back(y[i]);
    else
      yr.push_back(y[i]);

    if (left.count(p[i].id))
      pl.push_back(p[i]);
    else
      pr.push_back(p[i]);
  }

  double dl = cp(pl, xl, yl);
  double dr = cp(pr, xr, yr);
  double d = min(dl, dr);
  vector<point> yp; yp.reserve(p.size());
  for (int i = 0; i < p.size(); ++i) {
    if (fabs(y[i].x - l) < d)
      yp.push_back(y[i]);
  }
  for (int i = 0; i < yp.size(); ++i) {
    for (int j = i + 1; j < yp.size() && j < i + 7; ++j) {
      d = min(d, dist(yp[i], yp[j]));
    }
  }
  return d;
}

double closest_pair(vector<point> &p) {
  vector<point> x(p.begin(), p.end());
  sort(x.begin(), x.end(), [](const point &a, const point &b
      ) {
    return a.x < b.x;
  });
  vector<point> y(p.begin(), p.end());
  sort(y.begin(), y.end(), [](const point &a, const point &b
      ) {
    return a.y < b.y;
  });
  return cp(p, x, y);
}
```

4.7 Closest Point on Line

```
//From In 1010101 We Trust cheatsheet:
//the closest point on the line p1->p2 to p3
void closestpt( PT p1, PT p2, PT p3, PT &r ){
 if(fabs(triarea(p1, p2, p3)) < EPS){ r = p3; return; }
 PT v = p2-p1; v.normalize();
 double pr; // inner product
```

```
 pr = (p3.y-p1.y)*v.y + (p3.x-p1.x)*v.x;
 r = p1+v*pr;
}
```

4.8 Delaunay Triangulation

```
// Slow but simple Delaunay triangulation. Does not handle
// degenerate cases (from O'Rourke, Computational Geometry
    in C)
//
// Running time: O(n^4)
//
// INPUT:   x[] = x-coordinates
//          y[] = y-coordinates
//
// OUTPUT:  triples = a vector containing m triples of
    indices
//                  corresponding to triangle vertices

typedef double T;

struct triple {
   int i, j, k;
   triple() {}
   triple(int i, int j, int k) : i(i), j(j), k(k) {}
};

vector<triple> delaunayTriangulation(vector<T>& x, vector<T
    >& y) {
 int n = x.size();
 vector<T> z(n);
 vector<triple> ret;

 for (int i = 0; i < n; i++)
    z[i] = x[i] * x[i] + y[i] * y[i];

 for (int i = 0; i < n-2; i++) {
    for (int j = i+1; j < n; j++) {
  for (int k = i+1; k < n; k++) {
     if (j == k) continue;
     double xn = (y[j]-y[i])*(z[k]-z[i]) - (y[k]-y[i])*(z[j
         ]-z[i]);
     double yn = (x[k]-x[i])*(z[j]-z[i]) - (x[j]-x[i])*(z[k
         ]-z[i]);
     double zn = (x[j]-x[i])*(y[k]-y[i]) - (x[k]-x[i])*(y[j
         ]-y[i]);
     bool flag = zn < 0;
     for (int m = 0; flag && m < n; m++)
   flag = flag && ((x[m]-x[i])*xn +
     (y[m]-y[i])*yn +
     (z[m]-z[i])*zn <= 0);
      if (flag) ret.push_back(triple(i, j, k));
  }
    }
 }
 return ret;
}

int main()
{
   T xs[]={0, 0, 1, 0.9};
   T ys[]={0, 1, 0, 0.9};
   vector<T> x(&xs[0], &xs[4]), y(&ys[0], &ys[4]);
   vector<triple> tri = delaunayTriangulation(x, y);

   //expected: 0 1 3
   //          0 3 2

   int i;
   for(i = 0; i < tri.size(); i++)
      printf("%d %d %d\n", tri[i].i, tri[i].j, tri[i].k);
   return 0;
}
```

4.9 Latitude and Longitude

```
/*
Converts from rectangular coordinates to latitude/longitude
     and vice
versa. Uses degrees (not radians).
*/

using namespace std;

struct ll
{
  double r, lat, lon;
};

struct rect
{
  double x, y, z;
};

ll convert(rect& P)
{
  ll Q;
  Q.r = sqrt(P.x*P.x+P.y*P.y+P.z*P.z);
  Q.lat = 180/M_PI*asin(P.z/Q.r);
  Q.lon = 180/M_PI*acos(P.x/sqrt(P.x*P.x+P.y*P.y));

  return Q;
}

rect convert(ll& Q)
{
  rect P;
  P.x = Q.r*cos(Q.lon*M_PI/180)*cos(Q.lat*M_PI/180);
  P.y = Q.r*sin(Q.lon*M_PI/180)*cos(Q.lat*M_PI/180);
  P.z = Q.r*sin(Q.lat*M_PI/180);

  return P;
}

int main()
{
  rect A;
  ll B;

  A.x = -1.0; A.y = 2.0; A.z = -3.0;

  B = convert(A);
  cout << B.r << " " << B.lat << " " << B.lon << endl;

  A = convert(B);
  cout << A.x << " " << A.y << " " << A.z << endl;
}
```

4.10 Line Intersection

```
// Ax + By = C
A = y2 - y1
B = x1 - x2
C = A*x1 + B*y1
double det = A1*B2 - A2*B1
double x = (B2*C1 - B1*C2)/det
double y = (A1*C2 - A2*C1)/det

typedef pair<double, double> pointd;
#define X first
#define Y second
bool eqf(double a, double b) {
    return fabs(b - a) < 1e-6;
}
int crossVecs(pointd a, pointd b) {
    return a.X * b.Y - a.Y*b.X;
}
```

```
int cross(pointd o, pointd a, pointd b){
    return crossVecs(make_pair(a.X - o.X, a.Y - o.Y),
        make_pair(b.X - o.X, b.Y - o.Y));
}
int dotVecs(pointd a, pointd b) {
    return a.X * b.X + a.Y * b.Y;
}
int dot(pointd o, pointd a, pointd b) {
    return dotVecs(make_pair(a.X - o.X, a.Y - o.Y), make_pair
        (b.X - o.X, b.Y - o.Y));
}
bool onTheLine(const pointd& a, const pointd& p, const
    pointd& b) {
    return eqf(cross(p, a, b), 0) && dot(p, a, b) < 0 ;
}
class LineSegment {
    public:
    double A, B, C;
    pointd from, to;
    LineSegment(const pointd& a, const pointd& b) {
        A = b.Y - a.Y;
        B = a.X - b.X;
        C = A*a.X + B*a.Y;
        from = a;
        to = b;
    }

    bool between(double l, double a, double r) const {
        if(l > r) {
            swap(l, r);
        }
        return l <= a && a <= r;
    }

    bool pointOnSegment(const pointd& p) const {
        return eqf(A*p.X + B*p.Y, C) && between(from.X, p.X,
            to.X) && between(from.Y, p.Y, to.Y);
    }

    pair<bool, pointd> segmentsIntersect(const LineSegment& l
        ) const {
        double det = A * l.B - B * l.A;
        pair<bool, pointd> ret;
        ret.first = false;
        if(det != 0) {
            pointd inter((l.B*C - B*l.C)/det, (A*l.C - l.A*C)
                /det);
            if(l.pointOnSegment(inter) && pointOnSegment(
                inter)) {
                ret.first = true;
                ret.second = inter;
            }
        }
        return ret;
    }
};
```

4.11 Point in Polygon

```
// determine if point is in a possibly non-convex polygon (
    by William
// Randolph Franklin); returns 1 for strictly interior
    points, 0 for
// strictly exterior points, and 0 or 1 for the remaining
    points.
// Note that it is possible to convert this into an *exact*
    test using
// integer arithmetic by taking care of the division
    appropriately
// (making sure to deal with signs properly) and then by
    writing exact
// tests for checking point on polygon boundary
bool PointInPolygon(const vector<PT> &p, PT q) {
  bool c = 0;
  for (int i = 0; i < p.size(); i++){
    int j = (i+1)%p.size();
    if ((p[i].y <= q.y && q.y < p[j].y ||
      p[j].y <= q.y && q.y < p[i].y) &&
      q.x < p[i].x + (p[j].x - p[i].x) * (q.y - p[i].y) / (p[
          j].y - p[i].y))
      c = !c;
  }
  return c;
}
```

4.12 Polygon Centroid

```
// This code computes the area or centroid of a (possibly
    nonconvex)
// polygon, assuming that the coordinates are listed in a
    clockwise or
// counterclockwise fashion. Note that the centroid is often
     known as
// the "center of gravity" or "center of mass".
double ComputeSignedArea(const vector<PT> &p) {
  double area = 0;
  for(int i = 0; i < p.size(); i++) {
    int j = (i+1) % p.size();
    area += p[i].x*p[j].y - p[j].x*p[i].y;
  }
  return area / 2.0;
}

double ComputeArea(const vector<PT> &p) {
  return fabs(ComputeSignedArea(p));
}

PT ComputeCentroid(const vector<PT> &p) {
  PT c(0,0);
  double scale = 6.0 * ComputeSignedArea(p);
  for (int i = 0; i < p.size(); i++){
    int j = (i+1) % p.size();
    c = c + (p[i]+p[j])*(p[i].x*p[j].y - p[j].x*p[i].y);
  }
  return c / scale;
}
```

4.13 Rotation Around Origin by t

```
 x   = x.Cos(t) - y.Sin(t)
 y   = x.Sin(t) + y.Cos(t)
```

4.14 Two Point and Radius Circle

```
vector<point> find_center(point a, point b, long double r) {
  point d = (a - b) * 0.5;
  if (d.dot(d) > r * r) {
    return vector<point> ();
  }
  point e = b + d;
  long double fac = sqrt(r * r - d.dot(d));
  vector<point> ans;
  point x = point(-d.y, d.x);
  long double l = sqrt(x.dot(x));
  x = x * (fac / l);
  ans.push_back(e + x);
  x =  point(d.y, -d.x);
  x = x * (fac / l);
  ans.push_back(e + x);
  return ans;
}
```

5 Graph

5.1 2-SAT

```
//From "You Know Izad?" team cheat sheet
//fill the v array
//e.g. to push (p v !q) use the following code:
//  v[VAR(p)].push_back( NOT( VAR(q) ) )
//  v[NOT( VAR(q) )].push_back( VAR(p) )
//the result will be in color array
#define VAR(X) (X << 1)
#define NOT(X) (X ^ 1)
#define CVAR(X,Y) (VAR(X) | (Y))z
#define COL(X) (X & 1)
#define NVAR 400
int n;
vector<int> v[2 * NVAR];
int color[2 * NVAR];
int bc[2 * NVAR];
bool dfs( int a, int col ) {
    color[a] = col;
    int num = CVAR( a, col );
    for( int i = 0; i < v[num].size(); i++ ) {
        int adj = v[num][i] >> 1;
        int ncol = NOT( COL( v[num][i] ) );
        if( ( color[adj] == -1 && !dfs( adj, ncol ) ) ||
            ( color[adj] != -1 && color[adj] != ncol ) ) {
            color[a] = -1;
            return false;
        }
    }
    return true;
}
bool twosat() {
    memset( color, -1, sizeof color );
    for( int i = 0; i < n; i++ ){
        if( color[i] == -1 ){
            memcpy(bc, color, sizeof color);
            if( !dfs( i, 0 )){
                memcpy(color, bc, sizeof color);
                if(!dfs( i, 1 ))
                    return false;
            }
        }
    }
    return true;
}
```

5.2 Bidirectional Min Cost

```
define MAX_V 1+2*100
#define MAX_E 2*10001
typedef long long edge_type;
struct edge
{
 int start, to;
 ll cap, cost;
 edge(int _s, int _d, ll _c, ll _co)
 {
  start=_s, to=_d, cost=_co, cap=_c;
 }
 edge(){}
};
const edge_type INF = 1ll<<60;
int V,E,prevee[MAX_V],last[MAX_V];
edge_type flowVal, flowCost, pot[MAX_V], dist[MAX_V];
vector<int> adj[MAX_V];
vector<edge> yal;
void add(edge b)
{
 yal.push_back(b);
 adj[b.start].push_back(yal.size()-1);
 swap(b.start, b.to);
 b.cost*=-1, b.cap=0;
 yal.push_back(b);
 adj[b.start].push_back(yal.size()-1);
}
bool Bellman_Ford (int s)
{
 bool f;
 Rep(i, V+1) pot[i]=INF;
 pot[s]=0;
 for(int i=1;i<V;i++)
 {
  f=0;
  for(int j=0;j<yal.size();j++)
  {
   int k1=yal[j].start, k2=yal[j].to,w=yal[j].cost;
   if(pot[k2]>w+pot[k1])
   {
    pot[k2]=w+pot[k1];
    f=1;
   }
  }
  if(f==0)
   break;
 }
 for(int i=0;i<yal.size();i++)
 {
  int k1=yal[i].start,k2=yal[i].to,w=yal[i].cost;
  if(pot[k2]>w+pot[k1])
   return 0;
 }
 return 1;
}
void mcmf(int s, int t){
 flowVal = flowCost = 0;
 memset(pot,0,sizeof(pot));
 Bellman_Ford(s);
 while(true){
  for(int i = 0;i<V;++i) dist[i] = INF, prevee[i]=-1;
  priority_queue<pair<ll, ll> > q;
  q.push(MP(0, s));
  dist[s] = prevee[s] = 0;

  while(!q.empty()){
   int aux = q.top().second; q.pop();

   for(int i = 0;i<adj[aux].size(); i++){
    int e=adj[aux][i];
    if(yal[e].cap<=0) continue;

    edge_type new_dist = dist[aux]+yal[e].cost+pot[aux]-pot[
         yal[e].to];

    if(new_dist<dist[yal[e].to]){
     dist[yal[e].to] = new_dist;
     prevee[yal[e].to] = e;
     q.push(MP(-1*new_dist, yal[e].to));
    }
   }
  }

  if (prevee[t]==-1) break;

  edge_type f = INF;

  for(int i = t;i!=s;i = yal[prevee[i]^1].to)
   f = min(f,yal[prevee[i]].cap);

  for(int i = t;i!=s;i = yal[prevee[i]^1].to){
   yal[prevee[i]].cap -= f;
   yal[prevee[i]^1].cap += f;
  }

  flowVal += f;
  flowCost += f*(dist[t]-pot[s]+pot[t]);
```

```
  for(int i = 0;i<V;++i) if (prevee[i]!=-1) pot[i] += dist[i
       ];
 }
}

int main(){
 int N,M,u[5000],v[5000];
 long long cst[5000],D,K;
 freopen("a.in", "r", stdin);
 while(scanf("%d %d",&N,&M)==2){
  yal.clear();
  V = 2*N+1;
  for(int i=0; i<=V; i++) adj[i].clear();
  for(int i = 0;i<M;++i){
   scanf("%d %d %lld",&u[i],&v[i],&cst[i]);
   --u[i]; --v[i];
  }
  scanf("%lld %lld",&D,&K);
  E=0;
  add(edge(0, 1, D, 0));
  for(int i = 0;i<N;++i) add(edge(1+2*i,1+2*i+1,INF,0));

  for(int i = 0;i<M;++i){
   add(edge(1+2*u[i]+1,1+2*v[i],K,cst[i]));
   add(edge(1+2*v[i]+1,1+2*u[i],K,cst[i]));
  }

  mcmf(0,2*N-1);

  if(flowVal!=D) printf("Impossible.\n");
  else printf("%lld\n",flowCost);
 }

 return 0;
}
```

5.3 Bipartite Matching and Vertex Cover

```
//Bipartite Matching is O(M * N)
#define M 128
#define N 128
bool graph[M][N];
bool seen[N];
int matchL[M], matchR[N];
int n, m;
bool bpm( int u )
{
    for( int v = 0; v < n; v++ ) if( graph[u][v] )
    {
        if( seen[v] ) continue;
        seen[v] = true;

        if( matchR[v] < 0 || bpm( matchR[v] ) )
        {
            matchL[u] = v;
            matchR[v] = u;
            return true;
        }
    }
    return false;
}
vector<int> vertex_cover()
{
 // Comment : Vertices on the left side (n side) are labeled
       like this : m+i where i is the index
 set<int> s, t, um; // um = UnMarked
 vector<int> vc;
 for(int i = 0; i < m; i++)
  if(matchL[i]==-1)
   s.insert(i), um.insert(i);
 while( um.size() )
 {
  int v = *(um.begin());
  for(int i = 0; i < n; i++)
   if( graph[v][i] && matchL[v]!=i)
   {
    t.insert(i);
    if( s.find(matchR[i]) == s.end())
     s.insert(matchR[i]), um.insert(matchR[i]);
   }
  um.erase(v);
 }
 for(int i = 0; i < m; i++)
  if( s.find(i) == s.end() )
   vc.push_back(i);
 for(set<int>::iterator i = t.begin(); i != t.end(); i++)
  vc.push_back((*i) + m);
 return vc;
}
int main()
{
    // Read input and populate graph[][]
    // Set m, n
    memset( matchL, -1, sizeof( matchL ) );
    memset( matchR, -1, sizeof( matchR ) );
    int cnt = 0;
    for( int i = 0; i < m; i++ )
    {
        memset( seen, 0, sizeof( seen ) );
        if( bpm( i ) ) cnt++;
    }
    vector<int> vc = vertex_cover();
    // cnt contains the number of happy pigeons
    // matchL[i] contains the hole of pigeon i or -1 if
         pigeon i is unhappy
    // matchR[j] contains the pigeon in hole j or -1 if hole
         j is empty
    // vc contains the Vertex Cover
    return 0;
}
```

5.4 Bridge and Articulate Point Finding

```
typedef struct {
  int deg;
  int adj[MAX_N];
} Node;

Node alist[MAX_N];
bool art[MAX_N];
int df_num[MAX_N], low[MAX_N], father[MAX_N], count;
int bridge[MAX_N*MAX_N][2], bridges;

void add_bridge(int v1, int v2) {
  bridge[bridges][0] = v1;
  bridge[bridges][1] = v2;
  ++bridges;
}

void search(int v, bool root) {
  int w, child = 0;

  low[v] = df_num[v] = count++;

  for (int i = 0; i < alist[v].deg; ++i) {
    w = alist[v].adj[i];

    if (df_num[w] == -1) {
      father[w] = v;
      ++child;
      search(w, false);
      if (low[w] > df_num[v]) add_bridge(v, w);
      if (low[w] >= df_num[v] && !root) art[v] = true;
      low[v] = min(low[v], low[w]);
    }
    else if (w != father[v]) {
      low[v] = min(low[v], df_num[w]);
    }
```

```
  }

  if (root && child > 1) art[v] = true;
}

void articulate(int n) {
  int child = 0;

  for (int i = 0; i < n; ++i) {
    art[i] = false;
    df_num[i] = -1;
    father[i] = -1;
  }

  count = bridges = 0;

  search(0, true);
}
```

5.5 Center of Tree

```
struct node
{
    char ch;
    int col, big, sz;
    vector<int> adj;
}nd[MAXN];
int n, col;
vector<int> vec;
void DFS(int pos, int col)
{
    nd[pos].sz=1;
    nd[pos].col=col;
    int k;
    nd[pos].big=0;
    Rep(i, nd[pos].adj.size())
    {
        k=nd[pos].adj[i];
        if(nd[k].col==col || nd[k].col==-1) continue;
        DFS(k, col);
        nd[pos].sz+=nd[k].sz;
        nd[pos].big=max(nd[pos].big, nd[k].sz);
    }
    vec.push_back(pos);
}
void div(int r, char ch,int col)
{
    vec.clear();
    DFS(r, col);
    r=vec[0];
    int sz=vec.size();
    Rep(i, vec.size())
    {
        nd[vec[i]].big=max(nd[vec[i]].big, sz-nd[vec[i]].sz);
        if(nd[vec[i]].big<nd[r].big) r=vec[i];
    }
    nd[r].col=-1;
    nd[r].ch=ch;
    Rep(i, nd[r].adj.size()) if(nd[nd[r].adj[i]].col==col)
         div(nd[r].adj[i], ch+1, col+1);
}
```

5.6 Count Triangles

```
vector <int> adj[maxn], Adj[maxn];

int ord[maxn], f[maxn], fi[maxn], se[maxn], ans[maxn];

bool get(int v,int u) {
 int idx = lower_bound(adj[v].begin(), adj[v].end(), u) -
     adj[v].begin();
 if (idx != adj[v].size() && adj[v][idx] == u)
  return true;
 return false;
}

bool cmp(int v,int u) {
 if (adj[v].size() < adj[u].size())
  return true;
 if (adj[v].size() > adj[u].size())
  return false;
 return (v < u);
}

int main() {
 int n, m, q;
 cin >> n >> m >> q;
 for (int i = 0; i < m; i++) {
  cin >> fi[i] >> se[i];
  fi[i]--, se[i]--;
  adj[fi[i]].push_back(se[i]);
  adj[se[i]].push_back(fi[i]);
  Adj[fi[i]].push_back(se[i]);
  Adj[se[i]].push_back(fi[i]);
 }
 for (int i = 0; i < n; i++)
  sort(adj[i].begin(), adj[i].end()),
  sort(Adj[i].begin(), Adj[i].end(), cmp);
 for (int i = 0; i < n; i++)
  ord[i] = i;
 sort (ord, ord + n, cmp);
 for (int i = 0; i < n; i++)
  f[ord[i]] = i;
 for (int v = 0; v < n; v++) {
  int idx = -1;
  for (int j = 0; j < adj[v].size(); j++) {
   int u = Adj[v][j];
   if (f[u] > f[v])
    break;
   idx = j;
  }
  for (int i = 0; i <= idx; i++)
   for (int j = 0; j < i; j++) {
    int u = Adj[v][i];
    int w = Adj[v][j];
    if (get(u,w))
     ans[v]++, ans[u]++, ans[w]++;
   }
 }
 for (int i = 0; i < q; i++) {
  int v;
  cin >> v;
  v--;
  cout << ans[v] << '\n';
 }
 return 0;
}
```

5.7 DFS on Complement Graph

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

using namespace std;

const int maxn = 5e5 + 10;
int nxt[maxn], cmp, n;
vector <int> adj[maxn], ver[maxn];

bool con(int v,int u) {
    int idx = lower_bound(adj[v].begin(), adj[v].end(), u) -
         adj[v].begin();
    return (idx != adj[v].size() && adj[v][idx] == u);
}

int get(int v) {
    if (nxt[v] == v)
        return v;
```

```
    return (nxt[v] = get(nxt[v]));
}

void dfs(int v) {
    nxt[v] = get(v + 1);
    ver[cmp].push_back(v);
    for (int u = get(0); u < n; u = get(u + 1)) {
        if (!con(u, v))
            dfs(u);
    }
}

int main() {
    int m;
    scanf("%d%d", &n, &m);
    for (int i = 0; i < m; i++) {
        int v, u;
        scanf("%d%d", &v, &u);
        v--, u--;
        adj[v].push_back(u);
        adj[u].push_back(v);
    }
    for (int i = 0; i <= n; i++)
        sort (adj[i].begin(), adj[i].end());
    for (int i = 0; i < maxn; i++)
        nxt[i] = i;

    for (int i = 0; i < n; i++)
        if (get(i) == i)
            dfs(i), cmp++;
    printf("%d\n", cmp);
    for (int i = 0; i < cmp; i++) {
        printf("%d ", (int)ver[i].size());
        for (int j = 0; j < ver[i].size(); j++)
            printf("%d ", ver[i][j] + 1);
        printf("\n");
    }
    return 0;
}
```

5.8 DSU on Tree

```
// How many vertices in subtree of vertice v has some
    property in O(n lg n) time (for all of the queries).
// Approach 1

//sz[i] = size of subtree of node i

int cnt[maxn];
bool big[maxn];
void add(int v, int p, int x){
    cnt[ col[v] ] += x;
    for(auto u: g[v])
        if(u != p && !big[u])
            add(u, v, x)
}
void dfs(int v, int p, bool keep){
    int mx = -1, bigChild = -1;
    for(auto u : g[v])
        if(u != p && sz[u] > mx)
            mx = sz[u], bigChild = u;
    for(auto u : g[v])
        if(u != p && u != bigChild)
            dfs(u, v, 0); // run a dfs on small childs and
                clear them from cnt
    if(bigChild != -1)
        dfs(bigChild, v, 1), big[bigChild] = 1; // bigChild
            marked as big and not cleared from cnt
    add(v, p, 1);
    //now cnt[c] is the number of vertices in subtree of
        vertice v that has color c. You can answer the
        queries easily.
    if(bigChild != -1)
        big[bigChild] = 0;
    if(keep == 0)
        add(v, p, -1);
}
```

5.9 Dinic Max Flow

```
// adjacency matrix (fill this up)
// If you fill adj[][] yourself, make sure to include both u
    ->v and v->u.
int cap[NN][NN], deg[NN], adj[NN][NN];

// BFS stuff
int q[NN], prev[NN];

int dinic( int n, int s, int t )
{
//////////
 memset( deg, 0, sizeof( deg ) );
    for( int u = 0; u < n; u++ )
        for( int v = 0; v < n; v++ ) if( cap[u][v] || cap[v][
            u] )
            adj[u][deg[u]++] = v;
/////////////
    int flow = 0;

    while( true )
    {
        // find an augmenting path
        memset( prev, -1, sizeof( prev ) );
        int qf = 0, qb = 0;
        prev[q[qb++] = s] = -2;
        while( qb > qf && prev[t] == -1 )
            for( int u = q[qf++], i = 0, v; i < deg[u]; i++ )
                if( prev[v = adj[u][i]] == -1 && cap[u][v] )
                    prev[q[qb++] = v] = u;

        // see if we're done
        if( prev[t] == -1 ) break;

        // try finding more paths
        for( int z = 0; z < n; z++ ) if( cap[z][t] && prev[z]
            != -1 )
        {
            int bot = cap[z][t];
            for( int v = z, u = prev[v]; u >= 0; v = u, u =
                prev[v] )
                bot <?= cap[u][v];
            if( !bot ) continue;

            cap[z][t] -= bot;
            cap[t][z] += bot;
            for( int v = z, u = prev[v]; u >= 0; v = u, u =
                prev[v] )
            {
                cap[u][v] -= bot;
                cap[v][u] += bot;
            }
            flow += bot;
        }
    }

    return flow;
}
```

5.10 Eulerian Path

```
// Taken from https://github.com/lbv/pc-code/blob/master/
    code/graph.cpp
// Eulerian Trail

struct Euler {
  ELV adj; IV t;
  Euler(ELV Adj) : adj(Adj) {}
```

```
  void build(int u) {
    while(! adj[u].empty()) {
      int v = adj[u].front().v;
      adj[u].erase(adj[u].begin());
      build(v);
    }
    t.push_back(u);
  }
};
bool eulerian_trail(IV &trail) {
  Euler e(adj);
  int odd = 0, s = 0;
  /*
     for (int v = 0; v < n; v++) {
     int diff = abs(in[v] - out[v]);
     if (diff > 1) return false;
     if (diff == 1) {
     if (++odd > 2) return false;
     if (out[v] > in[v]) start = v;
     }
     }
     */
  e.build(s);
  reverse(e.t.begin(), e.t.end());
  trail = e.t;
  return true;
}
```

5.11 Floyd Cycle Finding

```
ll a, b, c;
vector<ll> vec;
ll f(ll x)
{
 return (a*x+(x%b))%c;
}
pii floydCycleFinding(ll x0)
{
 // mu : start of cycle , lambda : lenght of cycle, cnt for
      seting limits
 // 1st part: finding k*mu, hares speed is 2x tortoises
 ll tortoise = f(x0), hare = f(f(x0)); // f(x0) is the
      element/node next to x0
 int cnt=0;
 while (tortoise != hare && cnt<=20000000)
 { tortoise = f(tortoise); hare = f(f(hare)); cnt++;}
 if(cnt>20000000) return MP(-1, -1);
 // 2nd part: finding mu, hare and tortoise move at the same
       speed
 ll mu = 0; hare = x0;
 while (tortoise != hare) { tortoise = f(tortoise); hare = f
      (hare); mu++; }

 // 3rd part: finding lambda, hare moves, tortoise stays
 ll lambda = 1; hare = f(tortoise);
 while (tortoise != hare)
 { hare = f(hare); lambda++; }
 return pii(mu, lambda);
}
int main(){
 cin>>a>>b>>c;
 pii ans=floydCycleFinding(1);
 if(ans.first!=-1) cout<<ans.first+ans.second<<endl;
 else cout<<-1<<endl;
 return 0;
}
```

5.12 Heavy Light Decomposition

```
struct TreeDecomposition {
  vector<int> g[MAXN], c[MAXN];
  int s[MAXN]; // subtree size
  int p[MAXN]; // parent id
  int r[MAXN]; // chain root id
  int t[MAXN]; // index used in segtree/bit/...
  int d[MAXN]; // depht
  int ts;

  void dfs(int v, int f) {
    p[v] = f;
    s[v] = 1;
    if (f != -1) d[v] = d[f] + 1;
    else d[v] = 0;

    for (int i = 0; i < g[v].size(); ++i) {
      int w = g[v][i];
      if (w != f) {
        dfs(w, v);
        s[v] += s[w];
      }
    }
  }

  void hld(int v, int f, int k) {
    t[v] = ts++;
    c[k].push_back(v);
    r[v] = k;

    int x = 0, y = -1;
    for (int i = 0; i < g[v].size(); ++i) {
      int w = g[v][i];
      if (w != f) {
        if (s[w] > x) {
          x = s[w];
          y = w;
        }
      }
    }
    if (y != -1) {
      hld(y, v, k);
    }

    for (int i = 0; i < g[v].size(); ++i) {
      int w = g[v][i];
      if (w != f && w != y) {
        hld(w, v, w);
      }
    }
  }

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

  void add(int a, int b) {
    g[a].push_back(b);
    g[b].push_back(a);
  }

  void build() {
    ts = 0;
    dfs(0, -1);
    hld(0, 0, 0);
  }
};
```

5.13 Hopcroft Karp Max Flow

```
/// e*sqrt(v)
vector<int> adj[MAXN];
int dis1[MAXN], dis2[MAXN], g1[MAXN], g2[MAXN], n, inf
     =1<<30, n1, n2;
queue<int> q;
bool BFS()
{
```

```
 for(int i=0; i<n1; i++) dis1[i]=0;
 for(int i=0; i<n2; i++) dis2[i]=0;
 for(int i=0; i<n1; i++) if(g1[i]==-1) q.push(i);
 bool f=0;
 int v, u;
 while (!q.empty())
 {
  v=q.front(), q.pop();
  for(int i=0; i<adj[v].size(); i++)
  {
   u=adj[v][i];
   if(dis2[u]==0)
   {
    dis2[u]=dis1[v]+1;
    if(g2[u]==-1) f=1;
    else
    {
     dis1[g2[u]]=dis2[u]+1;
      q.push(g2[u]);
    }
   }
  }
 }
 return f;
}
bool DFS(int v)
{
 int u;
 for(int i=0; i<adj[v].size(); i++)
 {
  u=adj[v][i];
  if(dis2[u]==dis1[v]+1)
  {
   dis2[u]=0;
   if(g2[u]==-1 || DFS(g2[u]))
   {
    g1[v]=u;
    g2[u]=v;
    return 1;
   }
  }
 }
 return 0;
}
int Hopcroft_Karp()
{
 for(int i=0; i<n1; i++) g1[i]=-1;
 for(int i=0; i<n2; i++) g2[i]=-1;
 int matching=0;
 while (BFS()) for(int i=0; i<n1; i++)
  if(g1[i]==-1 && DFS(i)) matching++;
 return matching;
}
int col[MAXN];
int ind[MAXN];

void paint_geraph()
{
 memset(col, -1, sizeof col);
 int c, k;
 ind[0]=0;
 col[n1++]=1;
 q.push(0);
 while (!q.empty())
 {
  c=q.front(), q.pop();
  for(int i=0; i<adj[c].size(); i++)
  {
   k=adj[c][i];
   if(col[k]!=-1) continue;
   col[k]=!col[c];
   if(col[k]) ind[k]=n1++;
   else ind[k]=n2++;
   q.push(k);
  }
 }
}
int main(){
 int m, u, v;
 vector<pii> ed;
 cin>>n>>m;
 for(int i=0; i<m; i++)
 {
  cin>>u>>v;
  ed.push_back(make_pair(u-1, v-1));
  adj[u-1].push_back(v-1);
  adj[v-1].push_back(u-1);
 }
 n1=n2=0;
 paint_geraph();
 for(int i=0; i<n; i++) adj[i].clear();
 for(int i=0; i<m; i++)
 {
  u=ind[ed[i].first], v=ind[ed[i].second];
  if(col[ed[i].first]) adj[u].push_back(v);
  else adj[v].push_back(u);
 }
 int ans=Hopcroft_Karp();
 cout<<ans<<endl;
 bool f;
 for(int i=0; i<m; i++)
 {
  u=ind[ed[i].first], v=ind[ed[i].second];
  f=0;
  if(col[ed[i].first])
  {
   if(g1[u]==v)
    f=1;
  }
  else if(g2[u]==v) f=1;
  if(f) cout<<ed[i].first+1<<' '<<ed[i].second+1<<endl;
 }
 return 0;
}
```

5.14 Hungarian Algorithm

```
#define N 55 //max number of vertices in one part
#define INF 100000000 //just infinity

int cost[N][N]; //cost matrix
int n, max_match; //n workers and n jobs
int lx[N], ly[N]; //labels of X and Y parts
int xy[N]; //xy[x] - vertex that is matched with x,
int yx[N]; //yx[y] - vertex that is matched with y
bool S[N], T[N]; //sets S and T in algorithm
int slack[N]; //as in the algorithm description
int slackx[N]; //slackx[y] such a vertex, that
// l(slackx[y]) + l(y) - w(slackx[y],y) = slack[y]
int prv[N]; //array for memorizing alternating paths


void init_labels()
{
    memset(lx, 0, sizeof(lx));
    memset(ly, 0, sizeof(ly));
    for (int x = 0; x < n; x++)
        for (int y = 0; y < n; y++)
            lx[x] = max(lx[x], cost[x][y]);
}

void update_labels()
{
    int x, y, delta = INF; //init delta as infinity
    for (y = 0; y < n; y++) //calculate delta using slack
        if (!T[y])
            delta = min(delta, slack[y]);
    for (x = 0; x < n; x++) //update X labels
        if (S[x]) lx[x] -= delta;
```

```
    for (y = 0; y < n; y++) //update Y labels
        if (T[y]) ly[y] += delta;
    for (y = 0; y < n; y++) //update slack array
        if (!T[y])
            slack[y] -= delta;
}

void add_to_tree(int x, int prevx)
//x - current vertex,prevx - vertex from X before x in the
     alternating path,
//so we add edges (prevx, xy[x]), (xy[x], x)
{
    S[x] = true; //add x to S
    prv[x] = prevx; //we need this when augmenting
    for (int y = 0; y < n; y++) //update slacks, because we
         add new vertex to S
        if (lx[x] + ly[y] - cost[x][y] < slack[y])
        {
            slack[y] = lx[x] + ly[y] - cost[x][y];
            slackx[y] = x;
        }
}


void augment() //main function of the algorithm
{
    if (max_match == n) return; //check wether matching is
         already perfect
    int x, y, root; //just counters and root vertex
    int q[N], wr = 0, rd = 0; //q - queue for bfs, wr,rd -
         write and read
    //pos in queue
    memset(S, false, sizeof(S)); //init set S
    memset(T, false, sizeof(T)); //init set T
    memset(prv, -1, sizeof(prv)); //init set prev - for the
         alternating tree
    for (x = 0; x < n; x++) //finding root of the tree
        if (xy[x] == -1)
        {
            q[wr++] = root = x;
            prv[x] = -2;
            S[x] = true;
            break;
        }

    for (y = 0; y < n; y++) //initializing slack array
    {
        slack[y] = lx[root] + ly[y] - cost[root][y];
        slackx[y] = root;
    }
    //second part of augment() function
    while (true) //main cycle
    {
        while (rd < wr) //building tree with bfs cycle
        {
            x = q[rd++]; //current vertex from X part
            for (y = 0; y < n; y++) //iterate through all
                 edges in equality graph
                if (cost[x][y] == lx[x] + ly[y] && !T[y])
                {
                    if (yx[y] == -1) break; //an exposed
                         vertex in Y found, so
                    //augmenting path exists!
                    T[y] = true; //else just add y to T,
                    q[wr++] = yx[y]; //add vertex yx[y], which
                         is matched
                    //with y, to the queue
                    add_to_tree(yx[y], x); //add edges (x,y)
                         and (y,yx[y]) to the tree
                }
            if (y < n) break; //augmenting path found!
        }
        if (y < n) break; //augmenting path found!

        update_labels(); //augmenting path not found, so
             improve labeling
        wr = rd = 0;
        for (y = 0; y < n; y++)
            //in this cycle we add edges that were added to
                 the equality graph as a
            //result of improving the labeling, we add edge (
                 slackx[y], y) to the tree if
            //and only if !T[y] && slack[y] == 0, also with
                 this edge we add another one
            //(y, yx[y]) or augment the matching, if y was
                 exposed
            if (!T[y] && slack[y] == 0)
            {
                if (yx[y] == -1) //exposed vertex in Y found -
                     augmenting path exists!
                {
                    x = slackx[y];
                    break;
                }
                else
                {
                    T[y] = true; //else just add y to T,
                    if (!S[yx[y]])
                    {
                        q[wr++] = yx[y]; //add vertex yx[y],
                             which is matched with
                        //y, to the queue
                        add_to_tree(yx[y], slackx[y]); //and
                             add edges (x,y) and (y,
                        //yx[y]) to the tree
                    }
                }
            }
        if (y < n) break; //augmenting path found!
    }

    if (y < n) //we found augmenting path!
    {
        max_match++; //increment matching
        //in this cycle we inverse edges along augmenting
             path
        for (int cx = x, cy = y, ty; cx != -2; cx = prv[cx],
             cy = ty)
        {
            ty = xy[cx];
            yx[cy] = cx;
            xy[cx] = cy;
        }
        augment(); //recall function, go to step 1 of the
             algorithm
    }
}//end of augment() function

int hungarian()
{
    int ret = 0; //weight of the optimal matching
    max_match = 0; //number of vertices in current matching
    memset(xy, -1, sizeof(xy));
    memset(yx, -1, sizeof(yx));
    init_labels(); //step 0
    augment(); //steps 1-3
    for (int x = 0; x < n; x++) //forming answer there
        ret += cost[x][xy[x]];
    return ret;
}
```

5.15 List Dinic

```
//From "You Know Izad?" team cheat sheet
const int MAXN = 300;
struct Edge
{
    int a, b, cap, flow;
```

```cpp
};
int n, s, t, d[MAXN], ptr[MAXN];
vector<Edge> e;
vi adj[MAXN];
void init(){
    e.clear();
    fore(i, 0, MAXN)
        adj[i].clear();
}
void add_edge (int a, int b, int cap) {
    Edge e1 = { a, b, cap, 0 };
    Edge e2 = { b, a, 0, 0 };
    adj[a].push_back ((int) e.size());
    e.push_back (e1);
    adj[b].push_back ((int) e.size());
    e.push_back (e2);
}
bool bfs() {
    queue <int> q;
    q.push(s);
    memset(d, -1, sizeof d);
    d[s] = 0;
    while (!q.empty() && d[t] == -1){
        int v = q.front();
        q.pop();
        for (int i = 0; i < L(adj[v]); ++i)
        {
            int id = adj[v][i],
                to = e[id].b;
            if (d[to] == -1 && e[id].flow < e[id].cap)
            {
                q.push(to);
                d[to] = d[v] + 1;
            }
        }
    }
    return d[t] != -1;
}
int dfs (int v, int flow){
    if (!flow) return 0;
    if (v == t) return flow;
    for (; ptr[v] < L(adj[v]); ++ptr[v]){
        int id = adj[v][ptr[v]],
            to = e[id].b;
        if (d[to] != d[v] + 1)
            continue;
        int pushed = dfs (to, min (flow, e[id].cap - e[id].
             flow));
        if (pushed) {
            e[id].flow += pushed;
            e[id ^ 1].flow -= pushed;
            return pushed;
        }
    }
    return 0;
}
int dinic(){
    int flow = 0;
    while(true){
        if (!bfs())
            break;
        memset(ptr, 0, sizeof ptr);
        // overflow?
        while (int pushed = dfs (s, INF32))
            flow += pushed;
    }
    return flow;
}
int main()
{
    init();
    // set n, s, t
    // add edges using add_edge (directed edge)
    int result = dinic();
}
```

5.16 Matrix Dinic

```cpp
//From "You Know Izad?" team cheat sheet
#define MAXN 400
struct Edge
{
    int a, b;
    ll cap, flow;
};
int n, c[MAXN][MAXN], f[MAXN][MAXN], s, t, d[MAXN], ptr[MAXN
     ];
bool bfs()
{
    queue <int> q;
    q.push(s);
    memset (d, -1, sizeof d);
    d[s] = 0;
    while(!q.empty()){
        int v = q.front();
        q.pop();
        for (int to=0; to<n; ++to){
            if (d[to] == -1 && f[v][to] < c[v][to]){
                q.push(to);
                d[to] = d[v] + 1;
            }
        }
    }
    return d[t] != -1;
}
int dfs (int v, int flow)
{
    if (!flow) return 0;
    if (v == t) return flow;
    for (int & to=ptr[v]; to<n; ++to){
        if (d[to] != d[v] + 1) continue;
        int pushed = dfs (to, min (flow, c[v][to] - f[v][to])
             );
        if (pushed){
            f[v][to] += pushed;
            f[to][v] -= pushed;
            return pushed;
        }
    }
    return 0;
}
int dinic() {
    int flow = 0;
    // flow between any two vertices is initially zero
    memset(f, 0, sizeof f);
    while(true){
        if (!bfs()) break;
        memset(ptr, 0, sizeof ptr);
        // overflow?
        while (int pushed = dfs (s, INF32))
            flow += pushed;
    }
    return flow;
}
int main()
{
    // set s (source) , t (sink) , n (nodes)
    memset(c, 0, sizeof c);
    // add edges in capacity (c) matrix
    // call dinic function to get Maxflow
}
```

5.17 Max Flow

```cpp
int cap[MAXN][MAXN],n;
vector<int> adj[MAXN];
int BFS(int s, int e)
{
```

```
 bool v[MAXN]={0};
 int p[MAXN], i, t, k, c;
 for(i=1;i<=n;i++)
  p[i] = -1;
 queue <int> q;
 q.push(s);
 v[s]=1;
 while(!q.empty())
 {
  t=q.front();
  q.pop();
  for(i=0;i<adj[t].size();i++)
  {
   k=adj[t][i];
   if(v[k]==0 && cap[t][k]>0)
   {
    q.push(k);
    v[k]=1;
    p[k]=t;
    if(k==e)
     break;
   }
  }
  if(i<adj[t].size())
   break;
 }
 k=e,c=1<<28;
 while(p[k]>-1)
 {
  c=min(c,cap[p[k]][k]);
  k=p[k];
 }
 k=e;
 while(p[k]>-1)
 {
  cap[p[k]][k]-=c;
  cap[k][p[k]]+=c;
  k=p[k];
 }
 if(c==1<<28)
  return 0;
 return c;
}
int max_flow(int s, int e)
{
 int ans=0, c;
 while(1)
 {
  c=BFS(s, e);
  if(c==0)
   break;
  ans+=c;
 }
 return ans;
}
void add_edge(int u, int v, int c)
{
 adj[u].push_back(v), adj[v].push_back(u);
 if(c!=MOD) cap[u][v]+=c;
 else cap[u][v]=MOD;
}
```

5.18 Min Cost Bipartite Matching

```
//From "You Know Izad?" team cheat sheet
vi u (n+1), v (m+1), p (m+1), way (m+1);
for (int i=1; i<=n; ++i) {
    p[0] = i;
    int j0 = 0;
    vi minv (m+1, INF);
    vector<char> used (m+1, false);
    do {
        used[j0] = true;
        int i0 = p[j0], delta = INF, j1;
        for (int j=1; j<=m; ++j)
            if (!used[j]) {
                int cur = a[i0][j]-u[i0]-v[j];
                if (cur < minv[j])
                    minv[j] = cur, way[j] = j0;
                if (minv[j] < delta)
                    delta = minv[j], j1 = j;
            }
        for (int j=0; j<=m; ++j)
            if (used[j])
                u[p[j]] += delta, v[j] -= delta;
            else
                minv[j] -= delta;
        j0 = j1;
    } while (p[j0] != 0);
    do {
        int j1 = way[j0];
        p[j0] = p[j1];
        j0 = j1;
    } while (j0);
}
int cost = -v[0]; // minimum cost
// ans -> printable matching result
vi ans (n+1);
for (int j=1; j<=m; ++j)
    ans[p[j]] = j;
```

5.19 Min Cost Max Flow

```
//From "You Know Izad?" team cheat sheet
struct rib {
    int b, u, c, f;
    size_t back;
};
void add_rib (vector < vector<rib> > & g, int a, int b, int
     u, int c) {
    // u = capacity
    // c = cost per flow (maybe double)
    // add edge between a and b
    rib r1 = { b, u, c, 0, g[b].size() };
    rib r2 = { a, 0, -c, 0, g[a].size() };
    g[a].push_back (r1);
    g[b].push_back (r2);
}
int main() {
    // k = the exact amount of flow (cost is calculated
         according to this)
    // set k to infinity --> gives maxFlow (in flow variable)
    int n, m, k;
    vector < vector<rib> > g (n);
    int s, t;
    //reading the graph
    int flow = 0, cost = 0;
    while (flow < k) {
        vector<int> id (n, 0);
        vector<int> d (n, INF);
        vector<int> q (n);
        vector<int> p (n);
        vector<size_t> p_rib (n);
        int qh=0, qt=0;
        q[qt++] = s;
        d[s] = 0;
        while (qh != qt) {
            int v = q[qh++];
            id[v] = 2;
            if (qh == n) qh = 0;
            for (size_t i=0; i<g[v].size(); ++i) {
                rib & r = g[v][i];
                if (r.f < r.u && d[v] + r.c < d[r.b]) {
                    d[r.b] = d[v] + r.c;
                    if (id[r.b] == 0) {
                        q[qt++] = r.b;
                        if (qt == n) qt = 0;
                    }
```

```
                else if (id[r.b] == 2) {
                    if (--qh == -1) qh = n-1;
                    q[qh] = r.b;
                }
                id[r.b] = 1;
                p[r.b] = v;
                p_rib[r.b] = i;
            }
        }
    }
    if (d[t] == INF) break;
    int addflow = k - flow;
    for (int v=t; v!=s; v=p[v]) {
        int pv = p[v]; size_t pr = p_rib[v];
        addflow = min (addflow, g[pv][pr].u - g[pv][pr].f
             );
    }
    for (int v=t; v!=s; v=p[v]) {
        int pv = p[v]; size_t pr = p_rib[v], r = g[pv][pr
             ].back;
        g[pv][pr].f += addflow;
        g[v][r].f -= addflow;
        cost += g[pv][pr].c * addflow;
    }
    flow += addflow;
  }
  // output the result
}
```

5.20 Tarjan SCC

```
int n, low_link[MAXN], index[MAXN], ind, group, gr[MAXN];
stack<int> st;
vector<int> adj[MAXN];
bool instack[MAXN];
void tarjan(int c)
{
 index[c]=low_link[c]=ind++;
 instack[c]=1;
 st.push(c);
 int k;
 Rep(i, (int)adj[c].size())
 {
  k=adj[c][i];
  if(index[k]==-1)
  {
   tarjan(k);
   low_link[c]=min(low_link[c], low_link[k]);
  }
  else if(instack[k]) low_link[c]=min(low_link[c], index[k])
      ;
 }
 if(low_link[c]==index[c])
 {
  group++;
  do
  {
   k=st.top(), st.pop();
   gr[k]=group;
   instack[k]=0;
  }while (k!=c);
 }
}
int main(){
 Set(index, -1), Set(instack, 0);
 ind=group=0;
 Rep(i, n) if(index[i]==-1) tarjan(i);
 cout<<group<<endl;
 return 0;
}
```

5.21 Weighted Min Cut

```
// Maximum number of vertices in the graph
#define NN 256

// Maximum edge weight (MAXW * NN * NN must fit into an int)
#define MAXW 1000

// Adjacency matrix and some internal arrays
int g[NN][NN], v[NN], w[NN], na[NN];
bool a[NN];

int minCut( int n )
{
    // init the remaining vertex set
    for( int i = 0; i < n; i++ ) v[i] = i;

    // run Stoer-Wagner
    int best = MAXW * n * n;
    while( n > 1 )
    {
        // initialize the set A and vertex weights
        a[v[0]] = true;
        for( int i = 1; i < n; i++ )
        {
            a[v[i]] = false;
            na[i - 1] = i;
            w[i] = g[v[0]][v[i]];
        }

        // add the other vertices
        int prev = v[0];
        for( int i = 1; i < n; i++ )
        {
            // find the most tightly connected non-A vertex
            int zj = -1;
            for( int j = 1; j < n; j++ )
                if( !a[v[j]] && ( zj < 0 || w[j] > w[zj] ) )
                    zj = j;

            // add it to A
            a[v[zj]] = true;

            // last vertex?
            if( i == n - 1 )
            {
                // remember the cut weight
                best <?= w[zj];

                // merge prev and v[zj]
                for( int j = 0; j < n; j++ )
                    g[v[j]][prev] = g[prev][v[j]] += g[v[zj]][
                         v[j]];
                v[zj] = v[--n];
                break;
            }
            prev = v[zj];

            // update the weights of its neighbours
            for( int j = 1; j < n; j++ ) if( !a[v[j]] )
                w[j] += g[v[zj]][v[j]];
        }
    }
    return best;
}

int main()
{
    // read the graph's adjacency matrix into g[][]
    // and set n to equal the number of vertices
    int n, answer = minCut( n );
    return 0;
}
```

6 Math

6.1 Binary Gaussian Elimination

```
//Amin Anvari's solution to Shortest XOR Path problem
#include <bits/stdc++.h>
using namespace std;
typedef pair <int,int> pii;
#define L first
#define R second
const int maxn = 1e5, maxl = 31;
bool mark[maxn];
vector <pii> adj[maxn];
vector <int> all;
int n, s, w[maxn], pat[maxn], b[maxn];
void dfs(int v,int par = -1) {
    mark[v] = true;
    for (int i = 0; i < adj[v].size(); i++) {
        int u = adj[v][i].L, e = adj[v][i].R, W = w[e];
        if (!mark[u]) {
            pat[u] = pat[v] ^ W;
            dfs(u, e);
        }
        else if (e != par)
            all.push_back(pat[v] ^ pat[u] ^ W);
    }
}
int get(int x) {
    for (int i = maxl - 1; i >= 0; i--)
        if (x & (1 << i))
            return i;
    return -1;
}
void add(int x) {
    for (int i = 0; i < s; i++)
        if (get(b[i]) != -1 && (x & (1 << get(b[i]))))
            x ^= b[i];
    if (x == 0)
        return;
    for (int i = 0; i < s; i++)
        if (b[i] < x)
            swap(x, b[i]);
    b[s++] = x;
}
int GET(int x) {
    for (int i = 0; i < s; i++)
        if (get(b[i]) != -1 && (x & (1 << get(b[i]))))
            x ^= b[i];
    return x;
}
int main() {
    ios_base::sync_with_stdio(false);
    int m;
    cin >> n >> m;
    for (int i = 0; i < m; i++) {
        int v, u;
        cin >> v >> u >> w[i];
        v--, u--;
        adj[v].push_back(pii(u, i));
        adj[u].push_back(pii(v, i));
    }
    dfs(0);
    for (int i = 0; i < all.size(); i++)
        add(all[i]);
    cout << GET(pat[n - 1]) << endl;
    return 0;
}
```

6.2 Discrete Logarithm Solver

```
// discrete-logarithm, finding y for equation k = x^y % mod
int discrete_logarithm(int x, int mod, int k) {
  if (mod == 1) return 0;
  int s = 1, g;
  for (int i = 0; i < 64; ++i) {
    if (s == k) return i;
    s = (1ll * s * x) % mod;
  }
  while ((g = gcd(x, mod)) != 1) {
    if (k % g) return -1;
    mod /= g;
  }
  static unordered_map<int, int> M; M.clear();
  int q = int(sqrt(double(euler(mod)))) + 1; // mod-1 is
      also okay
  for (int i = 0, b = 1; i < q; ++i) {
    if (M.find(b) == M.end()) M[b] = i;
    b = (1ll * b * x) % mod;
  }
  int p = fpow(x, q, mod);
  for (int i = 0, b = 1; i <= q; ++i) {
    int v = (1ll * k * inverse(b, mod)) % mod;
    if (M.find(v) != M.end()) {
      int y = i * q + M[v];
      if (y >= 64) return y;
    }
    b = (1ll * b * p) % mod;
  }
  return -1;
}
```

6.3 Euler Totient Function

```
/* Returns the number of positive integers that are
 * relatively prime to n. As efficient as factor().
 * REQUIRES: factor()
 * REQUIRES: sqrt() must work on Int.
 * REQUIRES: the constructor Int::Int( double ).
 **/
int phi( int n ) {
 vector< int > p;
 factor( n, p );
 for( int i = 0; i < ( int )p.size(); i++ ) {
  if( i && p[i] == p[i - 1] ) continue;
  n /= p[i];
  n *= p[i] - 1;
 }
 return n;
}
```

6.4 Extended GCD

```
template< class Int >
struct Triple
{
 Int d, x, y;
 Triple( Int q, Int w, Int e ) : d( q ), x( w ), y( e ) {}
};

/* Given nonnegative a and b, computes d = gcd( a, b )
 * along with integers x and y, such that d = ax + by
 * and returns the triple (d, x, y).
 * WARNING: needs a small modification to work on
 * negative integers (operator% fails).
 **/

template< class Int >
Triple< Int > egcd( Int a, Int b )
{
 if( !b ) return Triple< Int >( a, Int( 1 ), Int( 0 ) );
 Triple< Int > q = egcd( b, a % b );
 return Triple< Int >( q.d, q.y, q.x - a / b * q.y );
}
```

6.5 Fibonacci Numbers Properties

Let A, B and n be integer numbers.

$$k = A - B \tag{1}$$

$$F_A F_B = F_{k+1} F_A^2 + F_k F_A F_{A-1} \tag{2}$$

$$\sum_{i=0}^{n} F_i^2 = F_{n+1} F_n \tag{3}$$

$ev(n)$ = returns 1 if n is even.

$$\sum_{i=0}^{n} F_i F_{i+1} = F_{n+1}^2 - ev(n) \tag{4}$$

$$\sum_{i=0}^{n} F_i F_{i-1} = \sum_{i=0}^{n-1} F_i F_{i+1} \tag{5}$$

6.6 Linear Diophantine Equation Solver

```
/* Solves integer equations of the form ax + by = c
 * for integers x and y. Returns a triple containing
 * the answer (in .x and .y) and a flag (in .d).
 * If the returned flag is zero, then there are no
 * solutions. Otherwise, there is an infinite number
 * of solutions of the form
 * x = t.x + k * b / t.d,
 * y = t.y - k * a / t.d;
 * where t is the returned triple, and k is any
 * integer.
 * REQUIRES: struct Triple, egcd
 **/
template< class Int >
Triple< Int > ldioph( Int a, Int b, Int c ) {
 Triple< Int > t = egcd( a, b );
 if( c % t.d ) return Triple< Int >( 0, 0, 0 );
 t.x *= c / t.d; t.y *= c / t.d;
 return t;
}
```

6.7 Maximum XOR (SGU 275)

```
int n;
long long x, ans;
vector<long long> st;
int main() {
 cin >> n;
 for (int i = 0; i < n; i++) {
  cin >> x;
  st.push_back(x);
 }
 for (int k = 0; k < n; k++)
  for (int i = 0; i < st.size(); i++)
   for (int j = i + 1; j < st.size(); j++)
    if (__builtin_clzll(st[j]) == __builtin_clzll(st[i]))
     st[j] ^= st[i];
 sort(st.begin(), st.end());
 reverse(st.begin(), st.end());
 for (auto e: st)
  ans = max(ans, ans ^ e);
 cout << ans << endl;
 return 0;
}
```

6.8 Modular Linear Equation Solver

```
/* Given a, b and n, solves the equation ax = b (mod n)
 * for x. Returns the vector of solutions, all smaller
 * than n and sorted in increasing order. The vector is
 * empty if there are no solutions.
 * REQUIRES: struct Triple, egcd
 **/
template< class Int >
vector< Int > msolve( Int a, Int b, Int n ) {
 if( n < 0 ) n = -n;
 Triple< Int > t = egcd( a, n );
 vector< Int > r;
 if( b % t.d ) return r;
 Int x = ( b / t.d * t.x ) % n;
 if( x < Int( 0 ) ) x += n;
 for( Int i = 0; i < t.d; i++ )
 r.push_back( ( x + i * n / t.d ) % n );
 return r;
}
```

6.9 Number of Divisors

```
/* Returns the number of positive divisors of n.
 * Complexity: about O(sqrt(n)).
 * REQUIRES: factor()
 * REQUIRES: sqrt() must work on Int.
 * REQUIRES: the constructor Int::Int( double ).
 **/
template< class Int >
Int divisors( Int n ) {
 vector< Int > f;
 factor( n, f );
 int k = f.size();
 vector< Int > table( k + 1, Int( 0 ) );
 table[k] = Int( 1 );

 for( int i = k - 1; i >= 0; i-- ) {
  table[i] = table[i + 1];
  for( int j = i + 1; ; j++ )
   if( j == k || f[j] != f[i] )
   { table[i] += table[j]; break; }
 }

 return table[0];
}
```

6.10 Prime Factors in n Factorial

```
using namespace std;
typedef long long ll;
typedef pair<ll ,int> pii;
vector <pii> v;
/////////// bozorgtarin i b shekli k N!%k^i==0
void fact(ll n) {
 ll x = 2;
 while (x * x <= n)
 {
  ll num = 0;
  while (n % x == 0) {
   num++;
   n /= x;
  }
  if (num) v.push_back(MP(x, num));
  x++;
  if (n == 1ll) break;
 }
 if(n > 1) v.push_back(MP(n, 1));
}

ll getfact(ll n) {
```

```
 ll ret = n;
 Rep(i, v.size()) {
  ll k = v[i].first;
  ll cnt = 0;
  ll t = n;
  while (k <= n) {
  cnt += n / k;
  n /= k;
  }
  n = t;
  ret = min(ret, cnt / v[i].second);
 }
 return ret;
}

int main() {
 int tc;
 ll n, k;
 cin >> tc;
 while (tc--) {
  v.clear();
  cin >> n >> k;
  fact(k);
  cout << getfact(n) << endl;
 }
 return 0;
}
```

6.11 Reduced Row Echelon Form

```
// Reduced row echelon form via Gauss-Jordan elimination
// with partial pivoting. This can be used for computing
// the rank of a matrix.
//
// Running time: O(n^3)
//
// INPUT:   a[][] = an nxm matrix
//
// OUTPUT:  rref[][] = an nxm matrix (stored in a[][])
//          returns rank of a[][]

#include <iostream>
#include <vector>
#include <cmath>

using namespace std;

const double EPSILON = 1e-10;

typedef double T;
typedef vector<T> VT;
typedef vector<VT> VVT;

int rref(VVT &a) {
  int n = a.size();
  int m = a[0].size();
  int r = 0;
  for (int c = 0; c < m && r < n; c++) {
    int j = r;
    for (int i = r + 1; i < n; i++)
      if (fabs(a[i][c]) > fabs(a[j][c])) j = i;
    if (fabs(a[j][c]) < EPSILON) continue;
    swap(a[j], a[r]);

    T s = 1.0 / a[r][c];
    for (int j = 0; j < m; j++) a[r][j] *= s;
    for (int i = 0; i < n; i++) if (i != r) {
      T t = a[i][c];
      for (int j = 0; j < m; j++) a[i][j] -= t * a[r][j];
    }
    r++;
  }
  return r;
}

int main() {
  const int n = 5, m = 4;
  double A[n][m] = {
    {16,  2,  3, 13},
    { 5, 11, 10,  8},
    { 9,  7,  6, 12},
    { 4, 14, 15,  1},
    {13, 21, 21, 13}};
  VVT a(n);
  for (int i = 0; i < n; i++)
    a[i] = VT(A[i], A[i] + m);

  int rank = rref(a);

  // expected: 3
  cout << "Rank: " << rank << endl;

  // expected: 1 0 0 1
  //           0 1 0 3
  //           0 0 1 -3
  //           0 0 0 3.10862e-15
  //           0 0 0 2.22045e-15
  cout << "rref: " << endl;
  for (int i = 0; i < 5; i++) {
    for (int j = 0; j < 4; j++)
      cout << a[i][j] << ' ';
    cout << endl;
  }
}
```

6.12 Solving Recursive Functions

```
//From "You Know Izad?" team cheat sheet
/*
a[i] = b[i] (for i <= k)
a[i] = c[1]*a[i-1] + c[2]a[i-2] + ... + c[k]a[i-k] (for i >
    k)
Given:
b[1], b[2], ..., b[k]
c[1], c[2], ..., c[k]
a[N]=?
*/
typedef vector<vector<ll> > matrix;
int K;
matrix mul(matrix A, matrix B){
    matrix C(K+1, vector<ll>(K+1));
    REP(i, K) REP(j, K) REP(k, K)
        C[i][j] = (C[i][j] + A[i][k] * B[k][j]) % INF32;
    return C;
}
matrix pow(matrix A, ll p){
    if (p == 1) return A;
    if (p % 2) return mul(A, pow(A, p-1));
    matrix X = pow(A, p/2);
    return mul(X, X);
}
ll solve() {
    // base (initial) values
    vector<ll> F1(K+1);
    REP (i, K)
        cin >> F1[i];
    matrix T(K+1, vector<ll>(K+1));
    REP(i, K) {
        REP(j, K) {
            if(j == i + 1) T[i][j] = 1;
            else if(i == K) cin >> T[i][K - j + 1]; //
                multipliers
            else T[i][j] = 0;
        }
    }
    ll N;
    cin >> N;
    if (N == 1) return 1;
```

```
    T = pow(T, N-1);
    ll res = 0;
    REP(i, K)
        res = (res + T[1][i] * F1[i]) % INF32; // Mod Value
    return res;
}
int main() {
    cin >> K;
    cout << solve() << endl;
}
```

7 Sequences Algorithms

7.1 FFT and Multiplication

```
//From "You Know Izad?" team cheatsheet
#define base complex<double>
void fft (vector<base> & a, bool invert){
    if (L(a) == 1) return;
    int n = L(a);
    vector <base> a0(n / 2), a1(n / 2);
    for (int i = 0, j = 0; i < n; i += 2, ++j){
        a0[j] = a[i];
        a1[j] = a[i + 1];
    }
    fft (a0, invert);
    fft (a1, invert);
    double ang = 2 * PI / n * (invert ? -1 : 1);
    base w(1), wn(cos(ang), sin(ang));
    fore(i, 0, n / 2) {
        a[i] = a0[i] + w * a1[i];
        3
        a[i + n / 2] = a0[i] - w * a1[i];
        if (invert)
            a[i] /= 2, a[i + n / 2] /= 2;
        w *= wn;
    }
}
void multiply (const vector<int> &a, const vector<int> & b,
     vector<int> &res){
    vector <base> fa(all(a)), fb(all(b));
    size_t n = 1;
    while (n < max(L(a), (L(b)))) n <<= 1;
    n <<= 1;
    fa.resize(n), fb.resize(n);
    fft(fa, false), fft(fb, false);
    fore(i, 0, n)
    fa[i] *= fb[i];
    fft (fa, true);
    res.resize (n);
    fore(i, 0, n)
    res[i] = int (fa[i].real() + 0.5);
}
```

7.2 LIS

```
void reconstruct_print(int end, int a[], int p[]) {
  int x = end;
  stack<int> s;
  for (; p[x] >= 0; x = p[x]) s.push(a[x]);
  printf("[%d", a[x]);
  for (; !s.empty(); s.pop()) printf(", %d", s.top());
  printf("]\n");
}

int main() {
  int n = 11, A[] = {-7, 10, 9, 2, 3, 8, 8, 1, 2, 3, 4};
  int L[MAX_N], L_id[MAX_N], P[MAX_N];

  int lis = 0, lis_end = 0;
  for (int i = 0; i < n; ++i) {
    int pos = lower_bound(L, L + lis, A[i]) - L;
    L[pos] = A[i];
    L_id[pos] = i;
    P[i] = pos ? L_id[pos - 1] : -1;
    if (pos + 1 > lis) {
      lis = pos + 1;
      lis_end = i;
    }
    printf("LIS ending at A[%d] is of length %d: ", i, pos +
        1);
    reconstruct_print(i, A, P);
    printf("\n");
  }

  printf("Final LIS is of length %d: ", lis);
  reconstruct_print(lis_end, A, P);
  return 0;
}
```

8 Strings

8.1 Aho Corasick

```
#include <bits/stdc++.h>
#define FOR(i, n) for (int i = 0; i < (n); ++i)
#define REP(i, n) for (int i = 1; i <= (n); ++i)
using namespace std;

struct AC_trie {
  int N, P;
  vector<map<char, int>> next; // trie
  vector<int> link, out_link;
  vector<vector<int>> out;
  AC_trie(): N(0), P(0) { node(); }
  int node() {
    next.emplace_back(); // trie
    link.emplace_back(0);
    out_link.emplace_back(0);
    out.emplace_back(0);
    return N++;
  }
  int add_pattern(const string T) {
    int u = 0;
    for (auto c : T) {
      if (!next[u][c]) next[u][c] = node();
      u = next[u][c];
    }
    out[u].push_back(P);
    return P++;
  }
  void compute() {
    queue<int> q;
    for (q.push(0); !q.empty(); ) {
      int u = q.front(); q.pop();
      // trie:
      for (auto e : next[u]) {
        int v = e.second;
        link[v] = u ? advance(link[u], e.first) : 0;
        out_link[v] = out[link[v]].empty() ? out_link[link[v
            ]] : link[v];
        q.push(e.second);
      }
    }
  }
  int advance(int u, char c) {
    // trie:
    while (u && next[u].find(c) == next[u].end())
      u = link[u];
    if (next[u].find(c) != next[u].end())
      u = next[u][c];
    return u;
  }
  void match(const string S) {
```

```
    int u = 0;
    for (auto c : S) {
      u = advance(u, c);
      for (int v = u; v; v = out_link[v])
        for (auto p : out[v])
          cout << "match " << p << endl;
    }
  }
};
struct AC_automaton {
  int N, P;
  vector<vector<int>> next; // automaton
  vector<int> link, out_link;
  vector<vector<int>> out;
  AC_automaton(): N(0), P(0) { node(); }
  int node() {
    next.emplace_back(26, 0); // automaton
    link.emplace_back();
    out_link.emplace_back();
    out.emplace_back();
    return N++;
  }
  int add_pattern(const string T) {
    int u = 0;
    for (auto c : T) {
      if (!next[u][c - 'a']) next[u][c - 'a'] = node();
      u = next[u][c - 'a'];
    }
    out[u].push_back(P);
    return P++;
  }
  void compute() {
    queue<int> q;
    for (q.push(0); !q.empty(); ) {
      int u = q.front(); q.pop();
      // automaton:
      for (int c = 0; c < 26; ++c) {
        int v = next[u][c];
        if (!v) next[u][c] = next[link[u]][c];
        else {
          link[v] = u ? next[link[u]][c] : 0;
          out_link[v] = out[link[v]].empty() ? out_link[link[
               v]] : link[v];
          q.push(v);
        }
      }
    }
  }
  int advance(int u, char c) {
    // automaton:
    while (u && !next[u][c - 'a']) u = link[u];
    u = next[u][c - 'a'];
    return u;
  }
  void match(const string S) {
    int u = 0;
    for (auto c : S) {
      u = advance(u, c);
      for (int v = u; v; v = out_link[v])
        for (auto p : out[v])
          cout << "match " << p << endl;
    }
  }
};
int main() {
  int P;
  string T;
  cin >> P;

  AC_trie match1;
  AC_automaton match2;
  REP (i, P) {
    cin >> T;
    match1.add_pattern(T); match2.add_pattern(T);
  }
  match1.compute();
  match2.compute();
  cin >> T;
  match1.match(T);
  match2.match(T);
  return 0;
}
```

8.2 KMP

```
//From "You Know Izad?" team cheat sheet
int fail[100005];
void build(const string &key){
    fail[0] = 0;
    fail[1] = 0;
    fore(i, 2, L(key)) {
        int j = fail[i - 1];
        while (true) {
            if (key[j] == key[i - 1]) {
                fail[i] = j + 1;
                break;
            }
            else if (j == 0) break;
            j = fail[j];
        }
    }
}
int KMP(const string &text, const string &key) {
    build(key);
    int i = 0, j = 0;
    while (true) {
        if (j == L(text)) return -1;
        if (text[j] == key[i]) {
            i++;
            j++;
            if (i == L(key)) return j - i;
        }
        else if (i > 0) i = fail[i];
        else j++;
    }
}
```

8.3 Manacher Longest Palindrome

```
string preProcess(string s) {
  int n = s.length();
  if (n == 0) return "^$";
  string ret = "^";
  for (int i = 0; i < n; i++)
    ret += "#" + s.substr(i, 1);

  ret += "#$";
  return ret;
}

string longestPalindrome(string s) {
  string T = preProcess(s);
  int n = T.length();
  int *P = new int[n];
  int C = 0, R = 0;
  for (int i = 1; i < n-1; i++) {
    int i_mirror = 2*C-i; // equals to i' = C - (i-C)
    P[i] = (R > i) ? min(R-i, P[i_mirror]) : 0;
    // Attempt to expand palindrome centered at i
    while (T[i + 1 + P[i]] == T[i - 1 - P[i]])
      P[i]++;
    // If palindrome centered at i expand past R,
    // adjust center based on expanded palindrome.
    if (i + P[i] > R) {
      C = i;
      R = i + P[i];
    }
  }
```

```
  // Find the maximum element in P.
  int maxLen = 0;
  int centerIndex = 0;
  for (int i = 1; i < n-1; i++) {
    if (P[i] > maxLen) {
      maxLen = P[i];
      centerIndex = i;
    }
  }
  delete[] P;

  return s.substr((centerIndex - 1 - maxLen)/2, maxLen);
}
```

8.4 Suffix Array and LCP

```
//From "You Know Izad?" team cheat sheet
const int MAXLG = 15;
const int MAXN = 3000;
int P[MAXLG][MAXN], stp;
string s;
struct entry {
    int nr[2], p;
} L[MAXN];
int cmp(entry a, entry b) {
    return a.nr[0] == b.nr[0] ? (a.nr[1] < b.nr[1] ? 1 : 0) :
         (a.nr[0] < b.nr[0] ? 1 : 0);
}
void init() {
    memset(P, 0, sizeof P);
    stp = 1;
    fore(i, 0, MAXN) {
        L[i].nr[0] = 0;
        L[i].nr[1] = 0;
        L[i].p = 0;
    }
}
int rangeComp(int idx, const string &t, int len){
    fore(i, 0, len) {
        if(i >= L(t) && i + idx >= L(s)) return 0;
        else if(i + idx >= L(s)) return 1;
        else if(i >= L(t)) return -1;
        if(s[i + idx] == t[i]) continue;
        if(s[i + idx] > t[i]) return 1;
        return -1;
    }
    return 0;
}
void construct() {
    init();
    for (int i = 0; i < L(s); i++)
        P[0][i] = s[i] - 'a';
    for (int cnt = 1; (cnt >> 1) < L(s); stp++, cnt <<= 1){
        for (int i = 0; i < L(s); i++){
            L[i].nr[0] = P[stp - 1][i];
            L[i].nr[1] = i + cnt < L(s) ? P[stp-1][i+cnt] :
                 -1;
            L[i].p = i;
        }
        sort(L, L + L(s), cmp);
        for (int i = 0; i < L(s); i ++)
            P[stp][L[i].p] = i > 0 && L[i].nr[0] == L[i - 1].
                 nr[0] && L[i].nr[1] == L[i - 1].nr[1] ? P[stp
                 ][L[i - 1].p] : i;
    }
}
ii stringMatching(const string &t){
    int low = 0, high = L(s) - 1, mid = low;
    while (low < high){
        mid = (low + high) / 2;
        int res = rangeComp(L[mid].p , t, L(t));
        if (res >= 0) high = mid;
        else low = mid + 1;
    }
    if (rangeComp(L[low].p , t, L(t)) != 0) return ii(-1, -1)
        ;
    ii ans;
    ans.first = low;
    low = 0; high = L(s) - 1; mid = low;
    while (low < high) {
        mid = (low + high) / 2;
        int res = rangeComp(L[mid].p, t, L(t));
        if (res > 0) high = mid;
        else low = mid + 1;
    }
    if (rangeComp(L[high].p, t, L(t)) != 0) high--;
    ans.second = high;
    return ans;
}
int lcp(int x, int y) {
    int ret = 0;
    if (x == y) return L(s) - x;
    for (int k = stp - 1; k >= 0 && x < L(s) && y < L(s); k
         --) {
        if (P[k][x] == P[k][y])
            x += (1 << k), y += (1 << k), ret += (1 << k);
    }
    return ret;
}
int main() {
    cin >> s;
    construct();
    string t;
// rangeComp and stringMatching are optional
    while(cin >> t) {
        ii ans = stringMatching(t);
        cout << ans.first << " " << ans.second << endl;
    }
}
```

8.5 Z Algorithm

```
// Z[i] => max len perfixi az s k az khuneye i e S shoru
    mishe

int L = 0, R = 0;
n=s.size();
for (int i = 1; i < n; i++)
{
 if (i > R) {
  L = R = i;
  while (R < n && s[R-L] == s[R]) R++;
  z[i] = R-L; R--;
 }
 else
 {
  int k = i-L;
  if (z[k] < R-i+1) z[i] = z[k];
  else
  {
   L = i;
   while (R < n && s[R-L] == s[R]) R++;
   z[i] = R-L; R--;
  }
 }
}
```

9 Tips, Tricks and Theorems

9.1 C++ Ordered Set

```
typedef tree<
int,
null_type,
less<int>,
```

```
rb_tree_tag,
tree_order_statistics_node_update>
ordered_set;

ordered_set X;
X.insert(1);
X.insert(2);
X.insert(4);
X.insert(8);
X.insert(16);

cout<<*X.find_by_order(1)<<endl; // 2
cout<<*X.find_by_order(2)<<endl; // 4
cout<<*X.find_by_order(4)<<endl; // 16
cout<<(end(X)==X.find_by_order(6))<<endl; // true

cout<<X.order_of_key(-5)<<endl; // 0
cout<<X.order_of_key(1)<<endl; // 0
cout<<X.order_of_key(3)<<endl; // 2
cout<<X.order_of_key(4)<<endl; // 2
cout<<X.order_of_key(400)<<endl; // 5
```

9.2 C++ Tricks

```
cout << fixed << setprecision(7) << M_PI << endl; //
    3.1415927
cout << scientific << M_PI << endl; // 3.1415927e+000
int x=15, y=12094;
cout << setbase(10) << x << " " << y << endl; // 15 12094
cout << setbase(8) << x << " " << y << endl; // 17 27476
cout << setbase(16) << x << " " << y << endl; // f 2f3e
x=5; y=9;
cout<<setfill('0')<<setw(2)<<x<< ":" << setw(2) << y << endl
    ; // 05:09
printf ("%10d\n", 111); // 111
printf ("%010d\n", 111); //0000000111
printf ("%d %x %X %o\n", 200, 200, 200, 200); //200 c8 C8
    310
printf ("%010.2f %e %E\n", 1213.1416, 3.1416, 3.1416); //
    0001213.14 3.141600e+00 3.141600E+00
printf ("%*.*d\n",10, 5, 111); // 00111
printf ("%-*.*d\n",10, 5, 111); //00111
printf ("%+*.*d\n",10, 5, 111); // +00111
char in[20]; int d;
scanf ("%s %*s %d",in,&d); //<- it's number 5
printf ("%s %d \n", in,d); //it's 5
```

9.3 Contest Tips

```
READ THE STATEMENT AGAIN. TELL YOUR TEAMMATE IF
 NECESSARY
Double check spell of literals
Graph: Multiple components, Multiple edges, Loops
Geometry: Be careful about +pi,-pi
Initialization: Use memset/clear(). Dont expect global
 variables to be zero. Care about multiple tests
Precision and Range: Use long long if necessary. Use
 BigInteger/BigDecimal
Derive recursive formulas that use sum instead of
 multiplication to avoid overflow.
Small cases (n=0,1,negative)
0-based <=> 1-based
Division by zero. Integer division a/(double)b
Stack overflow (DFS on 1e5)
Infinite loop?
array bound check. maxn or x*maxn
Dont use .size()-1 !
   (int)-3 < (unsigned int) 2 is false!
Check copy-pasted codes!
Be careful about -0.0
Remove debug info!
Output format: Spaces at the end of line. Blank lines.
 View the output in VIM if necessary
Add eps to double before getting floor or round
Convex Hull: Check if points are collinear
Geometry: Distance may not overflow, but its square may
 does
```

9.4 Dilworth Theorem

```
Let S be a finite partially ordered set. The size of a
     maximal antichain equals the size of a minimal chain
     cover of S. This is called the Dilworths theorem.

The width of a finite partially ordered set S is the maximum
      size of an antichain in S. In other words, the width
     of a finite partially ordered set S is the minimum
     number of chains needed to cover S, i.e. the minimum
     number of chains such that any element of S is in at
     least one of the chains.

Definition of chain : A chain in a partially ordered set is
     a subset of elements which are all comparable to each
     other.
Definition of antichain : An antichain is a subset of
     elements, no two of which are comparable to each other.
```

9.5 Gallai Theorem

```
a(G) := max{|C| | C is a stable set},
b(G) := min{|W| | W is a vertex cover},
c(G) := max{|M| | M is a matching},
d(G) := min{|F| | F is an edge cover}.
 Gallais  theorem: If G = (V, E) is a graph without isolated
      vertices, then
a(G) + b(G) = |V| = c(G) + d(G).
```

9.6 Konig Theorem

```
 Knig  theorem can be proven in a way that provides
     additional useful information beyond just its truth:
     the proof provides a way of constructing a minimum
     vertex cover from a maximum matching. Let {G=(V,E)} be
     a bipartite graph, and let the vertex set { V} be
     partitioned into left set { L} and right set { R}.
     Suppose that { M} is a maximum matching for { G}. No
     vertex in a vertex cover can cover more than one edge
     of { M} (because the edge half-overlap would prevent {
     M} from being a matching in the first place), so if a
     vertex cover with { |M|} vertices can be constructed,
     it must be a minimum cover.
To construct such a cover, let { U} be the set of unmatched
     vertices in { L} (possibly empty), and let { Z} be the
     set of vertices that are either in { U} or are
     connected to { U} by alternating paths (paths that
     alternate between edges that are in the matching and
     edges that are not in the matching). Let
{ K=(L - Z) Union (R Intersect Z).}
Every edge { e} in { E} either belongs to an alternating
     path (and has a right endpoint in { K}), or it has a
     left endpoint in { K}. For, if { e} is matched but not
     in an alternating path, then its left endpoint cannot
     be in an alternating path (for such a path could only
     end at { e}) and thus belongs to { L- Z}. Alternatively
     , if { e} is unmatched but not in an alternating path,
     then its left endpoint cannot be in an alternating path
     , for such a path could be extended by adding { e} to
     it. Thus, { K} forms a vertex cover.
Additionally, every vertex in { K} is an endpoint of a
     matched edge. For, every vertex in { L - Z} is matched
     because Z is a superset of U, the set of unmatched left
      vertices. And every vertex in { R intersect Z} must
```

```
also be matched, for if there existed an alternating
path to an unmatched vertex then changing the matching
by removing the matched edges from this path and adding
 the unmatched edges in their place would increase the
size of the matching. However, no matched edge can have
 both of its endpoints in { K}. Thus, { K} is a vertex
cover of cardinality equal to { M}, and must be a
minimum vertex cover.
```

9.7 Lucas Theorem

For non-negative integers m and n and a prime p, the following congruence relation holds: :

$$\binom{m}{n} \equiv \prod_{i=0}^{k} \binom{m_i}{n_i} \pmod p,$$

where :

$$m = m_k p^k + m_{k-1} p^{k-1} + \cdots + m_1 p + m_0,$$

and :

$$n = n_k p^k + n_{k-1} p^{k-1} + \cdots + n_1 p + n_0$$

are the base p expansions of m and n respectively. This uses the convention that $\binom{m}{n} = 0$ if $m \leq n$.

9.8 Minimum Path Cover in DAG

Given a directed acyclic graph $G = (V, E)$, we are to find the minimum number of vertex-disjoint paths to cover each vertex in V.

We can construct a bipartite graph $G' = (Vout \cup Vin, E')$ from G, where :

$$Vout = \{v \in V : v\ has\ positive\ out - degree\}$$

$$Vin = \{v \in V : v\ has\ positive\ in - degree\}$$

$$E' = \{(u, v) \in Vout \times Vin : (u, v) \in E\}$$

Then it can be shown, via König's theorem, that G' has a matching of size m if and only if there exists $n - m$ vertex-disjoint paths that cover each vertex in G, where n is the number of vertices in G and m is the maximum cardinality bipartite mathching in G'.

Therefore, the problem can be solved by finding the maximum cardinality matching in G' instead.

NOTE: If the paths are note necesarily disjoints, find the transitive closure and solve the problem for disjoint paths.

9.9 Planar Graph (Euler)

Euler's formula states that if a finite, connected, planar graph is drawn in the plane without any edge intersections, and v is the number of vertices, e is the number of edges and f is the number of faces (regions bounded by edges, including the outer, infinitely large region), then:

$$f + v = e + 2$$

It can be extended to non connected planar graphs with c connected components:

$$f + v = e + c + 1$$

9.10 Triangles

Let a, b, c be length of the three sides of a triangle.

$$p = (a + b + c) * 0.5$$

The inradius is defined by:

$$iR = \sqrt{\frac{(p-a)(p-b)(p-c)}{p}}$$

The radius of its circumcircle is given by the formula:

$$cR = \frac{abc}{\sqrt{(a+b+c)(a+b-c)(a+c-b)(b+c-a)}}$$

9.11 Uniform Random Number Generator

```
using namespace std;
//seed:
random_device rd;
mt19937 gen(rd());
uniform_int_distribution<> dis(0, n - 1);
//generate:
int r = dis(gen);
```