# Contents



# 1 basic

## 1.1 default

```cpp
#include <bits/stdc++.h>
using namespace std;
#define masterspark ios::sync_with_stdio(0), cin.tie(0)
    ,cout.tie(0),cin.exceptions(cin.failbit);

#define int long long
#define pp pair<int, int>
#define ff first
#define ss second

#define forr(i,n) for(int i = 1; i <= n;++i)
#define rep(i,j,n) for(int i = j; i < n;++i)
#define PB push_back
#define PF push_front
#define EB emplace_back
#define all(v) (v).begin(), (v).end()
#define FZ(x) memset(x, 0, sizeof(x)) //fill zero
#define SZ(x) ((int)x.size())
bool chmin(auto &a, auto b) { return (b < a) and (a = b
    , true); }
bool chmax(auto &a, auto b) { return (a < b) and (a = b
    , true); }
using i128 = __int128_t;
using i64 = __int64_t;
using i32 = __int32_t;

void solve(){

}
signed main()
{
    masterspark
    int t = 1;
    // freopen("stdin","r",stdin);
    // freopen("stdout","w",stdout);
    // cin >> t;
    while(t--){
        solve();
    }
    return 0;
}
```

## 1.2 godcode

```cpp
#pragma GCC optimize("O3,unroll-loops")
#pragma GCC target("avx2,bmi,bmi2,lzcnt,popcnt")
```

## 1.3 random

```cpp
mt19937 mt(chrono::steady_clock::now().time_since_epoch
    ().count());
//mt19937_64 mt() -> return randnum
int randint(int l, int r){
    uniform_int_distribution<> dis(l, r); return dis(mt
        );
}
```

## 1.4 run.bat

```
@echo off
g++ ac.cpp -o ac.exe
g++ wa.cpp -o wa.exe
set /a num=1
:loop
   echo %num%
   python gen.py > input
   ac.exe < input > ac
   wa.exe < input > wa
   fc ac wa
   set /a num=num+1
if not errorlevel 1 goto loop
```

## 1.5 run.sh

```
set -e
for ((i=0;;i++))
do
    echo "$i"
```

```
    python gen.py > in
    ./ac < in > ac.out
    ./wa < in > wa.out
    diff ac.out wa.out || break
done
```

# 2 binarysearch

## 2.1 二分搜

```
int bsearch_1(int l, int r)
{
    while (l < r)
    {
        int mid = l + r >> 1;
        if (check(mid)) r = mid;
        else l = mid + 1;
    }
    return l;
}
// ..............oooooooooo

int bsearch_2(int l, int r)
{
    while (l < r)
    {
        int mid = l + r + 1 >> 1;
        if (check(mid)) l = mid;
        else r = mid - 1;
    }
    return l;
}
// oooooooooo...................

int m = *ranges::partition_point(views::iota(0LL,(int)1
    e9+9),[&](int a){
    return check(a) > k;
    });
//[begin,last)
//11111110000000000
//搜左邊數過來第一個 0
//都是 1 會回傳 last
```

# 3 dataStructure

## 3.1 DSU

```
struct STRUCT_DSU {
    vector<int> f, sz;
    void init(int n) {
        f.resize(n), sz.resize(n);
        for (int i = 0; i < n; i++) {
            f[i] = i;
            sz[i] = 1;
        }
    }
    int find(int x) {
        if (x == f[x]) return x;
        f[x] = find(f[x]);
        return find(f[x]);
    }

    void merge(int x, int y) {
        x = find(x), y = find(y);
        if (x == y) return;
        if (sz[x] < sz[y])
            swap(x, y);
        sz[x] += sz[y];
        f[y] = x;
    }
    bool same(int a, int b) {
        return (find(a) == find(b));
    }
};
```

## 3.2 fenwickTree

```
struct fenwick{
  #define lowbit(x) (x&-x)
  int n;
  vector<int> v;
  fenwick(int _n) : n(_n+1),v(_n+2){}
  void add(int x,int u){
    ++x;
    for(;x < n; x += lowbit(x)) v[x] += u;
  }
  int qry(int x){
    ++x; int ret = 0;
    for(; x ; x -= lowbit(x)) ret += v[x];
    return ret;
  }
  int qry(int l,int r) { return qry(r) - qry(l-1); }
  int kth(int k){ // lower_bound(k)
    int x = 0; --k;
    for(int i = (1<<__lg(n)); i;i >>= 1){
      if(x + i <= n and k >= v[x + i]) x += i; k -= v[x
          ];
    }
    return x;
  }

};
```

## 3.3 segTree

```
#define cl(x) (x << 1)
#define cr(x) (x << 1) + 1

struct segTree {
#define MXN 200500
    int n;
    vector<int> seg;
    vector<int> arr, tag;
    // int seg[MXN], arr[MXN], tag[MXN];
    void init(int a) {
        n = a;
        seg.resize(4 * (n + 5), 0);
        tag.resize(4 * (n + 5), 0);
        arr.resize(n + 5, 0);
        for (int i = 0; i < n + 5; i++)
            arr[i] = 0;
        for (int i = 0; i < 4 * (n + 5); i++)
            seg[i] = tag[i] = 0;
    }
    void push(int id, int l, int r) {
        if (tag[id] != 0) {
            seg[id] += tag[id] * (r - l + 1);
            if (l != r) {
                tag[cl(id)] += tag[id];
                tag[cr(id)] += tag[id];
            }
            tag[id] = 0;
        }
    }
    void pull(int id, int l, int r) {
        int mid = (l + r) >> 1;
        push(cl(id), l, mid);
        push(cr(id), mid + 1, r);
        int a = seg[cl(id)];
        int b = seg[cr(id)];
        seg[id] = a + b;
    }
    void build(int id, int l, int r) {
        if (l == r) {
            seg[id] = arr[l];
            return;
        }
        int mid = (l + r) >> 1;
        build(cl(id), l, mid);
        build(cr(id), mid + 1, r);
        pull(id, l, r);
    }
    void update(int id, int l, int r, int ql, int qr,
        int v) {
        push(id, l, r);
        if (ql <= l && r <= qr) {
            tag[id] += v;
            return;
        }
        int mid = (l + r) >> 1;
        if (ql <= mid)
            update(cl(id), l, mid, ql, qr, v);
        if (qr > mid)
            update(cr(id), mid + 1, r, ql, qr, v);
```

```
        pull(id, l, r);
    }
    int query(int id, int l, int r, int ql, int qr) {
        push(id, l, r);
        if (ql <= l && r <= qr) {
            return seg[id];
        }
        int mid = (l + r) >> 1;
        int ans1, ans2;
        bool f1 = 0, f2 = 0;
        if (ql <= mid) {
            ans1 = query(cl(id), l, mid, ql, qr);
            f1 = 1;
        }
        if (qr > mid) {
            ans2 = query(cr(id), mid + 1, r, ql, qr);
            f2 = 1;
        }
        if (f1 && f2)
            return ans1 + ans2;
        if (f1)
            return ans1;
        return ans2;
    }
    void build() { build(1, 1, n); }
    int query(int ql, int qr) { return query(1, 1, n,
        ql, qr); }
    void update(int ql, int qr, int val) { update(1, 1,
         n, ql, qr, val); }
};
```

# 4 dp

## 4.1 digit

```
ll dp[MXN_BIT][PRE_NUM][LIMIT][F0];//字串位置, 根據題目
    的值, 是否上界, 前導0
ll dfs(int i,int pre, bool lim, bool f0, const string&
    str){
    if(v[i][pre][f0][lim])  return dp[i][pre][f0][lim];
    v[i][pre][f0][lim] = true;

    if(i == str.size())
        return dp[i][pre][f0][lim] = 1;

    ll ret = 0, h = lim ? str[i] : '9';

    for(int j='0'; j<=h; j++){
        if(abs(j-pre)>=2 || f0){
            ret += dfs(i+1, j, j==h && lim, f0 && j=='0
                ', str);
    }}
    return dp[i][pre][f0][lim] = ret;
}
```

## 4.2 p_median

```
void p_Median(){
    for (int i=1; i<=N; ++i)
        for (int j=i; j<=N; ++j){
            m = (i+j)/2,d[i][j] = 0;          // m是中位
                數, d[i][j]為距離的總和
            for (int k=i; k<=j; ++k) d[i][j] += abs(arr
                [k] - arr[m]);
        }
    for (int p=1; p<=P; ++p)
        for (int n=1; n<=N; ++n){
            dp[p][n] = 1e9;
            for (int k=p; k<=n; ++k)
                if (dp[p-1][k-1] + d[k][n] < dp[p][n]){
                    dp[p][n] = dp[p-1][k-1] + d[k][n];
                    r[p][n] = k;     // 從第k個位置往右
                        到第j個位置
                }
        }
}
```

## 4.3 sosdp

```
// 求子集和 或超集和 -> !(mask & (1 << i))
for(int i = 0; i<(1<<N); ++i) F[i] = A[i]; //預處理 狀
    態權重
for(int i = 0;i < N; ++i)
for (int s = 0; s < (1<<N) ; ++s)
  if (s & (1 << i))
    F[s] += F[s ^ (1 << i)];
```

# 5 flow

## 5.1 Dinic

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

## 5.2 isap

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

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

## 5.3 KM

```
struct KM{ // max weight, for min negate the weights
  int n, mx[MXN], my[MXN], pa[MXN];
  ll g[MXN][MXN], lx[MXN], ly[MXN], sy[MXN];
  bool vx[MXN], vy[MXN];
  void init(int _n) { // 1-based, N個節點
    n = _n;
    for(int i=1; i<=n; i++) fill(g[i], g[i]+n+1, 0);
  }
  void addEdge(int x, int y, ll w) {g[x][y] = w;} //左
      邊的集合節點x連邊右邊集合節點y權重為w
  void augment(int y) {
    for(int x, z; y; y = z)
      x=pa[y], z=mx[x], my[y]=x, mx[x]=y;
  }
  void bfs(int st) {
    for(int i=1; i<=n; ++i) sy[i]=INF, vx[i]=vy[i]=0;
    queue<int> q; q.push(st);
    for(;;) {
      while(q.size()) {
        int x=q.front(); q.pop(); vx[x]=1;
        for(int y=1; y<=n; ++y) if(!vy[y]){
          ll t = lx[x]+ly[y]-g[x][y];
          if(t==0){
            pa[y]=x;
            if(!my[y]){augment(y);return;}
            vy[y]=1, q.push(my[y]);
          }else if(sy[y]>t) pa[y]=x,sy[y]=t;
      } }
      ll cut = INF;
      for(int y=1; y<=n; ++y)
        if(!vy[y]&&cut>sy[y]) cut=sy[y];
      for(int j=1; j<=n; ++j){
        if(vx[j]) lx[j] -= cut;
        if(vy[j]) ly[j] += cut;
        else sy[j] -= cut;
      }
      for(int y=1; y<=n; ++y) if(!vy[y]&&sy[y]==0){
        if(!my[y]){augment(y);return;}
        vy[y]=1, q.push(my[y]);
  } } }
  ll solve(){ // 回傳值為完美匹配下的最大總權重
    fill(mx, mx+n+1, 0); fill(my, my+n+1, 0);
    fill(ly, ly+n+1, 0); fill(lx, lx+n+1, -INF);
    for(int x=1; x<=n; ++x) for(int y=1; y<=n; ++y) //
        1-base
      lx[x] = max(lx[x], g[x][y]);
    for(int x=1; x<=n; ++x) bfs(x);
    ll ans = 0;
    for(int y=1; y<=n; ++y) ans += g[my[y]][y];
    return ans;
} }graph;
```

## 5.4 匈牙利

```
bool dfs(int u){
    for(int i : edge[u]){
        if(!vis[i]){ // 有連通且未拜訪
            vis[i] = true; // 紀錄是否走過
            if(match[i]==-1 || dfs(match[i])){
                match[i] = u; match[u] = i; // 紀錄匹配
                return true;
            }
        }
    }
    return false;
}
int hungarian(){
    int ans = 0;
    memset(match, -1, sizeof(match));
    for(int i = 1 ;i <= lhs; i++){
        // 記得每次使用需清空vis陣列
        memset(vis, 0, sizeof(vis));
        if(dfs(i)) ans++;
    }
    return ans;
}
```

## 5.5 最小花費最大流 dijkstra 不能負值

```
struct MinCostMaxFlow{
typedef int Tcost;
  static const int MAXV = 20010;
  static const int INFf = 1000000;
  static const Tcost INFc  = 1e9;
  struct Edge{
    int v, cap;
    Tcost w;
    int rev;
    Edge(){}
    Edge(int t2, int t3, Tcost t4, int t5)
    : v(t2), cap(t3), w(t4), rev(t5) {}
  };
  int V, s, t;
  vector<Edge> g[MAXV];
  void init(int n, int _s, int _t){
    V = n; s = _s; t = _t;
    for(int i = 0; i <= V; i++) g[i].clear();
  }
  void addEdge(int a, int b, int cap, Tcost w){
    g[a].push_back(Edge(b, cap, w, (int)g[b].size()));
    g[b].push_back(Edge(a, 0, -w, (int)g[a].size()-1));
  }
  Tcost d[MAXV];
  int id[MAXV], mom[MAXV];
  bool inqu[MAXV];
  queue<int> q;
  pair<int,Tcost> solve(){
    int mxf = 0; Tcost mnc = 0;
    while(1){
      fill(d, d+1+V, INFc);
      fill(inqu, inqu+1+V, 0);
      fill(mom, mom+1+V, -1);
      mom[s] = s;
      d[s] = 0;
      q.push(s); inqu[s] = 1;
      while(q.size()){
        int u = q.front(); q.pop();
        inqu[u] = 0;
        for(int i = 0; i < (int) g[u].size(); i++){
          Edge &e = g[u][i];
          int v = e.v;
          if(e.cap > 0 && d[v] > d[u]+e.w){
            d[v] = d[u]+e.w;
            mom[v] = u;
            id[v] = i;
            if(!inqu[v]) q.push(v), inqu[v] = 1;
      } } }
      if(mom[t] == -1) break ;
      int df = INFf;
      for(int u = t; u != s; u = mom[u])
        df = min(df, g[mom[u]][id[u]].cap);
      for(int u = t; u != s; u = mom[u]){
        Edge &e = g[mom[u]][id[u]];
        e.cap             -= df;
        g[e.v][e.rev].cap += df;
      }
```

```
      mxf += df;
      mnc += df*d[t];
    }
    return {mxf,mnc};
} }flow;
```

### 5.6 最小花費最大流 SPFA

```
struct zkwflow{
  static const int maxN=10000;
  struct Edge{ int v,f,re; ll w;};
  int n,s,t,ptr[maxN]; bool vis[maxN]; ll dis[maxN];
  vector<Edge> E[maxN];
  void init(int _n,int _s,int _t){
    n=_n,s=_s,t=_t;
    for(int i=0;i<n;i++) E[i].clear();
  }
  void addEdge(int u,int v,int f,ll w){
    E[u].push_back({v,f,(int)E[v].size(),w});
    E[v].push_back({u,0,(int)E[u].size()-1,-w});
  }
  bool SPFA(){
    fill_n(dis,n,LLONG_MAX); fill_n(vis,n,false);
    queue<int> q; q.push(s); dis[s]=0;
    while (!q.empty()){
      int u=q.front(); q.pop(); vis[u]=false;
      for(auto &it:E[u]){
        if(it.f>0&&dis[it.v]>dis[u]+it.w){
          dis[it.v]=dis[u]+it.w;
          if(!vis[it.v]){
            vis[it.v]=true; q.push(it.v);
    } } } }
    return dis[t]!=LLONG_MAX;
  }
  int DFS(int u,int nf){
    if(u==t) return nf;
    int res=0; vis[u]=true;
    for(int &i=ptr[u];i<(int)E[u].size();i++){
      auto &it=E[u][i];
      if(it.f>0&&dis[it.v]==dis[u]+it.w&&!vis[it.v]){
        int tf=DFS(it.v,min(nf,it.f));
        res+=tf,nf-=tf,it.f-=tf;
        E[it.v][it.re].f+=tf;
        if(nf==0){ vis[u]=false; break; }
      }
    }
    return res;
  }
  pair<int,ll> flow(){
    int flow=0; ll cost=0;
    while (SPFA()){
      fill_n(ptr,n,0);
      int f=DFS(s,INT_MAX);
      flow+=f; cost+=dis[t]*f;
    }
    return{ flow,cost };
  } // reset: do nothing
} flow;
```

# 6 geometry

## 6.1 Point

```
using ld = long double;
template<class T>
struct pt{
  T x,y;
  pt(T _x,T _y):x(_x),y(_y){}
  pt():x(0),y(0){}

  pt operator * (T  c){ return pt(x*c,y*c);}
  pt operator / (T  c){ return pt(x/c,y/c);}
  pt operator + (pt a){ return pt(x+a.x,y+a.y);}
  pt operator - (pt a){ return pt(x-a.x,y-a.y);}
  T  operator * (pt a){ return x*a.x + y*a.y;}
  T  operator ^ (pt a){ return x*a.y - y*a.x;}

  auto operator<=>(pt o) const { return (x != o.x) ? x
      <=> o.x : y <=> o.y; } // c++20
  bool operator < (pt a) const { return x < a.x || (x
      == a.x && y < a.y);};
  bool operator== (pt a) const { return x == a.x and y
      == a.y;};
  friend T ori(pt a, pt b, pt c) { return (b - a) ^ (c
      - a); }
  friend T abs2(pt a) { return a * a; }
};
using numbers::pi; // c++20
const ld pi = acos(-1);
const ld eps = 1e-8L;
using Pt = pt<ld>;
int sgn(ld x) { return (x > -eps) - (x < eps); } //
    dcmp == sgn
ld abs(Pt a) { return sqrt(a * a); }
ld arg(Pt x) { return atan2(x.y, x.x); }
bool argcmp(Pt a, Pt b) { // arg(a) < arg(b)
    int f = (Pt{a.y, -a.x} > Pt{} ? 1 : -1) * (a != Pt
        {});
    int g = (Pt{b.y, -b.x} > Pt{} ? 1 : -1) * (b != Pt
        {});
    return f == g ? (a ^ b) > 0 : f < g;
}
Pt unit(Pt x) { return x / abs(x); }
Pt rotate(Pt u) { // pi / 2
    return {-u.y, u.x};
}
Pt rotate(Pt u, ld a) {
    Pt v{sin(a), cos(a)};
    return {u ^ v, u * v};
}


istream &operator>>(istream &s, Pt &a) { return s >> a.
    x >> a.y; }
ostream &operator<<(ostream &s, Pt &a) { return s << "(
    " << a.x << ", " << a.y << ")";}

bool collinearity(Pt a, Pt b, Pt c) {  // 三點共線
    return ((b - a) ^ (c - a)) == 0;
}
```

## 6.2 Line

```
struct Line {
    Pt a, b;
    Pt dir() const { return b - a; }
};
int PtSide(Pt p, Line L) {
    return sgn(ori(L.a, L.b, p) / abs(L.a - L.b));
}
bool PtOnSeg(Pt p, Line L) {
    return PtSide(p, L) == 0 and sgn((p - L.a) * (p - L
        .b)) <= 0;
}
Pt proj(Pt p, Line l) {
    Pt dir = unit(l.b - l.a);
    return l.a + dir * (dir * (p - l.a));
}
```

## 6.3 Circle

```
struct Cir {
    Pt o;
    ld r;
};
bool disjunct(const Cir &a, const Cir &b) {
    return sgn(abs(a.o - b.o) - a.r - b.r) >= 0;
}
bool contain(const Cir &a, const Cir &b) {
    return sgn(a.r - b.r - abs(a.o - b.o)) >= 0;
}
```

## 6.4 圓多邊形面積

```
double CirclePoly(Cir C, const vector<Pt> &P) {
    auto arg = [&](Pt p, Pt q) { return atan2(p ^ q, p
        * q); };
    double r2 = C.r * C.r / 2;
    auto tri = [&](Pt p, Pt q) {
        Pt d = q - p;
        auto a = (d * p) / abs2(d), b = (abs2(p) - C.r
            * C.r)/ abs2(d);
        auto det = a * a - b;
```

```
        if (det <= 0) return arg(p, q) * r2;
        auto s = max(0., -a - sqrt(det)), t = min(1., -
            a + sqrt(det));
        if (t < 0 or 1 <= s) return arg(p, q) * r2;
        Pt u = p + d * s, v = p + d * t;
        return arg(p, u) * r2 + (u ^ v) / 2 + arg(v, q)
             * r2;
    };
    double sum = 0.0;
    for (int i = 0; i < P.size(); i++)
    sum += tri(P[i] - C.o, P[(i + 1) % P.size()] - C.o)
        ;
    return sum;
}
```

## 6.5 圓三角形面積

```
double CircleTriangle(Pt a, Pt b, double r) {
    if (sgn(abs(a) - r) <= 0 and sgn(abs(b) - r) <= 0)
        {
        return abs(a ^ b) / 2;
    }
    if (abs(a) > abs(b)) swap(a, b);
    auto I = CircleLineInter({{}, r}, {a, b});
    erase_if(I, [&](Pt x) { return !PtOnSeg(x, {a, b});
         });
    if (I.size() == 1) return abs(a ^ I[0]) / 2 +
        SectorArea(I[0], b, r);
    if (I.size() == 2) {
        return SectorArea(a, I[0], r) + SectorArea(I
            [1], b, r) + abs(I[0] ^ I[1]) / 2;
    }
    return SectorArea(a, b, r);
}
```

## 6.6 半平面交

```
bool cover(Line L, Line P, Line Q) {
    // PtSide(LineInter(P, Q), L) <= 0 or P, Q parallel
    i128 u = (Q.a - P.a) ^ Q.dir();
    i128 v = P.dir() ^ Q.dir();
    i128 x = P.dir().x * u + (P.a - L.a).x * v;
    i128 y = P.dir().y * u + (P.a - L.a).y * v;
    return sgn(x * L.dir().y - y * L.dir().x) * sgn(v)
        >= 0;
}
vector<Line> HPI(vector<Line> P) {
    // line P.a -> P.b 的逆時針是半平面
    sort(all(P), [&](Line l, Line m) {
        if (argcmp(l.dir(), m.dir())) return true;
        if (argcmp(m.dir(), l.dir())) return false;
        return ori(m.a, m.b, l.a) > 0;
    });
    int n = P.size(), l = 0, r = -1;
    for (int i = 0; i < n; i++) {
        if (i and !argcmp(P[i - 1].dir(), P[i].dir()))
            continue;
        while (l < r and cover(P[i], P[r - 1], P[r])) r
            --;
        while (l < r and cover(P[i], P[l], P[l + 1])) l
            ++;
        P[++r] = P[i];
    }
    while (l < r and cover(P[l], P[r - 1], P[r])) r--;
    while (l < r and cover(P[r], P[l], P[l + 1])) l++;
    if (r - l <= 1 or !argcmp(P[l].dir(), P[r].dir()))
        return {}; // empty
    if (cover(P[l + 1], P[l], P[r]))
        return {}; // infinity
    return vector(P.begin() + l, P.begin() + r + 1);
}
```

## 6.7 圓線交

```
vector<Pt> CircleLineInter(Cir c, Line l) {
    Pt H = proj(c.o, l);
    Pt dir = unit(l.b - l.a);
    double h = abs(H - c.o);
    if (sgn(h - c.r) > 0) return {};
    double d = sqrt(max((double)0., c.r * c.r - h * h))
        ;
    if (sgn(d) == 0) return {H};
    return {H - dir *d, H + dir * d};
    // Counterclockwise
}
```

## 6.8 圓圓交

```
vector<Pt> CircleInter(Cir a, Cir b) {
    double d2 = abs2(a.o - b.o), d = sqrt(d2);
    if (d < max(a.r, b.r) - min(a.r, b.r) || d > a.r +
        b.r) return {};
    Pt u = (a.o + b.o) / 2 + (a.o - b.o) * ((b.r * b.r
        - a.r * a.r) / (2 * d2));
    double A = sqrt((a.r + b.r + d) * (a.r - b.r + d) *
         (a.r + b.r - d) * (-a.r + b.r + d));
    Pt v = rotate(b.o - a.o) * A / (2 * d2);
    if (sgn(v.x) == 0 and sgn(v.y) == 0) return {u};
    return {u - v, u + v}; // counter clockwise of a
}
```

## 6.9 線線交

```
bool isInter(Line l, Line m) {
    if (PtOnSeg(m.a, l) or PtOnSeg(m.b, l) or
        PtOnSeg(l.a, m) or PtOnSeg(l.b, m))
        return true;
    return PtSide(m.a, l) * PtSide(m.b, l) < 0 and
           PtSide(l.a, m) * PtSide(l.b, m) < 0;
}
Pt LineInter(Line l, Line m) {
    double s = ori(m.a, m.b, l.a), t = ori(m.a, m.b, l.
        b);
    return (l.b * s - l.a * t) / (s - t);
}
```

## 6.10 ConvexHull

```
vector<Pt> Hull(vector<Pt> P) {
    sort(all(P));
    P.erase(unique(all(P)), P.end());
    P.insert(P.end(), P.rbegin() + 1, P.rend());
    vector<Pt> stk;
    for (auto p : P) {
        auto it = stk.rbegin();
        while (stk.rend() - it >= 2 and \
            ori(*next(it), *it, p) <= 0 and \
            (*next(it) < *it) == (*it < p)) {
            it++;
        }
        stk.resize(stk.rend() - it);
        stk.push_back(p);
    }
    stk.pop_back();
    return stk;
}
```

## 6.11 Hulltrick

```
struct Convex {
    int n;
    vector<Pt> A, V, L, U;
    Convex(const vector<Pt> &_A) : A(_A), n(_A.size())
        { // n >= 3
        auto it = max_element(all(A));
        L.assign(A.begin(), it + 1);
        U.assign(it, A.end()), U.push_back(A[0]);
        for (int i = 0; i < n; i++) {
            V.push_back(A[(i + 1) % n] - A[i]);
        }
    }
    int inside(Pt p, const vector<Pt> &h, auto f) {
        auto it = lower_bound(all(h), p, f);
        if (it == h.end()) return 0;
        if (it == h.begin()) return p == *it;
        return 1 - sgn(ori(*prev(it), p, *it));
    }
    // 0: out, 1: on, 2: in
    int inside(Pt p) {
        return min(inside(p, L, less{}), inside(p, U,
            greater{}));
    }
    static bool cmp(Pt a, Pt b) { return sgn(a ^ b) >
        0; }
```

```
    // A[i] is a far/closer tangent point
    int tangent(Pt v, bool close = true) {
        assert(v != Pt{});
        auto l = V.begin(), r = V.begin() + L.size() -
            1;
        if (v < Pt{}) l = r, r = V.end();
        if (close) return (lower_bound(l, r, v, cmp) -
            V.begin()) % n;
        return (upper_bound(l, r, v, cmp) - V.begin())
            % n;
    }
    // closer tangent point
    array<int, 2> tangent2(Pt p) {
        array<int, 2> t{-1, -1};
        if (inside(p) == 2) return t;
        if (auto it = lower_bound(all(L), p); it != L.
            end() and p == *it) {
            int s = it - L.begin();
            return {(s + 1) % n, (s - 1 + n) % n};
        }
        if (auto it = lower_bound(all(U), p, greater{})
            ; it != U.end() and p == *it) {
            int s = it - U.begin() + L.size() - 1;
            return {(s + 1) % n, (s - 1 + n) % n};
        }
        for (int i = 0; i != t[0]; i = tangent((A[t[0]
            = i] - p), 0));
        for (int i = 0; i != t[1]; i = tangent((p - A[t
            [1] = i]), 1));
        return t;
    }
    int find(int l, int r, Line L) {
        if (r < l) r += n;
        int s = PtSide(A[l % n], L);
        return *ranges::partition_point(views::iota(l,
            r),
            [&](int m) {
                return PtSide(A[m % n], L) == s;
            }) - 1;
    };
    // Line A_x A_x+1 interset with L
    vector<int> intersect(Line L) {
        int l = tangent(L.a - L.b), r = tangent(L.b - L
            .a);
        if (PtSide(A[l], L) * PtSide(A[r], L) >= 0)
            return {};
        return {find(l, r, L) % n, find(r, l, L) % n};
    }
};
```

## 6.12 點線距

```
double PtSegDist(Pt p, Line l) {
    double ans = min(abs(p - l.a), abs(p - l.b));
    if (sgn(abs(l.a - l.b)) == 0)  return ans;
    if (sgn((l.a - l.b) * (p - l.b)) < 0) return ans;
    if (sgn((l.b - l.a) * (p - l.a)) < 0) return ans;
    return min(ans, abs(ori(p, l.a, l.b)) / abs(l.a - l
        .b));
}
double SegDist(Line l, Line m) {
    return PtSegDist({0, 0}, {l.a - m.a, l.b - m.b});
}
```

## 6.13 MEC

```
Pt Center(Pt a, Pt b, Pt c) {
    Pt x = (a + b) / 2;
    Pt y = (b + c) / 2;
    return LineInter({x, x + rotate(b - a)}, {y, y +
        rotate(c - b)});
}
Cir MEC(vector<Pt> P) {
    mt19937 rng(time(0));
    shuffle(all(P), rng);
    Cir C;
    for (int i = 0; i < P.size(); i++) {
        if (C.inside(P[i])) continue;
        C = {P[i], 0};
        for (int j = 0; j < i; j++) {
            if (C.inside(P[j])) continue;
            C = {(P[i] + P[j]) / 2, abs(P[i] - P[j]) /
                2};
            for (int k = 0; k < j; k++) {
                if (C.inside(P[k])) continue;
                C.o = Center(P[i], P[j], P[k]);
                C.r = abs(C.o - P[i]);
            }
        }
    }
    return C;
}
```

## 6.14 MEC2

```
PT arr[MXN];
int n = 10;
double checky(double x, double y) {
    double cmax = 0;
    for (int i = 0; i < n; i++) {  // 過程中回傳距離^2
        避免不必要的根號運算
        cmax = max(cmax, (arr[i].x - x) * (arr[i].x - x
            ) + (arr[i].y - y) * (arr[i].y - y));
    }
    return cmax;
}
double checkx(double x) {
    double yl = -1e9, yr = 1e9;
    while (yr - yl > EPS) {
        double ml = (yl + yl + yr) / 3, mr = (yl + yr +
            yr) / 3;
        if (checky(x, ml) < checky(x, mr))
            yr = mr;
        else
            yl = ml;
    }
}
signed main() {
    double xl = -1e9, xr = 1e9;
    while (xr - xl > EPS) {
        double ml = (xl + xl + xr) / 3, mr = (xl + xr +
            xr) / 3;
        if (checkx(ml) < checkx(mr))
            xr = mr;
        else
            xl = ml;
    }
}
```

## 6.15 旋轉卡尺

```
auto RotatingCalipers(const vector<Pt> &hull) { // 最遠
    點對 回傳距離平方
    int n = hull.size();
    auto ret = abs2(hull[0]);
    ret = 0;
    if (hull.size() <= 2) return abs2(hull[0] - hull
        [1]);
    for (int i = 0, j = 2; i < n; i++) {
        Pt a = hull[i], b = hull[(i + 1) % n];
        while(ori(hull[j], a, b) <
            (ori(hull[(j + 1) % n], a, b)))
            j = (j + 1) % n;
        chmax(ret, abs2(a - hull[j]));
        chmax(ret, abs2(b - hull[j]));
    }
    return ret;
}
```

## 6.16 Minkowski

```
// P, Q, R(return) are counterclockwise order convex
    polygon
vector<Pt> Minkowski(vector<Pt> P, vector<Pt> Q) {
    auto cmp = [&](Pt a, Pt b) {
        return Pt{a.y, a.x} < Pt{b.y, b.x};
    };
    auto reorder = [&](auto &R) {
        rotate(R.begin(), min_element(all(R), cmp), R.
            end());
        R.push_back(R[0]), R.push_back(R[1]);
    };
    const int n = P.size(), m = Q.size();
```

```
    reorder(P), reorder(Q);
    vector<Pt> R;
    for (int i = 0, j = 0, s; i < n or j < m; ) {
        R.push_back(P[i] + Q[j]);
        s = sgn((P[i + 1] - P[i]) ^ (Q[j + 1] - Q[j]));
        if (s >= 0) i++;
        if (s <= 0) j++;
    }
    return R;
}
```

## 6.17 PointInPolygon

```
int inPoly(Pt p, const vector<Pt> &P) {
    const int n = P.size();
    int cnt = 0;
    for (int i = 0; i < n; i++) {
        Pt a = P[i], b = P[(i + 1) % n];
        if (PtOnSeg(p, {a, b})) return 1; // on edge
        if ((sgn(a.y - p.y) == 1) ^ (sgn(b.y - p.y) ==
            1))
            cnt += sgn(ori(a, b, p));
    }
    return cnt == 0 ? 0 : 2; // out, in
}
```

## 6.18 UnionOfCircles

```
// Area[i] : area covered by at least i circle
// TODO:!!!aaa!!!
vector<double> CircleUnion(const vector<Cir> &C) {
    const int n = C.size();
    vector<double> Area(n + 1);
    auto check = [&](int i, int j) {
        if (!contain(C[i], C[j]))
            return false;
        return sgn(C[i].r - C[j].r) > 0 or (sgn(C[i].r
            - C[j].r) == 0 and i < j);
    };
    struct Teve {
        double ang; int add; Pt p;
        bool operator<(const Teve &b) { return ang < b.
            ang; }
    };
    auto ang = [&](Pt p) { return atan2(p.y, p.x); };
    for (int i = 0; i < n; i++) {
        int cov = 1;
        vector<Teve> event;
        for (int j = 0; j < n; j++) if (i != j) {
            if (check(j, i)) cov++;
            else if (!check(i, j) and !disjunct(C[i], C
                [j])) {
                auto I = CircleInter(C[i], C[j]);
                assert(I.size() == 2);
                double a1 = ang(I[0] - C[i].o), a2 =
                    ang(I[1] - C[i].o);
                event.push_back({a1, 1, I[0]});
                event.push_back({a2, -1, I[1]});
                if (a1 > a2) cov++;
            }
        }
        if (event.empty()) {
            Area[cov] += pi * C[i].r * C[i].r;
            continue;
        }
        sort(all(event));
        event.push_back(event[0]);
        for (int j = 0; j + 1 < event.size(); j++) {
            cov += event[j].add;
            Area[cov] += (event[j].p ^ event[j + 1].p)
                / 2.;
            double theta = event[j + 1].ang - event[j].
                ang;
            if (theta < 0) theta += 2 * pi;
            Area[cov] += (theta - sin(theta)) * C[i].r
                * C[i].r / 2.;
        }
    }
    return Area;
}
```

## 6.19 UnionOfPolygons

```
// Area[i] : area covered by at least i polygon
vector<double> PolyUnion(const vector<vector<Pt>> &P) {
    const int n = P.size();
    vector<double> Area(n + 1);
    vector<Line> Ls;
    for (int i = 0; i < n; i++)
        for (int j = 0; j < P[i].size(); j++)
            Ls.push_back({P[i][j], P[i][(j + 1) % P[i].
                size()]});
    auto cmp = [&](Line &l, Line &r) {
        Pt u = l.b - l.a, v = r.b - r.a;
        if (argcmp(u, v)) return true;
        if (argcmp(v, u)) return false;
        return PtSide(l.a, r) < 0;
    };
    sort(all(Ls), cmp);
    for (int l = 0, r = 0; l < Ls.size(); l = r) {
        while (r < Ls.size() and !cmp(Ls[l], Ls[r])) r
            ++;
        Line L = Ls[l];
        vector<pair<Pt, int>> event;
        for (auto [c, d] : Ls) {
            if (sgn((L.a - L.b) ^ (c - d)) != 0) {
                int s1 = PtSide(c, L) == 1;
                int s2 = PtSide(d, L) == 1;
                if (s1 ^ s2) event.emplace_back(
                    LineInter(L, {c, d}), s1 ? 1 : -1);
            } else if (PtSide(c, L) == 0 and sgn((L.a -
                L.b) * (c - d)) > 0) {
                event.emplace_back(c, 2);
                event.emplace_back(d, -2);
            }
        }
        sort(all(event), [&](auto i, auto j) {
            return (L.a - i.ff) * (L.a - L.b) < (L.a -
                j.ff) * (L.a - L.b);
        });
        int cov = 0, tag = 0;
        Pt lst{0, 0};
        for (auto [p, s] : event) {
            if (cov >= tag) {
                Area[cov] += lst ^ p;
                Area[cov - tag] -= lst ^ p;
            }
            if (abs(s) == 1) cov += s;
            else tag += s / 2;
            lst = p;
        }
    }
    for (int i = n - 1; i >= 0; i--) Area[i] += Area[i
        + 1];
    for (int i = 1; i <= n; i++) Area[i] /= 2;
    return Area;
};
```

## 6.20 圓公切線

```
vector<Line> CircleTangent(Cir c1, Cir c2, int sign1) {
    // sign1 = 1 for outer tang, -1 for inter tang
    vector<Line> ret;
    ld d_sq = abs2(c1.o - c2.o);
    if (sgn(d_sq) == 0) return ret;
    ld d = sqrt(d_sq);
    Pt v = (c2.o - c1.o) / d;
    ld c = (c1.r - sign1 * c2.r) / d;
    if (c * c > 1) return ret;
    ld h = sqrt(max(0.0, 1.0 - c * c));
    for (int sign2 = 1; sign2 >= -1; sign2 -= 2) {
        Pt n = Pt(v.x * c - sign2 * h * v.y, v.y * c +
            sign2 * h * v.x);
        Pt p1 = c1.o + n * c1.r;
        Pt p2 = c2.o + n * (c2.r * sign1);
        if (sgn(p1.x - p2.x) == 0 && sgn(p1.y - p2.y)
            == 0)
            p2 = p1 + rotate(c2.o - c1.o);
        ret.push_back({p1, p2});
    }
  return ret;
}
```

### 6.21 點圓切線

```
vector<Line> CircleTangent(Cir c, Pt p) {
    vector<Line> z;
    double d = abs(p - c.o);
    if (sgn(d - c.r) == 0) {
        Pt i = rotate(p - c.o);
        z.push_back({p, p + i});
    } else if (d > c.r) {
        double o = acos(c.r / d);
        Pt i = unit(p - c.o);
        Pt j = rotate(i, o) * c.r;
        Pt k = rotate(i, -o) * c.r;
        z.push_back({c.o + j, p});
        z.push_back({c.o + k, p});
    }
    return z;
}
```

# 7 graph

## 7.1 BCC

```
#define REP(i, n) for (int i = 0; i < n; i++)
struct BccVertex {
    int n, nScc, step, dfn[MXN], low[MXN];
    vector<int> E[MXN], sccv[MXN];
    int top, stk[MXN];
    void init(int _n) {
        n = _n;
        nScc = step = 0;
        for (int i = 0; i < n; i++) E[i].clear();
    }
    void addEdge(int u, int v) {
        E[u].PB(v);
        E[v].PB(u);
    }
    void DFS(int u, int f) {
        dfn[u] = low[u] = step++;
        stk[top++] = u;
        for (auto v : E[u]) {
            if (v == f) continue;
            if (dfn[v] == -1) {
                DFS(v, u);
                low[u] = min(low[u], low[v]);
                if (low[v] >= dfn[u]) {
                    int z;
                    sccv[nScc].clear();
                    do {
                        z = stk[--top];
                        sccv[nScc].PB(z);
                    } while (z != v);
                    sccv[nScc++].PB(u);
                }
            } else
                low[u] = min(low[u], dfn[v]);
        }
    }
    vector<vector<int>> solve() {
        vector<vector<int>> res;
        for (int i = 0; i < n; i++) dfn[i] = low[i] =
            -1;
        for (int i = 0; i < n; i++)
            if (dfn[i] == -1) {
                top = 0;
                DFS(i, i);
            }
        REP(i, nScc) res.PB(sccv[i]);
        return res;
    }
} graph;
```

## 7.2 SCC

```
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<= n; i++)
      E[i].clear(), rE[i].clear();
  }
  void addEdge(int u, int v){
    E[u].PB(v); rE[v].PB(u);
  }
  void DFS(int u){
    vst[u]=1;
    for (auto v : E[u]) if (!vst[v]) DFS(v);
    vec.PB(u);
  }
  void rDFS(int u){
    vst[u] = 1; bln[u] = nScc;
    for (auto v : rE[u]) if (!vst[v]) rDFS(v);
  }
  void solve(){
    nScc = 0;
    vec.clear();
    fill(vst, vst+n+1, 0);
    for (int i=0; i<=n; i++)
      if (!vst[i]) DFS(i);
    reverse(vec.begin(),vec.end());
    fill(vst, vst+n+1, 0);
    for (auto v : vec)
      if (!vst[v]){
        rDFS(v); nScc++;
      }
  }
};
```

## 7.3 支配樹

```
#define REP(i, s, e) for (int i = (s); i <= (e); i++)
#define REPD(i, s, e) for (int i = (s); i >= (e); i--)
struct DominatorTree {  // O(N) 1-base
    int n, s;
    vector<int> g[MAXN], pred[MAXN];
    vector<int> cov[MAXN];
    int dfn[MAXN], nfd[MAXN], ts;
    int par[MAXN];  // idom[u] s到u的最後一個必經點
    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) {
        ts = 0;
        n = _n;
        s = _s;
        REP(i, 1, n) g[i].clear(), pred[i].clear();
    }
    void addEdge(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() {
        REP(i, 1, n) {
            idom[i] = par[i] = dfn[i] = nfd[i] = 0;
            cov[i].clear();
            mom[i] = mn[i] = sdom[i] = i;
        }
        dfs(s);
        REPD(i, n, 2) {
            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();
    }
    REP(i, 2, n) {
        int u = nfd[i];
        if (u == 0) continue;
        if (idom[u] != sdom[u]) idom[u] = idom[idom
            [u]];
    }
  }
} domT;
```

## 7.4 最大團

```
struct MaxClique {  // 0-base
    typedef bitset<MXN> Int;
    Int linkto[MXN], v[MXN];
    int n;
    void init(int _n) {
        n = _n;
        for (int i = 0; i < n; i++) {
            linkto[i].reset();
            v[i].reset();
        }
    }
    void addEdge(int a, int b) { v[a][b] = v[b][a] = 1;
         }
    int popcount(const Int& val) { return val.count();
        }
    int lowbit(const Int& val) { return val._Find_first
        (); }
    int ans, stk[MXN];
    int id[MXN], di[MXN], deg[MXN];
    Int cans;
    void maxclique(int elem_num, Int candi) {
        if (elem_num > ans) {
            ans = elem_num;
            cans.reset();
            for (int i = 0; i < elem_num; i++) cans[id[
                stk[i]]] = 1;
        }
        int potential = elem_num + popcount(candi);
        if (potential <= ans) return;
        int pivot = lowbit(candi);
        Int smaller_candi = candi & (~linkto[pivot]);
        while (smaller_candi.count() && potential > ans
            ) {
            int next = lowbit(smaller_candi);
            candi[next] = !candi[next];
            smaller_candi[next] = !smaller_candi[next];
            potential--;
            if (next == pivot || (smaller_candi &
                linkto[next]).count()) {
                stk[elem_num] = next;
                maxclique(elem_num + 1, candi & linkto[
                    next]);
            }
        }
    }
    int solve() {
        for (int i = 0; i < n; i++) {
            id[i] = i;
            deg[i] = v[i].count();
        }
        sort(id, id + n, [&](int id1, int id2) { return
             deg[id1] > deg[id2]; });
        for (int i = 0; i < n; i++) di[id[i]] = i;
        for (int i = 0; i < n; i++)
            for (int j = 0; j < n; j++)
                if (v[i][j]) linkto[di[i]][di[j]] = 1;
        Int cand;
        cand.reset();
        for (int i = 0; i < n; i++) cand[i] = 1;
        ans = 1;
        cans.reset();
        cans[0] = 1;
        maxclique(0, cand);
        return ans;
    }
} solver;
```

## 7.5 最小圈

```
/* minimum mean cycle O(VE) */
struct MMC{
#define E 101010
#define V 1021
#define inf 1e9
#define eps 1e-6
  struct Edge { int v,u; double c; };
  int n, m, prv[V][V], prve[V][V], vst[V];
  Edge e[E];
  vector<int> edgeID, cycle, rho;
  double d[V][V];
  void init( int _n )
  { n = _n; m = 0; }
  // WARNING: TYPE matters
  void addEdge( int vi , int ui , double ci )
  { e[ m ++ ] = { vi , ui , ci }; }
  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 solve(){
    // returns inf if no cycle, mmc otherwise
    double mmc=inf;
    int st = -1;
    bellman_ford();
    for(int i=0; i<n; i++) {
      double avg=-inf;
      for(int k=0; k<n; k++) {
        if(d[n][i]<inf-eps) avg=max(avg,(d[n][i]-d[k][i
            ])/(n-k));
        else avg=max(avg,inf);
      }
      if (avg < mmc) tie(mmc, st) = tie(avg, i);
    }
    fill(vst,0); edgeID.clear(); cycle.clear(); rho.
        clear();
    for (int i=n; !vst[st]; st=prv[i--][st]) {
      vst[st]++;
      edgeID.PB(prve[i][st]);
      rho.PB(st);
    }
    while (vst[st] != 2) {
      if(rho.empty()) return inf;
      int v = rho.back(); rho.pop_back();
      cycle.PB(v);
      vst[v]++;
    }
    reverse(ALL(edgeID));
    edgeID.resize(SZ(cycle));
    return mmc;
} }mmc;
```

# 8 math

## 8.1 DiscreteSqrt

```
void calcH(i64 &t, i64 &h, const i64 p) {
  i64 tmp=p-1; for(t=0;(tmp&1)==0;tmp/=2) t++; h=tmp;
}
// solve equation x^2 mod p = a
// !!!! (a != 0) !!!!!
bool solve(i64 a, i64 p, i64 &x, i64 &y) {
  if(p == 2) { x = y = 1; return true; }
```

```
  int p2 = p / 2, tmp = mypow(a, p2, p);
  if (tmp == p - 1) return false;
  if ((p + 1) % 4 == 0) {
    x=mypow(a,(p+1)/4,p); y=p-x; return true;
  } else {
    i64 t, h, b, pb; calcH(t, h, p);
    if (t >= 2) {
      do {b = rand() % (p - 2) + 2;
      } while (mypow(b, p / 2, p) != p - 1);
      pb = mypow(b, h, p);
    } int s = mypow(a, h / 2, p);
    for (int step = 2; step <= t; step++) {
      int ss = (((i64)(s * s) % p) * a) % p;
      for(int i=0;i<t-step;i++) ss=mul(ss,ss,p);
      if (ss + 1 == p) s = (s * pb) % p;
          pb = ((i64)pb * pb) % p;
    } x = ((i64)s * a) % p; y = p - x;
  } return true;
}
```

## 8.2 excrt

```
typedef __int128 ll;
void exgcd(ll a,ll b,ll &g,ll &x,ll &y) {
    if (b == 0) {
        g = a;
        x = 1;
        y = 0;
        return;
    }
    exgcd(b,a%b,g,y,x);
    y-=(a/b)*x;
}
bool flag = false;
ll a1,a2,n1,n2;
ll abs(ll x) {
    return x>0?x:-x;
}
void china() {
    ll d = a2 - a1;
    ll g,x,y;
    exgcd(n1,n2,g,x,y);
    if (d % g == 0) {
        x = ((x*d/g)%(n2/g)+(n2/g))%(n2/g);
        a1 = x*n1 + a1;
        n1 = (n1*n2)/g;
    }
    else
        flag = true;
}
int n;
long long as[100001];  //算式答案 x
long long ns[100001];  //模數 MOD
ll realchina() {
    a1 = as[0];
    n1 = ns[0];
    for (ll i = 1;i<n;i++) {
        a2 = as[i];
        n2 = ns[i];
        china();
        if (flag)
            return -1;
    }
    return a1;
}
int main() {
    cin>>n;
    flag = false;
    for (ll i = 0;i<n;i++)
        cin>>ns[i]>>as[i];
    cout<<(long long)realchina()<<endl;
}
```

## 8.3 exgcd

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

## 8.4 FFT

```
const int MAXN = 262144;
// (must be 2^k)
// before any usage, run pre_fft() first
typedef long double ld;
typedef complex<ld> cplx; //real() ,imag()
const ld PI = acosl(-1);
const cplx I(0, 1);
cplx omega[MAXN+1];
void pre_fft(){
  for(int i=0; i<=MAXN; i++)
    omega[i] = exp(i * 2 * PI / MAXN * I);
}
// n must be 2^k
void fft(int n, cplx a[], bool inv=false){
  int basic = MAXN / n;
  int theta = basic;
  for (int m = n; m >= 2; m >>= 1) {
    int mh = m >> 1;
    for (int i = 0; i < mh; i++) {
      cplx w = omega[inv ? MAXN-(i*theta%MAXN)
                         : i*theta%MAXN];
      for (int j = i; j < n; j += m) {
        int k = j + mh;
        cplx x = a[j] - a[k];
        a[j] += a[k];
        a[k] = w * x;
    } }
    theta = (theta * 2) % MAXN;
  }
  int i = 0;
  for (int j = 1; j < n - 1; j++) {
    for (int k = n >> 1; k > (i ^= k); k >>= 1);
    if (j < i) swap(a[i], a[j]);
  }
  if(inv) for (i = 0; i < n; i++) a[i] /= n;
}
cplx arr[MAXN+1];
inline void mul(int _n,i64 a[],int _m,i64 b[],i64 ans
    []){
  int n=1,sum=_n+_m-1;
  while(n<sum)
    n<<=1;
  for(int i=0;i<n;i++) {
    double x=(i<_n?a[i]:0),y=(i<_m?b[i]:0);
    arr[i]=complex<double>(x+y,x-y);
  }
  fft(n,arr);
  for(int i=0;i<n;i++)
    arr[i]=arr[i]*arr[i];
  fft(n,arr,true);
  for(int i=0;i<sum;i++)
    ans[i]=(i64)(arr[i].real()/4+0.5);
}
```

## 8.5 josephus

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

## 8.6 Theorem

- Lucas's Theorem :
  For $n, m \in \mathbb{Z}^*$ and prime $P$, $C(m,n)$ mod $P = \Pi(C(m_i, n_i))$ where $m_i$ is the $i$-th digit of $m$ in base $P$.
- Stirling approximation :
  $n! \approx \sqrt{2\pi n}(\frac{n}{e})^n e^{\frac{1}{12n}}$
- Stirling Numbers(permutation $|P| = n$ with $k$ cycles):
  $S(n,k)$ = coefficient of $x^k$ in $\Pi_{i=0}^{n-1}(x+i)$
- Stirling Numbers(Partition $n$ elements into $k$ non-empty set):
  $S(n,k) = \frac{1}{k!}\sum_{j=0}^{k}(-1)^{k-j}\binom{k}{j}j^n$
- Pick's Theorem : $A = i + b/2 - 1$
  $A$: Area、$i$: grid number in the inner、$b$: grid number on the side

- Catalan number : $C_n = \binom{2n}{n}/(n+1)$
  $C_n^{n+m} - C_{n+1}^{n+m} = (m+n)!\frac{n-m+1}{n+1} \quad for \quad n \geq m$
  $C_n = \frac{1}{n+1}\binom{2n}{n} = \frac{(2n)!}{(n+1)!n!}$
  $C_0 = 1 \quad and \quad C_{n+1} = 2(\frac{2n+1}{n+2})C_n$
  $C_0 = 1 \quad and \quad C_{n+1} = \sum_{i=0}^{n} C_i C_{n-i} \quad for \quad n \geq 0$

- Euler Characteristic:
  planar graph: $V - E + F - C = 1$
  convex polyhedron: $V - E + F = 2$
  $V, E, F, C$: number of vertices, edges, faces(regions), and components

- Kirchhoff's theorem :
  $A_{ii} = deg(i), A_{ij} = (i,j) \in E \ ? -1 : 0$, Deleting any one row, one column, and cal the det(A)

- Polya' theorem ($c$ is number of color, $m$ is the number of cycle size):
  $(\sum_{i=1}^{m} c^{gcd(i,m)})/m$

- Burnside lemma:
  $|X/G| = \frac{1}{|G|}\sum_{g \in G} |X^g|$

- 錯排公式: ($n$ 個人中，每個人皆不再原來位置的組合數):
  $dp[0] = 1; dp[1] = 0;$
  $dp[i] = (i-1) * (dp[i-1] + dp[i-2]);$

- Bell 數 (有 $n$ 個人，把他們拆組的方法總數) :
  $B_0 = 1$
  $B_n = \sum_{k=0}^{n} s(n,k) \quad (second - stirling)$
  $B_{n+1} = \sum_{k=0}^{n} \binom{n}{k} B_k$

- Wilson's theorem :
  $(p-1)! \equiv -1 (mod \ p)$

- Fermat's little theorem :
  $a^p \equiv a (mod \ p)$

- Euler's totient function:
  $A^{B^C} \ mod \ p = pow(A, pow(B, C, p-1)) mod \ p$

- 歐拉函數降冪公式:
  $A^B \mod C = A^{B \mod \phi(c) + \phi(c)} \mod C$

- 6 的倍數:
  $(a-1)^3 + (a+1)^3 + (-a)^3 + (-a)^3 = 6a$

## 8.7 Primes

| Prime | Root | Prime | Root |
|---|---|---|---|
| 7681 | 17 | 167772161 | 3 |
| 12289 | 11 | 104857601 | 3 |
| 40961 | 3 | 985661441 | 3 |
| 65537 | 3 | 998244353 | 3 |
| 786433 | 10 | 1107296257 | 10 |
| 5767169 | 3 | 2013265921 | 31 |
| 7340033 | 3 | 2810183681 | 11 |
| 23068673 | 3 | 2885681153 | 3 |
| 469762049 | 3 | 605028353 | 3 |

## 8.8 millerrabin

```
// n < 4,759,123,141          3 :  2, 7, 61
// n < 1,122,004,669,633      4 :  2, 13, 23, 1662803
// n < 3,474,749,660,383          6 :  pirmes <= 13
// n < 2^64                       7 :
// 2, 325, 9375, 28178, 450775, 9780504, 1795265022
// Make sure testing integer is in range [2, n-2] if
// you want to use magic.
bool witness(i64 a,i64 n,i64 u,int t){
  if(!a) return 0;
  i64 x=mypow(a,u,n);
  for(int i=0;i<t;i++) {
    i64 nx=mul(x,x,n);
    if(nx==1&&x!=1&&x!=n-1) return 1;
    x=nx;
  }
  return x!=1;
}
bool mii64er_rabin(i64 n) {
  int s = 7;
  // iterate s times of witness on n
  if(n<2) return 0;
  if(!(n&1)) return n == 2;
  i64 u=n-1; int t=0;
  // n-1 = u*2^t
  while(!(u&1)) u>>=1, t++;
  while(s--){
    i64 a=magic[s]%n;
    if(witness(a,n,u,t)) return 0;
  }
  return 1;
}
```

## 8.9 phi

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

## 8.10 pollardrho

```
// does not work when n is prime  O(n^(1/4))
i64 f(i64 x, i64 c, i64 mod){ return add(mul(x,x,mod),c
    ,mod); }
i64 poi64ard_rho(i64 n) {
    i64 c = 1, x = 0, y = 0, p = 2, q, t = 0;
    while (t++ % 128 or gcd(p, n) == 1) {
        if (x == y) c++, y = f(x = 2, c, n);
        if (q = mul(p, abs(x-y), n)) p = q;
        x = f(x, c, n); y = f(f(y, c, n), c, n);
    }
    return gcd(p, n);
}
```

## 8.11 primes

```
/* 12721, 13331, 14341, 75577, 123457, 222557, 556679
* 999983, 1097774749, 1076767633, 100102021, 999997771
* 1001010013, 1000512343, 987654361, 999991231
* 999888733, 98789101, 987777733, 999991921, 1010101333
* 1010102101, 1000000000039, 1000000000000037
* 2305843009213693951, 4611686018427387847
* 9223372036854775783, 18446744073709551557 */
int mu[ N ] , p_tbl[ N ];
vector<int> primes;
void sieve() {
  mu[ 1 ] = p_tbl[ 1 ] = 1;
  for( int i = 2 ; i < N ; i ++ ){
    if( !p_tbl[ i ] ){
      p_tbl[ i ] = i;
      primes.push_back( i );
      mu[ i ] = -1;
    }
    for( int p : primes ){
      int x = i * p;
      if( x >= M ) break;
      p_tbl[ x ] = p;
      mu[ x ] = -mu[ i ];
      if( i % p == 0 ){
        mu[ x ] = 0;
        break;
} } } }
vector<int> factor( int x ){
  vector<int> fac{ 1 };
  while( x > 1 ){
    int fn = SZ(fac), p = p_tbl[ x ], pos = 0;
    while( x % p == 0 ){
      x /= p;
      for( int i = 0 ; i < fn ; i ++ )
        fac.PB( fac[ pos ++ ] * p );
  } }
  return fac;
}
```

## 8.12 Euler

```
int Euler(int n){
  int now = n;
  for (int i = 2; i * i <= n; i++)
    if (n % i == 0){
      now = now - now / i;
      while (n % i == 0) n = n / i;
        }
```

```
    if (n > 1) now = now - now / n;
    return now;
}
```

### 8.13 quickeuler

```
vector<int> pri;
bool not_prime[MXN + 10];
int phi[MXN + 10];
void quick_euler(int n) {
    phi[1] = 1;
    for (int i = 2; i <= n; i++) {
        if (!not_prime[i]) {
            pri.push_back(i);
            phi[i] = i - 1;
        }
        for (int pri_j : pri) {
            if (i * pri_j > n)
                break;
            not_prime[i * pri_j] = true;
            if (i % pri_j == 0) {
                phi[i * pri_j] = phi[i] * pri_j;
                break;
            }
            phi[i * pri_j] = phi[i] * phi[pri_j];
        }
    }
}
```

### 8.14 sieve

```
const int MXN = 1e8 + 50;
const int SQRTMXN = 1e4 + 50;
bitset<MXN> isprime;
void sieve() {
    isprime[1] = 1;
    for (int i = 2; i <= SQRTMXN; i++) {
        if (!isprime[i])
            for (i64 j = i * i; j < MXN; j += i)
                isprime[j] = 1;
    }
}
```

## 9 string

### 9.1 KMP

```
vector<int> prefunc(const string& s){
  int n = s.size();
  vector<int> pi(n);
  for(int i=1,j=0;i<n;++i){
    j = pi[i-1];
    while(j && s[j] != s[i]) j = pi[j-1]; //取次小LCP
    if(s[j] == s[i]) ++j;
    pi[i] = j;
  }
  return pi;
}
vector<int> kmp(string str, string s, vector<int>& nxt)
     {
    vector<int> ans;
    for (int i = 0, j = 0; i < SZ(str); i++) {
        while (j && str[i] != s[j]) j = nxt[j - 1];
        if (str[i] == s[j]) j++;
        if (j == SZ(s)) {
            ans.push_back(i - SZ(s) + 1);
            j = nxt[j - 1];
        }
    }
    return ans;
}
```

### 9.2 minRotation

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

### 9.3 PalindromeTree

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

### 9.4 RollingHash

```
struct RollingHash{
#define psz 2
    vector<ll> primes={17, 75577};
    vector<ll> MOD={998244353, 1000000007};
    vector<array<ll, psz>> hash, base;
    void init(const string &s){
        hash.clear(); hash.resize(s.size());
        base.clear(); base.resize(s.size());
        for(int i=0;i<psz;i++){
            hash[0][i] = s[0];
            base[0][i] = 1;
        }
        for(int i=1;i<s.size();i++){
            for(int j=0;j<psz;j++){
                hash[i][j] = (hash[i-1][j] * primes[j]
                    % MOD[j] + s[i]) % MOD[j];
                base[i][j] = base[i-1][j] * primes[j] %
                     MOD[j];
            }
        }
    }
```

```
    array<ll, psz> getHash(int l,int r){
        if(l == 0) return hash[r];
        array<ll, psz> ret = hash[r];
        for(int i=0;i<psz;i++){
            ret[i] -= hash[l-1][i] * base[r-l+1][i] %
                MOD[i];
            if(ret[i]<0) ret[i]+=MOD[i];
        }
        return ret;
    }
}Hash;
```

## 9.5 SuffixArray

```
const int N = 300010;
struct SA{
#define REP(i,n) for ( int i=0; i<int(n); i++ )
#define REP1(i,a,b) for ( int i=(a); i<=int(b); i++ )
  bool _t[N*2];
  int _s[N*2], _sa[N*2], _c[N*2], x[N], _p[N], _q[N*2],
      hei[N], r[N];
  int operator [] (int i){ return _sa[i]; }
  void build(int *s, int n, int m){
    memcpy(_s, s, sizeof(int) * n);
    sais(_s, _sa, _p, _q, _t, _c, n, m);
    mkhei(n);
  }
  void mkhei(int n){
    REP(i,n) r[_sa[i]] = i;
    hei[0] = 0;
    REP(i,n) if(r[i]) {
      int ans = i>0 ? max(hei[r[i-1]] - 1, 0) : 0;
      while(_s[i+ans] == _s[_sa[r[i]-1]+ans]) ans++;
      hei[r[i]] = ans;
    }
  }
  void sais(int *s, int *sa, int *p, int *q, bool *t,
      int *c, int n, int z){
    bool uniq = t[n-1] = true, neq;
    int nn = 0, nmxz = -1, *nsa = sa + n, *ns = s + n,
        lst = -1;
#define MS0(x,n) memset((x),0,n*sizeof(*(x)))
#define MAGIC(XD) MS0(sa, n); \
    memcpy(x, c, sizeof(int) * z); \
    XD; \
    memcpy(x + 1, c, sizeof(int) * (z - 1)); \
    REP(i,n) if(sa[i] && !t[sa[i]-1]) sa[x[s[sa[i
        ]-1]]++] = sa[i]-1; \
    memcpy(x, c, sizeof(int) * z); \
    for(int i = n - 1; i >= 0; i--) if(sa[i] && t[sa[i
        ]-1]) sa[--x[s[sa[i]-1]]] = sa[i]-1;
    MS0(c, z);
    REP(i,n) uniq &= ++c[s[i]] < 2;
    REP(i,z-1) c[i+1] += c[i];
    if (uniq) { REP(i,n) sa[--c[s[i]]] = i; return; }
    for(int i = n - 2; i >= 0; i--) t[i] = (s[i]==s[i
        +1] ? t[i+1] : s[i]<s[i+1]);
    MAGIC(REP1(i,1,n-1) if(t[i] && !t[i-1]) sa[--x[s[i
        ]]]=p[q[i]=nn++]=i);
    REP(i, n) if (sa[i] && t[sa[i]] && !t[sa[i]-1]) {
      neq=lst<0||memcmp(s+sa[i],s+lst,(p[q[sa[i]]+1]-sa
          [i])*sizeof(int));
      ns[q[lst=sa[i]]]=nmxz+=neq;
    }
    sais(ns, nsa, p + nn, q + n, t + n, c + z, nn, nmxz
        + 1);
    MAGIC(for(int i = nn - 1; i >= 0; i--) sa[--x[s[p[
        nsa[i]]]]] = p[nsa[i]]);
  }
}sa;
// H [i] 第 i 跟前面的最大共同前綴
// SA[i] 第 i 小是從第幾個字元開始
int H[ N ], SA[ N ];
void suffix_array(int* ip, int len) {
  // should padding a zero in the back
  // ip is int array, len is array length
  // ip[0..n-1] != 0, and ip[len] = 0
  ip[len++] = 0;
  sa.build(ip, len, 128); // 注意字元個數
  for (int i=0; i<len; i++) {
    H[i] = sa.hei[i + 1];
    SA[i] = sa._sa[i + 1];
  }
  // resulting height, sa array \in [0,len)
}
```

## 9.6 trie

```
//01 bitwise trie
struct trie{
    trie *nxt[2];  // 差別
    int cnt;    //紀錄有多少個數字以此節點結尾
    int sz;     //有多少數字的前綴包括此節點
    trie():cnt(0),sz(0){
        memset(nxt,0,sizeof(nxt));
    }
};
//創建新的字典樹
trie *root;
void insert(int x){
    trie *now = root;  // 每次從根節點開始
    for(int i=22;i>=0;i--){ // 從最高位元開始往低位元走
        now->sz++;
        //cout<<(x>>i&1)<<endl;
        if(now->nxt[x>>i&1] == NULL){ //判斷當前第 i 個
            位元是 0 還是 1
            now->nxt[x>>i&1] = new trie();
        }
        now = now->nxt[x>>i&1];  //走到下一個位元
    }
    now->cnt++;
    now->sz++;
}
```

## 9.7 Z-algorithm

```
vector<int> zfunc(string &s){ //求 s 跟 s[i..n-1] 的最
    長真共同前綴長度 z[0] = 0
  int n = s.size();
  vector<int> z(n);
  for(int i = 1,l = 0,r = 0; i < n;++i){
    if(i <= r && z[i - l] < r - i + 1) z[i] = z[i - l];
    else {
      z[i] = max(0LL,r - i + 1);
      while(i + z[i] < n && s[z[i]] == s[i + z[i]]) ++z
          [i];
    }
    if(i + z[i] - 1 > r) l = i, r = i + z[i] - 1;
  }
  return z;
}
```

## 9.8 馬拉車

```
void z_value_pal(char* s, int len, int* z) {
    len = (len << 1) + 1;
    for (int i = len - 1; i >= 0; i--)
        s[i] = i & 1 ? s[i >> 1] : '@';
    z[0] = 1;
    for (int i = 1, l = 0, r = 0; i < len; i++) {
        z[i] = i < r ? min(z[l + l - i], r - i) : 1;
        while (i - z[i] >= 0 && i + z[i] < len && s[i -
            z[i]] == s[i + z[i]])
            ++z[i];
        if (i + z[i] > r)
            l = i, r = i + z[i];
    }
}
```

# 10 tree

## 10.1 DSUONTREE

```
int ans[MXN], color[MXN], son[MXN];
map<int, int> mp[MXN];
void dfs(int x, int f){
    if(son[x]){
        dfs(son[x], x);
        swap(mp[x], mp[son[x]]);
        ans[x] = ans[son[x]];
    }
    mp[x][color[x]]++;
    ans[x] = max(ans[x], mp[x][color[x]]);
    for(int i : edge[x]){
```

```
        if(i == f || i == son[x])    continue;
        dfs(i, x);
        for(auto j : mp[i]){
            mp[x][j.first] += j.second;
            ans[x] = max(ans[x], mp[x][j.first]);
        }
    }
}
```

## 10.2 EularTour

```
int timing=0;
int in[N],out[N];
void dfs(int u){
    in[u] = ++timing;//這時進入u
    for(int nxt : g[u]){//跑過所有孩子
        dfs(nxt);
    }
    out[u] = timing;//這時離開u 不會++

}
```

## 10.3 LCA

```
int n, q;
int anc[MAXN][25], in[MAXN], out[MAXN];
vector<int> edge[MAXN];
int timing = 1;
void dfs(int cur, int fa) {
    anc[cur][0] = fa;
    in[cur] = timing++;
    for (int nex : edge[cur]) {
        if (nex == fa) continue;
        dfs(nex, cur);
    }
    out[cur] = timing++;
}
void init() {
    dfs(1, 0);
    for (int i = 1; i < 25; i++) {
        for (int cur = 1; cur <= n; cur++) {
            anc[cur][i] = anc[anc[cur][i - 1]][i - 1];
        }
    }
}
bool isanc(int u, int v) { return (in[u] <= in[v] &&
    out[v] <= out[u]); }
int lca(int a, int b) {
    if (isanc(a, b)) return a;
    if (isanc(b, a)) return b;
    for (int i = 24; i >= 0; i--) {
        if (anc[a][i] == 0) continue;
        if (!isanc(anc[a][i], b)) a = anc[a][i];
    }

    return anc[a][0];
}
```

## 10.4 treehash

```
i64 dfs(int u){
    vector<i64> h;
    subtree_sz[u] = 1;
    for(i64 child : edge[u]){
        h.push_back(dfs(child));
        subtree_sz[u] += subtree_sz[child];
    }
    sort(h.begin(), h.end());
    i64 ret = subtree_sz[u];
    for(i64 v : h){
        ret = (ret * base + v) % MOD;
    }
    return ret;
}
```