Contents

1 Basic

1.1 .vimrc

```
syn on
se ai nu ru cul mouse=a
se cin et ts=2 sw=2 sts=2
so $VIMRUNTIME/mswin.vim
colo desert
se gfn=Monospace\ 14
```

1.2 Increase Stack Size

```
//stack resize
asm( "mov %0,%%esp\n" ::"g"(mem+10000000) );
//change esp to rsp if 64-bit system

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

2 flow

2.1 DMST

```
/*
 * Edmond's algoirthm for Directed MST
 * runs in O(VE)
 */
const int MAXV = 10010;
const int MAXE = 10010;
const int INF  = 2147483647;
struct Edge{
  int u, v, c;
  Edge(){}
  Edge(int x, int y, int z) :
    u(x), v(y), c(z){}
};
int V, E, root;
Edge edges[MAXE];
inline int newV(){
  V++;
  return V;
}
inline void addEdge(int u, int v, int c){
  E++;
  edges[E] = Edge(u, v, c);
}
bool con[MAXV];
int mnInW[MAXV], prv[MAXV], cyc[MAXV], vis[MAXV];
inline int DMST(){
  fill(con, con+V+1, 0);
  int r1 = 0, r2 = 0;
  while(1){
    fill(mnInW, mnInW+V+1, INF);
    fill(prv, prv+V+1, -1);
    REP(i, 1, E){
      int u=edges[i].u, v=edges[i].v, c=edges[i].c;
      if(u != v && v != root && c < mnInW[v])
        mnInW[v] = c, prv[v] = u;
    }
    fill(vis, vis+V+1, -1);
    fill(cyc, cyc+V+1, -1);
    r1 = 0;
    bool jf = 0;
```

```
    REP(i, 1, V){
      if(con[i]) continue ;
      if(prv[i] == -1 && i != root) return -1;
      if(prv[i] > 0) r1 += mnInW[i];
      int s;
      for(s = i; s != -1 && vis[s] == -1; s = prv[s])
        vis[s] = i;
      if(s > 0 && vis[s] == i){
         // get a cycle
        jf = 1;
        int v = s;
        do{
          cyc[v] = s, con[v] = 1;
          r2 += mnInW[v];
          v = prv[v];
        }while(v != s);
        con[s] = 0;
      }
    }
    if(!jf) break ;
    REP(i, 1, E){
      int &u = edges[i].u;
      int &v = edges[i].v;
      if(cyc[v] > 0) edges[i].c -= mnInW[edges[i].v];
      if(cyc[u] > 0) edges[i].u = cyc[edges[i].u];
      if(cyc[v] > 0) edges[i].v = cyc[edges[i].v];
      if(u == v) edges[i--] = edges[E--];
    }
  }
  return r1+r2;
}
```

2.2 ISAP

```
#define SZ(c) ((int)(c).size())
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 flowinit(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 maxflow() {
    //puts("MF");
    int res = 0;
    gap[0] = tot;
    for(res = 0; d[s] < tot; res += dfs(s, INF));
    return res;
  }
} flow;
Maxflow::Edge e(1, 1, 1);
```

2.3 MinCostFlow

```
/*
  A template for Min Cost Max Flow
  tested with TIOJ 1724
*/
struct MinCostMaxFlow{
  static const int MAXV = 20010;
  static const int INF  = 1000000000;
  struct Edge{
    int v, cap, w, rev;
    Edge(){}
    Edge(int t2, int t3, int t4, int t5)
    : v(t2), cap(t3), w(t4), rev(t5) {}
  };
  int V, s, t;
  vector<Edge> g[MAXV];
  void init(int n){
    V = n+2;
    s = n+1, t = n+2;
    for(int i = 1; i <= V; i++) g[i].clear();
  }
  void addEdge(int a, int b, int cap, int 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));
  }
  int d[MAXV], id[MAXV], mom[MAXV];
  bool inqu[MAXV];
  int qu[2000000], ql, qr;
  //the size of qu should be much large than MAXV
  int mncmxf(){
    int mxf = 0, mnc = 0;
    while(1){
      fill(d+1, d+1+V, INF);
      fill(inqu+1, inqu+1+V, 0);
      fill(mom+1, mom+1+V, -1);
      mom[s] = s;
      d[s] = 0;
      ql = 1, qr = 0;
      qu[++qr] = s;
      inqu[s] = 1;
      while(ql <= qr){
        int u = qu[ql++];
        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]) qu[++qr] = v, inqu[v] = 1;
          }
        }
      }
      if(mom[t] == -1) break ;
      int df = INF;
      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 mnc;
  }
} flow;
```

2.4 SW min-cut

```
struct SW{ // O(V^3)
  static const int MXN = 514;
  int n,vst[MXN],del[MXN];
  int edge[MXN][MXN],wei[MXN];
  void init(int _n){
    n = _n;
    FZ(edge);
    FZ(del);
  }
  void add_edge(int u, int v, int w){
    edge[u][v] += w;
    edge[v][u] += w;
  }
  void search(int &s, int &t){
    FZ(vst); FZ(wei);
    s = t = -1;
    while (true){
      int mx=-1, cur=0;
      for (int i=0; i<n; i++)
        if (!del[i] && !vst[i] && mx<wei[i])
          cur = i, mx = wei[i];
      if (mx == -1) break;
      vst[cur] = 1;
      s = t;
      t = cur;
      for (int i=0; i<n; i++)
        if (!vst[i] && !del[i]) wei[i] += edge[cur][i];
    }
  }
  int solve(){
    int res = 2147483647;
    for (int i=0,x,y; i<n-1; i++){
      search(x,y);
      res = min(res,wei[y]);
      del[y] = 1;
      for (int j=0; j<n; j++)
        edge[x][j] = (edge[j][x] += edge[y][j]);
    }
    return res;
  }
}graph;
```

2.5 HLPPA

```
/* Highest-Label Preflow Push Algorithm */
// tested with sgu-212 (more testing suggested)
int n,m,src,sink;
int deg[MAXN],adj[MAXN][MAXN],res[MAXN][MAXN]; //
    residual capacity
// graph (i.e. all things above) should be constructed
    beforehand
int ef[MAXN],ht[MAXN]; // excess flow, height
int apt[MAXN]; // the next adj index to try push
int htodo; // highest label to check with
int hcnt[MAXN*2]; // number of nodes with height h
queue<int> ovque[MAXN*2]; // used to implement highest-
    label selection
bool inque[MAXN];
inline void push(int v,int u) {
  int a=min(ef[v],res[v][u]);
  ef[v]-=a; ef[u]+=a;
  res[v][u]-=a; res[u][v]+=a;
  if(!inque[u]) {
    inque[u]=1;
    ovque[ht[u]].push(u);
  }
}
inline void relabel(int v) {
  int i,u,oldh;
  oldh=ht[v]; ht[v]=2*n;
  for(i=0;i<deg[v];i++) {
    u=adj[v][i];
    if(res[v][u]) ht[v]=min(ht[u]+1,ht[v]);
  }
  // gap speedup
  hcnt[oldh]--; hcnt[ht[v]]++;
  if(0<oldh&&oldh<n&&hcnt[oldh]==0) {
    for(i=0;i<n;i++) {
      if(ht[i]>oldh&&ht[i]<n) {
        hcnt[ht[i]]--;
        hcnt[n]++;
        ht[i]=n;
      }
    }
  }
  // update queue
  htodo=ht[v]; ovque[ht[v]].push(v); inque[v]=1;
}
inline void initPreflow() {
  int i,u;
  for(i=0;i<n;i++) {
    ht[i]=ef[i]=0;
    apt[i]=0; inque[i]=0;
  }
  ht[src]=n;
  for(i=0;i<deg[src];i++) {
    u=adj[src][i];
    ef[u]=res[src][u];
    ef[src]-=ef[u];
    res[u][src]=ef[u];
    res[src][u]=0;
  }
  htodo=n-1;
  for(i=0;i<2*n;i++) {
    hcnt[i]=0;
    while(!ovque[i].empty()) ovque[i].pop();
  }
  for(i=0;i<n;i++) {
    if(i==src||i==sink) continue;
    if(ef[i]) {
      inque[i]=1;
      ovque[ht[i]].push(i);
    }
    hcnt[ht[i]]++;
  }
  // to ensure src & sink is never added to queue
  inque[src]=inque[sink]=1;
}
inline void discharge(int v) {
  int u;
  while(ef[v]) {
    if(apt[v]==deg[v]) {
      relabel(v);
      apt[v]=0;
      continue;
    }
    u=adj[v][apt[v]];
    if(res[v][u]&&ht[v]==ht[u]+1) push(v,u);
    else apt[v]++;
  }
}
inline void hlppa() {
  int v;
  list<int>::iterator it;
  initPreflow();
  while(htodo>=0) {
    if(!ovque[htodo].size()) {
      htodo--;
      continue;
    }
    v=ovque[htodo].front();
    ovque[htodo].pop();
    inque[v]=0;
    discharge(v);
  }
}
```

2.6 Hungarian

```
#define NIL -1
#define INF 100000000
int n,matched;
int cost[MAXN][MAXN];
bool sets[MAXN]; // whether x is in set S
bool sett[MAXN]; // whether y is in set T
int xlabel[MAXN],ylabel[MAXN];
int xy[MAXN],yx[MAXN]; // matched with whom
int slack[MAXN]; // given y: min{xlabel[x]+ylabel[y]-
    cost[x][y]} | x not in S
int prev[MAXN]; // for augmenting matching
inline void relabel() {
  int i,delta=INF;
  for(i=0;i<n;i++) if(!sett[i]) delta=min(slack[i],
      delta);
  for(i=0;i<n;i++) if(sets[i]) xlabel[i]-=delta;
  for(i=0;i<n;i++) {
    if(sett[i]) ylabel[i]+=delta;
    else slack[i]-=delta;
  }
}
inline void add_sets(int x) {
  int i;
  sets[x]=1;
  for(i=0;i<n;i++) {
    if(xlabel[x]+ylabel[i]-cost[x][i]<slack[i]) {
      slack[i]=xlabel[x]+ylabel[i]-cost[x][i];
      prev[i]=x;
    }
  }
}
inline void augment(int final) {
  int x=prev[final],y=final,tmp;
  matched++;
  while(1) {
    tmp=xy[x]; xy[x]=y; yx[y]=x; y=tmp;
    if(y==NIL) return;
    x=prev[y];
  }
}
inline void phase() {
  int i,y,root;
  for(i=0;i<n;i++) { sets[i]=sett[i]=0; slack[i]=INF; }
  for(root=0;root<n&&xy[root]!=NIL;root++);
  add_sets(root);
  while(1) {
    relabel();
    for(y=0;y<n;y++) if(!sett[y]&&slack[y]==0) break;
    if(yx[y]==NIL) { augment(y); return; }
    else { add_sets(yx[y]); sett[y]=1; }
  }
}
inline int hungarian() {
  int i,j,c=0;
  for(i=0;i<n;i++) {
    xy[i]=yx[i]=NIL;
    xlabel[i]=ylabel[i]=0;
    for(j=0;j<n;j++) xlabel[i]=max(cost[i][j],xlabel[i
        ]);
  }
  for(i=0;i<n;i++) phase();
  for(i=0;i<n;i++) c+=cost[i][xy[i]];
  return c;
}
```

2.7 Hungarian Unbalanced

```
const int nil = -1;
const int inf = 1000000000;
int xn,yn,matched;
int cost[MAXN][MAXN];
bool sets[MAXN]; // whether x is in set S
bool sett[MAXN]; // whether y is in set T
int xlabel[MAXN],ylabel[MAXN];
int xy[MAXN],yx[MAXN]; // matched with whom
int slack[MAXN]; // given y: min{xlabel[x]+ylabel[y]-
    cost[x][y]} | x not in S
int prev[MAXN]; // for augmenting matching
inline void relabel() {
  int i,delta=inf;
  for(i=0;i<yn;i++) if(!sett[i]) delta=min(slack[i],
      delta);
  for(i=0;i<xn;i++) if(sets[i]) xlabel[i]-=delta;
  for(i=0;i<yn;i++) {
    if(sett[i]) ylabel[i]+=delta;
    else slack[i]-=delta;
  }
}
inline void add_sets(int x) {
  int i;
  sets[x]=1;
  for(i=0;i<yn;i++) {
    if(xlabel[x]+ylabel[i]-cost[x][i]<slack[i]) {
      slack[i]=xlabel[x]+ylabel[i]-cost[x][i];
      prev[i]=x;
    }
  }
}
inline void augment(int final) {
  int x=prev[final],y=final,tmp;
  matched++;
  while(1) {
    tmp=xy[x]; xy[x]=y; yx[y]=x; y=tmp;
    if(y==nil) return;
    x=prev[y];
  }
}
inline void phase() {
  int i,y,root;
  for(i=0;i<xn;i++) sets[i]=0;
  for(i=0;i<yn;i++) { sett[i]=0; slack[i]=inf; }
  for(root=0;root<xn&&xy[root]!=nil;root++);
  add_sets(root);
  while(1) {
    relabel();
    for(y=0;y<yn;y++) if(!sett[y]&&slack[y]==0) break;
    if(yx[y]==nil) { augment(y); return; }
    else { add_sets(yx[y]); sett[y]=1; }
  }
}
inline int hungarian() {
  int i,j,c=0;
  matched=0;
  // we must have "xn<yn"
  bool swapxy=0;
  if(xn>yn) {
    swapxy=1;
    int mn=max(xn,yn);
    swap(xn,yn);
    for(int i=0;i<mn;i++)
      for(int j=0;j<i;j++)
        swap(cost[i][j],cost[j][i]);
  }
  for(i=0;i<xn;i++) {
    xy[i]=nil;
    xlabel[i]=0;
    for(j=0;j<yn;j++) xlabel[i]=max(cost[i][j],xlabel[i
        ]);
  }
  for(i=0;i<yn;i++) {
    yx[i]=nil;
    ylabel[i]=0;
  }
  for(i=0;i<xn;i++) phase();
  for(i=0;i<xn;i++) c+=cost[i][xy[i]];
  // recover cost matrix (if necessary)
  if(swapxy) {
    int mn=max(xn,yn);
    swap(xn,yn);
    for(int i=0;i<mn;i++)
      for(int j=0;j<i;j++)
        swap(cost[i][j],cost[j][i]);
  }
  // need special recovery if we want more info than
      matching value
  return c;
}
```

2.8 Gusfield

```
#define SOURCE 0
#define SINK 1
const unsigned int inf=4000000000u;
int n,m,deg[MAXN],adj[MAXN][MAXN];
unsigned int res[MAXN][MAXN],cap[MAXN][MAXN];
int nei[MAXN],gdeg[MAXN],gadj[MAXN][MAXN];
unsigned int gres[MAXN][MAXN];
unsigned int cut[MAXN][MAXN];
unsigned int cutarr[MAXN*MAXN];
int cutn,ql,qr,que[MAXN],pred[MAXN];
unsigned int aug[MAXN];
bool cutset[MAXN];
int visited[MAXN],visid=0;
inline void augment(int src,int sink) {
  int v=sink; unsigned a=aug[sink];
  while(v!=src) {
    res[pred[v]][v]-=a;
    res[v][pred[v]]+=a;
    v=pred[v];
  }
}
inline bool bfs(int src,int sink) {
  int i,v,u; ++visid;
  ql=qr=0; que[qr++]=src;
  visited[src]=visid; aug[src]=inf;
  while(ql<qr) {
    v=que[ql++];
    for(i=0;i<deg[v];i++) {
      u=adj[v][i];
      if(visited[u]==visid||res[v][u]==0) continue;
      visited[u]=visid; pred[u]=v;
      aug[u]=min(aug[v],res[v][u]);
      que[qr++]=u;
      if(u==sink) return 1;
    }
  }
  return 0;
}
void dfs_src(int v) {
  int i,u;
  visited[v]=visid;
  cutset[v]=SOURCE;
  for(i=0;i<deg[v];i++) {
    u=adj[v][i];
    if(visited[u]<visid&&res[v][u]) dfs_src(u);
  }
}
inline unsigned int maxflow(int src,int sink) {
  int i,j;
  unsigned int f=0;
  for(i=0;i<n;i++) {
    for(j=0;j<deg[i];j++) res[i][adj[i][j]]=cap[i][adj[
        i][j]];
    cutset[i]=SINK;
  }
  while(bfs(src,sink)) {
    augment(src,sink);
    f+=aug[sink];
  }
  ++visid;
  dfs_src(src);
  return f;
}
inline void gusfield() {
  int i,j;
  unsigned int f;
  for(i=0;i<n;i++) { nei[i]=0; gdeg[i]=0; }
  for(i=1;i<n;i++) {
    f=maxflow(i,nei[i]);
    gres[i][nei[i]]=gres[nei[i]][i]=f;
    gadj[i][gdeg[i]++]=nei[i];
    gadj[nei[i]][gdeg[nei[i]]++]=i;
    for(j=i+1;j<n;j++)
      if(nei[j]==nei[i]&&cutset[j]==SOURCE) nei[j]=i;
  }
}
void dfs(int v,int pred,int src,unsigned int cur) {
  int i,u;
  cut[src][v]=cur;
  for(i=0;i<gdeg[v];i++) {
    u=gadj[v][i];
    if(u==pred) continue;
    dfs(u,v,src,min(cur,gres[v][u]));
  }
}
inline void find_all_cuts() {
  int i;
  cutn=0; gusfield();
  for(i=0;i<n;i++) dfs(i,-1,i,inf);
}
```

2.9 Relabel to Front

```
/* Relabel-to-Front */
// tested with sgu-212 (more testing suggested)
int n,m,layer,src,sink,lvl[MAXN];
Edge ed[MAXM];
int deg[MAXN],adj[MAXN][MAXN];
int res[MAXN][MAXN]; // residual capacity
// graph (i.e. all things above) should be constructed
    beforehand
list<int> lst; // discharge list
int ef[MAXN],ht[MAXN];
// excess flow, height
int apt[MAXN]; // the next adj index to try push
inline void push(int v,int u) {
  int a=min(ef[v],res[v][u]);
  ef[v]-=a; ef[u]+=a;
  res[v][u]-=a; res[u][v]+=a;
}
inline void relabel(int v) {
  int i,u;
  ht[v]=2*n;
  for(i=0;i<deg[v];i++) {
    u=adj[v][i];
    if(res[v][u]) ht[v]=min(ht[u]+1,ht[v]);
  }
}
inline void initPreflow() {
  int i,u;
  lst.clear();
  for(i=0;i<n;i++) {
    ht[i]=ef[i]=0; apt[i]=0;
    if(i!=src&&i!=sink) lst.push_back(i);
  }
  ht[src]=n;
  for(i=0;i<deg[src];i++) {
    u=adj[src][i];
    ef[u]=res[src][u];
    ef[src]-=ef[u];
    res[u][src]=ef[u];
    res[src][u]=0;
  }
}
inline void discharge(int v) {
  int u;
  while(ef[v]) {
    if(apt[v]==deg[v]) {
      relabel(v);
      apt[v]=0;
      continue;
    }
    u=adj[v][apt[v]];
    if(res[v][u]&&ht[v]==ht[u]+1) push(v,u);
    else apt[v]++;
  }
}
inline void relabelToFront() {
  int oldh,v;
  list<int>::iterator it;
  initPreflow();
  for(it=lst.begin();it!=lst.end();it++) {
    v=*it; oldh=ht[v]; discharge(v);
    if(ht[v]>oldh) {
      lst.push_front(v);
      lst.erase(it);
      it=lst.begin();
    }
  }
```

```
}
```

2.10 Flow Method

```
Maximize c^T x subject to Ax ≤ b, x ≥ 0;
with the corresponding symmetric dual problem,
Minimize b^T y subject to A^T y ≥ c, y ≥ 0.

Maximize c^T x subject to Ax ≤ b;
with the corresponding asymmetric dual problem,
Minimize b^T y subject to A^T y = c, y ≥ 0.

有源匯，有下界，最大流，無费用。

    先從t連向s，容量設爲無限大。這樣就變成了無源匯的情
    況。將每條有下界的邊先滿上下界的流量，然後更新盈餘
    量（入的流量-出的流量）。新建超級源ss和超級匯tt，若
    某個點u的盈餘量>0則ss--->u，容量爲u的盈餘量。否則u
    --->tt，容量爲u的盈餘量的相反數。如果一個點的盈餘量
    >0，則它是一定要流出去的，所以要從ss連向它，使它去
    找這些流量的出路。建完了圖以後求一遍最大流，如果從
    ss連出的所有邊都滿流，則有解。在得到的殘留網路（原
    圖）上再求一次最大流即可。
```

3 Math

3.1 FFT

```
// const int MAXN = 262144;
// (must be 2^k)
// before any usage, run pre_fft() first
//
// To implement poly. multiply:
//
// fft( n , a );
// fft( n , b );
// for( int i = 0 ; i < n ; i++ )
//   c[ i ] = a[ i ] * b[ i ];
// fft( n , c , 1 );
//
// then you have the result in c :: [cplx]
typedef long double ld;
typedef complex<ld> cplx;
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;
}
```

3.2 NTT

```
LL P=2013265921,root=31;
int MAXNUM=4194304;
// Remember coefficient are mod P
/*
p=a*2^n+1
n   2^n         p           a     root
5   32          97          3     5
6   64          193         3     5
7   128         257         2     3
8   256         257         1     3
9   512         7681        15    17
10  1024        12289       12    11
11  2048        12289       6     11
12  4096        12289       3     11
13  8192        40961       5     3
14  16384       65537       4     3
15  32768       65537       2     3
16  65536       65537       1     3
17  131072      786433      6     10
18  262144      786433      3     10 (605028353,
    2308, 3)
19  524288      5767169     11    3
20  1048576     7340033     7     3
21  2097152     23068673    11    3
22  4194304     104857601   25    3
23  8388608     167772161   20    3
24  16777216    167772161   10    3
25  33554432    167772161   5     3 (1107296257, 33,
    10)
26  67108864    469762049   7     3
27  134217728   2013265921  15    31
*/
LL bigmod(LL a,LL b){
  if(b==0)return 1;
  return (bigmod((a*a)%P,b/2)*(b%2?a:1LL))%P;
}
LL inv(LL a,LL b){
  if(a==1)return 1;
  return (((LL)(a-inv(b%a,a))*b+1)/a)%b;
}
std::vector<LL> ps(MAXNUM);
std::vector<LL> rev(MAXNUM);
struct poly{
  std::vector<LL> co;
  int n;//polynomial degree = n
  poly(int d){n=d;co.resize(n+1,0);}
  void trans2(int NN){
    int r=0,st,N;
    unsigned int a,b;
    while((1<<r)<(NN>>1))++r;
    for(N=2;N<=NN;N<<=1,--r){
      for(st=0;st<NN;st+=N){
        int i,ss=st+(N>>1);
        for(i=(N>>1)-1;i>=0;--i){
          a=co[st+i]; b=(ps[i<<r]*co[ss+i])%P;
          co[st+i]=a+b; if(co[st+i]>=P)co[st+i]-=P;
          co[ss+i]=a+P-b; if(co[ss+i]>=P)co[ss+i]-=P;
        }
      }
    }
  }
  void trans1(int NN){
    int r=0,st,N;
    unsigned int a,b;
    for(N=NN;N>1;N>>=1,++r){
      for(st=0;st<NN;st+=N){
        int i,ss=st+(N>>1);
        for(i=(N>>1)-1;i>=0;--i){
          a=co[st+i]; b=co[ss+i];
          co[st+i]=a+b; if(co[st+i]>=P)co[st+i]-=P;
          co[ss+i]=((a+P-b)*ps[i<<r])%P;
        }
      }
    }
  }
```

```
  poly operator*(const poly& _b)const{
    poly a=*this,b=_b;
    int k=n+b.n,i,N=1;
    while(N<=k)N*=2;
    a.co.resize(N,0); b.co.resize(N,0);
    int r=bigmod(root,(P-1)/N),Ni=inv(N,P);
    ps[0]=1;
    for(i=1;i<N;++i)ps[i]=(ps[i-1]*r)%P;
    a.trans1(N);b.trans1(N);
    for(i=0;i<N;++i)a.co[i]=((LL)a.co[i]*b.co[i])%P;
    r=inv(r,P);
    for(i=1;i<N/2;++i)std::swap(ps[i],ps[N-i]);
    a.trans2(N);
    for(i=0;i<N;++i)a.co[i]=((LL)a.co[i]*Ni)%P;
    a.n=n+_b.n; return a;
  }
};
```

3.3 Fast Walsh Transform

```
/*
 * xor convolution:
 * x = (x0,x1) , y = (y0,y1)
 * z = ( x0y0 + x1y1 , x0y1 + x1y0 )
 * =>
 * x' = ( x0+x1 , x0-x1 ) , y' = ( y0+y1 , y0-y1 )
 * z' = ( ( x0+x1 )( y0+y1 ) , ( x0-x1 )( y0-y1 ) )
 * z = (1/2) * z''
 * or convolution:
 * x = ( x0 , x0+x1 )
 * and convolution:
 * x = ( x0+x1 , x1 )
 */
typedef long long LL;
const int MAXN = (1<<20)+10;
const LL MOD = 1e9+7;
inline LL pw( LL x , LL k ) {
  LL res = 1;
  for( LL bs = x ; k ; k >>= 1, bs = (bs * bs)%MOD ){
    if( k&1 ) res = ( res * bs ) % MOD;
  }
  return res;
}
inline LL inv( LL x ) {
  return pw( x , MOD-2 );
}
inline void fwt( LL x[ MAXN ] , int N , bool inv=0 ) {
  for( int d = 1 ; d < N ; d <<= 1 ) {
    int d2 = d<<1;
    for( int s = 0 ; s < N ; s += d2 ) {
      for( int i = s , j = s+d ; i < s+d ; i++, j++ ){
        LL ta = x[ i ] , tb = x[ j ];
        x[ i ] = ta+tb;
        x[ j ] = ta-tb;
        if( x[ i ] >= MOD ) x[ i ] -= MOD;
        if( x[ j ] < 0 ) x[ j ] += MOD;
      }
    }
  }
  if( inv )
    for( int i = 0 ; i < N ; i++ ) {
      x[ i ] *= inv( N );
      x[ i ] %= MOD;
    }
}
```

3.4 BigInt

```
struct Bigint{
  static const int LEN = 60;
  static const int BIGMOD = 10000;
  int s;
  int vl, v[LEN];
  //  vector<int> v;
  Bigint() : s(1) { vl = 0; }
  Bigint(long long a) {
    s = 1; vl = 0;
    if (a < 0) { s = -1; a = -a; }
    while (a) {
      push_back(a % BIGMOD);
      a /= BIGMOD;
    }
  }
  Bigint(string str) {
    s = 1; vl = 0;
    int stPos = 0, num = 0;
    if (!str.empty() && str[0] == '-') {
      stPos = 1;
      s = -1;
    }
    for (int i=SZ(str)-1, q=1; i>=stPos; i--) {
      num += (str[i] - '0') * q;
      if ((q *= 10) >= BIGMOD) {
        push_back(num);
        num = 0; q = 1;
      }
    }
    if (num) push_back(num);
    n();
  }
  int len() const {
    return vl;
    //    return SZ(v);
  }
  bool empty() const { return len() == 0; }
  void push_back(int x) {
    v[vl++] = x;
    //    v.PB(x);
  }
  void pop_back() {
    vl--;
    //    v.pop_back();
  }
  int back() const {
    return v[vl-1];
    //    return v.back();
  }
  void n() {
    while (!empty() && !back()) pop_back();
  }
  void resize(int nl) {
    vl = nl;
    fill(v, v+vl, 0);
    //    v.resize(nl);
    //    fill(ALL(v), 0);
  }
  void print() const {
    if (empty()) { putchar('0'); return; }
    if (s == -1) putchar('-');
    printf("%d", back());
    for (int i=len()-2; i>=0; i--) printf("%.4d",v[i]);
  }
  friend std::ostream& operator << (std::ostream& out,
      const Bigint &a) {
    if (a.empty()) { out << "0"; return out; }
    if (a.s == -1) out << "-";
    out << a.back();
    for (int i=a.len()-2; i>=0; i--) {
      char str[10];
      snprintf(str, 5, "%.4d", a.v[i]);
      out << str;
    }
    return out;
  }
  int cp3(const Bigint &b)const {
    if (s != b.s) return s - b.s;
    if (s == -1) return -(-*this).cp3(-b);
    if (len() != b.len()) return len()-b.len();//int
    for (int i=len()-1; i>=0; i--)
      if (v[i]!=b.v[i]) return v[i]-b.v[i];
    return 0;
  }
  bool operator<(const Bigint &b)const
    { return cp3(b)<0; }
  bool operator<=(const Bigint &b)const
    { return cp3(b)<=0; }
  bool operator==(const Bigint &b)const
    { return cp3(b)==0; }
  bool operator!=(const Bigint &b)const
    { return cp3(b)!=0; }
```

```
  bool operator>(const Bigint &b)const
    { return cp3(b)>0; }
  bool operator>=(const Bigint &b)const
    { return cp3(b)>=0; }
  Bigint operator - () const {
    Bigint r = (*this);
    r.s = -r.s;
    return r;
  }
  Bigint operator + (const Bigint &b) const {
    if (s == -1) return -(-(*this)+(-b));
    if (b.s == -1) return (*this)-(-b);
    Bigint r;
    int nl = max(len(), b.len());
    r.resize(nl + 1);
    for (int i=0; i<nl; i++) {
      if (i < len()) r.v[i] += v[i];
      if (i < b.len()) r.v[i] += b.v[i];
      if(r.v[i] >= BIGMOD) {
        r.v[i+1] += r.v[i] / BIGMOD;
        r.v[i] %= BIGMOD;
      }
    }
    r.n();
    return r;
  }
  Bigint operator - (const Bigint &b) const {
    if (s == -1) return -(-(*this)-(-b));
    if (b.s == -1) return (*this)+(-b);
    if ((*this) < b) return -(b-(*this));
    Bigint r;
    r.resize(len());
    for (int i=0; i<len(); i++) {
      r.v[i] += v[i];
      if (i < b.len()) r.v[i] -= b.v[i];
      if (r.v[i] < 0) {
        r.v[i] += BIGMOD;
        r.v[i+1]--;
      }
    }
    r.n();
    return r;
  }
  Bigint operator * (const Bigint &b) {
    Bigint r;
    r.resize(len() + b.len() + 1);
    r.s = s * b.s;
    for (int i=0; i<len(); i++) {
      for (int j=0; j<b.len(); j++) {
        r.v[i+j] += v[i] * b.v[j];
        if(r.v[i+j] >= BIGMOD) {
          r.v[i+j+1] += r.v[i+j] / BIGMOD;
          r.v[i+j] %= BIGMOD;
        }
      }
    }
    r.n();
    return r;
  }
  Bigint operator / (const Bigint &b) {
    Bigint r;
    r.resize(max(1, len()-b.len()+1));
    int oriS = s;
    Bigint b2 = b; // b2 = abs(b)
    s = b2.s = r.s = 1;
    for (int i=r.len()-1; i>=0; i--) {
      int d=0, u=BIGMOD-1;
      while(d<u) {
        int m = (d+u+1)>>1;
        r.v[i] = m;
        if((r*b2) > (*this)) u = m-1;
        else d = m;
      }
      r.v[i] = d;
    }
    s = oriS;
    r.s = s * b.s;
    r.n();
    return r;
  }
  Bigint operator % (const Bigint &b) {
    return (*this)-(*this)/b*b;
  }
};
```

3.5 Linear Recurrence

```
LL n, m;
LL dp[ N + N ];
void pre_dp(){
  dp[ 0 ] = 1;
  LL bdr = min( m + m , n );
  for( LL i = 1 ; i <= bdr ; i ++ )
    for( LL j = i - 1 ; j >= max(0LL , i - m) ; j -- )
      dp[ i ] = add( dp[ i ] , dp[ j ] );
}
vector<LL> Mul( vector<LL>& v1, vector<LL>& v2 ){
  int _sz1 = (int)v1.size();
  int _sz2 = (int)v2.size();
  assert( _sz1 == m );
  assert( _sz2 == m );
  vector<LL> _v( m + m );
  for( int i = 0 ; i < m + m ; i ++ ) _v[ i ] = 0;
// expand
  for( int i = 0 ; i < _sz1 ; i ++ )
    for( int j = 0 ; j < _sz2 ; j ++ )
      _v[ i + j + 1 ] = add( _v[ i + j + 1 ] ,
                             mul(v1[ i ] , v2[ j ]) );
// shrink
  for( int i = 0 ; i < m ; i ++ )
    for( int j = 1 ; j <= m ; j ++ )
      _v[ i + j ] = add( _v[ i + j ] , _v[ i ] );
  for( int i = 0 ; i < m ; i ++ )
    _v[ i ] = _v[ i + m ];
  _v.resize( m );
  return _v;
}
vector<LL> I, A;
void solve(){
  pre_dp();
  if( n <= m + m ){
    printf( "%lld\n" , dp[ n ] );
    exit( 0 );
  }
  I.resize( m );
  A.resize( m );
  for( int i = 0 ; i < m ; i ++ ) I[ i ] = A[ i ] = 1;
// dp[ n ] = /Sum_{i=0}^{m-1} A_i * dp[ n - i - 1 ]
  LL dlt = ( n - m ) / m;
  LL rdlt = dlt * m;
  while( dlt ){
    if( dlt & 1LL ) I = Mul( I , A );
    A = Mul( A , A );
    dlt >>= 1;
  }
  LL ans = 0;
  for( int i = 0 ; i < m ; i ++ )
    ans = add(ans, mul(I[i], dp[n - i - 1 - rdlt]));
  printf( "%lld\n" , ans );
}
```

3.6 Miller Rabin

```
// n < 4,759,123,141        3 :  2, 7, 61
// n < 1,122,004,669,633    4 :  2, 13, 23, 1662803
// n < 3,474,749,660,383          6 :  pirmes <= 13
// n < 2^64                       7 :
// 2, 325, 9375, 28178, 450775, 9780504, 1795265022
// Make sure testing integer is in range [2, n-2] if
// you want to use magic.
LL power(LL x,LL p,LL mod){
  LL s=1,m=x;
  while(p) {
    if(p&1) s=mult(s,m,mod);
    p>>=1;
    m=mult(m,m,mod);
  }
  return s;
}
bool witness(LL a,LL n,LL u,int t){
```

```
  LL x=power(a,u,n);
  for(int i=0;i<t;i++) {
    LL nx=mult(x,x,n);
    if(nx==1&&x!=1&&x!=n-1) return 1;
    x=nx;
  }
  return x!=1;
}
bool miller_rabin(LL n,int s=100) {
  // iterate s times of witness on n
  // return 1 if prime, 0 otherwise
  if(n<2) return 0;
  if(!(n&1)) return n==2;
  LL u=n-1;
  int t=0;
  // n-1 = u*2^t
  while(!(u&1)) {
    u>>=1;
    t++;
  }
  while(s--) {
    LL a=randll()%(n-1)+1;
    if(witness(a,n,u,t)) return 0;
  }
  return 1;
}
```

3.7 Simplex

```
const int MAXN = 111;
const int MAXM = 111;
const double eps = 1E-10;
double a[MAXN][MAXM], b[MAXN], c[MAXM], d[MAXN][MAXM];
double x[MAXM];
int ix[MAXN + MAXM]; // !!! array all indexed from 0
// max{cx} subject to {Ax<=b,x>=0}
// n: constraints, m: vars !!!
// x[] is the optimal solution vector
//
// usage :
// value = simplex(a, b, c, N, M);
double simplex(double a[MAXN][MAXM], double b[MAXN],
               double c[MAXM], int n, int m){
  ++m;
  int r = n, s = m - 1;
  memset(d, 0, sizeof(d));
  for (int i = 0; i < n + m; ++i) ix[i] = i;
  for (int i = 0; i < n; ++i) {
    for (int j = 0; j < m - 1; ++j) d[i][j] = -a[i][j];
    d[i][m - 1] = 1;
    d[i][m] = b[i];
    if (d[r][m] > d[i][m]) r = i;
  }
  for (int j = 0; j < m - 1; ++j) d[n][j] = c[j];
  d[n + 1][m - 1] = -1;
  for (double dd;; ) {
    if (r < n) {
      int t = ix[s]; ix[s] = ix[r + m]; ix[r + m] = t;
      d[r][s] = 1.0 / d[r][s];
      for (int j = 0; j <= m; ++j)
        if (j != s) d[r][j] *= -d[r][s];
      for (int i = 0; i <= n + 1; ++i) if (i != r) {
        for (int j = 0; j <= m; ++j) if (j != s)
          d[i][j] += d[r][j] * d[i][s];
        d[i][s] *= d[r][s];
      }
    }
    r = -1; s = -1;
    for (int j = 0; j < m; ++j)
      if (s < 0 || ix[s] > ix[j]) {
        if (d[n + 1][j] > eps ||
            (d[n + 1][j] > -eps && d[n][j] > eps))
          s = j;
      }
    if (s < 0) break;
    for (int i = 0; i < n; ++i) if (d[i][s] < -eps) {
      if (r < 0 ||
          (dd = d[r][m] / d[r][s] - d[i][m] / d[i][s])
              < -eps ||
          (dd < eps && ix[r + m] > ix[i + m]))
        r = i;
    }
    if (r < 0) return -1; // not bounded
  }
  if (d[n + 1][m] < -eps) return -1; // not executable
  double ans = 0;
  for(int i=0; i<m; i++) x[i] = 0;
  for (int i = m; i < n + m; ++i) { // the missing
      enumerated x[i] = 0
    if (ix[i] < m - 1){
      ans += d[i - m][m] * c[ix[i]];
      x[ix[i]] = d[i-m][m];
    }
  }
  return ans;
}
```

3.8 Faulhaber

```
/* faulhaber's formula -
 * cal power sum formula of all p=1~k in O(k^2) */
#define MAXK 2500
const int mod = 1000000007;
int b[MAXK];
// bernoulli number
int inv[MAXK+1];
// inverse
int cm[MAXK+1][MAXK+1]; // combinactories
int co[MAXK][MAXK+2];
// coeeficient of x^j when p=i
int add(int a,int b) { return a+b<mod?a+b:a+b-mod; }
int sub(int a,int b) { return a<b?a-b+mod:a-b; }
inline int getinv(int x) {
  int a=x,b=mod,a0=1,a1=0,b0=0,b1=1;
  while(b) {
    int q,t;
    q=a/b; t=b; b=a-b*q; a=t;
    t=b0; b0=a0-b0*q; a0=t;
    t=b1; b1=a1-b1*q; a1=t;
  }
  return a0<0?a0+mod:a0;
}
inline void pre() {
  /* combinational */
  for(int i=0;i<=MAXK;i++) {
    cm[i][0]=cm[i][i]=1;
    for(int j=1;j<i;j++)
      cm[i][j]=add(cm[i-1][j-1],cm[i-1][j]);
  }
  /* inverse */
  for(int i=1;i<=MAXK;i++) inv[i]=getinv(i);
  /* bernoulli */
  b[0]=1; b[1]=getinv(2); // with b[1] = 1/2
  for(int i=2;i<MAXK;i++) {
    if(i&1) { b[i]=0; continue; }
    b[i]=1;
    for(int j=0;j<i;j++)
      b[i]=sub(b[i],
               (LL)cm[i][j]*b[j]%mod*inv[i-j+1]%mod);
  }
  /* faulhaber */
  // sigma_x=1~n {x^p} = 1/(p+1) * sigma_j=0~p { C(p+1,
      j) * Bj * n^(p-j+1)}
  for(int i=1;i<MAXK;i++) {
    co[i][0]=0;
    for(int j=0;j<=i;j++)
      co[i][i-j+1]=
        (LL)inv[i+1]%mod*cm[i+1][j]%mod*b[j]%mod;
  }
}
inline int power(int x,int p) {
  int s=1,m=x;
  while(p) {
    if(p&1) s=(LL)s*m%mod;
    p>>=1; m=(LL)m*m%mod;
  }
  return s;
}
/* sample usage: return f(n,p) = sigma_x=1~n (x^p) */
inline int solve(int n,int p) {
```

```
  int sol=0,m=n;
  for(int i=1;i<=p+1;i++) {
    sol=add(sol,(LL)co[p][i]*m%mod);
    m=(LL)m*n%mod;
  }
  return sol;
}
```

3.9 Chinese Remainder

```
int pfn;
// number of distinct prime factors
int pf[MAXN]; // prime factor powers
int rem[MAXN]; // corresponding remainder
int pm[MAXN];
inline void generate_primes() {
  int i,j;
  pnum=1;
  prime[0]=2;
  for(i=3;i<MAXVAL;i+=2) {
    if(nprime[i]) continue;
    prime[pnum++]=i;
    for(j=i*i;j<MAXVAL;j+=i) nprime[j]=1;
  }
}
inline int inverse(int x,int p) {
  int q,tmp,a=x,b=p;
  int a0=1,a1=0,b0=0,b1=1;
  while(b) {
    q=a/b; tmp=b; b=a-b*q; a=tmp;
    tmp=b0; b0=a0-b0*q; a0=tmp;
    tmp=b1; b1=a1-b1*q; a1=tmp;
  }
  return a0;
}
inline void decompose_mod() {
  int i,p,t=mod;
  pfn=0;
  for(i=0;i<pnum&&prime[i]<=t;i++) {
    p=prime[i];
    if(t%p==0) {
      pf[pfn]=1;
      while(t%p==0) {
        t/=p;
        pf[pfn]*=p;
      }
      pfn++;
    }
  }
  if(t>1) pf[pfn++]=t;
}
inline int chinese_remainder() {
  int i,m,s=0;
  for(i=0;i<pfn;i++) {
    m=mod/pf[i];
    pm[i]=(LL)m*inverse(m,pf[i])%mod;
    s=(s+(LL)pm[i]*rem[i])%mod;
  }
  return s;
}
```

3.10 Pollard Rho

```
// does not work when n is prime
LL modit(LL x,LL mod) {
  if(x>=mod) x-=mod;
  //if(x<0) x+=mod;
  return x;
}
LL mult(LL x,LL y,LL mod) {
  LL s=0,m=x%mod;
  while(y) {
    if(y&1) s=modit(s+m,mod);
    y>>=1;
    m=modit(m+m,mod);
  }
  return s;
}
LL f(LL x,LL mod) {
  return modit(mult(x,x,mod)+1,mod);
}
LL pollard_rho(LL n) {
  if(!(n&1)) return 2;
  while (true) {
    LL y=2, x=rand()%(n-1)+1, res=1;
    for (int sz=2; res==1; sz*=2) {
      for (int i=0; i<sz && res<=1; i++) {
        x = f(x, n);
        res = __gcd(abs(x-y), n);
      }
      y = x;
    }
    if (res!=0 && res!=n) return res;
  }
}
```

3.11 Poly Generator

```
class PolyGen {
  /* for a nth-order polynomial f(x), *
   * given f(0), f(1), ..., f(n) *
   * express f(x) as sigma_i{c_i*C(x,i)} */
 public:
  int n;
  vector<LL> coef;
  // initialize and calculate f(x), vector _fx should
  // be filled with f(0) to f(n)
  PolyGen(int _n,vector<LL> _fx):n(_n),coef(_fx){
    for(int i=0;i<n;i++)
      for(int j=n;j>i;j--)
        coef[j]-=coef[j-1];
  }
  // evaluate f(x), runs in O(n)
  LL eval(int x) {
    LL m=1,ret=0;
    for(int i=0;i<=n;i++) {
      ret+=coef[i]*m;
      m=m*(x-i)/(i+1);
    }
    return ret;
  }
};
```

3.12 Matrix Pseudo Inverse

```
Mat pinv( Mat m ){
  Mat res = I;
  FZ( used );
  for( int i = 0 ; i < W ; i ++ ){
    int piv = -1;
    for( int j = 0 ; j < W ; j ++ ){
      if( used[ j ] ) continue;
      if( abs( m.v[ j ][ i ] ) > EPS ){
        piv = j;
        break;
      }
    }
    if( piv == -1 ) continue;
    used[ i ] = true;
    swap( m.v[ piv ], m.v[ i ] );
    swap( res.v[ piv ], res.v[ i ] );
    LD rat = m.v[ i ][ i ];
    for( int j = 0 ; j < W ; j ++ ){
      m.v[ i ][ j ] /= rat;
      res.v[ i ][ j ] /= rat;
    }
    for( int j = 0 ; j < W ; j ++ ){
      if( j == i ) continue;
      rat = m.v[ j ][ i ];
      for( int k = 0 ; k < W ; k ++ ){
        m.v[ j ][ k ] -= rat * m.v[ i ][ k ];
        res.v[ j ][ k ] -= rat * res.v[ i ][ k ];
      }
    }
  }
  for( int i = 0 ; i < W ; i ++ ){
```

```
    if( used[ i ] ) continue;
    for( int j = 0 ; j < W ; j ++ )
      res.v[ i ][ j ] = 0;
  }
  return res;
}
```

3.13 ax+by=gcd

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

3.14 Mod

```
/// _fd(a,b)  floor(a/b).
/// _rd(a,m)  a-floor(a/m)*m.
/// _pv(a,m,r) largest x s.t x<=a && x%m == r.
/// _nx(a,m,r) smallest x s.t x>=a && x%m == r.
/// _ct(a,b,m,r) |A| , A = { x : a<=x<=b && x%m == r }.
int _fd(int a,int b){ return a<0?(-~a/b-1):a/b; }
int _rd(int a,int m){ return a-_fd(a,m)*m; }
int _pv(int a,int m,int r){
    r=(r%m+m)%m;
    return _fd(a-r,m)*m+r;
}
int _nt(int a,int m,int r){
    m=abs(m);
    r=(r%m+m)%m;
    return _fd(a-r-1,m)*m+r+m;
}
int _ct(int a,int b,int m,int r){
    m=abs(m);
    a=_nt(a,m,r);
    b=_pv(b,m,r);
    return (a>b)?0:((b-a+m)/m);
}
```

3.15 Primes and μ function

```
/*
 * 12721
 * 13331
 * 14341
 * 75577
 * 123457
 * 222557
 * 556679
 * 999983
 * 1097774749
 * 1076767633
 * 100102021
 * 999997771
 * 1001010013
 * 1000512343
 * 987654361
 * 999991231
 * 999888733
 * 98789101
 * 987777733
 * 999991921
 * 1010101333
 * 1010102101
 * 1000000000039
 * 10000000000000037
 * 2305843009213693951
 * 4611686018427387847
 * 9223372036854775783
 * 18446744073709551557
 */
```

```
int mu[ N ] , p_tbl[ N ];
vector<int> primes;
void sieve() {
  mu[ 1 ] = p_tbl[ 1 ] = 1;
  for( int i = 2 ; i < N ; i ++ ){
    if( !p_tbl[ i ] ){
      p_tbl[ i ] = i;
      primes.push_back( i );
      mu[ i ] = -1;
    }
    for( int p : primes ){
      int x = i * p;
      if( x >= M ) break;
      p_tbl[ x ] = p;
      mu[ x ] = -mu[ i ];
      if( i % p == 0 ){
        mu[ x ] = 0;
        break;
      }
    }
  }
}
vector<int> factor( int x ){
  vector<int> fac{ 1 };
  while( x > 1 ){
    int fn = SZ(fac), p = p_tbl[ x ], pos = 0;
    while( x % p == 0 ){
      x /= p;
      for( int i = 0 ; i < fn ; i ++ )
        fac.PB( fac[ pos ++ ] * p );
    }
  }
  return fac;
}
```

3.16 Result

```
/*
Lucas' Theorem:
  For non-negative integer n,m and prime P,
  C(m,n) mod P = C(m/M,n/M) * C(m%M,n%M) mod P
  = mult_i ( C(m_i,n_i) )
  where m_i is the i-th digit of m in base P.
--
Sum of Two Squares Thm (Legendre)
  For a given positive integer N, let
  D1 = (# of d \in \N dividing N that d=1(mod 4))
  D3 = (# of d \in \N dividing N that d=3(mod 4))
  then N can be written as a sum of two squares in
  exactly R(N) = 4(D1-D3) ways.
--
Difference of D1-D3 Thm
  let N=2^t * [p1^e1 *...* pr^er] * [q1^f1 *...* qs^fs]
              <-mod 4 = 1 prime->   <-mod 4 = 3 prime->
  then D1 - D3 = (e1+1)(e2+1)...(er+1) if fi all even
                 0                     if any fi is odd
--
Pick's Theorem
A = i + b/2 - 1
*/
```

4 Geometry

4.1 halfPlaneIntersection

4.2 Intersection of 2 lines

```
Pt interPnt( Line l1, Line l2, bool &res ){
  Pt p1, p2, q1, q2;
  tie(p1, p2) = l1;
  tie(q1, q2) = l2;
  double f1 = (p2 - p1) ^ (q1 - p1);
  double f2 = (p2 - p1) ^ (p1 - q2);
  double f = (f1 + f2);
  if( fabs(f) < eps) {
    res = false;
```

```
    return {0, 0};
  }
  res = true;
  return q1 * (f2 / f) + q2 * (f1 / f);
}
bool isin( Line l0, Line l1, Line l2 ){
  // Check inter(l1, l2) in l0
  bool res;
  Pt p = interPnt(l1, l2, res);
  return ( (l0.SE - l0.FI) ^ (p - l0.FI) ) > eps;
}
/* If no solution, check: 1. ret.size() < 3
 * Or more precisely, 2. interPnt(ret[0], ret[1])
 * in all the lines. (use (l.S - l.F) ^ (p - l.F) > 0
 */
/* --^-- Line.FI --^-- Line.SE --^-- */
vector<Line> halfPlaneInter( vector<Line> lines ){
  int sz = lines.size();
  vector<double> ata(sz), ord(sz);
  for( int i=0; i<sz; i++) {
    ord[i] = i;
    Pt d = lines[i].SE - lines[i].FI;
    ata[i] = atan2(d.Y, d.X);
  }
  sort( ord.begin(), ord.end(), [&](int i, int j) {
    if( fabs(ata[i] - ata[j]) < eps ){
      return ( (lines[i].SE - lines[i].FI) ^
               (lines[j].SE - lines[i].FI) ) < 0;
    }
    return ata[i] < ata[j];
  });
  vector<Line> fin;
  for (int i=0; i<sz; i++)
    if (!i or fabs(ata[ord[i]] - ata[ord[i-1]]) > eps)
      fin.PB(lines[ord[i]]);
  deque<Line> dq;
  for (int i=0; i<(int)(fin.size()); i++) {
    while((int)(dq.size()) >= 2 and
        not isin(fin[i], dq[(int)(dq.size())-2],
                         dq[(int)(dq.size())-1]))
      dq.pop_back();
    while((int)(dq.size()) >= 2 and
        not isin(fin[i], dq[0], dq[1]))
      dq.pop_front();
    dq.push_back(fin[i]);
  }
  while( (int)(dq.size()) >= 3 and
      not isin(dq[0], dq[(int)(dq.size())-2],
                      dq[(int)(dq.size())-1]))
    dq.pop_back();
  while( (int)(dq.size()) >= 3 and
      not isin(dq[(int)(dq.size())-1], dq[0], dq[1]))
    dq.pop_front();
  vector<Line> res(dq.begin(),dq.end());
  return res;
}
```

4.3 Intersection of 2 circles

```
vector<Pt> interCircle( Pt o1 , D r1 , Pt o2 , D r2 ){
  D d2 = ( o1 - o2 ) * ( o1 - o2 );
  D d = sqrt(d2);
  if( d > r1 + r2 ) return {};
  Pt u = (o1+o2)*0.5 + (o1-o2)*((r2*r2-r1*r1)/(2*d2));
  D A = sqrt((r1+r2+d)*(r1-r2+d)*(r1+r2-d)*(-r1+r2+d));
  Pt v = Pt( o1.Y-o2.Y , -o1.X + o2.X ) * A / (2*d2);
  return {u+v, u-v};
}
```

4.4 Intersection of 2 segments

```
int ori( const PLL& o , const PLL& a , const PLL& b ){
  LL ret = ( a - o ) ^ ( b - o );
  return ret / max( 1ll , abs( ret ) );
}
// p1 == p2 || q1 == q2 need to be handled
bool banana( const PLL& p1 , const PLL& p2 ,
             const PLL& q1 , const PLL& q2 ){
  if( ( ( p2 - p1 ) ^ ( q2 - q1 ) ) == 0 ){ // parallel
    if( ori( p1 , p2 , q1 ) ) return false;
    return ( ( p1 - q1 ) * ( p2 - q1 ) ) <= 0 ||
           ( ( p1 - q2 ) * ( p2 - q2 ) ) <= 0 ||
           ( ( q1 - p1 ) * ( q2 - p1 ) ) <= 0 ||
           ( ( q1 - p2 ) * ( q2 - p2 ) ) <= 0;
  }
  return (ori( p1, p2, q1 ) * ori( p1, p2, q2 )<=0) &&
         (ori( q1, q2, p1 ) * ori( q1, q2, p2 )<=0);
}
```

4.5 KD Tree

```
const int MXN = 100005;
struct KDTree {
  struct Node {
    int x,y,x1,y1,x2,y2;
    int id,f;
    Node *L, *R;
  }tree[MXN];
  int n;
  Node *root;
  LL dis2(int x1, int y1, int x2, int y2) {
    LL dx = x1-x2;
    LL dy = y1-y2;
    return dx*dx+dy*dy;
  }
  static bool cmpx(Node& a, Node& b){ return a.x<b.x; }
  static bool cmpy(Node& a, Node& b){ return a.y<b.y; }
  void init(vector<pair<int,int>> ip) {
    n = ip.size();
    for (int i=0; i<n; i++) {
      tree[i].id = i;
      tree[i].x = ip[i].first;
      tree[i].y = ip[i].second;
    }
    root = build_tree(0, n-1, 0);
  }
  Node* build_tree(int L, int R, int dep) {
    if (L>R) return nullptr;
    int M = (L+R)/2;
    tree[M].f = dep%2;
    nth_element(tree+L, tree+M, tree+R+1, tree[M].f ?
        cmpy : cmpx);
    tree[M].x1 = tree[M].x2 = tree[M].x;
    tree[M].y1 = tree[M].y2 = tree[M].y;

    tree[M].L = build_tree(L, M-1, dep+1);
    if (tree[M].L) {
      tree[M].x1 = min(tree[M].x1, tree[M].L->x1);
      tree[M].x2 = max(tree[M].x2, tree[M].L->x2);
      tree[M].y1 = min(tree[M].y1, tree[M].L->y1);
      tree[M].y2 = max(tree[M].y2, tree[M].L->y2);
    }
    tree[M].R = build_tree(M+1, R, dep+1);
    if (tree[M].R) {
      tree[M].x1 = min(tree[M].x1, tree[M].R->x1);
      tree[M].x2 = max(tree[M].x2, tree[M].R->x2);
      tree[M].y1 = min(tree[M].y1, tree[M].R->y1);
      tree[M].y2 = max(tree[M].y2, tree[M].R->y2);
    }
    return tree+M;
  }
  int touch(Node* r, int x, int y, LL d2){
    LL dis = sqrt(d2)+1;
    if (x<r->x1-dis || x>r->x2+dis ||
        y<r->y1-dis || y>r->y2+dis)
      return 0;
    return 1;
  }
  void nearest(Node* r, int x, int y,
               int &mID, LL &md2){
    if (!r || !touch(r, x, y, md2)) return;
    LL d2 = dis2(r->x, r->y, x, y);
    if (d2 < md2 || (d2 == md2 && mID < r->id)) {
      mID = r->id;
      md2 = d2;
    }
    // search order depends on split dim
    if ((r->f == 0 && x < r->x) ||
```

```
        (r->f == 1 && y < r->y)) {
      nearest(r->L, x, y, mID, md2);
      nearest(r->R, x, y, mID, md2);
    } else {
      nearest(r->R, x, y, mID, md2);
      nearest(r->L, x, y, mID, md2);
    }
  }
  int query(int x, int y) {
    int id = 1029384756;
    LL d2 = 102938475612345678LL;
    nearest(root, x, y, id, d2);
    return id;
  }
}tree;
```

4.6 Poly Union

```
#define eps 1e-8
class PY{ public:
  int n;
  Pt pt[5];
  Pt& operator[](const int x){ return pt[x]; }
  void input(){
    int i; n=4;
    for(i=0;i<n;i++) scanf("%lf%lf",&pt[i].x,&pt[i].y);
  }
  double getArea(){
    int i; double s=pt[n-1]^pt[0];
    for(i=0;i<n-1;i++) s+=pt[i]^pt[i+1];
    return s/2;
  }
};
PY py[500];
pair<double,int> c[5000];
inline double segP(Pt &p,Pt &p1,Pt &p2){
  if(SG(p1.x-p2.x)==0) return (p.y-p1.y)/(p2.y-p1.y);
  return (p.x-p1.x)/(p2.x-p1.x);
}
double polyUnion(int n){
  int i,j,ii,jj,ta,tb,r,d;
  double z,w,s,sum,tc,td;
  for(i=0;i<n;i++) py[i][py[i].n]=py[i][0];
  sum=0;
  for(i=0;i<n;i++){
    for(ii=0;ii<py[i].n;ii++){
      r=0;
      c[r++]=make_pair(0.0,0);
      c[r++]=make_pair(1.0,0);
      for(j=0;j<n;j++){
        if(i==j) continue;
        for(jj=0;jj<py[j].n;jj++){
          ta=SG(tri(py[i][ii],py[i][ii+1],py[j][jj]));
          tb=SG(tri(py[i][ii],py[i][ii+1],py[j][jj+1]))
              ;
          if(ta==0 && tb==0){
            if((py[j][jj+1]-py[j][jj])*(py[i][ii+1]-py[
                i][ii])>0 && j<i){
              c[r++]=make_pair(segP(py[j][jj],py[i][ii
                  ],py[i][ii+1]),1);
              c[r++]=make_pair(segP(py[j][jj+1],py[i][
                  ii],py[i][ii+1]),-1);
            }
          }else if(ta>=0 && tb<0){
            tc=tri(py[j][jj],py[j][jj+1],py[i][ii]);
            td=tri(py[j][jj],py[j][jj+1],py[i][ii+1]);
            c[r++]=make_pair(tc/(tc-td),1);
          }else if(ta<0 && tb>=0){
            tc=tri(py[j][jj],py[j][jj+1],py[i][ii]);
            td=tri(py[j][jj],py[j][jj+1],py[i][ii+1]);
            c[r++]=make_pair(tc/(tc-td),-1);
          }
        }
      }
      sort(c,c+r);
      z=min(max(c[0].first,0.0),1.0);
      d=c[0].second; s=0;
      for(j=1;j<r;j++){
        w=min(max(c[j].first,0.0),1.0);
        if(!d) s+=w-z;
        d+=c[j].second; z=w;
      }
      sum+=(py[i][ii]^py[i][ii+1])*s;
    }
  }
  return sum/2;
}
int main(){
  int n,i,j,k;
  double sum,ds;
  scanf("%d",&n); sum=0;
  for(i=0;i<n;i++){
    py[i].input();
    ds=py[i].getArea();
    if(ds<0){
      for(j=0,k=py[i].n-1;j<k;j++,k--) swap(py[i][j],
          py[i][k]);
      ds=-ds;
    } sum+=ds;
  } printf("%.9f\n",sum/polyUnion(n));
}
```

4.7 Lower Concave Hull

```
/****
  maintain a "concave hull" that support the following
  1. insertion of a line
  2. query of height(y) on specific x on the hull
 ****/
/* set as needed */
typedef long double LD;
const LD eps=1e-9;
const LD inf=1e19;
class Seg {
 public:
  LD m,c,x1,x2; // y=mx+c
  bool flag;
  Seg(
    LD _m,LD _c,LD _x1=-inf,LD _x2=inf,bool _flag=0)
    :m(_m),c(_c),x1(_x1),x2(_x2),flag(_flag) {}
  LD evaly(LD x) const {
    return m*x+c;
  }
  const bool operator<(LD x) const {
    return x2-eps<x;
  }
  const bool operator<(const Seg &b) const {
    if(flag||b.flag) return *this<b.x1;
    return m+eps<b.m;
  }
};
class LowerConcaveHull { // maintain a hull like: \__/
 public:
  set<Seg> hull;
  /* functions */
  LD xintersection(Seg a,Seg b) {
    return (a.c-b.c)/(b.m-a.m);
  }
  inline set<Seg>::iterator replace(set<Seg> &
      hull,set<Seg>::iterator it,Seg s) {
    hull.erase(it);
    return hull.insert(s).first;
  }
  void insert(Seg s) {
    // insert a line and update hull
    set<Seg>::iterator it=hull.find(s);
    // check for same slope
    if(it!=hull.end()) {
      if(it->c+eps>=s.c) return;
      hull.erase(it);
    }
    // check if below whole hull
    it=hull.lower_bound(s);
    if(it!=hull.end()&&
       s.evaly(it->x1)<=it->evaly(it->x1)+eps) return;
    // update right hull
    while(it!=hull.end()) {
      LD x=xintersection(s,*it);
      if(x>=it->x2-eps) hull.erase(it++);
      else {
```

```
        s.x2=x;
        it=replace(hull,it,Seg(it->m,it->c,x,it->x2));
        break;
      }
    }
    // update left hull
    while(it!=hull.begin()) {
      LD x=xintersection(s,*(--it));
      if(x<=it->x1+eps) hull.erase(it++);
      else {
        s.x1=x;
        it=replace(hull,it,Seg(it->m,it->c,it->x1,x));
        break;
      }
    }
    // insert s
    hull.insert(s);
  }
  void insert(LD m,LD c) { insert(Seg(m,c)); }
  LD query(LD x) { // return y @ given x
    set<Seg>::iterator it =
      hull.lower_bound(Seg(0.0,0.0,x,x,1));
    return it->evaly(x);
  }
};
```

4.8 Min Enclosing Circle

```
struct Mec{
  // return pair of center and r
  static const int N = 101010;
  int n;
  Pt p[ N ], cen;
  double r2;
  void init( int _n , Pt _p[] ){
    n = _n;
    memcpy( p , _p , sizeof(Pt) * n );
  }
  double sqr(double a){ return a*a; }
  Pt center(Pt p0, Pt p1, Pt p2) {
    Pt a = p1-p0;
    Pt b = p2-p0;
    double c1=norm2( a ) * 0.5;
    double c2=norm2( b ) * 0.5;
    double d = a ^ b;
    double x = p0.X + (c1 * b.Y - c2 * a.Y) / d;
    double y = p0.Y + (a.X * c2 - b.X * c1) / d;
    return Pt(x,y);
  }
  pair<Pt,double> solve(){
    random_shuffle(p,p+n);
    r2=0;
    for (int i=0; i<n; i++){
      if (norm2(cen-p[i]) <= r2) continue;
      cen = p[i];
      r2 = 0;
      for (int j=0; j<i; j++){
        if (norm2(cen-p[j]) <= r2) continue;
        cen = Pt((p[i].X+p[j].X)*0.5, (p[i].Y+p[j].Y)
            *0.5);
        r2 = norm2(cen-p[j]);
        for (int k=0; k<j; k++){
          if (norm2(cen-p[k]) <= r2) continue;
          cen = center(p[i],p[j],p[k]);
          r2 = norm2(cen-p[k]);
        }
      }
    }
    return {cen,sqrt(r2)};
  }
} mec;
```

4.9 Minkowski sum

```
/* convex hull Minkowski Sum*/
#define INF 1000000000000000LL
int pos( const Pt& tp ){
  if( tp.Y == 0 ) return tp.X > 0 ? 0 : 1;
  return tp.Y > 0 ? 0 : 1;
}
#define N 300030
Pt pt[ N ], qt[ N ], rt[ N ];
LL Lx,Rx;
int dn,un;
inline bool cmp( Pt a, Pt b ){
  int pa=pos( a ),pb=pos( b );
  if(pa==pb) return (a^b)>0;
  return pa<pb;
}
int minkowskiSum(int n,int m){
  int i,j,r,p,q,fi,fj;
  for(i=1,p=0;i<n;i++){
    if( pt[i].Y<pt[p].Y ||
        (pt[i].Y==pt[p].Y && pt[i].X<pt[p].X) ) p=i; }
  for(i=1,q=0;i<m;i++){
    if( qt[i].Y<qt[q].Y ||
        (qt[i].Y==qt[q].Y && qt[i].X<qt[q].X) ) q=i; }
  rt[0]=pt[p]+qt[q];
  r=1; i=p; j=q; fi=fj=0;
  while(1){
    if((fj&&j==q) ||
       ( (!fi||i!=p) &&
         cmp(pt[(p+1)%n]-pt[p],qt[(q+1)%m]-qt[q]) ) ){
      rt[r]=rt[r-1]+pt[(p+1)%n]-pt[p];
      p=(p+1)%n;
      fi=1;
    }else{
      rt[r]=rt[r-1]+qt[(q+1)%m]-qt[q];
      q=(q+1)%m;
      fj=1;
    }
    if(r<=1 || ((rt[r]-rt[r-1])^(rt[r-1]-rt[r-2]))!=0)
        r++;
    else rt[r-1]=rt[r];
    if(i==p && j==q) break;
  }
  return r-1;
}
void initInConvex(int n){
  int i,p,q;
  LL Ly,Ry;
  Lx=INF; Rx=-INF;
  for(i=0;i<n;i++){
    if(pt[i].X<Lx) Lx=pt[i].X;
    if(pt[i].X>Rx) Rx=pt[i].X;
  }
  Ly=Ry=INF;
  for(i=0;i<n;i++){
    if(pt[i].X==Lx && pt[i].Y<Ly){ Ly=pt[i].Y; p=i; }
    if(pt[i].X==Rx && pt[i].Y<Ry){ Ry=pt[i].Y; q=i; }
  }
  for(dn=0,i=p;i!=q;i=(i+1)%n){ qt[dn++]=pt[i]; }
  qt[dn]=pt[q]; Ly=Ry=-INF;
  for(i=0;i<n;i++){
    if(pt[i].X==Lx && pt[i].Y>Ly){ Ly=pt[i].Y; p=i; }
    if(pt[i].X==Rx && pt[i].Y>Ry){ Ry=pt[i].Y; q=i; }
  }
  for(un=0,i=p;i!=q;i=(i+n-1)%n){ rt[un++]=pt[i]; }
  rt[un]=pt[q];
}
inline int inConvex(Pt p){
  int L,R,M;
  if(p.X<Lx || p.X>Rx) return 0;
  L=0;R=dn;
  while(L<R-1){ M=(L+R)/2;
    if(p.X<qt[M].X) R=M; else L=M; }
  if(tri(qt[L],qt[R],p)<0) return 0;
  L=0;R=un;
  while(L<R-1){ M=(L+R)/2;
    if(p.X<rt[M].X) R=M; else L=M; }
    if(tri(rt[L],rt[R],p)>0) return 0;
    return 1;
}
int main(){
  int n,m,i;
  Pt p;
  scanf("%d",&n);
  for(i=0;i<n;i++) scanf("%lld%lld",&pt[i].X,&pt[i].Y);
  scanf("%d",&m);
  for(i=0;i<m;i++) scanf("%lld%lld",&qt[i].X,&qt[i].Y);
```

```
  n=minkowskiSum(n,m);
  for(i=0;i<n;i++) pt[i]=rt[i];
  scanf("%d",&m);
  for(i=0;i<m;i++) scanf("%lld%lld",&qt[i].X,&qt[i].Y);
  n=minkowskiSum(n,m);
  for(i=0;i<n;i++) pt[i]=rt[i];
  initInConvex(n);
  scanf("%d",&m);
  for(i=0;i<m;i++){
    scanf("%lld %lld",&p.X,&p.Y);
    p.X*=3; p.Y*=3;
    puts(inConvex(p)?"YES":"NO");
  }
}
```

4.10 Min/Max Enclosing Rectangle

```
/******* NEED REVISION *******/
/* uva819 - gifts large and small */
#define MAXN 100005
const double eps=1e-8;
const double inf=1e15;
class Coor {
 public:
  double x,y;
  Coor() {}
  Coor(double xi,double yi) { x=xi; y=yi; }
  Coor& operator+=(const Coor &b) { x+=b.x; y+=b.y;
      return *this; }
  const Coor operator+(const Coor &b) const { return (
      Coor)*this+=b; }
  Coor& operator-=(const Coor &b) { x-=b.x; y-=b.y;
      return *this; }
  const Coor operator-(const Coor &b) const { return (
      Coor)*this-=b; }
  Coor& operator*=(const double b) { x*=b; y*=b; return
       *this; }
  const Coor operator*(const double b) const { return (
      Coor)*this*=b; }
  Coor& operator/=(const double b) { x/=b; y/=b; return
       *this; }
  const Coor operator/(const double b) const { return (
      Coor)*this/=b; }
  const bool operator<(const Coor& b) const { return y<
      b.y-eps||fabs(y-b.y)<eps&&x<b.x; }
  const double len2() const { return x*x+y*y; }
  const double len() const { return sqrt(len2()); }
  const Coor perp() const { return Coor(y,-x); }
  Coor& standardize() {
    if(y<0||y==0&&x<0) {
      x=-x;
      y=-y;
    }
    return *this;
  }
  const Coor standardize() const { return ((Coor)*this)
      .standardize(); }
};
double dot(const Coor &a,const Coor &b) { return a.x*b.
    x+a.y*b.y; }
double dot(const Coor &o,const Coor &a,const Coor &b) {
     return dot(a-o,b-o); }
double cross(const Coor &a,const Coor &b) { return a.x*
    b.y-a.y*b.x; }
double cross(const Coor &o,const Coor &a,const Coor &b)
     { return cross(a-o,b-o); }
Coor cmpo;
const bool cmpf(const Coor &a,const Coor &b) {
  return cross(cmpo,a,b)>eps||fabs(cross(cmpo,a,b))<eps
      &&
    dot(a,cmpo,b)<-eps;
}
class Polygon {
 public:
  int pn;
  Coor p[MAXN];
  void convex_hull() {
    int i,tn=pn;
    for(i=1;i<pn;++i) if(p[i]<p[0]) swap(p[0],p[i]);
    cmpo=p[0];
    std::sort(p+1,p+pn,cmpf);
    for(i=pn=1;i<tn;++i) {
      while(pn>2&&cross(p[pn-2],p[pn-1],p[i])<=eps) --
        pn;
      p[pn++]=p[i];
    }
    p[pn]=p[0];
  }
};
Polygon pol;
double minarea,maxarea;
int slpn;
Coor slope[MAXN*2];
Coor lrec[MAXN*2],rrec[MAXN*2],trec[MAXN*2],brec[MAXN
    *2];
inline double xproject(Coor p,Coor slp) { return dot(p,
    slp)/slp.len(); }
inline double yproject(Coor p,Coor slp) { return cross(
    p,slp)/slp.len(); }
inline double calcarea(Coor lp,Coor rp,Coor bp,Coor tp,
    Coor slp) {
  return (xproject(rp,slp)-xproject(lp,slp))*(yproject(
      tp,slp)-yproject(bp,slp)); }
  inline void solve(){
    int i,lind,rind,tind,bind,tn;
    double pro,area1,area2,l,r,m1,m2;
    Coor s1,s2;
    pol.convex_hull();
    slpn=0; /* generate all critical slope */
    slope[slpn++]=Coor(1.0,0.0);
    slope[slpn++]=Coor(0.0,1.0);
    for(i=0;i<pol.pn;i++) {
      slope[slpn]=(pol.p[i+1]-pol.p[i]).standardize();
      if(slope[slpn].x>0) slpn++;
      slope[slpn]=(pol.p[i+1]-pol.p[i]).perp().
        standardize();
      if(slope[slpn].x>0) slpn++;
    }
    cmpo=Coor(0,0);
    std::sort(slope,slope+slpn,cmpf);
    tn=slpn;
    for(i=slpn=1;i<tn;i++)
      if(cross(cmpo,slope[i-1],slope[i])>0) slope[slpn
        ++]=slope[i];
    lind=rind=0; /* find critical touchpoints */
    for(i=0;i<pol.pn;i++) {
      pro=xproject(pol.p[i],slope[0]);
      if(pro<xproject(pol.p[lind],slope[0])) lind=i;
      if(pro>xproject(pol.p[rind],slope[0])) rind=i;
    }
    tind=bind=0;
    for(i=0;i<pol.pn;i++) {
      pro=yproject(pol.p[i],slope[0]);
      if(pro<yproject(pol.p[bind],slope[0])) bind=i;
      if(pro>yproject(pol.p[tind],slope[0])) tind=i;
    }
    for(i=0;i<slpn;i++) {
      while(xproject(pol.p[lind+1],slope[i])<=xproject(
            pol.p[lind],slope[i])+eps)
        lind=(lind==pol.pn-1?0:lind+1);
      while(xproject(pol.p[rind+1],slope[i])>=xproject(
            pol.p[rind],slope[i])-eps)
        rind=(rind==pol.pn-1?0:rind+1);
      while(yproject(pol.p[bind+1],slope[i])<=yproject(
            pol.p[bind],slope[i])+eps)
        bind=(bind==pol.pn-1?0:bind+1);
      while(yproject(pol.p[tind+1],slope[i])>=yproject(
            pol.p[tind],slope[i])-eps)
        tind=(tind==pol.pn-1?0:tind+1);
      lrec[i]=pol.p[lind];
      rrec[i]=pol.p[rind];
      brec[i]=pol.p[bind];
      trec[i]=pol.p[tind];
    }
    minarea=inf; /* find minimum area */
    for(i=0;i<slpn;i++) {
      area1=calcarea(lrec[i],rrec[i],brec[i],trec[i],
          slope[i]);
      if(area1<minarea) minarea=area1;
    }
    maxarea=minarea; /* find maximum area */
    for(i=0;i<slpn-1;i++) {
```

```
      l=0.0; r=1.0;
      while(l<r-eps) {
        m1=l+(r-l)/3;
        m2=l+(r-l)*2/3;
        s1=slope[i]*(1.0-m1)+slope[i+1]*m1;
        area1=calcarea(lrec[i],rrec[i],brec[i],trec[i],
            s1);
        s2=slope[i]*(1.0-m2)+slope[i+1]*m2;
        area2=calcarea(lrec[i],rrec[i],brec[i],trec[i],
            s2);
        if(area1<area2) l=m1;
        else r=m2;
      }
      s1=slope[i]*(1.0-l)+slope[i+1]*l;
      area1=calcarea(lrec[i],rrec[i],brec[i],trec[i],s1
          );
      if(area1>maxarea) maxarea=area1;
    }
  }
int main(){
  int i,casenum=1;
  while(scanf("%d",&pol.pn)==1&&pol.pn) {
    for(i=0;i<pol.pn;i++)
      scanf("%lf %lf",&pol.p[i].x,&pol.p[i].y);
    solve();
    //minarea, maxarea
  }
}
```

5 Graph

5.1 HeavyLightDecomp

```
#define SZ(c) (int)(c).size()
#define ALL(c) (c).begin(), (c).end()
#define REP(i, s, e) for(int i = (s); i <= (e); i++)
#define REPD(i, s, e) for(int i = (s); i >= (e); i--)
typedef tuple< int , int > tii;
const int MAXN = 100010;
const int LOG  = 19;
struct HLD{
  int n;
  vector<int> g[MAXN];
  int sz[MAXN], dep[MAXN];
  int ts, tid[MAXN], tdi[MAXN], tl[MAXN], tr[MAXN];
  //  ts : timestamp , useless after yutruli
  //  tid[ u ] : pos. of node u in the seq.
  //  tdi[ i ] : node at pos i of the seq.
  //  tl , tr[ u ] : subtree interval in the seq. of
      node u
  int mom[MAXN][LOG], head[MAXN];
  // head[ u ] : head of the chain contains u
  void dfssz(int u, int p){
    dep[u] = dep[p] + 1;
    mom[u][0] = p;
    sz[u] = 1;
    head[u] = u;
    for(int& v:g[u]) if(v != p){
      dep[v] = dep[u] + 1;
      dfssz(v, u);
      sz[u] += sz[v];
    }
  }
  void dfshl(int u){
    //printf("dfshl %d\n", u);
    ts++;
    tid[u] = tl[u] = tr[u] = ts;
    tdi[tid[u]] = u;
    sort(ALL(g[u]),
         [&](int a, int b){return sz[a] > sz[b];});
    bool flag = 1;
    for(int& v:g[u]) if(v != mom[u][0]){
      if(flag) head[v] = head[u], flag = 0;
      dfshl(v);
      tr[u] = tr[v];
    }
  }
  inline int lca(int a, int b){
    if(dep[a] > dep[b]) swap(a, b);
    //printf("lca %d %d\n", a, b);
    int diff = dep[b] - dep[a];
    REPD(k, LOG-1, 0) if(diff & (1<<k)){
      //printf("b %d\n", mom[b][k]);
      b = mom[b][k];
    }
    if(a == b) return a;
    REPD(k, LOG-1, 0) if(mom[a][k] != mom[b][k]){
      a = mom[a][k];
      b = mom[b][k];
    }
    return mom[a][0];
  }
  void init( int _n ){
    n = _n;
    REP( i , 1 , n ) g[ i ].clear();
  }
  void addEdge( int u , int v ){
    g[ u ].push_back( v );
    g[ v ].push_back( u );
  }
  void yutruli(){
    dfssz(1, 0);
    ts = 0;
    dfshl(1);
    REP(k, 1, LOG-1) REP(i, 1, n)
      mom[i][k] = mom[mom[i][k-1]][k-1];
  }
  vector< tii > getPath( int u , int v ){
    vector< tii > res;
    while( tid[ u ] < tid[ head[ v ] ] ){
      res.push_back( tii(tid[ head[ v ] ] , tid[ v ]) )
          ;
      v = mom[ head[ v ] ][ 0 ];
    }
    res.push_back( tii( tid[ u ] , tid[ v ] ) );
    reverse( ALL( res ) );
    return res;
    /*
     * res : list of intervals from u to v
     * u must be ancestor of v
     * usage :
     * vector< tii >& path = tree.getPath( u , v )
     * for( tii tp : path ) {
     *   int l , r;tie( l , r ) = tp;
     *   upd( l , r );
     *   uu = tree.tdi[ l ] , vv = tree.tdi[ r ];
     *   uu ~> vv is a heavy path on tree
     * }
     */
  }
} tree;
```

5.2 DominatorTree

```
const int MAXN = 100010;
struct DominatorTree{
#define REP(i,s,e) for(int i=(s);i<=(e);i++)
#define REPD(i,s,e) for(int i=(s);i>=(e);i--)
  int n , m , s;
  vector< int > g[ MAXN ] , pred[ MAXN ];
  vector< int > cov[ MAXN ];
  int dfn[ MAXN ] , nfd[ MAXN ] , ts;
  int par[ MAXN ];
  int sdom[ MAXN ] , idom[ MAXN ];
  int mom[ MAXN ] , mn[ MAXN ];

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

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

  void init( int _n , int _m , int _s ){
```

```
    ts = 0; n = _n; m = _m; 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 ){
      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;
```

5.3 MaxClique

```
class MaxClique {
 public:
  static const int MV = 210;
  int V , ans;
  int el[MV][MV/30+1];
  int dp[MV];
  int s[MV][MV/30+1];
  vector<int> sol;
  void init(int v) {
    V = v; ans = 0;
    FZ(el); FZ(dp);
  }
  /* Zero Base */
  void addEdge(int u, int v) {
    if(u > v) swap(u, v);
    if(u == v) return;
    el[u][v/32] |= (1<<(v%32));
  }
  bool dfs(int v, int k) {
    int c = 0, d = 0;
    for(int i=0; i<(V+31)/32; i++) {
      s[k][i] = el[v][i];
      if(k != 1) s[k][i] &= s[k-1][i];
      c += __builtin_popcount(s[k][i]);
    }
    if(c == 0) {
      if(k > ans) {
        ans = k;
        sol.clear();
        sol.push_back(v);
        return 1;
      }
      return 0;
    }
    for(int i=0; i<(V+31)/32; i++) {
      for(int a = s[k][i]; a ; d++) {
        if(k + (c-d) <= ans) return 0;
        int lb = a&(-a), lg = 0;
        a ^= lb;
        while(lb!=1) {
          lb = (unsigned int)(lb) >> 1;
          lg ++;
        }
        int u = i*32 + lg;
        if(k + dp[u] <= ans) return 0;
        if(dfs(u, k+1)) {
          sol.push_back(v);
          return 1;
        }
      }
    }
    return 0;
  }
  int solve() {
    for(int i=V-1; i>=0; i--) {
      dfs(i, 1);
      dp[i] = ans;
    }
    return ans;
  }
};
```

5.4 Strongly Connected Component

```
struct Scc{
  int n, nScc, vst[MXN], bln[MXN];
  vector<int> E[MXN], rE[MXN], vec;
  void init(int _n){
    n = _n;
    for (int i=0; i<MXN; i++){
      E[i].clear();
      rE[i].clear();
    }
  }
  void add_edge(int u, int v){
    E[u].PB(v);
    rE[v].PB(u);
  }
  void DFS(int u){
    vst[u]=1;
    for (auto v : E[u])
      if (!vst[v]) DFS(v);
    vec.PB(u);
  }
  void rDFS(int u){
    vst[u] = 1;
    bln[u] = nScc;
    for (auto v : rE[u])
      if (!vst[v]) rDFS(v);
  }
  void solve(){
    nScc = 0;
    vec.clear();
    FZ(vst);
    for (int i=0; i<n; i++)
      if (!vst[i]) DFS(i);
    reverse(vec.begin(),vec.end());
    FZ(vst);
    for (auto v : vec){
      if (!vst[v]){
        rDFS(v);
        nScc++;
      }
    }
  }
};
```

5.5 Minimum General Weighted Matching

```
struct Graph {
  // Minimum General Weighted Matching (Perfect Match)
  static const int MXN = 105;
  int n, edge[MXN][MXN];
  int match[MXN],dis[MXN],onstk[MXN];
  vector<int> stk;
  void init(int _n) {
    n = _n;
    for( int i = 0 ; i < n ; i ++ )
      for( int j = 0 ; j < n ; j ++ )
        edge[ i ][ j ] = 0;
  }
  void add_edge(int u, int v, int w) {
    edge[u][v] = edge[v][u] = w;
  }
  bool SPFA(int u){
    if (onstk[u]) return true;
    stk.PB(u);
    onstk[u] = 1;
    for (int v=0; v<n; v++){
      if (u != v && match[u] != v && !onstk[v]){
        int m = match[v];
        if (dis[m] > dis[u] - edge[v][m] + edge[u][v]){
          dis[m] = dis[u] - edge[v][m] + edge[u][v];
          onstk[v] = 1;
          stk.PB(v);
          if (SPFA(m)) return true;
          stk.pop_back();
          onstk[v] = 0;
        }
      }
    }
    onstk[u] = 0;
    stk.pop_back();
    return false;
  }
  int solve() {
    // find a match
    for (int i=0; i<n; i+=2){
      match[i] = i+1;
      match[i+1] = i;
    }
    while (true){
      int found = 0;
      for( int i = 0 ; i < n ; i ++ )
        onstk[ i ] = dis[ i ] = 0;
      for (int i=0; i<n; i++){
        stk.clear();
        if (!onstk[i] && SPFA(i)){
          found = 1;
          while (SZ(stk)>=2){
            int u = stk.back(); stk.pop_back();
            int v = stk.back(); stk.pop_back();
            match[u] = v;
            match[v] = u;
          }
        }
      }
      if (!found) break;
    }
    int ret = 0;
    for (int i=0; i<n; i++)
      ret += edge[i][match[i]];
    ret /= 2;
    return ret;
  }
}graph;
```

6 String

6.1 PalTree

```
const int MAXN = 200010;
struct PalT{
  struct Node{
    int nxt[ 33 ] , len , fail;
    ll cnt;
  };
  int tot , lst;
  Node nd[ MAXN * 2 ];
  char* s;
  int newNode( int l , int _fail ){
    int res = ++tot;
    memset( nd[ res ].nxt , 0 , sizeof nd[ res ].nxt );
    nd[ res ].len = l;
    nd[ res ].cnt = 0;
    nd[ res ].fail = _fail;
    return res;
  }
  void push( int p ){
    int np = lst;
    int c = s[ p ] - 'a';
    while( p - nd[ np ].len - 1 < 0
        || s[ p ] != s[ p - nd[ np ].len - 1 ] )
      np = nd[ np ].fail;

    if( nd[ np ].nxt[ c ] ){
      nd[ nd[ np ].nxt[ c ] ].cnt++;
      lst = nd[ np ].nxt[ c ];
      return ;
    }
    int nq = newNode( nd[ np ].len + 2 , 0 );
    nd[ nq ].cnt++;
    nd[ np ].nxt[ c ] = nq;
    lst = nq;
    if( nd[ nq ].len == 1 ){
      nd[ nq ].fail = 2;
      return ;
    }
    int tf = nd[ np ].fail;
    while( p - nd[ tf ].len - 1 < 0
        || s[ p ] != s[ p - nd[ tf ].len - 1 ] )
      tf = nd[ tf ].fail;

    nd[ nq ].fail = nd[ tf ].nxt[ c ];
    return ;
  }
  void init( char* _s ){
    s = _s;
    tot = 0;
    newNode( -1 , 1 );
    newNode( 0 , 1 );
    lst = 2;
    for( int i = 0 ; s[ i ] ; i++ )
      push( i );
  }
  void yutruli(){
#define REPD(i, s, e) for(int i = (s); i >= (e); i--)
    REPD( i , tot , 1 )
      nd[ nd[ i ].fail ].cnt += nd[ i ].cnt;
    nd[ 1 ].cnt = nd[ 2 ].cnt = 0ll;
  }
} pA;
int main(){
  pA.init( sa );
}
```

6.2 SuffixArray

```
const int MAX = 1020304;
int ct[MAX], he[MAX], rk[MAX];
int sa[MAX], tsa[MAX], tp[MAX][2];
void suffix_array(char *ip){
  int len = strlen(ip);
  int alp = 256;
  memset(ct, 0, sizeof(ct));
```

```
  for(int i=0;i<len;i++) ct[ip[i]+1]++;
  for(int i=1;i<alp;i++) ct[i]+=ct[i-1];
  for(int i=0;i<len;i++) rk[i]=ct[ip[i]];

  for(int i=1;i<len;i*=2){
    for(int j=0;j<len;j++){
      if(j+i>=len) tp[j][1]=0;
      else tp[j][1]=rk[j+i]+1;
      tp[j][0]=rk[j];
    }
    memset(ct, 0, sizeof(ct));
    for(int j=0;j<len;j++) ct[tp[j][1]+1]++;
    for(int j=1;j<len+2;j++) ct[j]+=ct[j-1];
    for(int j=0;j<len;j++) tsa[ct[tp[j][1]]++]=j;

    memset(ct, 0, sizeof(ct));
    for(int j=0;j<len;j++) ct[tp[j][0]+1]++;
    for(int j=1;j<len+1;j++) ct[j]+=ct[j-1];
    for(int j=0;j<len;j++)
      sa[ct[tp[tsa[j]][0]]++]=tsa[j];

    rk[sa[0]]=0;
    for(int j=1;j<len;j++){
      if( tp[sa[j]][0] == tp[sa[j-1]][0] &&
        tp[sa[j]][1] == tp[sa[j-1]][1] )
        rk[sa[j]] = rk[sa[j-1]];
      else
        rk[sa[j]] = j;
    }
  }

  for(int i=0,h=0;i<len;i++){
    if(rk[i]==0) h=0;
    else{
      int j=sa[rk[i]-1];
      h=max(0,h-1);
      for(;ip[i+h]==ip[j+h];h++);
    }
    he[rk[i]]=h;
  }
}
```

6.3 SAIS

```
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;
int H[ N ], SA[ N ];
void suffix_array(int* ip, int len) {
  // should padding a zero in the back
  // ip is int array, len is array length
  // ip[0..n-1] != 0, and ip[len] = 0
  ip[len++] = 0;
  sa.build(ip, len, 128);
  for (int i=0; i<len; i++) {
    H[i] = sa.hei[i + 1];
    SA[i] = sa._sa[i + 1];
  }
  // resulting height, sa array \in [0,len)
}
```

6.4 SuffixAutomata

```
const int MAXM = 1000010;
struct SAM{
  int tot, root, lst, mom[MAXM], mx[MAXM];
  int acc[MAXM], nxt[MAXM][33];
  int newNode(){
    int res = ++tot;
    fill(nxt[res], nxt[res]+33, 0);
    mom[res] = mx[res] = acc[res] = 0;
    return res;
  }
  void init(){
    tot = 0;
    root = newNode();
    mom[root] = 0, mx[root] = 0;
    lst = root;
  }
  void push(int c){
    int p = lst;
    int np = newNode();
    mx[np] = mx[p]+1;
    for(; p && nxt[p][c] == 0; p = mom[p])
      nxt[p][c] = np;
    if(p == 0) mom[np] = root;
    else{
      int q = nxt[p][c];
      if(mx[p]+1 == mx[q]) mom[np] = q;
      else{
        int nq = newNode();
        mx[nq] = mx[p]+1;
        for(int i = 0; i < 33; i++)
          nxt[nq][i] = nxt[q][i];
        mom[nq] = mom[q];
        mom[q] = nq;
        mom[np] = nq;
        for(; p && nxt[p][c] == q; p = mom[p])
          nxt[p][c] = nq;
      }
    }
    lst = np;
  }
  void print(){
    REP(i, 1, tot){
      printf("node %d :\n", i);
```

```
      printf("mx %d, mom %d\n", mx[i], mom[i]);
      REP(j, 1, 26) if(nxt[i][j])
        printf("nxt %c %d\n", 'a'+j-1, nxt[i][j]);
      puts("----------------------------");
    }
  }
  void push(char *str){
    for(int i = 0; str[i]; i++)
      push(str[i]-'a'+1);
  }
} sam;
```

6.5 Aho-Corasick

```
struct ACautomata{
  struct Node{
    int cnt,dp;
    Node *go[26], *fail;
    Node (){
      cnt = 0;
      dp = -1;
      memset(go,0,sizeof(go));
      fail = 0;
    }
  };
  Node *root, pool[1048576];
  int nMem;
  Node* new_Node(){
    pool[nMem] = Node();
    return &pool[nMem++];
  }
  void init(){
    nMem = 0;
    root = new_Node();
  }
  void add(const string &str){
    insert(root,str,0);
  }
  void insert(Node *cur, const string &str, int pos){
    if (pos >= (int)str.size()){
      cur->cnt++;
      return;
    }
    int c = str[pos]-'a';
    if (cur->go[c] == 0){
      cur->go[c] = new_Node();
    }
    insert(cur->go[c],str,pos+1);
  }
  void make_fail(){
    queue<Node*> que;
    que.push(root);
    while (!que.empty()){
      Node* fr=que.front();
      que.pop();
      for (int i=0; i<26; i++){
        if (fr->go[i]){
          Node *ptr = fr->fail;
          while (ptr && !ptr->go[i]) ptr = ptr->fail;
          if (!ptr) fr->go[i]->fail = root;
          else fr->go[i]->fail = ptr->go[i];
          que.push(fr->go[i]);
        }
      }
    }
  }
};
```

6.6 Z Value

```
char s[MAXN];
int len,z[MAXN];
void Z_value() {
  int i,j,left,right;
  left=right=0; z[0]=len;
  for(i=1;i<len;i++) {
    j=max(min(z[i-left],right-i),0);
    for(;i+j<len&&s[i+j]==s[j];j++);
    z[i]=j;
    if(i+z[i]>right) {
      right=i+z[i];
      left=i;
    }
  }
}
```

6.7 ZValue Palindrome

```
const int MAX = 1000;
int len, zv[MAX*2];
char ip[MAX], op[MAX*2];
int main(){
  cin >> ip; len = strlen(ip);
  int l2 = len*2 - 1;
  for(int i=0; i<l2; i++){
    if(i&1) op[i] = '@';
    else op[i] = ip[i/2];
  }
  int l=0, r=0; zv[0] = 1;
  for(int i=1; i<l2; i++){
    if( i > r ){
      l = r = i;
      while( l>0 && r<l2-1 && op[l-1] == op[r+1] ){
        l --; r ++;
      }
      zv[i] = (r-l+1);
    }else{
      int md = (l+r)/2;
      int j = md + md - i;
      zv[i] = zv[j];
      int q = zv[i] / 2;
      int nr = i + q;
      if( nr == r ){
        l = i + i - r;
        while( l>0 && r<l2-1 && op[l-1] == op[r+1] ){
          l --; r ++;
        }
        zv[i] = r - l + 1;
      }else if( nr > r ){
        zv[i] = (r - i) * 2 + 1;
      }
    }
  }
}
```

6.8 Smallest Rotation

```
string mcp(string s){
  int n = s.length();
  s += s;
  int i=0, j=1, k=0;
  while (j<n && k<n){
    if (s[i+k] == s[j+k]) k++;
    else {
      if (s[i+k] < s[j+k]) {
        j += k + 1;
      } else {
        i = j;
        j = max(j+1, j+k);
      }
      k = 0;
    }
  }
  return s.substr(i, n);
}
```

6.9 Baker Bird

```
class Node { public:
  Node *fail;
  map<char,Node*> _next;
  int out;
  Node() { fail=NULL; out=-1; }
  ~Node() {
```

```
    for(map<char,Node*>::iterator it=_next.begin();it!=
        _next.end();it++)
      delete it->second;
  }
  Node* build(char ch) {
    if(_next.find(ch)==_next.end()) _next[ch]=new Node;
    return _next[ch];
  }
  Node* next(char ch) {
    if(_next.find(ch)==_next.end()) return NULL;
    return _next[ch];
  }
};
int srn,scn,prn,pcn,mrn,mcn;
char s[MAXN][MAXN],p[MAXN][MAXN];
int rm[MAXN][MAXN]; // rank matrix
int maxrank;
int seq[MAXN]; // index of patterns for radix sort
int rank[MAXN]; // rank of pattern on row r
int cnt[SIGMA+1],tmp[MAXN];
int pre[MAXN]; // pre-matrix for kmp
int ql,qr;
Node* que[MAXN*MAXN];
inline void radix_pass(int j,int *from,int *to) {
  int i;
  for(i=0;i<SIGMA;i++) cnt[i]=0;
  for(i=0;i<prn;i++) cnt[p[from[i]][j]+1]++;
  for(i=0;i<SIGMA;i++) cnt[i+1]+=cnt[i];
  for(i=0;i<prn;i++) to[cnt[p[from[i]][j]]++]=from[i];
}
inline void radix_sort_patterns() {
  int i,j;
  for(i=0;i<prn;i++) ((pcn&1)?tmp[i]:seq[i])=i;
  for(j=pcn-1;j>=0;j--) {
    if(j&1) radix_pass(j,seq,tmp);
    else radix_pass(j,tmp,seq);
  }
  maxrank=0;
  for(i=0;i<prn;i++) {
    if(i&&strcmp(p[seq[i-1]],p[seq[i]])) ++maxrank;
    rank[seq[i]]=maxrank;
  }
}
inline void construct(Node *v,char *p,int ind) {
  while(*p) { v=v->build(*p); p++; }
  v->out=ind;
}
inline void construct_all(Node *ac) {
  for(int i=0;i<prn;i++) construct(ac,p[i],rank[i]);
}
inline void find_fail(Node *ac) {
  Node *v,*u,*f;
  map<char,Node*>::iterator it;
  char ch;
  ql=qr=0; ac->fail=ac;
  for(it=ac->_next.begin();it!=ac->_next.end();it++) {
    u=it->second;
    u->fail=ac;
    que[qr++]=u;
  }
  while(ql<qr) {
    v=que[ql++];
    for(it=v->_next.begin();it!=v->_next.end();it++) {
      ch=it->first; u=it->second;
      f=v->fail;
      while(f!=ac&&f->next(ch)==NULL) f=f->fail;
      if(f->next(ch)) u->fail=f->next(ch);
      else u->fail=ac;
      que[qr++]=u;
    }
  }
}
inline void ac_match(Node *ac,char *s,int *arr) {
  int i;
  Node *v=ac;
  for(i=0;i<scn;i++) {
    while(v!=ac&&v->next(s[i])==NULL) v=v->fail;
    if(v->next(s[i])) v=v->next(s[i]);
    if(i>=pcn-1) arr[i-pcn+1]=v->out;
  }
}
inline void find_rank_matrix() {
  Node ac;
  radix_sort_patterns();
  construct_all(&ac);
  find_fail(&ac);
  mrn=srn; mcn=scn-pcn+1;
  for(int i=0;i<srn;i++) ac_match(&ac,s[i],rm[i]);
}
inline void find_pre(int *p,int plen) {
  int i,x;
  x=pre[0]=-1;
  for(i=1;i<plen;i++) {
    while(x>=0&&p[x+1]!=p[i]) x=pre[x];
    if(p[x+1]==p[i]) x++;
    pre[i]=x;
  }
}
inline int kmp_match(int col,int *p,int plen) {
  int i,x=-1,occ=0;
  for(i=0;i<mrn;i++) {
    while(x>=0&&p[x+1]!=rm[i][col]) x=pre[x];
    if(p[x+1]==rm[i][col]) x++;
    if(x==plen-1) { occ++; x=pre[x]; }
  }
  return occ;
}
inline int baker_bird() {
  int i,occ=0;
  find_rank_matrix();
  find_pre(rank,prn);
  for(i=0;i<mcn;i++) occ+=kmp_match(i,rank,prn);
  return occ;
}
```

6.10 Cyclic LCS

```
#define L 0
#define LU 1
#define U 2
const int mov[3][2]={0,-1, -1,-1, -1,0};
int al,bl;
char a[MAXL*2],b[MAXL*2]; // 0-indexed
int dp[MAXL*2][MAXL];
char pred[MAXL*2][MAXL];
inline int lcs_length(int r) {
  int i=r+al,j=bl,l=0;
  while(i>r) {
    char dir=pred[i][j];
    if(dir==LU) l++;
    i+=mov[dir][0];
    j+=mov[dir][1];
  }
  return l;
}
inline void reroot(int r) { // r = new base row
  int i=r,j=1;
  while(j<=bl&&pred[i][j]!=LU) j++;
  if(j>bl) return;
  pred[i][j]=L;
  while(i<2*al&&j<=bl) {
    if(pred[i+1][j]==U) {
      i++;
      pred[i][j]=L;
    } else if(j<bl&&pred[i+1][j+1]==LU) {
      i++;
      j++;
      pred[i][j]=L;
    } else {
      j++;
    }
  }
}
int cyclic_lcs() {
  // a, b, al, bl should be properly filled
  // note: a WILL be altered in process
  //       -- concatenated after itself
  char tmp[MAXL];
  if(al>bl) {
    swap(al,bl);
    strcpy(tmp,a);
    strcpy(a,b);
```

```
    strcpy(b,tmp);
  }
  strcpy(tmp,a);
  strcat(a,tmp);
  // basic lcs
  for(int i=0;i<=2*al;i++) {
    dp[i][0]=0;
    pred[i][0]=U;
  }
  for(int j=0;j<=bl;j++) {
    dp[0][j]=0;
    pred[0][j]=L;
  }
  for(int i=1;i<=2*al;i++) {
    for(int j=1;j<=bl;j++) {
      if(a[i-1]==b[j-1]) dp[i][j]=dp[i-1][j-1]+1;
      else dp[i][j]=max(dp[i-1][j],dp[i][j-1]);
      if(dp[i][j-1]==dp[i][j]) pred[i][j]=L;
      else if(a[i-1]==b[j-1]) pred[i][j]=LU;
      else pred[i][j]=U;
    }
  }
  // do cyclic lcs
  int clcs=0;
  for(int i=0;i<al;i++) {
    clcs=max(clcs,lcs_length(i));
    reroot(i+1);
  }
  // recover a
  a[al]='\0';
  return clcs;
}
```

7 Data Structure

7.1 Treap

```
struct Treap{
  int sz , val , pri , tag;
  Treap *l , *r;
  Treap( int _val ){
    val = _val; sz = 1;
    pri = rand(); l = r = NULL; tag = 0;
  }
};
void push( Treap * a ){
  if( a->tag ){
    Treap *swp = a->l; a->l = a->r; a->r = swp;
    int swp2;
    if( a->l ) a->l->tag ^= 1;
    if( a->r ) a->r->tag ^= 1;
    a->tag = 0;
  }
}
int Size( Treap * a ){ return a ? a->sz : 0; }
void pull( Treap * a ){
  a->sz = Size( a->l ) + Size( a->r ) + 1;
}
Treap* merge( Treap *a , Treap *b ){
  if( !a || !b ) return a ? a : b;
  if( a->pri > b->pri ){
    push( a );
    a->r = merge( a->r , b );
    pull( a );
    return a;
  }else{
    push( b );
    b->l = merge( a , b->l );
    pull( b );
    return b;
  }
}
void split( Treap *t , int k , Treap*&a , Treap*&b ){
  if( !t ){ a = b = NULL; return; }
  push( t );
  if( Size( t->l ) + 1 <= k ){
    a = t;
    split( t->r , k - Size( t->l ) - 1 , a->r , b );
    pull( a );
  }else{
    b = t;
    split( t->l , k , a , b->l );
    pull( b );
  }
}
```

7.2 Link-Cut Tree

```
const int MXN = 100005;
const int MEM = 100005;
struct Splay {
  static Splay nil, mem[MEM], *pmem;
  Splay *ch[2], *f;
  int val, rev, size;
  Splay () : val(-1), rev(0), size(0){
    f = ch[0] = ch[1] = &nil;
  }
  Splay (int _val) : val(_val), rev(0), size(1){
    f = ch[0] = ch[1] = &nil;
  }
  bool isr(){
    return f->ch[0] != this && f->ch[1] != this;
  }
  int dir(){
    return f->ch[0] == this ? 0 : 1;
  }
  void setCh(Splay *c, int d){
    ch[d] = c;
    if (c != &nil) c->f = this;
    pull();
  }
  void push(){
    if (rev){
      swap(ch[0], ch[1]);
      if (ch[0] != &nil) ch[0]->rev ^= 1;
      if (ch[1] != &nil) ch[1]->rev ^= 1;
      rev=0;
    }
  }
  void pull(){
    size = ch[0]->size + ch[1]->size + 1;
    if (ch[0] != &nil) ch[0]->f = this;
    if (ch[1] != &nil) ch[1]->f = this;
  }
} Splay::nil, Splay::mem[MEM], *Splay::pmem = Splay::
    mem;
Splay *nil = &Splay::nil;
void rotate(Splay *x){
  Splay *p = x->f;
  int d = x->dir();
  if (!p->isr()) p->f->setCh(x, p->dir());
  else x->f = p->f;
  p->setCh(x->ch[!d], d);
  x->setCh(p, !d);
  p->pull(); x->pull();
}

vector<Splay*> splayVec;
void splay(Splay *x){
  splayVec.clear();
  for (Splay *q=x;; q=q->f){
    splayVec.push_back(q);
    if (q->isr()) break;
  }
  reverse(begin(splayVec), end(splayVec));
  for (auto it : splayVec) it->push();
  while (!x->isr()) {
    if (x->f->isr()) rotate(x);
    else if (x->dir()==x->f->dir())
      rotate(x->f),rotate(x);
    else rotate(x),rotate(x);
  }
}
Splay* access(Splay *x){
  Splay *q = nil;
  for (;x!=nil;x=x->f){
    splay(x);
    x->setCh(q, 1);
```

```
    q = x;
  }
  return q;
}
void evert(Splay *x){
  access(x);
  splay(x);
  x->rev ^= 1;
  x->push(); x->pull();
}
void link(Splay *x, Splay *y){
//  evert(x);
  access(x);
  splay(x);
  evert(y);
  x->setCh(y, 1);
}
void cut(Splay *x, Splay *y){
//  evert(x);
  access(y);
  splay(y);
  y->push();
  y->ch[0] = y->ch[0]->f = nil;
}
int N, Q;
Splay *vt[MXN];
int ask(Splay *x, Splay *y){
  access(x);
  access(y);
  splay(x);
  int res = x->f->val;
  if (res == -1) res=x->val;
  return res;
}
int main(int argc, char** argv){
  scanf("%d%d", &N, &Q);
  for (int i=1; i<=N; i++)
    vt[i] = new (Splay::pmem++) Splay(i);
  while (Q--) {
    char cmd[105];
    int u, v;
    scanf("%s", cmd);
    if (cmd[1] == 'i') {
      scanf("%d%d", &u, &v);
      link(vt[v], vt[u]);
    } else if (cmd[0] == 'c') {
      scanf("%d", &v);
      cut(vt[1], vt[v]);
    } else {
      scanf("%d%d", &u, &v);
      int res=ask(vt[u], vt[v]);
      printf("%d\n", res);
    }
  }
}
```

7.3 Disjoint Set

```
struct DisjointSet{
  // save() is like recursive
  // undo() is like return
  int n, fa[ N ], sz[ N ];
  vector< pair<int*,int> > h;
  vector<int> sp;
  void init( int tn ){
    n=tn;
    for( int i = 0 ; i < n ; i ++ ){
      fa[ i ]=i;
      sz[ i ]=1;
    }
    sp.clear(); h.clear();
  }
  void assign( int *k, int v ){
    h.PB( {k, *k} );
    *k = v;
  }
  void save(){ sp.PB(SZ(h)); }
  void undo(){
    assert(!sp.empty());
    int last=sp.back(); sp.pop_back();
    while( SZ(h)!=last ){
      auto x=h.back(); h.pop_back();
      *x.first = x.second;
    }
  }
  int f( int x ){
    while( fa[ x ] != x ) x = fa[ x ];
    return x;
  }
  void uni( int x , int y ){
    x = f( x ); y = f( y );
    if( x == y ) return;
    if( sz[ x ] < sz[ y ] ) swap( x, y );
    assign( &sz[ x ] , sz[ x ] + sz[ y ] );
    assign( &fa[ y ] , x);
  }
}djs;
```

7.4 Pairing Heap

```
#include <bits/extc++.h>
using namespace __gnu_pbds;
typedef priority_queue<int> heap;
int main(){
  heap h1 , h2;
  h1.push( 1 );
  h2.push( 4 );
  h1.join( h2 );
  h1.size(); // 2
  h2.size(); // 0
  h1.top(); // 4
}
```

7.5 Leftist Heap

```
const int MAXN = 10000;
struct Node{
  int num,lc,rc;
  Node() : num(0), lc(-1), rc(-1){}
  Node( int _v ) : num(_v), lc(-1), rc(-1){}
}tree[ MAXN ];
int merge( int x, int y ){
  if( x == -1 ) return y;
  if( y == -1 ) return x;
  if( tree[ x ].num < tree[ y ].num )
    swap(x, y);
  tree[ x ].rc = merge(tree[ x ].rc, y);
  swap(tree[ x ].lc, tree[ x ].rc);
  return x;
}
/* Usage
merge: root = merge(x, y)
delmin: root = merge(root.lc, root.rc)
*/
```

7.6 Black Magic

```
#include <bits/extc++.h>
using namespace __gnu_pbds;
typedef tree<int,null_type,less<int>,rb_tree_tag,
    tree_order_statistics_node_update> set_t;
int main(){
  // Insert some entries into s.
  set_t s;
  s.insert(12);
  s.insert(505);
  // The order of the keys should be: 12, 505.
  assert(*s.find_by_order(0) == 12);
  assert(*s.find_by_order(3) == 505);
  // The order of the keys should be: 12, 505.
  assert(s.order_of_key(12) == 0);
  assert(s.order_of_key(505) == 1);
  // Erase an entry.
  s.erase(12);
  // The order of the keys should be: 505.
  assert(*s.find_by_order(0) == 505);
```

```
  // The order of the keys should be: 505.
  assert(s.order_of_key(505) == 0);
}
```

8 Others

8.1 Find max tangent(x,y is increasing)

```
typedef long long LL;
const int MAXN = 100010;
struct Coord{
  LL x, y;
  Coord operator - (Coord ag) const{
    Coord res;
    res.x = x - ag.x;
    res.y = y - ag.y;
    return res;
  }
}sum[MAXN], pnt[MAXN], ans, calc;

inline bool cross(Coord a, Coord b, Coord c){
  return (c.y-a.y)*(c.x-b.x) > (c.x-a.x)*(c.y-b.y);
}

int main(){
  int n, l, np, st, ed, now;
  scanf("%d %d\n", &n, &l);
  sum[0].x = sum[0].y = np = st = ed = 0;
  for (int i = 1, v; i <= n; i++){
    scanf("%d", &v);
    sum[i].y = sum[i - 1].y + v;
    sum[i].x = i;
  }
  ans.x = now = 1;
  ans.y = -1;
  for (int i = 0; i <= n - l; i++){
    while (np > 1 &&
           cross(pnt[np - 2], pnt[np - 1], sum[i]))
      np--;
    if (np < now && np != 0) now = np;
    pnt[np++] = sum[i];
    while (now < np &&
           !cross(pnt[now - 1], pnt[now], sum[i + l]))
      now++;
    calc = sum[i + l] - pnt[now - 1];
    if (ans.y * calc.x < ans.x * calc.y){
      ans = calc;
      st = pnt[now - 1].x;
      ed = i + l;
    }
  }
  double res = (sum[ed].y - sum[st].y) /
               (sum[ed].x - sum[st].x);
  printf("%f\n", res);
  return 0;
}
```

8.2 Exact Cover Set

```
// given n*m 0-1 matrix
// find a set of rows s.t.
// for each column, there's exactly one 1
#include <stdio.h>
#include <string.h>
#define N 1024 //row
#define M 1024 //column
#define NM ((N+2)*(M+2))
char A[N][M]; //n*m 0-1 matrix
int used[N]; //answer: the row used
int id[N][M];
int L[NM],R[NM],D[NM],U[NM],C[NM],S[NM],ROW[NM];
void remove(int c){
  L[R[c]]=L[c]; R[L[c]]=R[c];
  for( int i=D[c]; i!=c; i=D[i] )
    for( int j=R[i]; j!=i; j=R[j] ){
      U[D[j]]=U[j]; D[U[j]]=D[j]; S[C[j]]--;
    }
}
void resume(int c){
  for( int i=D[c]; i!=c; i=D[i] )
    for( int j=L[i]; j!=i; j=L[j] ){
      U[D[j]]=D[U[j]]=j; S[C[j]]++;
    }
  L[R[c]]=R[L[c]]=c;
}
int dfs(){
  if(R[0]==0) return 1;
  int md=100000000,c;
  for( int i=R[0]; i!=0; i=R[i] )
    if(S[i]<md){ md=S[i]; c=i; }
  if(md==0) return 0;
  remove(c);
  for( int i=D[c]; i!=c; i=D[i] ){
    used[ROW[i]]=1;
    for( int j=R[i]; j!=i; j=R[j] ) remove(C[j]);
    if(dfs()) return 1;
    for( int j=L[i]; j!=i; j=L[j] ) resume(C[j]);
    used[ROW[i]]=0;
  }
  resume(c);
  return 0;
}
int exact_cover(int n,int m){
  for( int i=0; i<=m; i++ ){
    R[i]=i+1; L[i]=i-1; U[i]=D[i]=i;
    S[i]=0; C[i]=i;
  }
  R[m]=0; L[0]=m;
  int t=m+1;
  for( int i=0; i<n; i++ ){
    int k=-1;
    for( int j=0; j<m; j++ ){
      if(!A[i][j]) continue;
      if(k==-1) L[t]=R[t]=t;
      else{ L[t]=k; R[t]=R[k]; }
      k=t; D[t]=j+1; U[t]=U[j+1];
      L[R[t]]=R[L[t]]=U[D[t]]=D[U[t]]=t;
      C[t]=j+1; S[C[t]]++; ROW[t]=i; id[i][j]=t++;
    }
  }
  for( int i=0; i<n; i++ ) used[i]=0;
  return dfs();
}
```