Algorithms

Algorithms by Yu Dongfeng
First version on April 12, 2013
Latest version on February 14, 2016

Contents

CHAPTER 1

Computational Geometry

1.1   Convex Hull

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Convex Hull.hpp (1063 bytes, 36 lines)

```cpp
 1  #include<bits/stdc++.h>
    using namespace std;
    template<class T>struct ConvexHull{
        struct point{
            T x,y;
            point(T _x,T _y):
                x(_x),y(_y){
            }
            point operator-(point a){
                return point(x-a.x,y-a.y);
11          }
            T operator*(point a){
                return x*a.y-y*a.x;
            }
            int operator<(point a){
                return x==a.x?y<a.y:x<a.x;
            }
        };
        static int check(point a,point b,point c){
            return (a-c)*(b-c)<=0;
21      }
        static vector<vector<point> >run(vector<point>a){
            sort(a.begin(),a.end());
            vector<point>u,d;
            for(int i=0;i<a.size();u.push_back(a[i++]))
                while(u.size()>1&&check(a[i],u.back(),u[u.size()-2]))
                    u.pop_back();
            for(int i=int(a.size()-1);i>=0;d.push_back(a[i--]))
                while(d.size()>1&&check(a[i],d.back(),d[d.size()-2]))
                    d.pop_back();
31          vector<vector<point> >r;
            r.push_back(u);
            r.push_back(d);
            return r;
        }
```

```
};
```

1.2   Delaunay Triangulation

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Delaunay Triangulation.hpp (4889 bytes, 159 lines)

```
   #include<bits/stdc++.h>
   using namespace std;
   template<class T>struct DelaunayTriangulation{
4      const static double E;
       struct poi{
           T x,y;
           poi(T _x=0,T _y=0):
               x(_x),y(_y){
           }
           poi operator−(poi b){
               return poi(x−b.x,y−b.y);
           }
           int operator<(poi b)const{
14             if(fabs(x−b.x)<E)
                   return y<b.y;
               return x<b.x;
           }
       };
       int n;
       vector<pair<poi,int> >pts;
       vector<vector<int> >egs;
       T det(poi a,poi b){
           return a.x*b.y−a.y*b.x;
24     }
       T dot(poi a,poi b){
           return a.x*b.x+a.y*b.y;
       }
       int dir(poi a,poi b,poi c){
           T r=det(c−a,b−a);
           if(r<−E)
               return −1;
           return r>E?1:0;
```

```
         }
34       int inc(poi a,poi b,poi c,poi d){
             a=a−d;
             b=b−d;
             c=c−d;
             T az=a.x*a.x+a.y*a.y,bz=b.x*b.x+b.y*b.y,cz=c.x*c.x+c.y*c.y;
             return a.x*b.y*cz+b.x*c.y*az+c.x*a.y*bz−a.x*bz*c.y−b.x*a.y*cz−c.x*
         b.y*az>E;
         }
         int crs(poi a,poi b,poi c,poi d){
             return dir(a,b,c)*dir(a,b,d)==−1&&dir(c,d,a)*dir(c,d,b)==−1;
         }
44       DelaunayTriangulation():
             n(0),pts(1){
         }
         void add(T x,T y){
             poi a;
             a.x=x;
             a.y=y;
             pts.push_back(make_pair(a,++n));
         }
         poi&pot(int a){
54           return pts[a].first;
         }
         void con(int a,int b){
             egs[a].push_back(b);
             egs[b].push_back(a);
         }
         void dco(int a,int b){
             egs[a].erase(find(egs[a].begin(),egs[a].end(),b));
             egs[b].erase(find(egs[b].begin(),egs[b].end(),a));
         }
64       void dnc(int l,int r){
             if(r==l)
                 return;
             if(r==l+1){
                 con(l,r);
                 return;
             }
             if(r==l+2){
                 if(dir(pot(l),pot(l+1),pot(r)))
```

```
                    con(l,l+1),con(l+1,r),con(l,r);
74          else{
                if(dot(pot(l+1)−pot(l),pot(r)−pot(l))<0)
                    con(l,l+1),con(l,r);
                else if(dot(pot(l)−pot(l+1),pot(r)−pot(l+1))<0)
                    con(l,l+1),con(l+1,r);
                else
                    con(l,r),con(l+1,r);}
            return;
        }
        int m=(l+r)/2,pl=l,pr=r;
84      dnc(l,m);
        dnc(m+1,r);
        for(int f=0;;f=0){
            for(int i=0;i<egs[pl].size();++i){
                int a=egs[pl][i],d=dir(pot(pl),pot(pr),pot(a));
                if(d>0||(d==0&&dot(pot(pl)−pot(a),pot(pr)−pot(a))<0)){
                    pl=a;
                    f=1;
                    break;
                }
94          }
            for(int i=0;i<egs[pr].size();++i){
                int a=egs[pr][i],d=dir(pot(pl),pot(pr),pot(a));
                if(d>0||(d==0&&dot(pot(pl)−pot(a),pot(pr)−pot(a))<0)){
                    pr=a;
                    f=1;
                    break;
                }
            }
            if(!f)
104             break;
        }
        con(pl,pr);
        for(int pn=−1,wh=0;;pn=−1,wh=0){
            for(int i=0;i<egs[pl].size();++i){
                int a=egs[pl][i],d=dir(pot(pl),pot(pr),pot(a));
                if(d<0&&(pn==−1||inc(pot(pl),pot(pr),pot(pn),pot(a))))
                    pn=a;
            }
            for(int i=0;i<egs[pr].size();++i){
```

```
114                    int a=egs[pr][i],d=dir(pot(pl),pot(pr),pot(a));
                       if(d<0&&(pn==−1||inc(pot(pl),pot(pr),pot(pn),pot(a))))
                           pn=a,wh=1;
                   }
                   if(pn==−1)
                       break;
                   vector<int>ne;
                   if(!wh){
                       for(int i=0;i<egs[pl].size();++i){
                           int a=egs[pl][i];
124                        if(!crs(pot(pn),pot(pr),pot(pl),pot(a)))
                               ne.push_back(a);
                           else
                               egs[a].erase(find(egs[a].begin(),egs[a].end(),pl));
                       }
                       egs[pl]=ne;
                       con(pr,pn);
                       pl=pn;
                   }else{
                       for(int i=0;i<egs[pr].size();++i){
134                        int a=egs[pr][i];
                           if(!crs(pot(pn),pot(pl),pot(pr),pot(a)))
                               ne.push_back(a);
                           else
                               egs[a].erase(find(egs[a].begin(),egs[a].end(),pr));
                       }
                       egs[pr]=ne;
                       con(pl,pn);
                       pr=pn;
                   }
144            }
           }
       vector<vector<int> >run(){
           egs.resize(n+1);
           sort(pts.begin()+1,pts.end());
           dnc(1,n);
           vector<vector<int> >res(n+1);
           for(int u=1;u<=n;++u)
               for(int i=0;i<egs[u].size();++i){
                   int v=egs[u][i];
154                res[pts[u].second].push_back(pts[v].second);
```

```
          }
        return res;
      }
};
template<class T>const double DelaunayTriangulation<T>::E=1e−8;
```

1.3   Dynamic Convex Hull (Set)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Dynamic Convex Hull (Set).hpp (2239 bytes, 77 lines)

```
 1  #include<bits/stdc++.h>
    using namespace std;
    template<class T>struct DynamicConvexHull{
        struct point{
            T x,y;
            point(T _x=0,T _y=0):
                x(_x),y(_y){
            }
            point operator−(const point&a)const{
                point p(x−a.x,y−a.y);
11              return p;
            }
            T operator*(const point&a)const{
                return x*a.y−y*a.x;
            }
        };
        struct node{
            node**nxt;point p;
            node(node** _n,point _p):
                nxt(_n),p(_p){
21          }
            node(const node&a):
                nxt(new node*(*a.nxt)),p(a.p){
            }
            ~node(){
                delete nxt;
            }
            int operator<(const node&a)const{
```

```
                if(ctp)
                    return p.x==a.p.x?p.y<a.p.y:p.x<a.p.x;
31              point p1,p2;
                int f=1;
                if(nxt)
                    p1=*nxt?(*nxt)−>p−p:point(0,−1),p2=a.p;
                else
                    f=0,p1=*a.nxt?(*a.nxt)−>p−a.p:point(0,−1),p2=p;
                T x=p1*p2;
                return f?x<0:x>0;
            }
        };
41      static int ctp;
        set<node>nds;
        typedef typename set<node>::iterator P;
        int check(P a,P b,P c){
            return (b−>p−a−>p)*(c−>p−b−>p)>=0;
        }
        void next(P a,P b){
            *(a−>nxt)=(node*)&*b;
        }
        void insert(T x,T y){
51          ctp=1;
            node t(new node*(0),point(x,y));
            P it=nds.insert(t).first,itl1=it,itl2=it,itr1=it,itr2=it;
            if(it!=nds.begin())
                for(next(−−itl1,it);itl1!=nds.begin()&&check(−−(itl2=itl1),
    itl1,it);)
                    next(itl2,it),nds.erase(itl1),itl1=itl2;
            if(++(itr1=it)!=nds.end())
                next(it,itr1);
            if(itl1!=it&&itr1!=nds.end()&&check(itl1,it,itr1)){
                next(itl1,itr1);
61              nds.erase(it);
                return;
            }
            if(itr1!=nds.end())
                for(;++(itr2=itr1)!=nds.end()&&check(it,itr1,itr2);)
                    next(it,itr2),nds.erase(itr1),itr1=itr2;
        }
        int size(){
```

```
            return nds.size();
        }
71      pair<T,T>query(T x,T y){
            ctp=0;
            node t=*nds.lower_bound(node(0,point(x,y)));
            return make_pair(t.p.x,t.p.y);
        }
    };
    template<class T>int DynamicConvexHull<T>::ctp=0;
```

1.4 Dynamic Convex Hull (Treap)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Dynamic Convex Hull (Treap).hpp (9485 bytes, 327 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
 3  template<class T>struct DynamicConvexHull{
        struct point{
            T x,y;
            point(T _x,T _y):
                x(_x),y(_y){
            }
            point operator-(const point&a)const{
                point p(x-a.x,y-a.y);
                return p;
            }
13          T operator*(const point&a)const{
                return x*a.y-y*a.x;
            }
            int operator<(const point&a)const{
                return x==a.x?y<a.y:x<a.x;
            }
            int operator==(const point&a)const{
                return x==a.x&&y==a.y;
            }
        };
23      struct hull{
            point*pt;
```

```
            hull*ch[2],*nb[2];
            int sz,fx;
            hull(point*_pt):
                pt(_pt),sz(1),fx(rand()*1.0/RAND_MAX*1e9){
                ch[0]=ch[1]=nb[0]=nb[1]=0;
            }
            T check(point p){
                return (nb[1]?*nb[1]->pt-*pt:point(0,-1))*p;
33          }
            void update(){
                sz=1;
                for(int i=0;i<2;++i)
                    if(ch[i])
                        sz+=ch[i]->sz;
            }
        };
        static int sz(hull*x){
            return x?x->sz:0;
43      }
        static point&pt(hull*x){
            return*x->pt;
        }
        static struct memory{
            hull*ps,*pp,**ss,**sp;
            int pm,sm;
            vector<hull*>ns;
            memory():
                ps((hull*)malloc(sizeof(hull))),pp(ps),pm(1),ss((hull**)malloc(
        sizeof(hull*))),sp(ss),sm(1){
53              ns.push_back(ps);
            }
            ~memory(){
                free(ss);
                for(int i=0;i<ns.size();++i)
                    free(ns[i]);
            }
            hull*create(const hull&x){
                if(sp!=ss){
                    --sp;
63                  **sp=x;
                    return*sp;
```

```
                }
                if(pp==ps+pm){
                    pp=ps=(hull*)malloc(sizeof(hull)*(pm<<=1));
                    ns.push_back(ps);
                }
                *pp=x;
                return pp++;
            }
73          void destroy(hull*x){
                if(sp==ss+sm){
                    hull**t=(hull**)malloc(sizeof(hull*)*sm<<1);
                    memcpy(t,ss,sm*sizeof(hull*));
                    free(ss);
                    sp=(ss=t)+sm;
                    sm<<=1;}
                *(sp++)=x;
            }
        }me;
83      struct array{
            hull**ps,**pp;
            int pm;
            array():
                ps((hull**)malloc(sizeof(hull*))),pp(ps),pm(1){
            }
            ~array(){
                free(ps);
            }
            int size(){
93              return pp-ps;
            }
            hull*operator[](int i){
                return ps[i];
            }
            void push(hull*x){
                if(pp==ps+pm){
                    hull**t=(hull**)malloc(sizeof(hull*)*pm<<1);
                    memcpy(t,ps,pm*sizeof(hull*));
                    free(ps);
103                 pp=(ps=t)+pm;
                    pm<<=1;
                }
```

```
                *(pp++)=x;
            }
        };
        static hull*link(hull*x,hull*y,hull*lb,hull*rb,int d,array&ns){
            hull*r=me.create(*x);
            if(x==lb||x==rb){
                r->nb[d]=y;
113             if(y)
                    y->nb[!d]=r;
            }else
                r->ch[d]=link(r->ch[d],y,lb,rb,d,ns);
            r->update();
            ns.push(r);
            return r;
        }
        static hull*merge(hull*x,hull*y,hull*lb,hull*rb,array&ns){
            if(!x)
123             return y;
            if(!y)
                return x;
            int d=x->fx>y->fx;
            hull*r=me.create(d?*x:*y);
            r->ch[d]=d?merge(r->ch[1],y,lb,rb,ns):merge(x,y->ch[0],lb,rb,ns);
            if(d&&x==lb||!d&&y==rb)
                r->ch[d]=link(r->ch[d],r,lb,rb,!d,ns);
            r->update();
            ns.push(r);
133         return r;
        }
        static pair<hull*,hull*>split(hull*x,int k,array&ns){
            if(!x)
                return make_pair((hull*)0,(hull*)0);
            int t=sz(x->ch[0])+1;
            hull*r=me.create(*x);
            ns.push(r);
            pair<hull*,hull*>s=split(x->ch[k>=t],k-t*(k>=t),ns);
            if(k>=t){
143             r->ch[1]=s.first;r->update();
                return make_pair(r,s.second);
            }else{
                r->ch[0]=s.second;r->update();
```

```
                    return make_pair(s.first,r);
                }
            }
            static void turn(hull*&x,int d,int&k){
                k+=(sz((x=x->ch[d])->ch[!d])+1)*(2*d-1);
            }
153         static pair<T,T>range(hull*x){
                hull*l=x,*r=x;
                while(l->ch[0])
                    l=l->ch[0];
                while(r->ch[1])
                    r=r->ch[1];
                return make_pair(pt(l).x,pt(r).x);
            }
            static hull*merge(hull*x,hull*y,array&ns){
                int kp=sz(x->ch[0])+1,kq=sz(y->ch[0])+1,pd[2],qd[2];
163             pair<T,T>pr=range(x),qr=range(y);
                int pf=1;
                hull*p=x,*q=y;
                if(pr.second==qr.first&&pr.first==pr.second&&p->ch[pf=0])
                    turn(p,0,kp);
                for(point pq=pt(q)-pt(p);;pq=pt(q)-pt(p)){
                    pd[0]=(p->nb[0]&&(pt(p->nb[0])-pt(p))*pq<=0)*pf;
                    qd[1]=(q->nb[1]&&(pt(q->nb[1])-pt(q))*pq<=0);
                    pd[1]=(p->nb[1]&&(pt(p->nb[1])-pt(p))*pq<0)*pf;
                    qd[0]=(q->nb[0]&&(pt(q->nb[0])-pt(q))*pq<0);
173                 if(!(pd[0]+pd[1]+qd[0]+qd[1])){
                        hull*l=split(x,kp,ns).first,*r=split(y,kq-1,ns).second,*lb=
        l,*rb=r;
                        while(lb->ch[1])
                            lb=lb->ch[1];
                        while(rb->ch[0])
                            rb=rb->ch[0];
                        return merge(l,r,lb,rb,ns);
                    }
                    if(!(pd[0]+pd[1]))
                        turn(q,qd[1],kq);
183                 if(!(qd[0]+qd[1]))
                        turn(p,pd[1],kp);
                    if(pd[0]&&qd[1])
                        turn(p,0,kp),turn(q,1,kq);
```

```
                    if(pd[1]&&qd[1])
                        turn(q,1,kq);
                    if(pd[0]&&qd[0])turn(p,0,kp);
                    if(pd[1]&&qd[0]){
                        point vp=pt(p->nb[1])-pt(p),vq=pt(q->nb[0])-pt(q);
                        if(vp.x==0&&vq.x==0)
193                         turn(p,1,kp),turn(q,0,kq);
                        else if(vp.x==0)
                            turn(p,1,kp);
                        else if(vq.x==0)
                            turn(q,0,kq);
                        else{
                            long double m=pr.second,pb=vp.y*(m-pt(p).x),qb=vq.y*(m-
    pt(q).x);
                            pb=pb/vp.x+pt(p).y;
                            qb=qb/vq.x+pt(q).y;
                            if(qb>pb+1e-8)
203                             turn(q,0,kq);
                            else if(pb>qb+1e-8)
                                turn(p,1,kp);
                            else if(pt(q->nb[0]).x+pt(p->nb[1]).x<2*m)
                                turn(q,0,kq);
                            else
                                turn(p,1,kp);
                        }
                    }
                }
213     }
        hull*query(hull*x,point p){
            for(hull*y=0;;){
                T d=x->check(p);
                if(d>0)
                    y=x,x=x->ch[0];
                else if(d<0)
                    x=x->ch[1];
                else
                    y=x;
223             if(!d||!x)
                    return y;
            }
        }
```

```
        struct treap{
            int fx,ct,sz;
            point pt;
            treap*ch[2];
            struct hull*ip,*hu;
            array ns;
233         treap(point _pt):
                fx(rand()*1.0/RAND_MAX*1e9),ct(1),sz(1),pt(_pt),ip(me.create(
        hull(&pt))),hu(ip){
                ch[0]=ch[1]=0;
            }
            ~treap(){
                for(hull**i=ns.ps;i!=ns.pp;++i)
                    me.destroy(*i);
                me.destroy(ip);
            }
            void update(){
243             for(hull**i=ns.ps;i!=ns.pp;++i)
                    me.destroy(*i);
                ns.pp=ns.ps;
                sz=1;
                hu=ip;
                if(ch[0])
                    hu=merge(ch[0]->hu,hu,ns),sz+=ch[0]->sz;
                if(ch[1])
                    hu=merge(hu,ch[1]->hu,ns),sz+=ch[1]->sz;
            }
253     }*root;
        void rotate(treap*&x,int d){
            treap*y=x->ch[d];
            x->ch[d]=y->ch[!d];
            y->ch[!d]=x;
            x=y;
        }
        int insert(treap*&x,point p){
            if(!x)
                x=new treap(p);
263         else if(p==x->pt){
                ++x->ct;
                return 0;
            }else{
```

```
                int d=x->pt<p;
                if(!insert(x->ch[d],p))
                    return 0;
                if(x->ch[d]->fx>x->fx)
                    rotate(x,d),x->ch[!d]->update();
                x->update();
273         }
            return 1;
        }
        int erase(treap*&x,point p){
            if(p==x->pt){
                if(x->ct>1){
                    --x->ct;
                    return 0;
                }
                treap*y=x;
283             if(!x->ch[0])
                    x=x->ch[1],delete y;
                else if(!x->ch[1])
                    x=x->ch[0],delete y;
                else{
                    int d=x->ch[0]->fx<x->ch[1]->fx;
                    rotate(x,d);
                    erase(x->ch[!d],p);
                    x->update();
                }
293             return 1;
            }
            if(erase(x->ch[x->pt<p],p)){
                x->update();
                return 1;
            }else{
                --x->sz;
                return 0;
            }
        }
303     void clear(treap*x){
            if(x)
                clear(x->ch[0]),clear(x->ch[1]),delete x;
        }
        DynamicConvexHull():
```

```
          root(0){
      }
      ~DynamicConvexHull(){
          clear(root);
      }
313   int size(){
          return root?root->sz:0;
      }
      void insert(T x,T y){
          insert(root,point(x,y));
      }
      void erase(T x,T y){
          erase(root,point(x,y));
      }
      pair<T,T>query(T x,T y){
323       point r=pt(query(root->hu,point(x,y)));
          return make_pair(r.x,r.y);
      }
};
template<class T>typename DynamicConvexHull<T>::memory DynamicConvexHull<T
    >::me;
```

1.5   Geometry 2D

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Geometry 2D.hpp (5031 bytes, 159 lines)

```
#include<bits/stdc++.h>
using namespace std;
3 namespace Geometry2D{
    double eps=1e-8;
    long double pi=acos((long double)-1);
    template<class T>T sqr(T a){
        return a*a;
    }
    template<class T>int cmp(T a,T b){
        if(typeid(T)==typeid(int)||typeid(T)==typeid(long long)){
            if(a==b)
                return 0;
```

```
13          return a<b?−1:1;
        }
        if(a<b−eps)
            return −1;
        if(a>b+eps)
            return 1;
        return 0;
    }
    template<class T>struct Point{
        T x,y;
23      Point(T _x=0,T _y=0):
            x(_x),y(_y){
        }
        Point<T>&operator+=(const Point<T>&a){
            return*this=*this+a;
        }
        Point<T>&operator−=(const Point<T>&a){
            return*this=*this−a;
        }
    };
33  #define Vector Point
    template<class T>Point<T>operator+(const Point<T>&a,const Point<T>&b){
        return Point<T>(a.x+b.x,a.y+b.y);
    }
    template<class T>Point<T>operator−(const Point<T>&a,const Point<T>&b){
        return Point<T>(a.x−b.x,a.y−b.y);
    }
    template<class T>Point<T>operator*(T a,const Point<T>&b){
        return Point<T>(b.x*a,b.y*a);
    }
43  template<class T>Point<T>operator*(const Point<T>&a,T b){
        return b*a;
    }
    template<class T>Point<T>operator/(const Point<T>&a,T b){
        return Point<T>(a.x/b,a.y/b);
    }
    template<class T>bool operator==(const Point<T>&a,const Point<T>&b){
        return !cmp(a.x,b.x)&&!cmp(a.y,b.y);
    }
    template<class T>bool operator!=(const Point<T>&a,const Point<T>&b){
53      return !(a==b);
```

```
        }
        template<class T>bool operator<(const Point<T>&a,const Point<T>&b){
            int t=cmp(a.x,b.x);
            if(t)
                return t<0;
            return cmp(a.y,b.y)<0;
        }
        template<class T>bool operator>(const Point<T>&a,const Point<T>&b){
            return b<a;
63      }
        template<class T>Point<T>NaP(){
            T t=numeric_limits<T>::max();
            return Point<T>(t,t);
        }
        template<class T>T det(const Point<T>&a,const Point<T>&b){
            return a.x*b.y−a.y*b.x;
        }
        template<class T>T dot(const Point<T>&a,const Point<T>&b){
            return a.x*b.x+a.y*b.y;
73      }
        template<class T>T abs(const Point<T>&a){
            return sqrt(sqr(a.x)+sqr(a.y));
        }
        template<class T>T dis(const Point<T>&a,const Point<T>&b){
            return abs(a−b);
        }
        template<class T>istream&operator>>(istream&s,Point<T>&a){
            return s>>a.x>>a.y;
        }
83      template<class T>ostream&operator<<(ostream&s,const Point<T>&a){
            return s<<a.x<<" "<<a.y;
        }
        template<class T>struct Segment;
        template<class T>struct Line{
            Point<T>u,v;
            Line(const Point<T>&_u=Point<T>(),const Point<T>&_v=Point<T>()):
                u(_u),v(_v){
            }
            Line(const Segment<T>&a):
93              u(a.u),v(a.v){
            }
```

```
        };
        template<class T>Point<T>nor(const Line<T>&a){
            Point<T>t=a.v−a.u;
            return Point<T>(t.y,−t.x);
        }
        template<class T>Point<T>dir(const Line<T>&a){
            return a.v−a.u;
        }
103     template<class T>int dir(const Line<T>a,const Point<T>b){
            return cmp(det(b−a.u,a.v−a.u),T(0));
        }
        template<class T>Point<T>operator&(const Line<T>&a,const Line<T>&b){
            T p=det(b.u−a.v,b.v−b.u),q=det(a.u−b.v,b.v−b.u);
            return (a.u*p+a.v*q)/(p+q);
        }
        template<class T>struct Segment{
            Point<T>u,v;
            Segment(const Point<T>&_u=Point<T>(),const Point<T>&_v=Point<T>()):
113             u(_u),v(_v){
            }
        };
        template<class T>Point<T>nor(const Segment<T>&a){
            Point<T>t=a.v−a.u;
            return Point<T>(t.y,−t.x);
        }
        template<class T>Point<T>dir(const Segment<T>&a){
            return a.v−a.u;
        }
123     template<class T>int dir(const Segment<T>a,const Point<T>b){
            return cmp(b−a.u,a.v−a.u);
        }
        template<class T>Point<T>operator&(const Line<T>&a,const Segment<T>&b){
            if(dir(a,b.u)*dir(a,b.v)<=0)
                return a&Line<T>(b);
            return NaP<T>();
        }
        template<class T>Point<T>operator&(const Segment<T>&a,const Line<T>&b){
            return b&a;
133     }
        template<class T>pair<T,T>dis(const Segment<T>&a,const Point<T>&b){
            pair<T,T>d(dis(a.u,b),dis(a.v,b));
```

```
            if(d.first>d.second)
                swap(d.first,d.second);
            Point<T>t=Line<T>(b,b+nor(a))&a;
            if(t!=NaP<T>())
                d.first=dis(t,b);
            return d;
        }
143     template<class T>pair<T,T>dis(const Point<T>&a,const Segment<T>&b){
            return dis(b,a);
        }
        template<class T>struct Circle{
            Point<T>c;
            T r;
            Circle(const Point<T>&_c=Point<T>(),T _r=0):
                c(_c),r(_r){
            }
        };
153     template<class T>T abs(const Circle<T>&a){
            return pi*sqr(a.r);
        }
        template<class T>bool col(const Point<T>&a,const Point<T>&b,const Point
        <T>&c){
            return !cmp(det(a−c,b−c),T(0));
        }
    }
```

1.6 Half-Plane Intersection

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Half-Plane Intersection.hpp (1950 bytes, 70 lines)

```
1   #include<bits/stdc++.h>
    using namespace std;
    namespace HalfPlaneIntersection{
        const double E=1e−8;
        struct pot{
            pot(double a=0,double b=0):
                x(a),y(b){
            }
```

```
          double x,y;
      };
11    double ag(pot p){
          return atan2(double(p.x),double(p.y));
      }
      pot operator+(pot p,pot q){
          return pot(p.x+q.x,p.y+q.y);
      }
      pot operator−(pot p,pot q){
          return pot(p.x−q.x,p.y−q.y);
      }
      pot operator*(pot p,double q){
21        return pot(p.x*q,p.y*q);
      }
      pot operator/(pot p,double q){
          return pot(p.x/q,p.y/q);
      }
      double det(pot p,pot q){
          return p.x*q.y−q.x*p.y;
      }
      double dot(pot p,pot q){
          return p.x*q.x+p.y*q.y;
31    }
      struct lin{
          pot p,q;
          double a;
          lin(pot a,pot b):
              p(a),q(b),a(ag(b−a)){
          }
      };
      pot operator*(lin a,lin b){
          double a1=det(b.p−a.q,b.q−b.p);
41        double a2=det(a.p−b.q,b.q−b.p);
          return (a.p*a1+a.q*a2)/(a1+a2);
      }
      bool cmp(lin a,lin b){
          if(fabs(a.a−b.a)>E)
              return a.a<b.a;
          else
              return det(a.q−b.p,b.q−b.p)<−E;
      }
```

```
      bool left(lin a,lin b,lin c){
51         pot t=a*b;
           return det(t−c.p,c.q−c.p)<−E;
      }
      deque<lin>run(vector<lin>lns){
          deque<lin>ans;
          sort(lns.begin(),lns.end(),cmp);
          for(int i=0;i<lns.size();++i){
              while(ans.size()>1&&!left(ans.back(),ans[ans.size()−2],lns[i]))
                  ans.pop_back();
              while(ans.size()>1&&!left(ans[0],ans[1],lns[i]))
61                ans.pop_front();
              if(ans.empty()||fabs(ans.back().a−lns[i].a)>E)
                  ans.push_back(lns[i]);}
          while(ans.size()>1&&!left(ans[ans.size()−1],ans[ans.size()−2],ans.
      front()))
              ans.pop_back();
          if(ans.size()<3)
              ans.clear();
          return ans;
      }
  }
```

CHAPTER 2

Data Structures

2.1   Binary Heap

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Binary Heap.hpp (1629 bytes, 73 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
template<class T,class C>struct BinaryHeap{
    struct node{
        node(int _p,T _v):
            p(_p),v(_v){
        }
        int p;
        T v;
    };
    vector<node*>a;
    BinaryHeap():
        a(1){
    }
    ~BinaryHeap(){
        clear();
    }
    void move(int i,int j){
        swap(a[i]->p,a[j]->p);
        swap(a[i],a[j]);
    }
    int check(int i,int j){
        if(!j||j>=a.size()||a[i]->v==a[j]->v)
            return 0;
        return a[i]->v<a[j]->v?-1:1;
    }
    int up(int i){
        if(check(i,i>>1)<0){
            move(i,i>>1);
            return i>>1;
        }else
            return 0;
    }
    int down(int i){
        if(check(i,i<<1)<=0&&check(i,i<<1^1)<=0)
```

```
                return a.size();
            if(check(i<<1,i<<1^1)<=0){
                move(i,i<<1);
                return i<<1;
40          }else{
                move(i,i<<1^1);
                return i<<1^1;
            }
        }
        void maintain(int i){
            for(int j=up(i);j;i=j,j=up(i));
            for(int j=down(i);j<a.size();i=j,j=down(i));
        }
        void clear(){
50          for(int i=1;i<a.size();++i)
                delete a[i];
            a.resize(1);
        }
        node*push(T v){
            a.push_back(new node(a.size(),v));
            node*r=a.back();
            maintain(a.size()−1);
            return r;
        }
60      T top(){
            return a[1]−>v;
        }
        void pop(){
            move(1,a.size()−1);
            delete a.back();
            a.pop_back();
            maintain(1);
        }
        void modify(node*x,T v){
70          x−>v=v;
            maintain(x−>p);
        }
    };
```

2.2   Dynamic Sequence

warning: old style will be replaced ... see Suffix Array (DC3) for new style

<div align="center">Dynamic Sequence.hpp (4119 bytes, 177 lines)</div>

```cpp
     #include<bits/stdc++.h>
     using namespace std;
     template<class T>struct DynamicSequence{
         struct node{
             node(T _i):
                 i(_i),v(_i),s(1),r(0){
7                    c[0]=c[1]=0;
                     static int g;
                     w=g=(214013*g+2531011);
             }
             T i,v;
             int s,r,w;
             node*c[2];
         }*rt,*sl,*sr;
         struct pool{
             node*ps,*pp,**ss,**sp;
17           int pm,sm;
             vector<node*>ns;
             pool():
                 ps((node*)malloc(sizeof(node))),pp(ps),pm(1),ss((node**)malloc(
         sizeof(node*))),sp(ss),sm(1){
                     ns.push_back(ps);
             }
             ~pool(){
                 free(ss);
                 for(int i=0;i<ns.size();++i)
                     free(ns[i]);
27           }
             node*crt(T a){
                 if(sp!=ss){
                     --sp;
                     **sp=node(a);
                     return*sp;
                 }
                 if(pp==ps+pm){
```

```
                    pp=ps=(node*)malloc(sizeof(node)*(pm<<=1));
                    ns.push_back(ps);
37              }
                *pp=node(a);
                return pp++;
            }
            void des(node*x){
                if(sp==ss+sm){
                    node**t=(node**)malloc(sizeof(node*)*sm<<1);
                    memcpy(t,ss,sm*sizeof(node*));
                    free(ss);
                    sp=(ss=t)+sm;
47                  sm<<=1;
                }
                *(sp++)=x;
            }
        }me;
        node*bud(T*a,int l,int r){
            if(l>r)
                return 0;
            int m=l+r>>1;
            node*t=me.crt(a[m]);
57          t->c[0]=bud(a,l,m-1);
            t->c[1]=bud(a,m+1,r);
            pup(t);
            return t;
        }
        void pdw(node*x){
            for(int d=0;d<2&&(x->i>x->v,1);++d)
                if(x->c[d])
                    x->i>x->c[d]->i;
            *x->i;
67          *x->v;
            if(x->r){
                -x->i;
                for(int d=0;d<2;++d)
                    if(x->c[d])
                        x->c[d]->r^=1;
                swap(x->c[0],x->c[1]);
                x->r=0;
            }
```

```
        }
77      void pup(node*x){
            x−>i=x−>v;
            x−>s=1;
            for(int d=0;d<2;++d)
                if(x−>c[d])
                    pdw(x−>c[d]),x−>s+=x−>c[d]−>s,x−>i=d?x−>i+x−>c[d]−>i:x−>
        c[d]−>i+x−>i;
        }
        void jon(node*x){
            rt=jon(jon(sl,x),sr);
        }
87      node*jon(node*x,node*y){
            if(!x)
                return y;
            if(!y)
                return x;
            pdw(x);
            pdw(y);
            if(x−>w<y−>w){
                x−>c[1]=jon(x−>c[1],y);
                pup(x);
97              return x;
            }else{
                y−>c[0]=jon(x,y−>c[0]);
                pup(y);
                return y;
            }
        }
        node*spt(int l,int r){
            spt(rt,l−1);
            node*t=sl;
107         spt(sr,r−l+1);
            swap(sl,t);
            return t;
        }
        void spt(node*x,int p){
            if(!x){
                sl=sr=0;
                return;
            }
```

```
            pdw(x);
117         int t=x->c[0]?x->c[0]->s:0;
            if(t<p)
                spt(x->c[1],p-t-1),x->c[1]=sl,sl=x;
            else
                spt(x->c[0],p),x->c[0]=sr,sr=x;
            pup(x);
        }
        void clr(node*x){
            if(x)
                clr(x->c[0]),clr(x->c[1]),me.des(x);
127     }
        DynamicSequence(T*a=0,int n=0){
            rt=bud(a,1,n);
        }
        ~DynamicSequence(){
            clr(rt);
        }
        void clear(){
            clr(rt);
            rt=0;
137     }
        void insert(T a,int p){
            insert(&a-1,1,p);
        }
        void insert(T*a,int n,int p){
            spt(p+1,p);
            jon(bud(a,1,n));
        }
        void erase(int p){
            erase(p,p);
147     }
        void erase(int l,int r){
            clr(spt(l,r));
            jon(0);
        }
        T query(int p){
            return query(p,p);
        }
        T query(int l,int r){
            node*t=spt(l,r);
```

```
157          T i=t->i;
             jon(t);
             return i;
         }
         void modify(T a,int l){
             modify(a,l,l);
         }
         void modify(T a,int l,int r){
             node*t=spt(l,r);
             a>t->i;
167          jon(t);
         }
         void reverse(int l,int r){
             node*t=spt(l,r);
             t->r=1;
             jon(t);
         }
         int length(){
             return rt?rt->s:0;
         }
177  };
```

2.3   Fenwick Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Fenwick Tree.hpp (529 bytes, 25 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
 3  template<class T>struct FenwickTree{
        FenwickTree(int _n):
            n(_n),l(log2(n)),a(n+1){
        }
        void add(int v,T d){
            for(;v<=n;v+=v&-v)
                a[v]+=d;
        }
        T sum(int v){
            T r=0;
```

```
13          for(;v;v-=v&-v)
                r+=a[v];
            return r;
        }
        int kth(T k,int r=0){
            for(int i=1<<l;i;i>>=1)
                if(r+i<=n&&a[r+i]<k)
                    k-=a[r+=i];
            return r+1;
        }
23      int n,l;
        vector<T>a;
    };
```

2.4   K-D Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

K-D Tree.hpp (2467 bytes, 80 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
    struct KDTree{
        struct node{
5           node(int x0,int x1,int d):
                color(1),cover(0),dir(d){
                    ch[0]=ch[1]=0;
                    x[0]=mi[0]=mx[0]=x0;
                    x[1]=mi[1]=mx[1]=x1;
                }
            node*ch[2];
            int x[2],mi[2],mx[2],color,cover,dir;
        }*root;
        KDTree(pair<int,int>*a,int n){
15          root=build(a,1,n,0);
        }
        static int direct;
        static int cmp(pair<int,int>a,pair<int,int>b){
            if(direct)
                return make_pair(a.second,a.first)<make_pair(b.second,b.first);
```

```
        return a<b;
    }
    node*build(pair<int,int>*a,int l,int r,int d){
        int m=(r+l)/2;
25      direct=d;
        nth_element(a+l,a+m,a+r+1,cmp);
        node*p=new node((a+m)->first,(a+m)->second,d);
        if(l!=m)
            p->ch[0]=build(a,l,m-1,!d);
        if(r!=m)
            p->ch[1]=build(a,m+1,r,!d);
        for(int i=0;i<2;++i)
            for(int j=0;j<2;++j)
                if(p->ch[j]){
35                  p->mi[i]=min(p->mi[i],p->ch[j]->mi[i]);
                    p->mx[i]=max(p->mx[i],p->ch[j]->mx[i]);
                }
        return p;
    }
    void down(node*a){
        if(a->cover){
            for(int i=0;i<2;++i)
                if(a->ch[i])
                    a->ch[i]->cover=a->cover;
45          a->color=a->cover;
            a->cover=0;
        }
    }
    void modify(node*a,int mi0,int mx0,int mi1,int mx1,int c){
        if(mi0>a->mx[0]||mx0<a->mi[0]||mi1>a->mx[1]||mx1<a->mi[1])
            return;
        if(mi0<=a->mi[0]&&mx0>=a->mx[0]&&mi1<=a->mi[1]&&mx1>=a->mx[1]){
            a->cover=c;
            return;
55      }
        down(a);
        if(mi0<=a->x[0]&&mx0>=a->x[0]&&mi1<=a->x[1]&&mx1>=a->x[1])
            a->color=c;
        for(int i=0;i<2;++i)
            if(a->ch[i])
                modify(a->ch[i],mi0,mx0,mi1,mx1,c);
```

```
        }
        void modify(int mi0,int mx0,int mi1,int mx1,int c){
            modify(root,mi0,mx0,mi1,mx1,c);
65      }
        int query(node*a,int x0,int x1){
            down(a);
            if(x0==a->x[0]&&x1==a->x[1])
                return a->color;
            direct=a->dir;
            if(cmp(make_pair(x0,x1),make_pair(a->x[0],a->x[1])))
                return query(a->ch[0],x0,x1);
            else
                return query(a->ch[1],x0,x1);
75      }
        int query(int x0,int x1){
            return query(root,x0,x1);
        }
    };
    int KDTree::direct=0;
```

2.5   Link-Cut Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Link-Cut Tree.hpp (5518 bytes, 215 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
    template<class T>struct LinkCutTree{
        struct node{
            node():
                ch({0,0}),pr(0),rev(0){
            }
            node*ch[2],*pr;
            T ifo;
10          int rev;
        }*ptrs;
        LinkCutTree(int n):
            ptrs(new node[n]-1){
        }
```

```
        ~LinkCutTree(){
            delete ptrs;
        }
        int direct(node*x){
            if(!x−>pr)
20              return 2;
            if(x==x−>pr−>ch[0])
                return 0;
            if(x==x−>pr−>ch[1])
                return 1;
            return 2;
        }
        void down(node*x){
            if(x−>rev){
                x−>ifo.reverse();
30              swap(x−>ch[0],x−>ch[1]);
                for(int i=0;i<2;++i)
                    if(x−>ch[i])
                        x−>ch[i]−>rev^=1;
                x−>rev=0;
            }
            x−>ifo.down(x−>ch[0]?&x−>ch[0]−>ifo:0,x−>ch[1]?&x−>ch[1]−>ifo:0);
        }
        void up(node*x){
            for(int i=0;i<2;++i)
40              if(x−>ch[i])
                    down(x−>ch[i]);
            x−>ifo.up(x−>ch[0]?&x−>ch[0]−>ifo:0,x−>ch[1]?&x−>ch[1]−>ifo:0);
        }
        void setchild(node*x,node*y,int d){
            x−>ch[d]=y;
            if(y)
                y−>pr=x;
            up(x);
        }
50      void rotate(node*x){
            node*y=x−>pr,*z=y−>pr;
            int d1=direct(x),d2=direct(y);
            setchild(y,x−>ch[!d1],d1);
            setchild(x,y,!d1);
            if(d2<2)
```

```
                    setchild(z,x,d2);
                else
                    x->pr=z;
            }
60      void release(node*x){
            if(direct(x)<2)
                release(x->pr);
            down(x);
        }
        void splay(node*x){
            for(release(x);direct(x)<2;){
                node*y=x->pr;
                if(direct(y)==2)
                    rotate(x);
70              else if(direct(x)==direct(y))
                    rotate(y),rotate(x);
                else
                    rotate(x),rotate(x);
            }
        }
        node*access(node*x){
            node*y=0;
            for(;x;y=x,x=x->pr){
                splay(x);
80              setchild(x,y,1);
            }
            return y;
        }
        void evert(node*x){
            access(x);
            splay(x);
            x->rev=1;
        }
        void set(int x,T v){
90          ptrs[x].ifo=v;
        }
        int linked(int a,int b){
            access((ptrs+a));
            node*z=access((ptrs+b));
            return z==access((ptrs+a));
        }
```

```
        void link(int a,int b){
            evert((ptrs+b));
            (ptrs+b)->pr=(ptrs+a);
100     }
        void cut(int a,int b){
            access((ptrs+b));
            node*z=access((ptrs+a));
            if(z==(ptrs+a))
                splay((ptrs+b)),(ptrs+b)->pr=0;
            else
                access((ptrs+b)),splay((ptrs+a)),(ptrs+a)->pr=0;
        }
        int root(int a){
110         access((ptrs+a));
            splay((ptrs+a));
            node*r=(ptrs+a);
            while(r->ch[1])
                r=r->ch[1];
            return r-ptrs;
        }
        void evert(int a){
            evert((ptrs+a));
        }
120     int lca(int a,int b){
            access((ptrs+a));
            return access((ptrs+b))-ptrs;
        }
        T query(int a){
            splay((ptrs+a));
            T p=(ptrs+a)->ifo;
            p.up(0,0);
            return p;
        }
130     T query(int a,int b){
            if((ptrs+a)==(ptrs+b))
                return query((ptrs+a));
            access((ptrs+a));
            node*c=access((ptrs+b));
            T p=c.ifo;
            if(c==(ptrs+b)){
                splay((ptrs+a));
```

```
                    T q=(ptrs+a)−>ifo;
                    q.reverse();
140                 p.up(&q,0);
                    return p;
                }else if(c==(ptrs+a))
                    p.up(0,&(ptrs+a)−>ch[1]−>ifo);
                else{
                    splay((ptrs+a));
                    T q=(ptrs+a)−>ifo;
                    q.reverse();
                    p.up(&q,&c−>ch[1]−>ifo);
                }
150         return p;
        }
        T equery(int a){
            return query(a);
        }
        T equery(int a,int b){
            access((ptrs+a));
            node*c=access((ptrs+b));
            if(c==(ptrs+b)){
                splay((ptrs+a));
160             T q=(ptrs+a)−>ifo;
                q.reverse();
                return q;
            }else if(c==(ptrs+a))
                return (ptrs+a)−>ch[1]−>ifo;
            else{
                splay((ptrs+a));
                node*t=c−>ch[1];
                while(t−>ch[0])
                    t=t−>ch[0];
170             splay(t);
                if(t−>ch[1])
                    down(t−>ch[1]);
                T p=t−>ifo,q=(ptrs+a)−>ifo;
                q.reverse();
                p.up(&q,t−>ch[1]?&t−>ch[1]−>ifo:0);
                return p;
            }
        }
```

```
       template<class F>void modify(int a,F f){
180        splay((ptrs+a));
           f(&(ptrs+a)−>ifo);
           up((ptrs+a));
       }
       template<class F>void modify(int a,int b,F f){
           if((ptrs+a)==(ptrs+b)){
               splay((ptrs+a));
               f(0,&(ptrs+a)−>ifo,0);
               up((ptrs+a));
               return;
190        }
           access((ptrs+a));
           node*c=access((ptrs+b));
           if(c==(ptrs+b))
               splay((ptrs+a)),f(&(ptrs+a)−>ifo,&(ptrs+b)−>ifo,0);
           else if(c==a)
               f(0,&(ptrs+a)−>ifo,&(ptrs+a)−>ch[1]−>ifo);
           else
               splay(a),f(&(ptrs+a)−>ifo,&c−>ifo,&c−>ch[1]−>ifo);
           up(c);
200    }
       template<class F>void emodify(int a,F f){
           modify(a,f);
       }
       template<class F>void emodify(int a,int b,F f){
           access((ptrs+a));
           node*c=access((ptrs+b));
           if(c==(ptrs+b))
               splay((ptrs+a)),f(&(ptrs+a)−>ifo,0);
           else if(c==a)
210            f(0,&(ptrs+a)−>ch[1]−>ifo);
           else
               splay(a),f(&(ptrs+a)−>ifo,&c−>ch[1]−>ifo);
           up(c);
       }
   };
```

2.6   Pairing Heap

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Pairing Heap.hpp (2226 bytes, 102 lines)

```
     #include<bits/stdc++.h>
     using namespace std;
     template<class T,class C>struct PairingHeap{
         PairingHeap():
5            root(0),siz(0){
         }
         ~PairingHeap(){
             clear(root);
         }
         struct node{
             node(const T&_val):
                 val(_val),ch(0),br(0),pr(0){
             }
             T val;
15           node*ch,*br,*pr;
         }*root;
         int siz;
         void merge(node*&x,node*y){
             if(!x)
                 x=y;
             else if(y){
                 if(C()(y->val,x->val))
                     swap(x,y);
                 y->br=x->ch;
25               if(x->ch)
                     x->ch->pr=y;
                 y->pr=x;
                 x->ch=y;
             }
         }
         void cut(node*&x,node*y){
             if(x==y)
                 x=0;
             else{
35               if(y==y->pr->ch)
```

```
                    y−>pr−>ch=y−>br;
                else
                    y−>pr−>br=y−>br;
                if(y−>br)
                    y−>br−>pr=y−>pr;
                y−>pr=y−>br=0;
            }
        }
        node*split(node*x){
45          vector<node*>t;
            for(node*i=x−>ch;i;i=i−>br)
                t.push_back(i);
            x−>ch=0;
            node*r=0;
            for(int i=0;i<t.size();++i)
                t[i]−>pr=t[i]−>br=0;
            for(int i=0;i+1<t.size();i+=2)
                merge(t[i],t[i+1]);
            for(int i=0;i<t.size();i+=2)
55              merge(r,t[i]);
            return r;
        }
        void clear(node*x){
            if(x){
                clear(x−>ch);
                clear(x−>br);
                delete x;
            }
        }
65      void clear(){
            clear(root);
            root=0;
            siz=0;
        }
        node*push(T a){
            node*r=new node(a);
            merge(root,r);
            ++siz;
            return r;
75      }
        void erase(node*x){
```

```
            cut(root,x);
            merge(root,split(x));
            --siz;
        }
        T top(){
            return root->val;
        }
        void pop(){
85          erase(root);
        }
        void merge(PairingHeap<T,C>&a){
            merge(root,a.root);
            a.root=0;
            siz+=a.siz;
            a.siz=0;
        }
        void modify(node*x,T v){
            if(C()(x->val,v))
95              x->val=v,merge(root,split(x));
            else
                x->val=v,cut(root,x),merge(root,x);
        }
        int size(){
            return siz;
        }
    };
```

2.7   Red-Black Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Red-Black Tree.hpp (7432 bytes, 307 lines)

```
#include<bits/stdc++.h>
using namespace std;
template<class T,class C>struct RedBlackTree{
    struct node{
        node(T _v,node*l,node*r,node*_p,int _b,int _s):
            v(_v),p(_p),b(_b),s(_s){
            c[0]=l;
```

```
 8                c[1]=r;
             }
             T v;
             node*c[2],*p;
             int b,s;
         }*root,*nil;
         void clear(node*x){
             if(x!=nil){
                 clear(x->c[0]);
                 clear(x->c[1]);
18               delete x;
             }
         }
         void rotate(node*x,int d){
             node*y=x->c[!d];
             x->c[!d]=y->c[d];
             if(y->c[d]!=nil)
                 y->c[d]->p=x;
             y->p=x->p;
             if(x->p==nil)
28               root=y;
             else
                 x->p->c[x!=x->p->c[0]]=y;
             y->c[d]=x;
             x->p=y;
             y->s=x->s;
             x->s=x->c[0]->s+x->c[1]->s+1;
         }
         void insert_fixup(node*z){
             while(!z->p->b){
38               int d=z->p==z->p->p->c[0];
                 node*y=z->p->p->c[d];
                 if(!y->b)
                     z->p->b=1,y->b=1,(z=z->p->p)->b=0;
                 else{
                     if(z==z->p->c[d])
                         rotate(z=z->p,!d);
                     z->p->b=1;
                     z->p->p->b=0;
                     rotate(z->p->p,d);
48               }
```

```
              }
              root->b=1;
          }
          void erase(node*z){
              node*y;
              for(y=z;y!=nil;y=y->p)
                  --y->s;
              if(z->c[0]==nil||z->c[1]==nil)
                  y=z;
58            else{
                  for(y=z->c[1];y->c[0]!=nil;)
                      y=y->c[0];
                  z->v=y->v;
                  y=z->c[1];
                  while(y->c[0]!=nil)
                      --y->s,y=y->c[0];
              }
              node*x=y->c[y->c[0]==nil];
              x->p=y->p;
68            if(y->p==nil)
                  root=x;
              else
                  y->p->c[y!=y->p->c[0]]=x;
              if(y->b)
                  erase_fixup(x);
              delete y;
          }
          void erase_fixup(node*x){
              while(x!=root&&x->b){
78                int d=x==x->p->c[0];
                  node*w=x->p->c[d];
                  if(!w->b){
                      w->b=1;
                      x->p->b=0;
                      rotate(x->p,!d);
                      w=x->p->c[d];
                  }
                  if(w->c[0]->b&&w->c[1]->b)
                      w->b=0,x=x->p;
88                else{
                      if(w->c[d]->b)
```

```
                  w−>c[!d]−>b=1,w−>b=0,rotate(w,d),w=x−>p−>c[d];
              w−>b=x−>p−>b;
              x−>p−>b=1;
              w−>c[d]−>b=1;
              rotate(x−>p,!d);
              x=root;
          }
      }
98    x−>b=1;
   }
   node*clone(node*x,node*y){
       if(x.size==0)
           return nil;
       node*z=new node(*x);
       z−>c[0]=clone(x−>c[0],z);
       z−>c[1]=clone(x−>c[1],z);
       z−>p=y;
       return z;
108 }
   node*precursor(node*x){
       if(x−>c[0]−>count){
           for(x=x−>c[0];x−>c[1]−>count;)
               x=x−>c[1];
           return x;
       }else{
           node*y=x−>p;
           while(y−>count&&x==y−>c[0])
               x=y,y=y−>p;
118         return y;
       }
   }
   node*successor(node*x){
       if(x−>c[1]−>count){
           for(x=x−>c[1];x−>c[0]−>count;)
               x=x−>c[0];
           return x;
       }else{
           node*y=x−>p;
128         while(y−>count&&x==y−>c[1])
               x=y,y=y−>p;
           return y;
```

```
            }
        }
        RedBlackTree(){
            root=nil=(node*)malloc(sizeof(node));
            nil->b=1;
            nil->s=0;
        }
138     RedBlackTree(const RedBlackTree&a){
            nil=new node(*a.nil);
            root=clone(a.root,nil);
        }
        ~RedBlackTree(){
            clear(root);
            free(nil);
        }
        RedBlackTree&operator=(const RedBlackTree&a){
            clear(root);
148         root=clone(a.root,nil);
            return*this;
        }
        node*begin(){
            node*z=root;
            while(z!=nil&&z->c[0]!=nil)
                z=z->c[0];
            return z;
        }
        node*reverse_begin(){
158         node*z=root;
            while(z!=nil&&z->c[1]!=nil)
                z=z->c[1];
            return z;
        }
        node*end(){
            return nil;
        }
        node*reverse_end(){
            return nil;
168     }
        void clear(){
            clear(root);
            root=nil;
```

```
          }
          void insert(T a){
              node*y=nil,*x=root;
              while(x!=nil)
                  y=x,++x−>s,x=x−>c[C()(x−>v,a)];
              node*z=new node(a,nil,nil,y,0,1);
178       if(y==nil)
                  root=z;
              else
                  y−>c[C()(y−>v,z−>v)]=z;
              insert_fixup(z);
          }
          void erase(T a){
              node*z=root;
              for(;;)
                  if(C()(a,z−>v))
188               z=z−>c[0];
                  else if(C()(z−>v,a))
                      z=z−>c[1];
                  else
                      break;
              erase(z);
          }
          int count(T a){
              return count_less_equal(a)−count_less(a);
          }
198     int count_less(T a){
              int r=0;
              node*z=root;
              while(z!=nil)
                  if(C()(z−>v,a))
                      r+=z−>c[0]−>s+1,z=z−>c[1];
                  else
                      z=z−>c[0];
              return r;
          }
208     int count_less_equal(T a){
              int r=0;
              node*z=root;
              while(z!=nil){
                  if(!C()(a,z−>v))
```

```
                    r+=z−>c[0]−>s+1,z=z−>c[1];
                else
                    z=z−>c[0];
            }
            return r;
218     }
        int count_greater(T a){
            int r=0;
            node*z=root;
            while(z!=nil)
                if(C()(a,z−>v))
                    r+=z−>c[1]−>s+1,z=z−>c[0];
                else
                    z=z−>c[1];
            return r;
228     }
        int count_greater_equal(T a){
            int r=0;
            node*z=root;
            while(z!=nil)
                if(!C()(z−>v,a))
                    r+=z−>c[1]−>s+1,z=z−>c[0];
                else
                    z=z−>c[1];
            return r;
238     }
        node*nth_element(int a){
            node*z=root;
            for(;;)
                if(z−>c[0]−>s>=a)
                    z=z−>c[0];
                else if((z−>c[0]−>s+1)<a)
                    a−=z−>c[0]−>s+1,z=z−>c[1];
                else
                    return z;
248     }
        node*precursor(T a){
            node*z=root,*r=nil;
            while(z!=nil)
                if(C()(z−>v,a))
                    r=z,z=z−>c[1];
```

```
                else
                    z=z->c[0];
            return r;
        }
258     node*successor(T a){
            node*z=root,*r=nil;
            while(z!=nil)
                if(C()(a,z->v))
                    r=z,z=z->c[0];
                else
                    z=z->c[1];
            return r;
        }
        node*find(T a){
268         node*z=root,*r=nil;
            while(z!=nil)
                if(C()(a,z->v))
                    z=z->c[0];
                else if(C()(z->v,a))
                    z=z->c[1];
                else
                    break;
            return r;
        }
278     node*lower_bound(T a){
            node*z=root,*r=nil;
            while(z!=nil)
                if(C()(z->v,a))
                    r=z,z=z->c[1];
                else if(C()(a,z->v))
                    z=z->c[0];
                else
                    r=z,z=z->c[0];
            return r;
288     }
        node*upper_bound(T a){
            return successor(a);
        }
        pair<node*,node*> equal_range(T a){
            return make_pair(lower_bound(a),upper_bound(a));
        }
```

```
        int size(){
            return root->s;
        }
298     int empty(){
            return !root->s;
        }
        T front(){
            return*begin();
        }
        T back(){
            return*reverse_begin();
        }
    };
```

2.8   Self-Adjusting Top Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Self-Adjusting Top Tree.hpp (12629 bytes, 443 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
 3  struct SelfAdjustingTopTree{
        const static int inf=~0u>>1;
        static void gmin(int&a,int b){
            a=min(a,b);
        }
        static void gmax(int&a,int b){
            a=max(a,b);
        }
        struct treap{
            SelfAdjustingTopTree*tr;
13          treap(struct SelfAdjustingTopTree*a,int n):
                tr(a),ns(n){
            }
            struct node{
                node(){
                }
                node(int a,int b,int c,int d,int e){
                    ch[0]=ch[1]=0;
```

```
                    val=a;
                    fix=rand();
23                  add=0;
                    mi=vmi=b;
                    mx=vmx=c;
                    sum=vsum=d;
                    siz=vsiz=e;
                    sam=inf;
                }
                node*ch[2];
                int val,fix,vmi,vmx,vsum,vsiz,mi,mx,sum,siz,add,sam;
            };
33          vector<node>ns;
            void down(node*a){
                if(a->sam!=inf){
                    a->mi=a->mx=a->vmi=a->vmx=a->sam;
                    a->vsum=a->sam*a->vsiz;
                    a->sum=a->sam*a->siz;
                    (&tr->ns[0]+(a-&ns[0]))->viradd=0;
                    (&tr->ns[0]+(a-&ns[0]))->virsam=a->sam;
                    (&tr->ns[0]+(a-&ns[0]))->add=0;
                    (&tr->ns[0]+(a-&ns[0]))->sam=a->sam;
43                  for(int i=0;i<=1;++i)
                        if(a->ch[i])
                            a->ch[i]->add=0,a->ch[i]->sam=a->sam;
                    a->sam=inf;
                }
                if(a->add){
                    a->mi+=a->add;
                    a->mx+=a->add;
                    a->vmi+=a->add;
                    a->vmx+=a->add;
53                  a->vsum+=a->add*a->vsiz;
                    a->sum+=a->add*a->siz;
                    (&tr->ns[0]+(a-&ns[0]))->viradd+=a->add;
                    (&tr->ns[0]+(a-&ns[0]))->add+=a->add;
                    for(int i=0;i<=1;++i)
                        if(a->ch[i])
                            a->ch[i]->add+=a->add;
                    a->add=0;
                }
```

```
              }
63          void update(node*a){
                for(int i=0;i<=1;++i)
                    if(a->ch[i])
                        down(a->ch[i]);
                a->mi=a->vmi;
                for(int i=0;i<=1;++i)
                    if(a->ch[i])
                        gmin(a->mi,a->ch[i]->mi);
                a->mx=a->vmx;
                for(int i=0;i<=1;++i)
73                  if(a->ch[i])
                        gmax(a->mx,a->ch[i]->mx);
                a->sum=a->vsum;
                for(int i=0;i<=1;++i)
                    if(a->ch[i])
                        a->sum+=a->ch[i]->sum;
                a->siz=a->vsiz;
                for(int i=0;i<=1;++i)
                    if(a->ch[i])
                        a->siz+=a->ch[i]->siz;
83          }
            void rotate(node*&a,int d){
                node*b=a->ch[d];
                a->ch[d]=b->ch[!d];
                b->ch[!d]=a;
                update(a);
                update(b);
                a=b;
            }
            void insert(node*&a,node*b){
93              if(!a)
                    a=b;
                else{
                    down(a);
                    int d=b->val>a->val;
                    insert(a->ch[d],b);
                    update(a);
                    if(a->ch[d]->fix<a->fix)
                        rotate(a,d);
                }
```

```
103              }
             void erase(node*&a,int b){
                 down(a);
                 if(a->val==b){
                     if(!a->ch[0])
                         a=a->ch[1];
                     else if(!a->ch[1])
                         a=a->ch[0];
                     else{
                         int d=a->ch[1]->fix<a->ch[0]->fix;
113                     down(a->ch[d]);
                         rotate(a,d);
                         erase(a->ch[!d],b);
                         update(a);
                     }
                 }else{
                     int d=b>a->val;
                     erase(a->ch[d],b);
                     update(a);
                 }
123          }
         };
         int n;
         SelfAdjustingTopTree(int _n,vector<int>*to,int*we,int rt):
             trp(this,_n+1),ns(_n+1),n(_n){
             build(to,we,rt);
         }
         struct node{
             node(){}
             node(int a,node*b){
133              ch[0]=ch[1]=0;
                 pr=b;
                 vir=0;
                 val=a;
                 mi=mx=a;
                 siz=1;
                 rev=virsum=add=0;
                 virmi=inf;
                 virmx=-inf;
                 sam=inf;
143              virsam=inf;
```

```
                virsiz=0;
                viradd=0;
            }
            node*ch[2],*pr;
            int val,mi,mx,sum,virmi,virmx,virsum,virsam,viradd,virsiz,rev,sam,
        siz,add;
            treap::node*vir;
        };
        vector<node>ns;
        treap trp;
153     int direct(node*a){
            if(!a−>pr)
                return 3;
            else if(a==a−>pr−>ch[0])
                return 0;
            else if(a==a−>pr−>ch[1])
                return 1;
            else
                return 2;
        }
163     void down(node*a){
            if(a−>rev){
                swap(a−>ch[0],a−>ch[1]);
                for(int i=0;i<=1;++i)
                    if(a−>ch[i])
                        a−>ch[i]−>rev^=1;
                a−>rev=0;
            }
            if(a−>sam!=inf){
                a−>val=a−>mi=a−>mx=a−>sam;
173             a−>sum=a−>sam*a−>siz;
                for(int i=0;i<=1;++i)
                    if(a−>ch[i])a−>ch[i]−>sam=a−>sam,a−>ch[i]−>add=0;
                a−>sam=inf;
            }
            if(a−>add){
                a−>val+=a−>add;
                a−>mi+=a−>add;
                a−>mx+=a−>add;
                a−>sum+=a−>add*a−>siz;
183             for(int i=0;i<=1;++i)
```

```
                    if(a->ch[i])a->ch[i]->add+=a->add;
                a->add=0;
            }
            if(a->virsam!=inf){
                if(a->virsiz){
                    a->virmi=a->virmx=a->virsam;
                    a->virsum=a->virsam*a->virsiz;
                    if(a->vir)
                        a->vir->add=0,a->vir->sam=a->virsam;
193                 for(int i=0;i<=1;++i)
                        if(a->ch[i])
                            a->ch[i]->viradd=0,a->ch[i]->virsam=a->virsam;
                }
                a->virsam=inf;
            }
            if(a->viradd){
                if(a->virsiz){
                    a->virmi+=a->viradd;
                    a->virmx+=a->viradd;
203                 a->virsum+=a->viradd*a->virsiz;
                    if(a->vir)a->vir->add+=a->viradd;
                    for(int i=0;i<=1;++i)
                        if(a->ch[i])
                            a->ch[i]->viradd+=a->viradd;
                }
                a->viradd=0;
            }
        }
        void update(node*a){
213         for(int i=0;i<=1;++i)
                if(a->ch[i])
                    down(a->ch[i]);
            if(a->vir)
                trp.down(a->vir);
            a->mi=a->val;
            for(int i=0;i<=1;++i)
                if(a->ch[i])
                    gmin(a->mi,a->ch[i]->mi);
            a->virmi=inf;
223         for(int i=0;i<=1;++i)
                if(a->ch[i])
```

```
                     gmin(a−>virmi,a−>ch[i]−>virmi);
             if(a−>vir)
                 gmin(a−>virmi,a−>vir−>mi);
             a−>mx=a−>val;
             for(int i=0;i<=1;++i)
                 if(a−>ch[i])
                     gmax(a−>mx,a−>ch[i]−>mx);
             a−>virmx=−inf;
233          for(int i=0;i<=1;++i)
                 if(a−>ch[i])
                     gmax(a−>virmx,a−>ch[i]−>virmx);
             if(a−>vir)
                 gmax(a−>virmx,a−>vir−>mx);
             a−>sum=a−>val;
             for(int i=0;i<=1;++i)
                 if(a−>ch[i])
                     a−>sum+=a−>ch[i]−>sum;
             a−>virsum=0;
243          for(int i=0;i<=1;++i)
                 if(a−>ch[i])
                     a−>virsum+=a−>ch[i]−>virsum;
             if(a−>vir)
                 a−>virsum+=a−>vir−>sum;
             a−>siz=1;
             for(int i=0;i<=1;++i)
                 if(a−>ch[i])
                     a−>siz+=a−>ch[i]−>siz;
             a−>virsiz=0;
253          for(int i=0;i<=1;++i)
                 if(a−>ch[i])
                     a−>virsiz+=a−>ch[i]−>virsiz;
             if(a−>vir)
                 a−>virsiz+=a−>vir−>siz;
         }
         void setchd(node*a,node*b,int d){
             a−>ch[d]=b;
             if(b)
                 b−>pr=a;
263          update(a);
         }
         void connect(node*a,node*b){
```

```
            down(a);
            *(&trp.ns[0]+(a-&ns[0]))=treap::node(a-&ns[0],min(a->virmi,a->mi),
        max(a->virmx,a->mx),a->virsum+a->sum,a->virsiz+a->siz);
            trp.insert(b->vir,&trp.ns[0]+(a-&ns[0]));
        }
        void disconnect(node*a,node*b){
            trp.erase(b->vir,a-&ns[0]);
        }
273     void rotate(node*a){
            node*b=a->pr,*c=a->pr->pr;
            int d1=direct(a),d2=direct(b);
            setchd(b,a->ch[!d1],d1);
            setchd(a,b,!d1);
            if(d2<2)
                setchd(c,a,d2);
            else if(d2==2){
                disconnect(b,c);
                connect(a,c);
283             a->pr=c;
            }else
                a->pr=0;
        }
        void release(node*a){
            if(direct(a)<2)
                release(a->pr);
            else if(a->pr)
                disconnect(a,a->pr),connect(a,a->pr);
            down(a);
293     }
        void splay(node*a){
            release(a);
            while(direct(a)<2){
                node*b=a->pr;
                if(!b->pr||direct(b)>1)
                    rotate(a);
                else if(direct(a)==direct(b))
                    rotate(b),rotate(a);
                else
303                 rotate(a),rotate(a);
            }
        }
```

```
        node*access(node*a){
            node*b=0;
            while(a){
                splay(a);
                if(a->ch[1])
                    connect(a->ch[1],a);
                if(b)
313                 disconnect(b,a);
                setchd(a,b,1);
                b=a;
                a=a->pr;
            }
            return b;
        }
        void evert(node*a){
            access(a);
            splay(a);
323         a->rev=1;
        }
        int qchain(node*a,node*b,int d){
            access(a);
            node*c=access(b);
            splay(c);
            splay(a);
            int ret=c->val;
            if(d==1){
                if(a!=c)
333                 gmin(ret,a->mi);
                if(c->ch[1])
                    down(c->ch[1]),gmin(ret,c->ch[1]->mi);
            }else if(d==2){
                if(a!=c)
                    gmax(ret,a->mx);
                if(c->ch[1])
                    down(c->ch[1]),gmax(ret,c->ch[1]->mx);
            }else if(d==3){
                if(a!=c)
343                 ret+=a->sum;
                if(c->ch[1])
                    down(c->ch[1]),ret+=c->ch[1]->sum;
            }
```

```
              return ret;
          }
          void mchain(node*a,node*b,int u,int d){
              access(a);
              node*c=access(b);
              splay(c);
353           splay(a);
              if(d==1){
                  c->val+=u;
                  if(a!=c)
                      a->add=u,disconnect(a,c),connect(a,c);
                  if(c->ch[1])
                      down(c->ch[1]),c->ch[1]->add=u;
              }else if(d==2){
                  c->val=u;
                  if(a!=c)
363                   a->sam=u,disconnect(a,c),connect(a,c);
                  if(c->ch[1])
                      down(c->ch[1]),c->ch[1]->sam=u;
              }
              update(c);
          }
          int qtree(node*a,int d){
              access(a);
              splay(a);
              int ret=a->val;
373           if(d==1){
                  if(a->vir)
                      trp.down(a->vir),gmin(ret,a->vir->mi);
              }else if(d==2){
                  if(a->vir)
                      trp.down(a->vir),gmax(ret,a->vir->mx);
              }else if(d==3){
                  if(a->vir)
                      trp.down(a->vir),ret+=a->vir->sum;
              }
383           return ret;
          }
          void mtree(node*a,int u,int d){
              access(a);
              splay(a);
```

```
            if(d==1){
                a−>val+=u;
                if(a−>vir)
                    trp.down(a−>vir),a−>vir−>add=u;
            }else if(d==2){
393             a−>val=u;
                if(a−>vir)
                    trp.down(a−>vir),a−>vir−>sam=u;
            }
            update(a);
        }
        void stparent(node*a,node*b){
            access(b);
            if(access(a)!=a){
                splay(a);
403             node*c=a−>ch[0];
                down(c);
                while(c−>ch[1])
                    c=c−>ch[1],down(c);
                splay(c);
                c−>ch[1]=0;
                update(c);
                access(b);
                splay(b);
                connect(a,b);
413             a−>pr=b;
                update(b);
            }
        }
        void build(vector<int>*to,int*we,int rt){
            vector<int>pr(n);
            vector<int>vec;
            queue<int>qu;
            qu.push(rt);
            while(!qu.empty()){
423             int u=qu.front();
                qu.pop();
                vec.push_back(u);
                for(int i=0;i<to[u].size();++i){
                    int v=to[u][i];
                    if(v!=pr[u])
```

```
                              qu.push(v),pr[v]=u;
                          }
                  }
                  for(int i=0;i<n;++i){
433                   int u=vec[i];
                      ns[u]=node(we[u],pr[u]?&ns[0]+pr[u]:0);
                  }
                  for(int i=n−1;i>=0;−−i){
                      int u=vec[i];
                      update(&ns[0]+u);
                      if(pr[u])
                          connect(&ns[0]+u,&ns[0]+pr[u]);
                  }
          }
443   };
```

2.9   Skew Heap

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Skew Heap.hpp (1220 bytes, 61 lines)

```
#include<bits/stdc++.h>
using namespace std;
template<class T,class C>struct SkewHeap{
    SkewHeap():
        root(0),siz(0){
    }
7   ~SkewHeap(){
        clear(root);
    }
    struct node{
        node(T _val):
            val(_val){
            ch[0]=ch[1]=0;
        }
        T val;
        node*ch[2];
17  }*root;
    int siz;
```

```
        node*merge(node*x,node*y){
            if(!x)
                return y;
            if(!y)
                return x;
            if(C()(y->val,x->val))
                swap(x,y);
            swap(x->ch[0],x->ch[1]=merge(x->ch[1],y));
27          return x;
        }
        void clear(node*x){
            if(x){
                clear(x->ch[0]);
                clear(x->ch[1]);
                delete x;
            }
        }
        void clear(){
37          clear(root);
            root=0;
            siz=0;
        }
        void push(T a){
            root=merge(root,new node(a));
            ++siz;
        }
        T top(){
            return root->val;
47      }
        void pop(){
            root=merge(root->ch[0],root->ch[1]);
            --siz;
        }
        void merge(SkewHeap<T,C>&a){
            root=merge(root,a.root);
            a.root=0;
            siz+=a.siz;
            a.siz=0;
57      }
        int size(){
            return siz;
```

```
    }
};
```

CHAPTER 3

Graph Algorithms

3.1   Chordality Test

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Chordality Test.hpp (1343 bytes, 42 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
struct ChordalityTest{
    int n,ns;
    vector<vector<int> >to;
    ChordalityTest(int _n):
        n(_n),ns(n),to(n+1){
    }
    void add(int u,int v){
        to[u].push_back(v),to[v].push_back(u);
    }
    bool run(){
        vector<int>pos(n+1),idx(n+2),lab(n+1),tab(n+1);
        vector<list<int>>qu(n);
        for(int i=1;i<=n;++i)
            qu[0].push_back(i);
        for(int b=0,i=1,u=0;i<=n;++i,u=0){
            for(;u?++b,0:1;--b)
                for(auto j=qu[b].begin();j!=qu[b].end()&&!u;qu[b].erase(j++)
)
                    if(!pos[*j]&&lab[*j]==b)
                        u=*j;
            pos[u]=ns,idx[ns--]=u;
            for(int v:to[u])
                if(!pos[v])
                    b=max(b,++lab[v]),qu[lab[v]].push_back(v);}
        for(int i=1,u=idx[1],v=-1;i<=n;++i,u=idx[i],v=-1){
            for(int w:to[u])
                if(pos[w]>pos[u]&&(v==-1||pos[w]<pos[v]))
                    v=w;
            if(v!=-1){
                for(int w:to[v])
                    tab[w]=1;
                for(int w:to[u])
                    if(pos[w]>pos[u]&&w!=v&&!tab[w])
```

```
                             return false;
                    for(int w:to[v])
                        tab[w]=0;
                }
39          }
            return true;
        }
    };
```

3.2   Dominator Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Dominator Tree.hpp (2916 bytes, 94 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
    struct DominatorTree{
        int n,r;
        vector<vector<int> >to,rto,chd,rsemi;
        vector<int>dfn,res,prt,rdfn,semi,misemi;
        DominatorTree(int _n,int _r):n(_n),r(_r),to(n+1),rto(n+1),dfn(n+1),res(
        n+1),prt(n+1),rdfn(1),semi(n+1),misemi(n+1),chd(n+1),rsemi(n+1){
 8      }
        int fd(int a){
            stack<int>stk;
            for(int b=a;prt[b]!=prt[prt[b]];b=prt[b])
                stk.push(b);
            for(int b;stk.empty()?0:(b=stk.top(),stk.pop(),1);){
                if(dfn[semi[misemi[prt[b]]]]<dfn[semi[misemi[b]]])
                    misemi[b]=misemi[prt[b]];
                prt[b]=prt[prt[b]];
            }
18          return prt[a];
        }
        void add(int a,int b){
            to[a].push_back(b);
            rto[b].push_back(a);
        }
        void dfs(){
```

```
            stack<pair<int,int> >stk;
            semi[r]=r;
            for(stk.push(make_pair(r,0));!stk.empty();){
28              int a=stk.top().first,i=stk.top().second;
                stk.pop();
                if(!i)
                    dfn[a]=rdfn.size(),rdfn.push_back(a);
                if(i<to[a].size()){
                    stk.push(make_pair(a,i+1));
                    int b=to[a][i];
                    if(!semi[b])
                        semi[b]=a,chd[a].push_back(b),
                        stk.push(make_pair(b,0));
38              }
            }
            semi[r]=0;
        }
        void calcsemi(){
            for(int i=1;i<=n;++i)
                prt[i]=i,misemi[i]=i;
            for(int i=rdfn.size()−1;i>=1;−−i){
                int a=rdfn[i];
                for(int b:rto[a]){
48                  if(!dfn[b])
                        continue;
                    if(dfn[b]<dfn[a]){
                        if(dfn[b]<dfn[semi[a]])
                            semi[a]=b;
                    }else{
                        int c=fd(b);
                        if(dfn[semi[c]]<dfn[semi[a]])
                            semi[a]=semi[c];
                        if(dfn[semi[misemi[b]]]<dfn[semi[a]])
58                          semi[a]=semi[misemi[b]];
                    }
                }
                for(int b:chd[a])
                    prt[b]=a;
            }
        }
        void calcres(){
```

```
            for(int i=1;i<=n;++i)
                prt[i]=i,misemi[i]=i,rsemi[semi[i]].push_back(i);
68          for(int i=rdfn.size()−1;i>=1;−−i){
                int a=rdfn[i];
                for(int b:rsemi[a]){
                    fd(b);
                    int c=misemi[b];
                    if(dfn[semi[c]]>dfn[semi[prt[b]]])
                        c=prt[b];
                    if(semi[c]==semi[b])
                        res[b]=semi[b];
                    else
78                      res[b]=−c;}
                for(int b:chd[a])
                    prt[b]=a;
            }
            for(int i=1;i<rdfn.size();++i){
                int a=rdfn[i];
                if(res[a]<0)
                    res[a]=res[−res[a]];
            }
        }
88      vector<int>run(){
            dfs();
            calcsemi();
            calcres();
            return res;
        }
    };
```

3.3 K Shortest Path

Description

Find the length of k shortest path between two vertices in a given weighted directed graph. The path does not need to be loopless. But the edge weights must be non-negative.

Methods

template<class T>KShortestPath<T>::KShortestPath(int n);	
Description	construct an object of KShortestPath
Parameters	Description
T	type of edge weights, be careful since the result can be $\Theta(nkC)$
n	number of vertices
Time complexity	$\Theta(n)$
Space complexity	$\Theta(11n)$
Return value	an object of KShortestPath
template<class T>void KShortestPath<T>::add(int a,int b,T c);	
Description	add a directed weighted edge to the graph
Parameters	Description
a	start vertex of the edge, indexed from one
b	end vertex of the edge, indexed from one
c	weight of the edge, should be non-negative
Time complexity	$\Theta(1)$ (amortized)
Space complexity	$\Theta(1)$ (amortized)
Return value	none
template<class T>T KShortestPath<T>::run(int s,int t,int k);	
Description	find the length of k shortest path
Parameters	Description
s	start vertex of the path, indexed from one
t	end vertex of the path, indexed from one
k	k in 'k shortest path'
Time complexity	$O((n+m)\log n + k\log(nmk))$
Space complexity	$O(n\log n + m + k\log(nm))$
Return value	length of k shortest path from s to t or -1 if it doesn't exist

Fields

Name	Description

Performance

Problem	Constraints	Time	Memory	Date
JDFZ P2978	$N = 10^4, M = 10^5, K = 10^4$	324 ms	14968 kB	2016-02-13

References

Title	Author
堆的可持久化和 k 短路	俞鼎力

Code

K Shortest Path.hpp (5105 bytes, 170 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
template<class T>struct KShortestPath{
    KShortestPath(int _n):
        n(_n),m(1<<(int)ceil(log2(n)+1e-8)),from(n+1,-1),
        tov(n+1),wev(n+1),to(n+1),we(n+1),inf(numeric_limits<T>::max()),
        sg(2*m,make_pair(inf,0)),di(n+1,inf),nxt(n+1),chd(n+1),torev(n+1){
    }
    ~KShortestPath(){
        for(int i=0;i<all.size();++i)
            free(all[i]);
    }
    void add(int u,int v,T w){
        tov[v].push_back(u);
        wev[v].push_back(w);
        to[u].push_back(v);
        we[u].push_back(w);
        torev[v].push_back(to[u].size()-1);
    }
    int upd(T&a,T b,T c){
        if(b!=inf&&c!=inf&&b+c<a){
            a=b+c;
            return 1;
        }
        return 0;
    }
    void mod(int u,T d){
        for(sg[u+m-1]=make_pair(d,u),u=u+m-1>>1;u;u>>=1)
            sg[u]=min(sg[u<<1],sg[u<<1^1]);
    }
    template<class T2>struct node{
        node(T2 _v):
```

```
                v(_v),s(0),l(0),r(0){
            }
            T2 v;
36          int s;
            node*l,*r;
        };
        template<class T2>node<T2>*merge(node<T2>*a,node<T2>*b){
            if(!a||!b)
                return a?a:b;
            if(a->v>b->v)
                swap(a,b);
            a->r=merge(a->r,b);
            if(!a->l||a->l->s<a->r->s)
46              swap(a->l,a->r);
            a->s=(a->r?a->r->s:-1)+1;
            return a;
        }
        template<class T2>node<T2>*mak(T2 v){
            node<T2>*t=(node<T2>*)malloc(sizeof(node<T2>));
            *t=node<T2>(v);
            all.push_back(t);
            return t;
        }
56      template<class T2>node<T2>*pmerge(node<T2>*a,node<T2>*b){
            if(!a||!b)
                return a?a:b;
            if(a->v>b->v)
                swap(a,b);
            node<T2>*r=mak(a->v);
            r->l=a->l;
            r->r=pmerge(a->r,b);
            if(!r->l||r->l->s<r->r->s)
                swap(r->l,r->r);
66          r->s=(r->r?r->r->s:-1)+1;
            return r;
        }
        struct edge{
            edge(T _l,int _v):
                l(_l),v(_v){
            }
            bool operator>(const edge&a){
```

```
                return l>a.l;
            }
76          T l;
            int v;
        };
        struct edgeheap{
            edgeheap(node<edge>*r):
                root(r){
            }
            bool operator>(const edgeheap&a){
                return root->v.l>a.root->v.l;
            }
86          node<edge>*root;
        };
        edgeheap merge(edgeheap a,edgeheap b){
            return edgeheap(pmerge(a->root,b->root));
        }
        edgeheap popmin(edgeheap a){
            return edgeheap(pmerge(a.root->l,a.root->r));
        }
        node<edgeheap>*popmin(node<edgeheap>*a){
                node<edgeheap>*x=pmerge(a->l,a->r);
96              a=mak(popmin(a->v));
                if(a->v.root)
                    x=pmerge(x,a);
                return x;
        }
        struct path{
            path(int _vp,int _v,T _l,T _d,node<edgeheap>*_c):
                vp(_vp),v(_v),l(_l),d(_d),can(_c){
            }
            bool operator<(const path&a)const{
106             return l>a.l;
            }
            int vp,v;
            T l,d;
            node<edgeheap>*can;
        };
        T run(int s,int t,int k){
            di[t]=0;
            for(int i=1;i<=n;++i)
```

```
              sg[i+m−1]=make_pair(di[i],i);
116       for(int i=m−1;i>=1;−−i)
              sg[i]=min(sg[i<<1],sg[i<<1^1]);
          for(int u=sg[1].second;sg[1].first!=inf;u=sg[1].second){
              mod(u,inf),tre.push_back(u);
              for(int i=0;i<tov[u].size();++i){
                  int v=tov[u][i];
                  T w=wev[u][i];
                  if(upd(di[v],di[u],w))
                      mod(v,di[v]),nxt[v]=u,
                      from[v]=torev[u][i];
126           }
          }
          for(int i=0;i<tre.size();++i){
              queue<node<edge>*>qu;
              for(int j=0;j<to[tre[i]].size();++j)
                  if(di[to[tre[i]][j]]!=inf&&j!=from[tre[i]])
                      qu.push(mak(edge(we[tre[i]][j]−di[tre[i]]+di[to[tre[i]][
      j]],to[tre[i]][j])));
              for(node<edge>*x,*y;qu.size()>1;)
                  x=qu.front(),qu.pop(),y=qu.front(),qu.pop(),
                  qu.push(merge(x,y));
136           if(qu.size())
                  chd[tre[i]]=pmerge(mak(edgeheap(qu.front())),chd[nxt[tre[i
      ]]]);
              else
                  chd[tre[i]]=chd[nxt[tre[i]]];
          }
          priority_queue<path>pth;
          if(di[s]==inf)
              return −1;
          pth.push(path(0,s,di[s],0,0));
          for(int i=1;i<k;++i){
146           if(pth.empty())
                  return −1;
              path p=pth.top();
              pth.pop();
              if(p.can){
                  edge t=p.can−>v.root−>v;
                  pth.push(path(p.vp,t.v,p.l−p.d+t.l,t.l,popmin(p.can)));
              }
```

```
            if(chd[p.v]){
                edge t=chd[p.v]−>v.root−>v;
156            pth.push(path(p.v,t.v,p.l+t.l,t.l,popmin(chd[p.v])));
            }
        }
        return pth.size()?pth.top().l:−1;
    }
    T inf;
    int n,m;
    vector<T>di;
    vector<int>nxt,tre,from;
    vector<void*>all;
166    vector<node<edgeheap>*>chd;
    vector<pair<T,int> >sg;
    vector<vector<T> >wev,we;
    vector<vector<int> >tov,to,torev;
};
```

3.4   Maximal Clique Count

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Maximal Clique Count.hpp (927 bytes, 34 lines)

```
#include<bits/stdc++.h>
using namespace std;
template<int N>struct MaximalCliqueCount{
    int n,r;
    vector<bitset<N> >e,rht,msk;
    MaximalCliqueCount(int _n):
        n(_n),e(n),rht(n),msk(n),r(0){
    }
    void add(int u,int v){
10        e[u−1][v−1]=e[v−1][u−1]=1;
    }
    void dfs(int u,bitset<N>cur,bitset<N>can){
        if(cur==can){
            ++r;
            return;
        }
```

```
            for(int v=0;v<u;++v)
                if(can[v]&&!cur[v]&&(e[v]&rht[u]&can)==(rht[u]&can))
                    return;
20          for(int v=u+1;v<n;++v)
                if(can[v])
                    dfs(v,cur|msk[v],can&e[v]);
        }
        int run(){
            for(int i=1;i<=n;++i){
                rht[i−1]=bitset<N>(string(n−i,'1')+string(i,'0'));
                msk[i−1]=bitset<N>(1)<<i−1;
                e[i−1]|=msk[i−1];
            }
30          for(int i=0;i<n;++i)
                dfs(i,msk[i],e[i]);
            return r;
        }
    };
```

3.5   Maximal Planarity Test

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Maximal Planarity Test.hpp (5195 bytes, 165 lines)

```
#include<bits/stdc++.h>
using namespace std;
struct MaximalPlanarityTesting{
    int n,m;
    vector<set<int> >to2;
6   vector<vector<int> >to;
    vector<int>dec,rmd,mrk,invc,rt;
    vector<list<int>::iterator>dpos,pos;
    bool order(int v1,int v2,int vn){
        rt[0]=v1;
        rt[1]=v2;
        rt[n−1]=vn;
        fill(invc.begin(),invc.end(),0);
        invc[v1]=1;
        invc[v2]=1;
```

```
16          invc[vn]=1;
            list<int>deg;
            dpos[vn]=deg.insert(deg.begin(),vn);
            fill(dec.begin(),dec.end(),0);
            dec[v1]=2;
            dec[v2]=2;
            dec[vn]=2;
            for(int i=n−1;i>=2;−−i){
                if(deg.empty())
                    return false;
26              int v=*deg.begin();
                deg.erase(deg.begin());
                invc[v]=−1;
                rt[i]=v;
                for(int u:to[v]){
                    if(invc[u]==1){
                        if(u!=v1&&u!=v2&&dec[u]==2)
                            deg.erase(dpos[u]);
                        −−dec[u];
                        if(u!=v1&&u!=v2&&dec[u]==2)
36                          dpos[u]=deg.insert(deg.begin(),u);
                    }else if(invc[u]==0)
                        invc[u]=2;
                }
                for(int u:to[v])
                    if(invc[u]==2)
                        for(int w:to[u])
                            if(invc[w]==1){
                                if(w!=v1&&w!=v2&&dec[w]==2)
                                    deg.erase(dpos[w]);
46                              ++dec[w];
                                if(w!=v1&&w!=v2&&dec[w]==2)
                                    dpos[w]=deg.insert(deg.begin(),w);
                                ++dec[u];
                            }else if(invc[w]==2)
                                ++dec[u];
                for(int u:to[v]){
                    if(invc[u]==2){
                        invc[u]=1;
                        if(dec[u]==2)
56                          dpos[u]=deg.insert(deg.begin(),u);
```

```
                    }
                }
            }
            return true;
        }
        bool embed(){
            list<int>ext;
            int mker=0;
            fill(mrk.begin(),mrk.end(),0);
66          pos[rt[1]]=ext.insert(ext.begin(),rt[1]);
            pos[rt[2]]=ext.insert(ext.begin(),rt[2]);
            pos[rt[0]]=ext.insert(ext.begin(),rt[0]);
            fill(rmd.begin(),rmd.end(),0);
            rmd[rt[1]]=1;
            rmd[rt[2]]=1;
            rmd[rt[0]]=1;
            for(int i=3;i<n;++i){
                int v=rt[i];
                rmd[v]=1;
76              vector<int>can;
                ++mker;
                for(int u:to[v])
                    if(rmd[u])
                        mrk[u]=mker,can.push_back(u);
                int start=−1,end=−1;
                for(int u:can){
                    list<int>::iterator it=pos[u];
                    if(it==list<int>::iterator())
                        return false;
86                  if(it==ext.begin()){
                        if(start!=−1)
                            return false;
                        start=u;
                    }else{
                        list<int>::iterator tmp=it;
                        if(mrk[*(−−tmp)]!=mker){
                            if(start!=−1)
                                return false;
                            start=u;
                        }
96                  }
                }
```

```
                    list<int>::iterator tmp=it;++tmp;
                    if(tmp==ext.end()){
                        if(end!=−1)
                            return false;
                        end=u;
                    }else{
                        if(mrk[*tmp]!=mker){
                            if(end!=−1)
106                             return false;
                            end=u;
                        }
                    }
                }
                if(start==−1||end==−1)
                    return false;
                for(int u:can)
                    if(u!=start&&u!=end)
                        ext.erase(pos[u]),pos[u]=list<int>::iterator();
116             pos[v]=ext.insert(pos[end],v);
            }
            return true;
        }
        bool istri(int u,int v,int w){
            return to2[u].count(v)&&to2[v].count(w)&&to2[w].count(u);
        }
        MaximalPlanarityTesting(int _n):
            n(_n),to(n),to2(n),m(0),rt(n),invc(n),dec(n),dpos(n),pos(n),rmd(n),
        mrk(n){
        }
126     void add(int u,int v){
            to[u−1].push_back(v−1);
            to[v−1].push_back(u−1);
            to2[u−1].insert(v−1);
            to2[v−1].insert(u−1);++m;
        }
        bool run(){
            if(n==1&&m==0)
                return true;
            if(n==2&&m==1)
136             return true;
            if(n==3&&m==3)
```

```
            return true;
        if(n<=3)
            return false;
        if(m!=3*n−6)
            return false;
        int v1;
        for(v1=0;v1<n;++v1)
            if(to[v1].size()<3)
                return false;
        for(v1=0;v1<n;++v1)
            if(to[v1].size()<=5)
                break;
        if(v1>=n)
            return false;
        int v2=to[v1].back();
        for(int i=0;i+1<to[v1].size();++i){
            int vn=to[v1][i];
            if(istri(v1,v2,vn)){
                if(!order(v1,v2,vn))
                    continue;
                if(!embed())
                    continue;
                return true;
            }
        }
        return false;
    }
};
```

3.6   Maximum Flow

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Maximum Flow.hpp (2311 bytes, 79 lines)

```
#include<bits/stdc++.h>
using namespace std;
template<class T>struct MaximumFlow{
    struct edge{
        int v;
```

```
            T c,l;
            edge(int _v,T _c):
                v(_v),c(_c),l(_c){
            }
        };
        int n,src,snk;
        vector<edge>egs;
        vector<vector<int> >bge;
        vector<int>hei,gap,cur,frm;
15      MaximumFlow(int _n,int _src,int _snk):
            bge(_n),hei(_n,_n),gap(_n+1),n(_n),cur(_n),frm(_n),src(_src−1),snk(
        _snk−1){
        }
        void lab(){
            hei[snk]=0;
            queue<int>qu;
            qu.push(snk);
            for(int u;qu.empty()?0:(u=qu.front(),qu.pop(),1);)
                for(int i=0;i<bge[u].size();++i){
                    edge&e=egs[bge[u][i]],&ev=egs[bge[u][i]^1];
25                  if(ev.c>0&&hei[e.v]==n)
                        hei[e.v]=hei[u]+1,qu.push(e.v);
                }
            for(int i=0;i<n;++i)
                ++gap[hei[i]];
        }
        T aug(){
            T f=0;
            for(int u=snk;u!=src;u=egs[frm[u]^1].v)
                if(f<=0||f>egs[frm[u]].c)
35                  f=egs[frm[u]].c;
            for(int u=snk;u!=src;u=egs[frm[u]^1].v)
                egs[frm[u]].c−=f,egs[frm[u]^1].c+=f;
            return f;
        }
        void add(int u,int v,T c){
            bge[u−1].push_back(egs.size());
            egs.push_back(edge(v−1,c));
            bge[v−1].push_back(egs.size());
            egs.push_back(edge(u−1,0));
45      }
```

```
        T run(){
            lab();
            T r=0;
            for(int u=src;hei[src]!=n;){
                if(u==snk)
                    r+=aug(),u=src;
                int f=0;
                for(int i=cur[u];i<bge[u].size();++i){
                    edge&e=egs[bge[u][i]];
55                  if(e.c>0&&hei[u]==hei[e.v]+1){
                        f=1;
                        frm[e.v]=bge[u][i];
                        u=e.v;
                        break;
                    }
                }
                if(!f){
                    int mh=n−1;
                    for(int i=0;i<bge[u].size();++i){
65                      edge&e=egs[bge[u][i]];
                        if(e.c>0&&mh>hei[e.v])
                            mh=hei[e.v];
                    }
                    if(!−−gap[hei[u]])
                        break;
                    ++gap[hei[u]=mh+1];
                    cur[u]=0;
                    if(u!=src)
                        u=egs[frm[u]^1].v;
75              }
            }
            return r;
        }
    };
```

3.7   Maximum Matching

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Maximum Matching.hpp (3123 bytes, 112 lines)

```cpp
 1  #include<bits/stdc++.h>
    using namespace std;
    struct MaximumMatching{
        int n;
        vector<int>res,nxt,mrk,vis,top,prt,rnk;
        vector<vector<int> >to;
        queue<int>qu;
        MaximumMatching(int _n):
            n(_n),res(n+1),nxt(n+1),mrk(n+1),vis(n+1),top(n+1),to(n+1),prt(n+1)
        ,rnk(n+1){
        }
11      int fd(int x){
            return x==prt[x]?x:prt[x]=fd(prt[x]);
        }
        void lk(int x,int y){
            if(rnk[x=fd(x)]>rnk[y=fd(y)])
                prt[y]=x;
            else if(rnk[x]<rnk[y])
                prt[x]=y;
            else
                prt[x]=y,++rnk[y];
21      }
        int lca(int x,int y){
            static int t;
            ++t;
            for(;;swap(x,y))
                if(x){
                    x=top[fd(x)];
                    if(vis[x]==t)
                        return x;
                    vis[x]=t;
31              if(res[x])
                    x=nxt[res[x]];
                else
                    x=0;
                }
        }
        void uni(int x,int p){
            for(;fd(x)!=fd(p);){
                int y=res[x],z=nxt[y];
```

```
                    if(fd(z)!=fd(p))
41                      nxt[z]=y;
                    if(mrk[y]==2)
                        mrk[y]=1,qu.push(y);
                    if(mrk[z]==2)
                        mrk[z]=1,qu.push(z);
                    int t=top[fd(z)];
                    lk(x,y);
                    lk(y,z);
                    top[fd(z)]=t;
                    x=z;
51              }
            }
        void aug(int s){
            for(int i=1;i<=n;++i)
                nxt[i]=0,mrk[i]=0,top[i]=i,prt[i]=i,rnk[i]=0;
            mrk[s]=1;
            qu=queue<int>();
            for(qu.push(s);!qu.empty();){
                int x=qu.front();
                qu.pop();
61              for(int i=0;i<to[x].size();++i){
                    int y=to[x][i];
                    if(res[x]==y||fd(x)==fd(y)||mrk[y]==2)
                        continue;
                    if(mrk[y]==1){
                        int z=lca(x,y);
                        if(fd(x)!=fd(z))
                            nxt[x]=y;
                        if(fd(y)!=fd(z))
                            nxt[y]=x;
71                      uni(x,z);
                        uni(y,z);
                    }else if(!res[y]){
                        for(nxt[y]=x;y;){
                            int z=nxt[y],mz=res[z];
                            res[z]=y;
                            res[y]=z;
                            y=mz;
                        }
                        return;
```

```
81                  }else{
                        nxt[y]=x;
                        mrk[res[y]]=1;
                        qu.push(res[y]);
                        mrk[y]=2;
                    }
                }
            }
        }
        void add(int x,int y){
91          to[x].push_back(y);
            to[y].push_back(x);
        }
        int run(){
            for(int i=1;i<=n;++i)
                if(!res[i])
                    for(int j=0;j<to[i].size();++j)
                        if(!res[to[i][j]]){
                            res[to[i][j]]=i;
                            res[i]=to[i][j];
101                         break;
                        }
            for(int i=1;i<=n;++i)
                if(!res[i])
                    aug(i);
            int r=0;
            for(int i=1;i<=n;++i)
                if(res[i])
                    ++r;
            return r/2;
111     }
    };
```

3.8   Minimum Cost Maximum Flow

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Minimum Cost Maximum Flow.hpp (2278 bytes, 82 lines)

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

```cpp
   using namespace std;
   template<class F=int,class C=int>struct MinimumCostMaximumFlow{
       struct edge{
           edge(int _v,F _c,C _w):
               v(_v),c(_c),w(_w){
           }
8          int v;
           F c;
           C w;
       };
       MinimumCostMaximumFlow(int _n,int _src,int _snk,F _all):
           n(_n),src(_src−1),snk(_snk−1),bg(_n),vis(n),dis(n),all(_all),flow
       (0),cost(0){}
       void add(int u,int v,F c,C w){
           bg[u−1].push_back(eg.size());
           eg.push_back(edge(v−1,c,w));
           bg[v−1].push_back(eg.size());
18         eg.push_back(edge(u−1,0,−w));
       }
       int spfa(){
           vector<int>in(n,0);
           queue<int>qu;
           fill(vis.begin(),vis.end(),0);
           dis[src]=0;
           vis[src]=in[src]=1;
           qu.push(src);
           while(!qu.empty()){
28             int u=qu.front();
               qu.pop();
               in[u]=0;
               for(int i=0;i<bg[u].size();++i){
                   edge&e=eg[bg[u][i]];
                   if(e.c!=0&&(!vis[e.v]||dis[u]+e.w<dis[e.v])){
                       dis[e.v]=dis[u]+e.w;
                       vis[e.v]=1;
                       if(!in[e.v]){
                           in[e.v]=1;
38                         qu.push(e.v);
                       }
                   }
               }
```

```
        }
        return vis[snk]&&dis[snk]<0;
    }
    F dfs(int u,F f){
        if(u==snk)
            return f;
48      F g=f;
        vis[u]=1;
        for(int i=0;i<bg[u].size();++i){
            edge&e=eg[bg[u][i]],&ev=eg[bg[u][i]^1];
            if(e.c!=0&&dis[e.v]==dis[u]+e.w&&!vis[e.v]){
                F t=dfs(e.v,min(g,e.c));
                g−=t;
                e.c−=t;
                ev.c+=t;
                cost+=t*e.w;
58              if(g==0)
                    return f;
            }
        }
        return f−g;
    }
    pair<F,C>run(){
        while(all!=0&&spfa()){
            F t;
            do{
68              fill(vis.begin(),vis.end(),0);
                flow+=(t=dfs(src,all));
                all−=t;
            }while(t!=0);
        }
        return make_pair(flow,cost);
    }
    int n,src,snk;
    vector<vector<int> >bg;
    vector<edge>eg;
78  vector<int>vis;
    vector<C>dis;
    F all,flow;
    C cost;
};
```

3.9   Minimum Spanning Arborescence

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Minimum Spanning Arborescence.hpp (1933 bytes, 64 lines)

```
#include<bits/stdc++.h>
using namespace std;
template<class T>struct MinimumSpanningArborescence{
    struct eg{
        int u,v;
        T w;
    };
    int n,rt;
    vector<eg>egs;
    vector<int>vi,in,id;
    vector<T>inw;
    MinimumSpanningArborescence(int _n,int _rt):
        n(_n),rt(_rt),vi(n+1),in(n+1),inw(n+1),id(n+1){
    }
    void add(int u,int v,T w){
        eg e;
        e.u=u;
        e.v=v;
        e.w=w;
        egs.push_back(e);
    }
    T run(){
        int nv=0;
        for(T r=0;;n=nv,nv=0,rt=id[rt]){
            for(int i=1;i<=n;++i)
                in[i]=−1;
            for(int i=0;i<egs.size();++i)
                if(egs[i].u!=egs[i].v&&(in[egs[i].v]==−1||egs[i].w<inw[egs[
i].v]))
                    in[egs[i].v]=egs[i].u,inw[egs[i].v]=egs[i].w;
            for(int i=1;i<=n;++i)
                if(i!=rt&&in[i]==−1)
                    return numeric_limits<T>::max();
            for(int i=1;i<=n;++i){
                if(i!=rt)
```

```
                            r+=inw[i];
                        id[i]=−1,vi[i]=0;
                    }
38                  for(int i=1;i<=n;++i)
                        if(i!=rt&&!vi[i]){
                            int u=i;
                            do{
                                vi[u]=i;
                                u=in[u];
                            }while(!vi[u]&&u!=rt);
                            if(u!=rt&&vi[u]==i){
                                int v=u;
                                ++nv;
48                          do{
                                    id[v]=nv;
                                    v=in[v];
                                }while(v!=u);
                            }
                        }
                if(nv==0)
                    return r;
                for(int i=1;i<=n;++i)
                    if(id[i]==−1)
58                      id[i]=++nv;
                for(int i=0;i<egs.size();++i)
                    egs[i].w−=inw[egs[i].v],egs[i].u=id[egs[i].u],
                    egs[i].v=id[egs[i].v];
            }
        }
};
```

3.10   Minimum Spanning Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Minimum Spanning Tree.hpp (1049 bytes, 44 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
template<class T,class C=less<T> >struct MinimumSpanningTree{
```

```
      struct edge{
          T w;
 6        int u,v;
          int operator<(const edge&b)const{
              return C()(w,b.w);
          }
      };
      int n;
      vector<edge>egs;
      vector<int>pr;
      MinimumSpanningTree(int _n):
          n(_n),pr(n+1){
16    }
      void add(int u,int v,T w){
          edge e;
          e.u=u;
          e.v=v;
          e.w=w;
          egs.push_back(e);
      }
      int fd(int x){
          return x==pr[x]?x:pr[x]=fd(pr[x]);
26    }
      void lk(int x,int y){
          pr[fd(x)]=y;
      }
      pair<T,vector<edge> >run(){
          vector<edge>ret;
          T sum=0;
          sort(egs.begin(),egs.end());
          for(int i=1;i<=n;++i)
              pr[i]=i;
36        for(int i=0;i<egs.size();++i){
              int u=egs[i].u,v=egs[i].v;
              T w=egs[i].w;
              if(fd(u)!=fd(v))
                  lk(u,v),ret.push_back(egs[i]),sum+=w;
          }
          return make_pair(sum,ret);
      }
  };
```

3.11   Shortest Path

warning: old style will be replaced ... see Suffix Array (DC3) for new style

---

Shortest Path.hpp (1293 bytes, 45 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
template<class T>struct ShortestPath{
    int n,m;
    vector<vector<int> >to;
    vector<vector<T> >we;
    T inf;
    vector<pair<T,int> >sg;
    vector<T>di;
    ShortestPath(int _n):
        n(_n),m(1<<(int)ceil(log2(n)+1e-8)),to(n+1),we(n+1),inf(
    numeric_limits<T>::max()),sg(2*m,make_pair(inf,0)),di(n+1,inf){
    }
    void set(int u,T d){
        di[u]=d;
    }
    void add(int u,int v,T w){
        to[u].push_back(v);
        we[u].push_back(w);
    }
    int upd(T&a,T b,T c){
        if(b!=inf&&c!=inf&&b+c<a){
            a=b+c;
            return 1;
        }
        return 0;
    }
    void mod(int u,T d){
        for(sg[u+m-1]=make_pair(d,u),u=(u+m-1)>>1;u;u>>=1)
            sg[u]=min(sg[u<<1],sg[u<<1^1]);
    }
    vector<T>run(){
        for(int i=1;i<=n;++i)
            sg[i+m-1]=make_pair(di[i],i);
        for(int i=m-1;i>=1;--i)
```

```
                sg[i]=min(sg[i<<1],sg[i<<1^1]);
36          for(int u=sg[1].second;sg[1].first!=inf?(mod(u,inf),1):0;u=sg[1].
        second)
                for(int i=0;i<to[u].size();++i){
                    int v=to[u][i];
                    T w=we[u][i];
                    if(upd(di[v],di[u],w))
                        mod(v,di[v]);
                }
            return di;
        }
    };
```

3.12   Steiner Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Steiner Tree.hpp (1745 bytes, 56 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
    template<class T>struct SteinerTree{
        int n,k,z;
5       T inf=numeric_limits<T>::max();
        vector<vector<T> >wei,dp;
        vector<int>im;
        SteinerTree(int _n):
            n(_n),k(0),wei(n+1,vector<T>(n+1,inf)),im(n+1){
        }
        void set(int u){
            if(!im[u])
                im[z=u]=++k;
        }
15      void add(int u,int v,T w){
            wei[u][v]=wei[v][u]=min(w,wei[u][v]);
        }
        int upd(T&a,T b,T c){
            if(b!=inf&&c!=inf&&b+c<a){
                a=b+c;
                return 1;
```

```
            }
            return 0;
        }
25      int ins(int s,int u){
            return im[u]&&((s>>im[u]−1)&1);
        }
        T run(){
            for(int l=1;l<=n;++l)
                for(int i=1;i<=n;++i)
                    for(int j=1;j<=n;++j)
                        upd(wei[i][j],wei[i][l],wei[l][j]);
            dp=vector<vector<T> >(1<<k−1,vector<T>(n+1,inf));
            fill(begin(dp[0]),end(dp[0]),0);
35          for(int s=1;s<(1<<k−1);++s){
                queue<int>qu;
                vector<int>in(n+1);
                for(int u=1;u<=n;++u){
                    if(ins(s,u))
                        continue;
                    qu.push((u));
                    in[u]=1;
                    for(int t=(s−1)&s;t;t=(t−1)&s)
                        upd(dp[s][u],dp[t][u],dp[s^t][u]);
45                  for(int v=1;v<=n;++v)
                        if(ins(s,v))
                            upd(dp[s][u],dp[s^(1<<im[v]−1)][v],wei[u][v]);
                }
                for(int u;qu.empty()?0:(u=qu.front(),qu.pop(),in[u]=0,1);)
                    for(int v=1;v<=n;++v)
                        if(!ins(s,v)&&upd(dp[s][v],dp[s][u],wei[u][v])&&!in[v])
                            in[v]=1,qu.push(v);
                }
            return k?dp[(1<<k−1)−1][z]:0;
55      }
    };
```

3.13   Virtual Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Virtual Tree.hpp (2375 bytes, 77 lines)

```
     #include<bits/stdc++.h>
     using namespace std;
     struct VirtualTree{
4        int n,r,l;
         vector<vector<int> >to,vto,up;
         vector<int>lst,dp,dfn,edf,imp;
         VirtualTree(int _n,int _r):
             n(_n),r(_r),l(ceil(log2(n)+1e-8)),to(n+1),vto(n+1),up(n+1,vector<
         int>(l+1)),dp(n+1),dfn(n+1),edf(n+1),imp(n+1){
         }
         void add(int u,int v){
             to[u].push_back(v);
             to[v].push_back(u);
         }
14       void vadd(int u,int v){
             vto[u].push_back(v);
         }
         int lca(int u,int v){
             if(dp[u]<dp[v])
                 swap(u,v);
             for(int i=0;i<=l;++i)
                 if(((dp[u]-dp[v])>>i)&1)
                     u=up[u][i];
             if(u==v)
24               return u;
             for(int i=l;i>=0;--i)
                 if(up[u][i]!=up[v][i])
                     u=up[u][i],v=up[v][i];
             return up[u][0];
         }
         void dfs(int u){
             dfn[u]=++dfn[0];
             for(int i=1;i<=l;++i)
                 up[u][i]=up[up[u][i-1]][i-1];
34           for(int i=0;i<to[u].size();++i){
                 int v=to[u][i];
                 if(v!=up[u][0])
                     up[v][0]=u,dp[v]=dp[u]+1,dfs(v);
             }
             edf[u]=dfn[0];
```

```
        }
        void build(){
            dfs(r);
        }
44      void run(int*a,int m){
            for(int i=0;i<lst.size();++i)
                imp[lst[i]]=0,vto[lst[i]].clear();
            vector<pair<int,int> >b(m+1);
            for(int i=1;i<=m;++i)
                imp[a[i]]=1,b[i]=make_pair(dfn[a[i]],a[i]);
            sort(b.begin()+1,b.end());
            vector<int>st(1,r);
            lst=st;
            for(int i=1;i<=m;++i){
54              int u=b[i].second,v=st.back();
                if(u==r)
                    continue;
                if(dfn[u]<=edf[v])
                    st.push_back(u);
                else{
                    int w=lca(u,v);
                    while(st.size()>=2&&dp[st[st.size()−2]]>=dp[w]){
                        vadd(st[st.size()−2],*st.rbegin());
                        lst.push_back(*st.rbegin()),st.pop_back();
64                  }
                    if(st.size()>=2&&w!=st[st.size()−1]){
                        vadd(w,*st.rbegin()),lst.push_back(*st.rbegin());
                        st.pop_back(),st.push_back(w);
                    }
                    st.push_back(u);
                }
            }
            while(st.size()>=2){
                vadd(st[st.size()−2],*st.rbegin());
74              lst.push_back(*st.rbegin()),st.pop_back();
            }
        }
    };
```

CHAPTER 4

Number Theory

4.1   Discrete Logarithm

warning: old style will be replaced ... see Suffix Array (DC3) for new style

---

Discrete Logarithm.hpp (1819 bytes, 74 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
 3  namespace DiscreteLogarithm{
        typedef long long T;
        int ti[1<<16],va[1<<16],mp[1<<16],nx[1<<16],hd[1<<16],tm,nw;
        void ins(int x,int v){
            int y=x&65535;
            if(ti[y]!=tm)
                ti[y]=tm,hd[y]=0;
            for(int i=hd[y];i;i=nx[i])
                if(va[i]==x){
                    mp[i]=v;
13                  return;
                }
            va[++nw]=x;
            mp[nw]=v;
            nx[nw]=hd[y];
            hd[y]=nw;
        }
        int get(int x){
            int y=x&65535;
            if(ti[y]!=tm)
23              ti[y]=tm,hd[y]=0;
            for(int i=hd[y];i;i=nx[i])
                if(va[i]==x){
                    return mp[i];
                }
            return −1;
        }
        T pow(T a,T b,T c){
            T r=1;
            for(;b;b&1?r=r*a%c:0,b>>=1,a=a*a%c);
33          return r;
        }
        T gcd(T a,T b){
```

```
                return b?gcd(b,a%b):a;
            }
            void exg(T a,T b,T&x,T&y){
                if(!b)
                    x=1,y=0;
                else
                    exg(b,a%b,y,x),y−=a/b*x;
43          }
            T inv(T a,T b){
                T x,y;
                exg(a,b,x,y);
                return x+b;
            }
            T bgs(T a,T b,T c){
                ++tm;
                nw=0;
                T m=sqrt(c);
53              for(T i=m−1,u=pow(a,i,c),v=inv(a,c);i>=0;−−i,u=u*v%c)
                    ins(u,i);
                for(T i=0,u=1,v=inv(pow(a,m,c),c);i*m<=c;++i,u=u*v%c){
                    T t=u*b%c,j;
                    if((j=get(t))!=−1)
                        return i*m+j;
                }
                return −1;
            }
            T run(T a,T b,T c){
63              T u=1,t=0;
                a=(a%c+c)%c;
                b=(b%c+c)%c;
                for(int i=0;i<32;++i)
                    if(pow(a,i,c)==b)
                        return i;
                for(T d;(d=gcd(a,c))!=1;++t,u=a/d*u%c,b/=d,c/=d)
                    if(b%d)
                        return −1;
                return (u=bgs(a,b*inv(u,c)%c,c))<0?−1:u+t;
73          }
        }
```

4.2   Integer Factorization (Pollard's Rho Algorithm)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Integer Factorization (Pollard's Rho Algorithm).hpp (2848 bytes, 93 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
namespace IntegerFactorization{
    template<class T>T mul(T x,T y,T z){
        if(typeid(T)==typeid(int))
            return (long long)x*y%z;
        else if(typeid(T)==typeid(long long))
            return (x*y-(T)(((long double)x*y+0.5)/z)*z+z)%z;
        else
            return x*y%z;
    }
    template<class T>T pow(T a,T b,T c){
        T r=1;
        for(;b;b&1?r=mul(r,a,c):0,b>>=1,a=mul(a,a,c));
        return r;
    }
    template<class T>int chk(T a,int c=10){
        if(a==2)
            return 1;
        if(a%2==0||a<2)
            return 0;
        static int pi[]={2,7,61},pl
    []={2,325,9375,28178,450775,9780504,1795265022};
        if(typeid(T)==typeid(int))
            c=3;
        else if(typeid(T)==typeid(long long))
            c=7;
        T u=a-1,t=0,p=1;
        for(;u%2==0;u/=2,++t);
        for(int i=0;i<c;++i){
            if(typeid(T)==typeid(int))
                p=pi[i]%a;
            else if(typeid(T)==typeid(long long))
                p=pl[i]%a;
            else
```

```
                    p=(p*29+7)%a;
36              if(!p||p==1||p==a−1)
                    continue;
                T x=pow(p,u,a);
                if(x==1)
                    continue;
                for(int j=0;x!=a−1&&j<t;++j){
                    x=mul(x,x,a);
                    if(x==1)
                        return 0;
                }
46              if(x==a−1)
                    continue;
                return 0;
            }
            return 1;
        }
        template<class T>T gcd(T a,T b){
            if(a<0)
                a=−a;
            if(b<0)
56              b=−b;
            return b?gcd(b,a%b):a;
        }
        template<class T>T rho(T a,T c){
            T x=double(rand())/RAND_MAX*(a−1),y=x;
            for(int i=1,k=2;;){
                x=(mul(x,x,a)+c)%a;
                T d=gcd(y−x,a);
                if(d!=1&&d!=a)
                    return d;
66              if(y==x)
                    return a;
                if(++i==k)
                    y=x,k=2*k;
            }
        }
        template<class T>vector<pair<T,int> >run(T a){
            if(a==1)
                return vector<pair<T,int> >();
            if(chk(a))
```

```
76          return vector<pair<T,int> >(1,make_pair(a,1));
        T b=a;
        while((b=rho(b,T(double(rand())/RAND_MAX*(a−1))))==a);
        vector<pair<T,int> >u=run(b),v=run(a/b),r;
        for(int pu=0,pv=0;pu<u.size()||pv<v.size();){
            if(pu==u.size())
                r.push_back(v[pv++]);
            else if(pv==v.size())
                r.push_back(u[pu++]);
            else if(u[pu].first==v[pv].first)
86              r.push_back(make_pair(u[pu].first,(u[pu].second+v[pv].second
    ))),++pu,++pv;
            else if(u[pu].first>v[pv].first)
                r.push_back(v[pv++]);
            else
                r.push_back(u[pu++]);}
        return r;
    }
}
```

4.3   Integer Factorization (Shanks' Square Forms Factorization)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Integer Factorization (Shanks' Square Forms Factorization).hpp (4675 bytes, 147 lines)

```
#include<bits/stdc++.h>
using namespace std;
namespace IntegerFactorization{
    typedef long long ll;
    typedef unsigned long long ull;
    ll lim=3689348814694258326ll;
7   ull srt(const ull&a){
        ull b=sqrt(a);
        b−=b*b>a;
        return b+=(b+1)*(b+1)<=a;
    }
    int sqr(const ull&a,ll&b){
```

```
        b=srt(a);
        return b*b==a;
    }
    ull gcd(const ull&a,const ull&b){
17      return b?gcd(b,a%b):a;
    }
    ll amb(ll a,const ll&B,const ll&dd,const ll&D){
        for(ll q=(dd+B/2)/a,b=q*a*2−B,c=(D−b*b)/4/a,qc,qcb,a0=a,b0=a,b1=b,
    c0=c;;b1=b,c0=c){
            if(c0>dd)
                qcb=c0−b,b=c0+qcb,c=a−qcb;
            else{
                q=(dd+b/2)/c0;
                if(q==1)
                    qcb=c0−b,b=c0+qcb,c=a−qcb;
27              else
                    qc=q*c0,qcb=qc−b,b=qc+qcb,c=a−q*qcb;
            }
            if(a=c0,b==b1)
                break;
            if(b==b0&&a==a0)
                return 0;
        }
        return a&1?a:a>>1;
    }
37  ull fac(const ull&n){
        if(n&1^1)
            return 2;
        if(n%3==0)
            return 3;
        if(n%5==0)
            return 5;
        if(srt(n)*srt(n)==n)
            return srt(n);
        static ll d1,d2,a1,b1,c1,dd1,L1,a2,b2,c2,dd2,L2,a,q,c,qc,qcb,D1,D2,
    bl1[1<<19],bl2[1<<19];
47      int p1=0,p2=0,ac1=1,ac2=1,j,nm4=n&3;
        if(nm4==1)
            D1=n,D2=5*n,d2=srt(D2),dd2=d2/2+d2%2,b2=(d2−1)|1;
        else
            D1=3*n,D2=4*n,dd2=srt(D2),d2=dd2*2,b2=d2;
```

```
        d1=srt(D1),b1=(d1−1)|1,c1=(D1−b1*b1)/4,c2=(D2−b2*b2)/4,L1=srt(d1),
   L2=srt(d2),dd1=d1/2+d1%2;
        for(int i=a1=a2=1;ac1||ac2;++i){
            #define m(t)\
            if(ac##t){\
                c=c##t;\
                q=c>dd##t?1:(dd##t+b##t/2)/c;\
                if(q==1)\
                    qcb=c−b##t,b##t=c+qcb,c##t=a##t−qcb;\
                else\
                    qc=q*c,qcb=qc−b##t,b##t=qc+qcb,c##t=a##t−q*qcb;\
                if((a##t=c)<=L##t)\
                    bl##t[p##t++]=a##t;\
            }
            m(1)m(2)
            if(i&1)
                continue;
            #define m(t)\
            if((ac##t=ac##t&a##t!=1)&&sqr(a##t,a)){\
                if(a<=L##t)\
                    for(j=0;j<p##t;j++)\
                        if(a==bl##t[j]){\
                            a=0;\
                            break;\
                        }\
                if(a>0){\
                    if((q=gcd(a,b##t))>1)\
                        return q*q;\
                    q=amb(a,b##t,dd##t,D##t);\
                    if(nm4==5−2*t&&(q=amb(a,b##t,dd##t,D##t))%(2*t+1)==0)\
                        q/=2*t+1;\
                    if(q>1)\
                        return q;\
                }\
            }
            m(1)m(2)
            #undef m
        }
        for(int i=3;;i+=2)
            if(n%i==0)
                return i;
```

```
        }
        ll mul(const ll&x,const ll&y,const ll&z){
            return(x*y−(ll)(((long double)x*y+0.5)/z)*z+z)%z;
        }
        ll pow(ll a,ll b,const ll&c){
97          ll r=1;
            for(;b;b&1?r=mul(r,a,c):0,b>>=1,a=mul(a,a,c));
            return r;
        }
        int chk(const ll&a){
            if(a==2)
                return 1;
            if(a%2==0||a<2)
                return 0;
            static int pf[]={2,325,9375,28178,450775,9780504,1795265022};
107         ll u=a−1,t=0,p;
            for(;u%2==0;u/=2,++t);
            for(int i=0;i<7;++i){
                p=pf[i]%a;
                if(!p||p==a−1)
                    continue;
                ll x=pow(p,u,a);
                if(x==1)
                    continue;
                for(int j=0;x!=a−1&&j<t;++j){
117                 x=mul(x,x,a);
                    if(x==1)
                        return 0;
                }
                if(x==a−1)
                    continue;
                return 0;
            }
            return 1;
        }
127     vector<pair<ll,int> >run(const ll&a){
            if(a==1)
                return vector<pair<ll,int> >();
            if(chk(a))
                return vector<pair<ll,int> >(1,make_pair(a,1));
            ll b=fac(a);
```

```
          vector<pair<ll,int> >u=run(b),v=run(a/b),r;
          for(int pu=0,pv=0;pu<u.size()||pv<v.size();){
              if(pu==u.size())
                  r.push_back(v[pv++]);
137           else if(pv==v.size())
                  r.push_back(u[pu++]);
              else if(u[pu].first==v[pv].first)
                  r.push_back(make_pair(u[pu].first,(u[pu].second+v[pv].second
     ))),++pu,++pv;
              else if(u[pu].first>v[pv].first)
                  r.push_back(v[pv++]);
              else
                  r.push_back(u[pu++]);}
          return r;
      }
147 }
```

4.4   Modular Integer

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Modular Integer.hpp (2886 bytes, 98 lines)

```
   #include<bits/stdc++.h>
   using namespace std;
 3 template<class T>struct ModularInteger{
       ModularInteger(T t=0):
           v(t){
           if(v<0||v>=p)
               v=(v%p+p)%p;
       }
       ModularInteger<T>&operator=(T a){
           v=a;
           if(v<0||v>=p)
               v%=p;
13         return*this;
       }
       ModularInteger<T>operator−(){
           return v?p−v:0;
       }
```

```
        ModularInteger<T>&operator+=(ModularInteger<T>a){
            return*this=*this+a;
        }
        ModularInteger<T>&operator-=(ModularInteger<T>a){
            return*this=*this-a;
23      }
        ModularInteger<T>&operator*=(ModularInteger<T>a){
            return*this=*this*a;
        }
        ModularInteger<T>&operator/=(ModularInteger<T>a){
            return*this=*this/a;
        }
        T v;
        static T p;
    };
33  template<class T>ModularInteger<T>pow(ModularInteger<T>a,long long b){
        ModularInteger<T>r(1);
        for(;b;b>>=1,a=a*a)
            if(b&1)
                r=r*a;
        return r;
    }
    template<class T>ModularInteger<T>inv(ModularInteger<T>a){
        return pow(a,a.p-2);
    }
43  template<class T>vector<ModularInteger<T> >sqrt(ModularInteger<T>a){
        vector<ModularInteger<T> >r;
        if(!a.v)
            r.push_back(ModularInteger<T>(0));
        else if(pow(a,a.p-1>>1).v==1){
            int s=a.p-1,t=0;
            ModularInteger<T>b=1;
            for(;pow(b,a.p-1>>1).v!=a.p-1;b=rand()*1.0/RAND_MAX*(a.p-1));
            for(;s%2==0;++t,s/=2);
            ModularInteger<T>x=pow(a,(s+1)/2),e=pow(a,s);
53          for(int i=1;i<t;++i,e=x*x/a)
                if(pow(e,1<<t-i-1).v!=1)
                    x=x*pow(b,(1<<i-1)*s);
            r.push_back(x);
            r.push_back(-x);
        }
```

```
        return r;
    }
    template<class T>ModularInteger<T>operator+(ModularInteger<T>a,
        ModularInteger<T>b){
        ModularInteger<T>c(a.v+b.v);
63      if(c.v>=a.p)
            c.v−=a.p;
        return c;
    }
    template<class T>ModularInteger<T>operator−(ModularInteger<T>a,
        ModularInteger<T>b){
        ModularInteger<T>c(a.v−b.v);
        if(c.v<0)
            c.v+=a.p;
        return c;
    }
73  template<class T>ModularInteger<T>operator*(ModularInteger<T>a,
        ModularInteger<T>b){
        if(typeid(T)!=typeid(int))
            return ModularInteger<T>((a.v*b.v−(long long)(((long double)a.v*b.v
        +0.5)/a.p)*a.p+a.p)%a.p);
        else
            return ModularInteger<T>((long long)a.v*b.v%a.p);
    }
    template<class T>ModularInteger<T>operator/(ModularInteger<T>a,
        ModularInteger<T>b){
        return a*inv(b);
    }
    template<class T>bool operator==(ModularInteger<T>a,ModularInteger<T>b){
83      return a.v==b.v;
    }
    template<class T>bool operator!=(ModularInteger<T>a,ModularInteger<T>b){
        return a.v!=b.v;
    }
    template<class T>istream&operator>>(istream&s,ModularInteger<T>&a){
        s>>a.v;
        return s;
    }
    template<class T>ostream&operator<<(ostream&s,ModularInteger<T>a){
93      s<<a.v;
        if(a.v<0||a.v>=a.p)
```

```
        a.v%=a.p;
    return s;
}
template<class T>T ModularInteger<T>::p=1e9+7;
```

4.5   Möbius Function

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Möbius Function.hpp (534 bytes, 21 lines)

```
   #include<bits/stdc++.h>
2  using namespace std;
   namespace MobiusFunction{
       vector<int>run(int n){
           vector<int>p,ntp(n+1),u(n+1);
           ntp[1]=1;
           u[1]=1;
           for(int i=2;i<=n;++i){
               if(!ntp[i])
                   p.push_back(i),u[i]=−1;
               for(int j=0;j<p.size()&&p[j]*i<=n;++j){
12                 ntp[p[j]*i]=1;
                   if(i%p[j]==0)
                       break;
                   else
                       u[p[j]*i]=−u[i];
               }
           }
           return u;
       }
   }
```

4.6   Primality Test

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Primality Test.hpp (1509 bytes, 52 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
namespace PrimalityTest{
    template<class T>T mul(T x,T y,T z){
        if(typeid(T)==typeid(int))
            return (long long)x*y%z;
        else if(typeid(T)==typeid(long long))
            return (x*y-(T)(((long double)x*y+0.5)/z)*z+z)%z;
        else
            return x*y%z;
    }
    template<class T>T pow(T a,T b,T c){
        T r=1;
        for(;b;b&1?r=mul(r,a,c):0,b>>=1,a=mul(a,a,c));
        return r;
    }
    template<class T>int run(T a,int c=10){
        if(a==2)
            return 1;
        if(a%2==0||a<2)
            return 0;
        static int pi[]={2,7,61},pl
[]={2,325,9375,28178,450775,9780504,1795265022};
        if(typeid(T)==typeid(int))
            c=3;
        else if(typeid(T)==typeid(long long))
            c=7;
        T u=a-1,t=0,p=1;
        for(;u%2==0;u/=2,++t);
        for(int i=0;i<c;++i){
            if(typeid(T)==typeid(int))
                p=pi[i]%a;
            else if(typeid(T)==typeid(long long))
                p=pl[i]%a;
            else
                p=(p*29+7)%a;
            if(!p||p==1||p==a-1)
                continue;
            T x=pow(p,u,a);
            if(x==1)
```

```
                  continue;
              for(int j=0;x!=a−1&&j<t;++j){
                  x=mul(x,x,a);
                  if(x==1)
                      return 0;
              }
              if(x==a−1)
                  continue;
              return 0;
49        }
          return 1;
      }
  }
```

4.7   Prime Number

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Prime Number.hpp (473 bytes, 18 lines)

```
  #include<bits/stdc++.h>
  using namespace std;
  namespace PrimeNumber{
      pair<vector<int>,vector<int> >run(int n){
          vector<int>p,ntp(n+1);
          ntp[1]=1;
          for(int i=2;i<=n;++i){
8             if(!ntp[i])
                  p.push_back(i);
              for(int j=0;j<p.size()&&p[j]*i<=n;++j){
                  ntp[p[j]*i]=1;
                  if(i%p[j]==0)
                      break;
              }
          }
          return make_pair(p,ntp);
      }
18 }
```

4.8   Primitive Root

warning: old style will be replaced ... see Suffix Array (DC3) for new style

<div style="text-align:center">Primitive Root.hpp (3256 bytes, 106 lines)</div>

```
   #include<bits/stdc++.h>
 2 using namespace std;
   namespace PrimitiveRoot{
       template<class T>T mul(T x,T y,T z){
           if(typeid(T)==typeid(int))
               return (long long)x*y%z;
           else
               return (x*y-(T)(((long double)x*y+0.5)/z)*z+z)%z;
       }
       template<class T>T pow(T a,T b,T c){
           T r=1;
12         for(;b;b&1?r=mul(r,a,c):0,b>>=1,a=mul(a,a,c));
           return r;
       }
       template<class T>bool chk(T a,int c=10){
           if(a==1)
               return false;
           T u=a-1,t=0;
           for(;u%2==0;u/=2,++t);
           for(int i=0;i<c;++i){
               T x=pow(T(rand()*1.0/RAND_MAX*(a-2)+1),u,a),y;
22             for(int j=0;j<t;++j){
                   y=x;
                   x=mul(x,x,a);
                   if(x==1&&y!=1&&y!=a-1)
                       return false;
               }
               if(x!=1)
                   return false;
           }
           return true;
32     }
       template<class T>T gcd(T a,T b){
           if(a<0)
               a=-a;
```

```
        if(b<0)
            b=−b;
        return b?gcd(b,a%b):a;
    }
    template<class T>T rho(T a,T c){
        T x=double(rand())/RAND_MAX*(a−1),y=x;
42      for(int i=1,k=2;;){
            x=(mul(x,x,a)+c)%a;
            T d=gcd(y−x,a);
            if(d!=1&&d!=a)
                return d;
            if(y==x)
                return a;
            if(++i==k)
                y=x,k=2*k;
        }
52  }
    template<class T>vector<pair<T,int> >fac(T a){
        if(a==1)
            return vector<pair<T,int> >();
        if(chk(a))
            return vector<pair<T,int> >(1,make_pair(a,1));
        T b=a;
        while((b=rho(b,T(double(rand())/RAND_MAX*(a−1))))==a);
        vector<pair<T,int> >u=fac(b),v=fac(a/b),r;
        for(int pu=0,pv=0;pu<u.size()||pv<v.size();){
62          if(pu==u.size())
                r.push_back(v[pv++]);
            else if(pv==v.size())
                r.push_back(u[pu++]);
            else if(u[pu].first==v[pv].first)
                r.push_back(make_pair(u[pu].first,(u[pu].second+v[pv].second
    ))),++pu,++pv;
            else if(u[pu].first>v[pv].first)
                r.push_back(v[pv++]);
            else
                r.push_back(u[pu++]);}
72      return r;
    }
    template<class T>void dfs(vector<pair<T,int> >&f,int i,T now,vector<T>&
    r){
```

```
              if(i==f.size()){
                  r.push_back(now);
                  return;
              }
              for(int j=0;j<=f[i].second;++j,now*=f[i].first)
                  dfs(f,i+1,now,r);
          }
82        template<class T>T run(T a){
              vector<pair<T,int> >fa=fac(a),fpa;
              if(fa.size()==0||fa.size()>2)
                  return −1;
              if(fa.size()==1&&fa[0].first==2&&fa[0].second>2)
                  return −1;
              if(fa.size()==2&&fa[0]!=make_pair(T(2),1))
                  return −1;
              T pa=a;
              for(int i=0;i<fa.size();++i)
92                pa=pa/fa[i].first*(fa[i].first−1);
              fpa=fac(pa);
              vector<T>fs;
              dfs(fpa,0,1,fs);
              for(T g=1,f=0;;++g,f=0){
                  for(int i=0;i<fs.size();++i)
                      if(fs[i]!=pa&&pow(g,fs[i],a)==1){
                          f=1;
                          break;
                      }
102               if(!f)
                      return g;
              }
          }
      }
```

4.9   Sequence

Numbers n such that a Hadamard matrix of order n exists.
1, 2, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80, 84, 88, 92, 96, 100, 104, 108, 112, 116, 120, 124, 128, 132, 136, 140, 144, 148, 152, 156, 160, 164, 168, 172, 176, 180, 184, 188, 192, 196, 200, 204, 208, 212, 216, 220, 224, 228, 232, 236, 240, ...

Catalan numbers: $C_n = \frac{1}{n+1}\binom{2n}{n} = \frac{(2n)!}{(n+1)!n!}$. Also called Segner numbers.
1, 1, 2, 5, 14, 42, 132, 429, 1430, 4862, 16796, 58786, 208012, 742900, 2674440, 9694845, 35357670, 129644790, 477638700, 1767263190, 6564120420, 24466267020, 91482563640, 343059613650, 1289904147324, 4861946401452, 18367353072152, 69533550916004, 263747951750360, 1002242216651368, 3814986502092304, ...

Bell or exponential numbers: number of ways to partition a set of n labeled elements.
1, 1, 2, 5, 15, 52, 203, 877, 4140, 21147, 115975, 678570, 4213597, 27644437, 190899322, 1382958545, 10480142147, 82864869804, 682076806159, 5832742205057, 51724158235372, 474869816156751, 4506715738447323, 44152005855084346, 445958869294805289, 4638590332229999353, 49631246523618756274, ...

CHAPTER 5

Numerical Algorithms

5.1   Convolution (Fast Fourier Transform)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

---

Convolution (Fast Fourier Transform).hpp (1300 bytes, 39 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
namespace Convolution{
    typedef complex<double>T;
    void fft(vector<T>&a,int n,double s,vector<int>&rev){
        T im(0,1);
        double pi=acos(-1);
        for(int i=0;i<n;++i)
            if(i<rev[i])
                swap(a[i],a[rev[i]]);
        for(int i=1,m=2;(1<<i)<=n;++i,m<<=1){
            T wm=exp(s*im*2.0*pi/double(m)),w;
            for(int j=(w=1,0);j<n;j+=m,w=1)
                for(int k=0;k<(m>>1);++k,w*=wm){
                    T u=a[j+k],v=w*a[j+k+(m>>1)];
                    a[j+k]=u+v;
                    a[j+k+(m>>1)]=u-v;
                }
        }
    }
    vector<double>run(const vector<double>&a,const vector<double>&b){
        int l=ceil(log2(a.size()+b.size()-1)),n=1<<l;
        vector<int>rv;
        for(int i=(rv.resize(n),0);i<n;++i)
            rv[i]=(rv[i>>1]>>1)|((i&1)<<(l-1));
        vector<T>ta(n),tb(n);
        copy(a.begin(),a.end(),ta.begin());
        copy(b.begin(),b.end(),tb.begin());
        fft(ta,n,1,rv);
        fft(tb,n,1,rv);
        for(int i=0;i<n;++i)
            ta[i]*=tb[i];
        fft(ta,n,-1,rv);
        vector<double>c(a.size()+b.size()-1);
        for(int i=0;i<c.size();++i)
```

```
            c[i]=real(ta[i])/n;
        return c;
    }
}
```

5.2   Convolution (Karatsuba Algorithm)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Convolution (Karatsuba Algorithm).hpp (1416 bytes, 43 lines)

```
 1  #include<bits/stdc++.h>
    using namespace std;
    namespace Convolution{
        template<class T>void kar(T*a,T*b,int n,int l,T**r){
            T*rl=r[l],*rll=r[l-1];
            for(int i=0;i<2*n;++i)
                *(rl+i)=0;
            if(n<=30){
                for(int i=0;i<n;++i)
                    for(int j=0;j<n;++j)
11                      *(rl+i+j)+=*(a+i)**(b+j);
                return;
            }
            kar(a,b,n>>1,l-1,r);
            for(int i=0;i<n;++i)
                *(rl+i)+=*(rll+i),*(rl+i+(n>>1))+=*(rll+i);
            kar(a+(n>>1),b+(n>>1),n>>1,l-1,r);
            for(int i=0;i<n;++i)
                *(rl+i+n)+=*(rll+i),*(rl+i+(n>>1))+=*(rll+i);
            for(int i=0;i<(n>>1);++i){
21              *(rl+(n<<1)+i)=*(a+(n>>1)+i)-*(a+i);
                *(rl+i+(n>>1)*5)=*(b+i)-*(b+(n>>1)+i);
            }
            kar(rl+(n<<1),rl+(n>>1)*5,n>>1,l-1,r);
            for(int i=0;i<n;++i)
                *(rl+i+(n>>1))+=*(rll+i);}
        template<class T>vector<T>run(vector<T>a,vector<T>b){
            int l=ceil(log2(max(a.size(),b.size()))+1e-8);
            vector<T>rt(a.size()+b.size()-1);
```

```
            a.resize(1<<l);
31          b.resize(1<<l);
            T**r=new T*[l+1];
            for(int i=0;i<=l;++i)
                r[i]=new T[(1<<i)*3];
            kar(&a[0],&b[0],1<<l,l,r);
            for(int i=0;i<rt.size();++i)
                rt[i]=*(r[l]+i);
            for(int i=0;i<=l;++i)
                delete r[i];
            delete r;
41          return rt;
        }
}
```

5.3   Convolution (Number Theoretic Transform)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Convolution (Number Theoretic Transform).hpp (1620 bytes, 51 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
    namespace Convolution{
        typedef long long T;
        T pow(T a,T b,T c){
            T r=1;
7           for(;b;b&1?r=r*a%c:0,b>>=1,a=a*a%c);
            return r;
        }
        void ntt(vector<T>&a,int n,int s,vector<int>&rev,T p,T g){
            g=s==1?g:pow(g,p−2,p);
            vector<T>wm;
            for(int i=0;1<<i<=n;++i)
                wm.push_back(pow(g,(p−1)>>i,p));
            for(int i=0;i<n;++i)
                if(i<rev[i])
17                  swap(a[i],a[rev[i]]);
            for(int i=1,m=2;1<<i<=n;++i,m<<=1){
                vector<T>wmk(1,1);
```

```
                for(int k=1;k<(m>>1);++k)
                    wmk.push_back(wmk.back()*wm[i]%p);
                for(int j=0;j<n;j+=m)
                    for(int k=0;k<(m>>1);++k){
                        T u=a[j+k],v=wmk[k]*a[j+k+(m>>1)]%p;
                        a[j+k]=u+v;
                        a[j+k+(m>>1)]=u−v+p;
                        if(a[j+k]>=p)
                            a[j+k]−=p;
                        if(a[j+k+(m>>1)]>=p)
                            a[j+k+(m>>1)]−=p;
                    }
            }
        }
        vector<T>run(vector<T>a,vector<T>b,T p=15*(1<<27)+1,T g=31){
            int tn,l=ceil(log2(tn=a.size()+b.size()−1)),n=1<<l;
            vector<int>rv;
            for(int i=(rv.resize(n),0);i<n;++i)
                rv[i]=(rv[i>>1]>>1)|((i&1)<<(l−1));
            a.resize(n);
            b.resize(n);
            ntt(a,n,1,rv,p,g);
            ntt(b,n,1,rv,p,g);
            for(int i=0;i<n;++i)
                a[i]=a[i]*b[i]%p;
            ntt(a,n,−1,rv,p,g);
            n=pow(n,p−2,p);
            for(T&v:a)
                v=v*n%p;
            return a.resize(tn),a;
        }
    }
```

5.4 Fraction

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Fraction.hpp (2217 bytes, 100 lines)

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

```cpp
using namespace std;
template<class T>struct Fraction{
    T p,q;
    int s;
    T gcd(T a,T b){
        return b?gcd(b,a%b):a;
    }
    void reduce(){
        T d=gcd(p,q);
        p/=d;
        q/=d;
        if(p==0)
            s=0;
    }
    Fraction(int _s=0,T _p=0,T _q=1):
        s(_s),p(_p),q(_q){
        reduce();
    }
    Fraction(string a){
        if(a[0]=='−'){
            s=−1;
            a=a.substr(1,a.size()−1);
        }else if(a[0]=='+'){
            s=1;
            a=a.substr(1,a.size()−1);
        }else
            s=1;
        stringstream ss;
        char tc;
        ss<<a;
        ss>>p>>tc>>q;
        reduce();
    }
    Fraction(const char*a){
        *this=Fraction(string(a));
    }
    Fraction<T>&operator=(string a){
        return*this=Fraction<T>(a);
    }
    Fraction<T>&operator=(const char*a){
        return*this=Fraction<T>(a);
```

```
          }
      };
      template<class T>ostream&operator<<(ostream&s,const Fraction<T>&a){
          if(a.s==-1)
              s<<'-';
          return s<<a.p<<'/'<<a.q;
49    }
      template<class T>istream&operator>>(istream&s,Fraction<T>&a){
          string t;
          s>>t;
          a=t;
          return s;
      }
      template<class T>vector<string>real(const Fraction<T>&a){
          vector<string>r;
          stringstream ss;
59        string st;
          if(a.s<0)
              r.push_back("-");
          else
              r.push_back("+");
          T p=a.p,q=a.q;
          ss<<p/q;
          ss>>st;
          r.push_back(st);
          p%=q;
69        st.clear();
          map<T,int>mp;
          while(true){
              if(p==0){
                  r.push_back(st);
                  r.push_back("");
                  return r;
              }
              if(mp.count(p)){
                  r.push_back(st.substr(0,mp[p]));
79                r.push_back(st.substr(mp[p],st.size()-mp[p]));
                  return r;
              }
              p*=10;
              mp[p/10]=st.size();
```

```
            st.push_back('0'+p/q);
            p%=q;
        }
        return r;
    }
89  template<class T>string decimal(const Fraction<T>&a){
        string r;
        vector<string>t=real(a);
        if(t[0]=="−")
            r.push_back('−');
        r+=t[1];
        if(t[2].size()||t[3].size())
            r+="."+t[2];
        if(t[3].size())
            r+="("+t[3]+")";
99      return r;
    }
```

5.5   Integer

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Integer.hpp (6378 bytes, 269 lines)

```
#include<bits/stdc++.h>
using namespace std;
struct Integer operator+(Integer a,Integer b);
Integer operator+(Integer a,int b);
Integer operator−(Integer a,Integer b);
Integer operator*(Integer a,Integer b);
Integer operator*(Integer a,Integer b);
Integer operator/(Integer a,Integer b);
Integer operator%(Integer a,Integer b);
10  Integer operator%(Integer a,int b);
Integer operator%(Integer a,long long b);
bool operator!=(Integer a,int b);
bool operator<=(Integer a,int b);
struct Integer{
    operator bool(){
        return *this!=0;
```

```
        }
        Integer(long long a=0){
            if(a<0){
20              s=-1;
                a=-a;
            }else
                s=a!=0;
            do{
                d.push_back(a%B);
                a/=B;
            }while(a);
        }
        Integer(string a){
30          s=(a[0]=='-')?-1:(a!="0");
            for(int i=a.size()-1;i>=(a[0]=='-');i-=L){
                int t=0,j=max(i-L+1,int(a[0]=='-'));
                for(int k=j;k<=i;++k)
                    t=t*10+a[k]-'0';
                d.push_back(t);
            }
        }
        Integer(const Integer&a){
            d=a.d;
40          s=a.s;
        }
        Integer&operator=(long long a){
            return*this=Integer(a);
        }
        Integer&operator+=(Integer a){
            return*this=*this+a;
        }
        Integer&operator-=(Integer a){
            return*this=*this-a;
50      }
        Integer&operator*=(Integer a){
            return*this=*this*a;
        }
        Integer&operator/=(Integer a){
            return*this=*this/a;
        }
        Integer&operator%=(Integer a){
```

```
              return*this=*this%a;
          }
60        Integer&operator++(){
              return*this=*this+1;
          }
          operator string()const{
              string r;
              for(int i=0;i<d.size();++i){
                  stringstream ts;
                  ts<<d[i];
                  string tt;
                  ts>>tt;
70                reverse(tt.begin(),tt.end());
                  while(i+1!=d.size()&&tt.size()<L)
                      tt.push_back('0');
                  r+=tt;
              }
              reverse(r.begin(),r.end());
              return r;
          }
          int s;
          vector<int>d;
80        static const int B=1e8,L=8;
      };
      string str(const Integer&a){
          return string(a);
      }
      bool operator<(Integer a,Integer b){
          if(a.s!=b.s)
              return a.s<b.s;
          if(a.d.size()!=b.d.size())
              return (a.s!=1)^(a.d.size()<b.d.size());
90        for(int i=a.d.size()-1;i>=0;--i)
              if(a.d[i]!=b.d[i])
                  return (a.s!=1)^(a.d[i]<b.d[i]);
          return false;
      }
      bool operator>(Integer a,Integer b){
          return b<a;
      }
      bool operator<=(Integer a,Integer b){
```

```
            return !(a>b);
100     }
        bool operator>=(Integer a,Integer b){
            return !(a<b);
        }
        bool operator==(Integer a,Integer b){
            return !(a<b)&&!(a>b);
        }
        bool operator!=(Integer a,Integer b){
            return !(a==b);
        }
110 istream&operator>>(istream&s,Integer&a){
            string t;
            s>>t;
            a=Integer(t);
            return s;
        }
        ostream&operator<<(ostream&s,Integer a){
            if(a.s==−1)
                s<<'−';
            for(int i=a.d.size()−1;i>=0;−−i){
120         if(i!=a.d.size()−1)
                    s<<setw(Integer::L)<<setfill('0');
                s<<a.d[i];
            }
            s<<setw(0)<<setfill(' ');
            return s;
        }
        void dzero(Integer&a){
            while(a.d.size()>1&&a.d.back()==0)
                a.d.pop_back();
130     }
        Integer operator−(Integer a){
            a.s*=−1;
            if(a.d.size()==1&&a.d[0]==0)
                a.s=1;
            return a;
        }
        Integer operator+(Integer a,int b){
            return a+Integer(b);
        }
```

```
140   Integer operator*(Integer a,int b){
          return a*Integer(b);
      }
      Integer operator%(Integer a,int b){
          return a%Integer(b);
      }
      Integer operator%(Integer a,long long b){
          return a%Integer(b);
      }
      bool operator!=(Integer a,int b){
150       return a!=Integer(b);
      }
      bool operator<=(Integer a,int b){
          return a<=Integer(b);
      }
      Integer operator+(Integer a,Integer b){
          if(a.s*b.s!=−1){
              Integer c;c.s=a.s?a.s:b.s;
              c.d.resize(max(a.d.size(),b.d.size())+1);
              for(int i=0;i<c.d.size()−1;++i){
160               if(i<a.d.size())
                      c.d[i]+=a.d[i];
                  if(i<b.d.size())
                      c.d[i]+=b.d[i];
                  if(c.d[i]>=Integer::B){
                      c.d[i]−=Integer::B;
                      ++c.d[i+1];
                  }
              }
              dzero(c);
170           return c;
          }
          return a−(−b);
      }
      Integer operator−(Integer a,Integer b){
          if(a.s*b.s==1){
              if(a.s==−1)
                  return (−b)−(−a);
              if(a<b)
                  return −(b−a);
180           if(a==b)
```

```
                    return 0;
                for(int i=0;i<b.d.size();++i){
                    a.d[i]-=b.d[i];
                    if(a.d[i]<0){
                        a.d[i]+=Integer::B;
                        --a.d[i+1];
                    }
                }
                dzero(a);
190             return a;
            }
            return a+(-b);
        }
        Integer operator*(Integer a,Integer b){
            vector<long long>t(a.d.size()+b.d.size());
            for(int i=0;i<a.d.size();++i)
                for(int j=0;j<b.d.size();++j)
                    t[i+j]+=(long long)a.d[i]*b.d[j];
            for(int i=0;i<t.size()-1;++i){
200             t[i+1]+=t[i]/Integer::B;
                t[i]%=Integer::B;
            }
            Integer c;
            c.s=a.s*b.s;c.d.resize(t.size());
            copy(t.begin(),t.end(),c.d.begin());
            dzero(c);
            return c;
        }
        Integer div2(Integer a){
210         for(int i=a.d.size()-1;i>=0;--i){
                if(i)
                    a.d[i-1]+=(a.d[i]&1)*Integer::B;
                a.d[i]>>=1;
            }
            dzero(a);
            if(a.d.size()==1&&a.d[0]==0)
                a.s=0;
            return a;
        }
220 Integer operator/(Integer a,Integer b){
            if(!a.s)
```

```
            return 0;
        if(a.s<0)
            return−((−a)/b);
        if(a<b)
            return 0;
        Integer l=1,r=1;
        while(r*b<=a)
            r=r*2;
230     while(l+1<r){
            Integer m=div2(l+r);
            if(m*b>a)
                r=m;
            else
                l=m;
        }
        return l;
    }
    Integer operator%(Integer a,Integer b){
240     return a−a/b*b;
    }
    Integer gcd(Integer a,Integer b){
        Integer r=1;
        while(a!=0&&b!=0){
            if(!(a.d[0]&1)&&!(b.d[0]&1)){
                a=div2(a);
                b=div2(b);
                r=r*2;
            }else if(!(a.d[0]&1))
250             a=div2(a);
            else if(!(b.d[0]&1))
                b=div2(b);
            else{
                if(a<b)
                    swap(a,b);
                a=div2(a−b);
            }
        }
        if(a!=0)
260         return r*a;
        return r*b;
    }
```

```
int length(Integer a){
    a.s=1;
    return string(a).size();
}
int len(Integer a){
    return length(a);
}
```

5.6   Linear Programming

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Linear Programming.hpp (2522 bytes, 89 lines)

```
 1  #include<bits/stdc++.h>
    using namespace std;
    struct LinearProgramming{
        const double E;
        int n,m,p;
        vector<int>mp,ma,md;
        vector<vector<double> >a;
        vector<double>res;
        LinearProgramming(int _n,int _m):
            n(_n),m(_m),p(0),a(n+2,vector<double>(m+2)),mp(n+1),ma(m+n+2),md(m
    +2),res(m+1),E(1e-8){
11      }
        void piv(int l,int e){
            swap(mp[l],md[e]);
            ma[mp[l]]=l;
            ma[md[e]]=-1;
            double t=-a[l][e];
            a[l][e]=-1;
            vector<int>qu;
            for(int i=0;i<=m+1;++i)
                if(fabs(a[l][i]/=t)>E)
21                  qu.push_back(i);
            for(int i=0;i<=n+1;++i)
                if(i!=l&&fabs(a[i][e])>E){
                    t=a[i][e];
                    a[i][e]=0;
```

```cpp
                for(int j=0;j<qu.size();++j)
                    a[i][qu[j]]+=a[l][qu[j]]*t;
            }
            if(-p==l)
                p=e;
31          else if(p==e)
                p=-l;
        }
        int opt(int d){
            for(int l=-1,e=-1;;piv(l,e),l=-1,e=-1){
                for(int i=1;i<=m+1;++i)
                    if(a[d][i]>E){
                        e=i;
                        break;
                    }
41              if(e==-1)
                    return 1;
                double t;
                for(int i=1;i<=n;++i)
                    if(a[i][e]<-E&&(l==-1||a[i][0]/-a[i][e]<t))
                        t=a[i][0]/-a[i][e],l=i;
                if(l==-1)
                    return 0;
            }
        }
51      double&at(int x,int y){
            return a[x][y];
        }
        vector<double>run(){
            for(int i=1;i<=m+1;++i)
                ma[i]=-1,md[i]=i;
            for(int i=m+2;i<=m+n+1;++i)
                ma[i]=i-(m+1),mp[i-(m+1)]=i;
            double t;
            int l=-1;
61          for(int i=1;i<=n;++i)
                if(l==-1||a[i][0]<t)
                    t=a[i][0],l=i;
            if(t<-E){
                for(int i=1;i<=n;++i)
                    a[i][m+1]=1;
```

```
              a[n+1][m+1]=−1;
              p=m+1;
              piv(1,m+1);
              if(!opt(n+1)||fabs(a[n+1][0])>E)
71                return vector<double>();
              if(p<0)
                  for(int i=1;i<=m;++i)
                      if(fabs(a[−p][i])>E){
                          piv(−p,i);
                          break;
                      }
              for(int i=0;i<=n;++i)
                  a[i][p]=0;
          }
81        if(!opt(0))
              return vector<double>();
          res[0]=a[0][0];
          for(int i=1;i<=m;++i)
              if(ma[i]!=−1)
                  res[i]=a[ma[i]][0];
          return res;
      }
  };
```

5.7   Linear System

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Linear System.hpp (1477 bytes, 56 lines)

```
1   #include<bits/stdc++.h>
    using namespace std;
    template<class T>struct LinearSystem{
        int n;
        vector<vector<T> >a;
        vector<int>main,pos;
        vector<T>ans;
        int cmp(T a){
            if(typeid(T)==typeid(double)||typeid(T)==typeid(long double)||
        typeid(T)==typeid(float)){
```

```
                if(a<-1e-8)
11                    return -1;
                if(a>1e-8)
                    return 1;
                return 0;
            }
            if(a<0)
                return -1;
            if(a>0)
                return 1;
            return 0;
21      }
        T&at(int i,int j){
            return a[i][j];
        }
        vector<T>&at(int i){
            return a[i];
        }
        LinearSystem(int _n):
            n(_n),a(n+1,vector<T>(n+1)),main(n+1),pos(n+1),ans(n){
        }
31      vector<T>run(){
            for(int i=1;i<=n;++i){
                int j=1;
                for(;j<=n&&!cmp(a[i][j]);++j);
                if(j<=n){
                    main[i]=j;
                    pos[j]=i;
                    T t=a[i][j];
                    for(int k=0;k<=n;++k)
                        a[i][k]/=t;
41                  for(int k=1;k<=n;++k)
                        if(k!=i&&cmp(a[k][j])){
                            t=a[k][j];
                            for(int l=0;l<=n;++l)
                                a[k][l]-=a[i][l]*t;
                        }
                }
            }
            for(int i=1;i<=n;++i){
                if(!pos[i])
```

```
51              return vector<T>();
            ans[i−1]=a[pos[i]][0];
        }
        return ans;
    }
};
```

5.8   Matrix

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Matrix.hpp (1457 bytes, 51 lines)

```
#include<bits/stdc++.h>
template<class T,int N>struct Matrix{
    Matrix(T t=0){
        for(int i=0;i<N;++i)
            for(int j=0;j<N;++j)
                u[i][j]=i==j?t:0;
    }
    T u[N][N];
};
template<class T,int N>Matrix<T,N>operator+(const Matrix<T,N>&a,const
    Matrix<T,N>&b){
    Matrix<T,N>c;
    for(int i=0;i<N;++i)
        for(int j=0;j<N;++j)
            c.u[i][j]=a.u[i][j]+b.u[i][j];
    return c;
}
template<class T,int N>Matrix<T,N>operator*(const Matrix<T,N>&a,const
    Matrix<T,N>&b){
    Matrix<T,N>c;
    for(int i=0;i<N;++i)
        for(int j=0;j<N;++j)
            for(int k=0;k<N;++k)
                c.u[i][j]+=a.u[i][k]*b.u[k][j];
    return c;
}
template<class T,int N>Matrix<T,N>operator*(const Matrix<T,N>&a,const T&b){
```

```
    Matrix<T,N>c=a;
    for(int i=0;i<N;++i)
        for(int j=0;j<N;++j)
            c.u[i][j]*=b;
    return c;
}
template<class T,int N>Matrix<T,N>operator/(const Matrix<T,N>&a,const T&b){
    Matrix<T,N>c=a;
    for(int i=0;i<N;++i)
        for(int j=0;j<N;++j)
            c.u[i][j]/=b;
    return c;
}
template<class T,int N>Matrix<T,N>pow(Matrix<T,N>a,long long b){
    Matrix<T,N>r(1);
    for(;b;a=a*a,b>>=1)
        if(b&1)
            r=r*a;
    return r;
}
template<class T,int N>ostream&operator<<(ostream&s,const Matrix<T,N>a){
    for(int i=0;i<N;++i)
        for(int j=0;j<N;++j)
            s<<a.u[i][j]<<(j+1==N?'\n':' ');
    return s;
}
```

5.9   Polynomial Interpolation

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Polynomial Interpolation.hpp (372 bytes, 15 lines)

```
#include<bits/stdc++.h>
using namespace std;
template<class T>T PolynomialInterpolation(vector<T>x,vector<T>y,T x0){
    T r=0;
    for(int i=0;i<x.size();++i){
        T p=1,q=1;
        for(int j=0;j<x.size();++j)
```

```
            if(j!=i){
9               p*=(x0−x[j]);
                q*=(x[i]−x[j]);
            }
        r+=p/q*y[i];
    }
    return r;
}
```

CHAPTER 6

String Algorithms

6.1   Aho-Corasick Automaton

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Aho-Corasick Automaton.hpp (1369 bytes, 50 lines)

```
     #include<bits/stdc++.h>
     using namespace std;
     struct AhoCorasickAutomaton{
         struct node{
 5           node(int m):
                 tr(m),fail(0),cnt(0){
             }
             vector<node*>tr;
             node*fail;
             int cnt;
         };
         int m;
         node*root;
         vector<node*>all;
15       AhoCorasickAutomaton(int _m):
             m(_m),root(new node(m)),all(1,root){
         }
         ~AhoCorasickAutomaton(){
             for(int i=0;i<all.size();++i)
                 delete all[i];
         }
         node*insert(int*s){
             node*p;
             for(p=root;*s!=−1;p=p−>tr[*(s++)])
25               if(!p−>tr[*s])
                     p−>tr[*s]=new node(m);
             return p;
         }
         void build(){
             queue<node*>qu;
             for(int i=0;i<m;++i)
                 if(!root−>tr[i])
                     root−>tr[i]=root;
                 else
35                   root−>tr[i]−>fail=root,qu.push(root−>tr[i]);
```

```
        for(node*u;qu.size()?(u=qu.front(),qu.pop(),all.push_back(u),1):0;)
            for(int i=0;i<m;++i)
                if(!u−>tr[i])
                    u−>tr[i]=u−>fail−>tr[i];
                else
                    u−>tr[i]−>fail=u−>fail−>tr[i],qu.push(u−>tr[i]);
        }
        void run(int*s){
            for(node*p=root;*s!=−1;++(p=p−>tr[*(s++)])−>cnt);
        }
        void count(){
            for(int i=all.size()−1;i>=1;−−i)
                all[i]−>fail−>cnt+=all[i]−>cnt;
        }
    };
```

6.2   Factor Oracle

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Factor Oracle.hpp (569 bytes, 16 lines)

```
#include<bits/stdc++.h>
using namespace std;
template<class T,int N,int M,T D>struct FactorOracle{
    void insert(T*s,int n){
        memset(tr,(lrs[0]=0,sp[0]=−1),4*M);
        for(int i=0,j,c=s[i]−D,u,v;i<n;c=s[++i]−D){
            memset(tr+i+1,(lrs[i+1]=0)−1,4*M);
            for(j=i;j>−1&&tr[j][c]<0;tr[j][c]=i+1,j=sp[u=j]);
            if(v=sp[i+1]=j<0?0:tr[j][c]){
                for(v=v−1==sp[u]?u:v−1;sp[u]!=sp[v];v=sp[v]);
                lrs[i+1]=min(lrs[u],lrs[v])+1;
            }
        }
    }
    int sp[N+1],lrs[N+1],tr[N+1][M];
};
```

6.3   Longest Common Substring

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Longest Common Substring.hpp (1181 bytes, 28 lines)

```
   #include<bits/stdc++.h>
   using namespace std;
   template<class T,int N,int M,T D>struct LongestCommonSubstring{
4      void ins(int c){
           memset(tr+i+1,(lrs[i+1]=0)−1,4*M);
           for(j=i;j>−1&&((v=tr[j][c])>=l1+2&&v<=l1+lb+1||v<0);tr[j][c]=i+1+lb
   ,j=sp[u=j]);
           if(v=sp[i+1]=j<0?0:tr[j][c]−(tr[j][c]>l1+1)*lb){
               for(v=v−1==sp[u]?u:v−1;sp[u]!=sp[v];v=sp[v]);
               lrs[i+1]=min(lrs[u],lrs[v])+1;
           }
           if(sp[i+1]<=l1)
               tm[sp[i+1]]=max(tm[sp[i+1]],lrs[i+1]);
       }
14     int run(vector<pair<int,T*> >s){
           swap(s[0],*min_element(s.begin(),s.end()));
           l1=s[k=lb=0].first;
           memset(mi,63,4*N+4);
           memset(tr,(lrs[0]=0,sp[0]=−1),4*M+4);
           for(i=0;i<l1;ins(*(s[0].second+i)−D),++i);
           for(k=1,ins(M);k<s.size();lb+=s[k++].first){
               memset(tm,0,4*N+4);
               for(i=l1+1;i−l1−1<s[k].first;ins(*(s[k].second+i−l1−1)−D),++i)
   ;
               for(i=l1;i;mi[i]=min(mi[i],tm[i]),tm[sp[i]]=max(tm[sp[i]],lrs[i
   ]*!!tm[i]),−−i);
24         }
           return min(*max_element(mi+1,mi+l1+1),l1);
       }
       int sp[2*N+2],lrs[2*N+2],tr[2*N+2][M+1],mi[N+1],tm[N+1],l1,lb,i,j,k,u,v
   ;
   };
```

6.4   Palindromic Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Palindromic Tree.hpp (1327 bytes, 50 lines)

```cpp
   #include<bits/stdc++.h>
2  using namespace std;
   template<class T>struct PalindromicTree{
       struct node{
           node(int m,node*f,int l):
               nxt(m),fail(f),len(l){
           }
           vector<node*>nxt;
           node*fail;
           T val;
           int len;
12     }*root;
       int m;
       vector<int>str;
       vector<node*>all;
       PalindromicTree(int _m):
           m(_m){
           node*n0=new node(m,0,-2),*n1=new node(m,n0,-1),*n2=new node(m,n1,0)
       ;
           all.push_back(n0);
           all.push_back(n1);
           all.push_back(n2);
22         fill(n0->nxt.begin(),n0->nxt.end(),n2);
           root=n1;
       }
       ~PalindromicTree(){
           for(int i=0;i<all.size();++i)
               delete all[i];
       }
       node*find(node*x){
           while(x->fail&&str[str.size()-x->len-2]!=str[str.size()-1])
               x=x->fail;
32         return x;
       }
       node*insert(node*p,int c,T v){
```

```
        if(p==root)
            str=vector<int>(1,−1);
        str.push_back(c);
        p=find(p);
        if(!p−>nxt[c]){
            node*np=(p−>nxt[c]=new node(m,find(p−>fail)−>nxt[c],p−>len+2))
    ;
            all.push_back(np);
        }
        p−>nxt[c]−>val+=v;
        return p−>nxt[c];
    }
    void count(){
        for(int i=all.size()−1;i>=1;−−i)
            all[i]−>fail−>val+=all[i]−>val;
    }
};
```

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6.5   String Matching

Description

Find the occurrences of a pattern in a text.

Methods

template<class T>StringMatching<T>::StringMatching(T*p);	
Description	construct an object of SuffixMatching for a given pattern
Parameters	Description
T	type of character
p	pattern, indexed from one, ended by zero
Time complexity	$\Theta(|p|)$
Space complexity	$\Theta(|p|)$
Return value	an object of StringMatching

template<class T>int StringMatching<T>::run(T*t,int k=0);	
Description	given an occurence of the pattern in a text, find the next occurrence
Parameters	Description
t	text, indexed from one, ended by zero
k	start index of the last occurence of the pattern, use zero if there is none
Time complexity	$O(|t|)$
Space complexity	$\Theta(1)$
Return value	start index of the next occurence of the pattern

Fields

Name	Description

Performance

Problem	Constraints	Time	Memory	Date
POJ P3461	$|p| = 10^4, |t| = 10^6$	141 ms	1340 kB	2016-02-14

References

Title	Author
Fast pattern matching in strings	Donald E. Knuth, James H. Morris, Vaughan R. Pratt

Code

String Matching.hpp (682 bytes, 25 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
template<class T>struct StringMatching{
    StringMatching(T*p):
        b(2,p[1]),f(2),l(2){
        for(int i=0;p[l]?1:(--l,0);b.push_back(p[l++])){
            for(;i&&p[i+1]!=p[l];i=f[i]);
            f.push_back(i=i+(p[i+1]==p[l]));
        }
        for(int i=2;i<l;++i)
            if(p[f[i]+1]==p[i+1])
```

```
              f[i]=f[f[i]];
        }
        int run(T*t,int k=0){
            for(int i=k?k+l:1,j=k?f[l]:0;t[i];++i){
                for(;j&&b[j+1]!=t[i];j=f[j]);
                if((j+=b[j+1]==t[i])==l)
                    return i−l+1;
            }
            return 0;
        }
        int l;
        vector<T>b;
        vector<int>f;
};
```

6.6 Suffix Array (DC3 Algorithm)

Description

Construct a suffix array and it's height array from a given string using DC3 algorithm.

Methods

template<class T,int M,T D>SuffixArray<T,M,D>::SuffixArray(T*s,int n);	
Description	construct an object of SuffixArray and in the mean time consturct the suffix array and height array
Parameters	Description
T	type of character, usually char
M	size of alphabet
D	offset of alphabet, use 'a' for lowercase letters
s	string from which to build a suffix array, indexed from one
n	length of s
Time complexity	$\Theta(n + M)$
Space complexity	$\Theta(10n + M)$
Return value	an object of SuffixArray

Fields

Name	Description
sa	suffix array, indexed from one
ht	height array, indexed from one

Performance

Problem	Constraints	Time	Memory	Date
UOJ P35	$N = 10^5, M = 26$	416 ms (18+ cases)	4248 kB	2016-02-14

References

Title	Author
后缀数组——处理字符串的有力工具	罗穗骞

Code

<div align="center">Suffix Array (DC3 Algorithm).hpp (2656 bytes, 82 lines)</div>

```cpp
#include<bits/stdc++.h>
using namespace std;
template<class T,int M,int D>struct SuffixArray{
    int*sa,*ht,*rk,*ts,*ct,*st;
    SuffixArray(T*s,int n){
        crt(st,n),crt(sa,n),crt(ht,n);
        crt(rk,n),crt(ts,n),crt(ct,max(n,M));
        for(int i=1;i<=n;++i)st[i]=s[i]-D+1;
        dc3(st,n,M,sa,rk);
        for(int i=1;i<=n;++i){
            if(rk[i]==1){ht[1]=0;continue;}
            int&d=ht[rk[i]]=max(i==1?0:ht[rk[i-1]]-1,0);
            for(;i+d<=n&&sa[rk[i]-1]+d<=n
                &&st[i+d]==st[sa[rk[i]-1]+d];++d);
        }
    }
    ~SuffixArray(){
        del(sa),del(ht),del(rk);
        del(ts),del(ct),del(st);
    }
```

```
        void crt(int*&a,int n){
            a=new int[n+1];
        }
        void del(int*a){
25          delete a;
        }
        #define fc(i)(p0[i]+d>n||!p0[i]?0:s[p0[i]+d])
        int cmp(int*p0,int i,int*s,int n){
            for(int d=0;d<3;++d)
                if(fc(i)!=fc(i−1))return 1;
            return 0;
        }
        void sot(int*p0,int n0,int*s,int n,int m,int d){
            memset(ct,0,(m+1)*4);
35          for(int i=1;i<=n0;++i)++ct[fc(i)];
            for(int i=1;i<=m;++i)ct[i]+=ct[i−1];
            for(int i=n0;i>=1;−−i)ts[ct[fc(i)]−−]=p0[i];
            memcpy(p0+1,ts+1,n0*4);
        }
        #define fc(d)\
            if(s[i+d]!=s[j+d])return s[i+d]<s[j+d];\
            if(i==n−d||j==n−d)return i==n−d;
        bool cmp(int*s,int n,int*r,int i,int j){
            fc(0)
45          if(j%3==1)return r[i+1]<r[j+1];
            fc(1)
            return r[i+2]<r[j+2];
        }
        #undef fc
        void dc3(int*s,int n,int m,int*a,int*r){
            int n0=n−(n/3)+1,*a0,*s0,i,j=0,k=n/3+bool(n%3)+1,l;
            crt(s0,n0),s0[k]=1,crt(a0,n0+1),a0[k]=0;
            for(i=1;i<=n;i+=3)a0[++j]=i,a0[j+k]=i+1;
            for(i=2;i>=0;−−i)sot(a0,n0,s,n,m,i);
55          for(r[a0[1]]=1,i=2;i<=n0;++i)
                r[a0[i]]=r[a0[i−1]]+cmp(a0,i,s,n);
            for(i=1,j=0;i<=n;i+=3)
                s0[++j]=r[i],s0[j+k]=r[i+1];
            if(r[a0[n0]]==n0){
                memcpy(r+1,s0+1,n0*4);
                for(i=1;i<=n0;++i)a0[a[i]=r[i]]=i;
```

```
            }else
                dc3(s0,n0,r[a0[n0]],a0,a);
            for(i=1,j=0;i<=n;i+=3)
                r[i]=a[++j],r[i+1]=a[j+k];
            if(j=0,n%3==0)
                s0[++j]=n;
            for(i=1;i<=n0;++i)
                if(a0[i]>=k)
                    a0[i]=(a0[i]−k)*3−1;
                else
                    if((a0[i]=3*a0[i]−2)!=1)s0[++j]=a0[i]−1;
            sot(s0,j,s,n,m,0);
            for(i=1,k=2,l=0;i<=j||k<=n0;)
                if(k>n0||i<=j&&cmp(s,n,r,s0[i],a0[k]))
                    a[++l]=s0[i++];
                else
                    a[++l]=a0[k++];
            for(i=1;i<=n;++i)r[a[i]]=i;
            del(a0),del(s0);
        }
};
```

6.7   Suffix Array (Factor Oracle)

Description

Use a factor oracle to construct a suffix array and it's height array from a given string. It is theoretically slow, but usually fast in practice. Object of it should be static since it has large data members.

Methods

template<class T,int N,int M,T D>SuffixArray<T,N,M,D>::SuffixArray();	
Description	construct an object of SuffixArray
Parameters	Description
T	type of character, usually char
N	maximum length of input string
M	size of alphabet
D	offset of alphabet, use 'a' for lowercase letters
Time complexity	$\Theta(1)$
Space complexity	$\Theta((M+13)N)$
Return value	an object of SuffixArray
template<class T,int N,int M,T D>void SuffixArray<T,N,M,D>::build(T*s,int n);	
Description	build suffix array and height array
Parameters	Description
s	string from which to build a suffix array, indexed from zero
n	length of s
Time complexity	$O((M+n)n)$
Space complexity	$\Theta(n)$
Return value	none

Fields

Name	Description
sa	suffix array, indexed from one
ht	height array, indexed from one

Performance

Problem	Constraints	Time	Memory	Date
Tyvj P1860	$N = 2 \times 10^5, M = 26$	1154 ms (10 cases)	33012 kB	2016-02-14

References

Title	Author
Factor oracle, suffix oracle	Cyril Allauzen, Maxime Crochemore, Mathieu Raffinot
Computing repeated factors with a factor oracle	Arnaud Lefebvre, Thierry Lecroq

Code

<div align="center">Suffix Array (Factor Oracle).hpp (2640 bytes, 71 lines)</div>

```cpp
#include<bits/stdc++.h>
using namespace std;
template<class T,int N,int M,T D>struct SuffixArray{
    int val(int i,int d){
        return d<0?(d>-2?lrs[i]:n-1-lrs[i]):s[n-i+lrs[i]+d]-D;
    }
    void sort(int*a,int*b,int m,int d){
        static int c[N];
        memset(c,0,4*(d>=0?M:n));
        for(i=1;i<=m;++c[val(a[i],d)],++i);
        for(i=1;i<(d>=0?M:n);c[i]+=c[i-1],++i);
        for(i=m;i>=1;b[c[val(a[i],d)]--]=a[i],--i);
    }
    void sort(int a,int b,int d,int l){
        sort(z+a-1,t,b-a+1,d);
        memcpy(z+a,t+1,(b-a+1)*4);
        for(i=a,j;i<=b;i=j+1){
            for(j=i;j+1<=b&&val(z[j],d)==val(z[j+1],d);++j);
            if(j-i)
                sort(i,j,d+1,l);
        }
    }
    void add(int&b,int v){
        cv[++cp]=v,cn[cp]=b,b=cp;
    }
    void dfs(int u){
        #define m(p,q)\
            for(int i=p##b[u],j;i;){\
                for(*z=0,j=i;cn[j]&&lrs[cv[j]]==lrs[cv[cn[j]]];z[++z[0]]=cv[j],j=cn[j]);\
                z[++z[0]]=cv[j],sort(1,*z,0,q);\
                for(z[0]=1;i!=cn[j];cv[i]=z[z[0]++],i=cn[i]);\
            }
        m(l,0)
        for(int i=lb[u];i;dfs(cv[i]),i=cn[i]);
        sa[++*sa]=n+1-u,*sa-=!u;
        m(r,1)
```

```
              for(int i=rb[u];i;dfs(cv[i]),i=cn[i]);
38         }
         void build(T*_s,int _n){
              n=_n,s=_s,memset(tr,(cp=*sa=*vl=*vr=*lb=*rb=*lrs=0,*z=-1),4*M);
              for(int i=0,c=s[n-1-i]-D,u,v;i<n;c=s[n-1-++i]-D){
                  memset(tr+i+1,(lb[i+1]=rb[i+1]=lrs[i+1]=0)-1,4*M);
                  for(j=i;j>-1&&tr[j][c]<0;tr[j][c]=i+1,j=z[u=j]);
                  if(v=z[i+1]=j<0?0:tr[j][c]){
                      for(v=v-1==z[u]?u:v-1;z[u]!=z[v];v=z[v]);
                      lrs[i+1]=min(lrs[u],lrs[v])+1;
                  }
48                  for(j=0;n-(z[i+1]-lrs[i+1]-j)<n&&s[n-(z[i+1]-lrs[i+1]-j)]==s[
      n-1-i+lrs[i+1]+j];++j);
                  if(n-(z[i+1]-lrs[i+1]-j)<n&&s[n-(z[i+1]-lrs[i+1]-j)]>s[n-1-i
      +lrs[i+1]+j])
                      vl[++*vl]=i+1;
                  else
                      vr[++*vr]=i+1;
              }
              sort(vl,t,*vl,-1),sort(vr,vl,*vr,-2);
              for(i=*vl;i;add(lb[z[t[i]]],t[i]),--i);
              for(i=*vr;i;add(rb[z[vl[i]]],vl[i]),--i);
              dfs(0);
58            for(i=1;i<=n;++i)
                  rk[sa[i]]=i;
              for(i=1;i<=n;++i){
                  if(rk[i]==1){
                      ht[1]=0;
                      continue;
                  }
                  int&d=ht[rk[i]]=max(i==1?0:ht[rk[i-1]]-1,0);
                  for(;i+d<=n&&sa[rk[i]-1]+d<=n&&s[i+d-1]==s[sa[rk[i]-1]+d-1];++
      d);
              }
68        }
         T*s;
         int n,sa[N+1],ht[N+1],rk[N+1],lrs[N+1],tr[N+1][M],i,j,lb[N+1],rb[N+1],
      cv[N+1],cn[N+1],cp,vl[N+1],vr[N+1],t[N+1],z[N+1];
      };
```

6.8   Suffix Array (Prefix-Doubling Algorithm)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Suffix Array (Prefix-Doubling Algorithm).hpp (1357 bytes, 55 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
struct SuffixArray{
    int*a,*h,*r,*t,*c,n,m;
    #define lp(u,v)for(int i=u;i<=v;++i)
    #define rp(u,v)for(int i=u;i>=v;--i)
    void sort(){
        memset(c+1,0,m*4);
        lp(1,n)
            ++c[r[t[i]]];
        lp(2,m)
            c[i]+=c[i-1];
        rp(n,1)
            a[c[r[t[i]]]--]=t[i];
    }
    SuffixArray(int*s){
        for(n=m=0;s[n+1];m=max(m,s[++n]));
        a=new int[4*n+max(n,m)+3];
        h=a+n;
        r=h+n+1;
        t=r+n+1;
        c=t+n;
        lp(1,n)
            t[i]=i,r[i]=s[i];
        sort();
        for(int l=1;l<=n;l<<=1,r[a[n]]==n?l=n+1:m=r[a[n]]){
            t[0]=0;
            lp(n-l+1,n)
                t[++t[0]]=i;
            lp(1,n)
                if(a[i]>l)
                    t[++t[0]]=a[i]-l;
            sort();
            swap(r,t);
            r[a[1]]=1;
```

```
                lp(2,n)
                        r[a[i]]=r[a[i−1]]+(t[a[i]]!=t[a[i−1]]||a[i]+l>n||a[i−1]+l>n
        ||t[a[i]+l]!=t[a[i−1]+l]);
                }
39          int l=0;
            a[0]=n+1;
            lp(1,n){
                if(r[i]==1)
                    l=0;
                l−=(l>0);
                int j=a[r[i]−1];
                for(;s[i+l]==s[j+l];++l);
                h[r[i]]=l;
            }
49      }
        #undef lp
        #undef rp
        ~SuffixArray(){
            delete a;
        }
    };
```

6.9   Suffix Array (Suffix Tree)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Suffix Array (Suffix Tree).hpp (2849 bytes, 115 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
    template<class T,int N,int M,T D>struct SuffixTree{
        struct node;
5       struct edge{
            edge():
                l(0),r(0),t(0){
            }
            int length(){
                return r−l;
            }
            T*l,*r;
```

```
            node*t;
        }pe[2*N],*ep=pe;
15      edge*newedge(T*l,T*r,node*t){
            ep->l=l;
            ep->r=r;
            ep->t=t;
            return ep++;
        }
        struct node{
            node():
                s(0),c({0}){
            }
25          node*s;
            edge*c[M+1];
        }pn[2*N+1],*np=pn;
        SuffixTree():
            root(np++),ct(0){
        }
        void extend(T*s){
            for(;ae&&al>=ae->length();){
                s+=ae->length();
                al-=ae->length();
35              an=ae->t;
                ae=al?an->c[*s-D]:0;
            }
        }
        bool extend(int c){
            if(ae){
                if(*(ae->l+al)-D-c)
                    return true;
                ++al;
            }else{
45              if(!an->c[c])
                    return true;
                ae=an->c[c];
                al=1;
                if(pr)
                    pr->s=an;
            }
            extend(ae->l);
            return false;
```

```
        }
55      void dfs(node*u,int d){
            int t=0,s=0;
            for(int i=0;i<M+1;++i)
                if(u−>c[i]){
                    if(!t)
                        t=1;
                    else if(!s){
                        s=1;
                        *sp++=d;
                    }
65                  dfs(u−>c[i]−>t,d+u−>c[i]−>length());
                }
            if(s)
                −−sp;
            else if(!t&&sp!=sk){
                *hp++=*(sp−1);
                *fp++=ct−d+1;
            }
        }
        void build(T*s,int n){
75          s[n++]=M+D;
            ct+=n;
            an=root;
            ae=al=0;
            for(T*p=s;p!=s+n;++p)
                for(pr=0;extend(*p−D);){
                    edge*x=newedge(p,s+n,np++);
                    if(!ae)
                        an−>c[*p−D]=x;
                    else{
85                      edge*&y=an−>c[*ae−>l−D];
                        y=newedge(ae−>l,ae−>l+al,np++);
                        y−>t−>c[*(ae−>l+=al)−D]=ae;
                        y−>t−>c[*p−D]=x;
                        ae=y;
                    }
                    if(pr)
                        pr−>s=ae?ae−>t:an;
                    pr=ae?ae−>t:an;
                    int r=1;
```

```
95                    if(an==root&&!al)
                          break;
                      if(an==root)
                          --al;
                      else{
                          an=an->s?an->s:root;
                          r=0;
                      }
                      if(al){
                          T*t=ae->l+(an==root)*r;
105                       ae=an->c[*t-D];
                          extend(t);
                      }else
                          ae=0;
                  }
              dfs(root,0);
          }
          edge*ae;
          node*root,*an,*pr;
          int al,ct,sk[N],*sp=sk,ht[N],*hp=ht,sa[N],*fp=sa;
115 };
```

6.10   Suffix Array (Treap)

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Suffix Array (Treap).hpp (3803 bytes, 147 lines)

```
    #include<bits/stdc++.h>
    using namespace std;
    template<class T>struct SuffixArray{
        struct node{
5           node*c[2],*p;
            T v;
            int f,s,l,h,m;
            double t;
            node(node*_p,T _v,int _l):
                f(rand()*1.0/RAND_MAX*1e9),p(_p),v(_v),s(1),l(_l),h(0),m(0),t(5
    e8){
                c[0]=c[1]=0;
```

```
               }
        }*root;
        vector<T>a;
15      SuffixArray():
            root(new node(0,0,0)),a(1){
        }
        ~SuffixArray(){
            clear(root);
        }
        void relabel(node*x,double l,double r){
            x->t=(l+r)/2;
            if(x->c[0])
                relabel(x->c[0],l,x->t);
25          if(x->c[1])
                relabel(x->c[1],x->t,r);
        }
        void update(node*x){
            x->s=1;
            x->m=x->h;
            for(int i=0;i<2;++i)
                if(x->c[i])
                    x->s+=x->c[i]->s,x->m=min(x->m,x->c[i]->m);
        }
35      void rotate(node*&x,int d){
            node*y=x->c[d];
            x->c[d]=y->c[!d];
            y->c[!d]=x;
            y->s=x->s;
            y->m=x->m;
            update(x);
            x=y;
        }
        void clear(node*x){
45          if(!x)
                return;
            clear(x->c[0]);
            clear(x->c[1]);
            delete x;
        }
        node*insert(node*&x,node*p,T v,node*l,node*r){
            int d=x->v!=v?x->v<v:x->p->t<p->t;
```

```
            double tl=l?l->t:0,tr=r?r->t:1e9;
            node*y;
55          if(d)
                l=x;
            else
                r=x;
            if(!x->c[d]){
                y=new node(p,v,p->l+1);
                y->t=((l?l->t:0)+(r?r->t:1e9))/2;
                y->m=y->h=l->v==y->v?lcp(l->p,y->p)+1:0;
                if(r)
                    r->h=r->v==y->v?lcp(r->p,y->p)+1:0;
65              x->c[d]=y;
            }else
                y=insert(x->c[d],p,v,l,r);
            update(x);
            if(x->c[d]->f>x->f)
                rotate(x,d),relabel(x,tl,tr);
            return y;
        }
        node*insert(node*p,T v){
            a.push_back(v);
75          return insert(root,p,v,0,0);
        }
        void erase(node*&x,node*y){
            if(x==y){
                if(!x->c[0]){
                    x=x->c[1];
                    delete y;
                }else if(!x->c[1]){
                    x=x->c[0];
                    delete y;
85              }else{
                    int d=x->c[0]->f<x->c[1]->f;
                    rotate(x,d);
                    erase(x->c[!d],y);
                    --x->s;
                }
            }else
                erase(x->c[x->t<y->t],y),update(x);
        }
```

```
        void erase(node*y){
 95         erase(root,y);
            a.pop_back();
        }
        bool check(node*x,T*y,node*&p,int&l){
            if(p){
                int t=x−>c[p−>t>x−>t]?x−>c[p−>t>x−>t]−>m:~0u>>1;
                if(p−>t>x−>t)
                    t=min(t,p−>h);
                else
                    t=min(t,x−>h);
105             if(t<l)
                    return x−>t<p−>t;
            }
            for(p=x;l+1<=x−>l&&y[l+1];++l)
                if(a[x−>l−l]!=y[l+1])
                    return a[x−>l−l]<y[l+1];
            return y[l+1]!=0;
        }
        int count(node*x,T*y){
            int r=0,l=0;
115         for(node*p=0;x;)
                if(check(x,y,p,l))
                    r+=(x−>c[0]?x−>c[0]−>s:0)+1,x=x−>c[1];
                else
                    x=x−>c[0];
            return r;
        }
        int count(T*y){
            T*t=y;
            while(*(t+1))
125             ++t;
            int r=−count(root,y);
            ++*t;
            r+=count(root,y);
            −−*t;
            return r;
        }
        int lcp(node*x,double u,double v,double l,double r){
            if(v<l||u>r||!x)
                return ~0u>>1;
```

```
135          if(u<l&&v>=r)
                 return x->m;
             int t=u<x->t&&v>=x->t?x->h:~0u>>1;
             t=min(t,lcp(x->c[0],u,v,l,x->t));
             t=min(t,lcp(x->c[1],u,v,x->t,r));
             return t;
         }
         int lcp(node*x,node*y){
             if(x->t>y->t)
                 swap(x,y);
145          return lcp(root,x->t,y->t,0,1e9);
         }
     };
```

6.11   Suffix Automaton

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Suffix Automaton.hpp (1694 bytes, 59 lines)

```
   #include<bits/stdc++.h>
   using namespace std;
 3 template<class T>struct SuffixAutomaton{
       struct node{
           node(vector<node*>&all,int m,node*_pr=0,int _ln=0,T _va=T()):
               pr(_pr),tr(m),ln(_ln),va(_va){
               all.push_back(this);
           }
           T va;
           int ln;
           node*pr;
           vector<node*>tr;
13     };
       SuffixAutomaton(int _m):
           root(new node(all,m)),m(_m){
       }
       ~SuffixAutomaton(){
           for(int i=0;i<all.size();++i)
               delete all[i];
       }
```

```
        node*insert(node*lst,int c,T v){
            node*p=lst,*np=p->tr[c]?0:new node(all,m,0,lst->ln+1,v);
23          for(;p&&!p->tr[c];p=p->pr)
                p->tr[c]=np;
            if(!p)np->pr=root;
            else{
                node*q=p->tr[c];
                if(p==lst)
                    np=q;
                if(q->ln==p->ln+1)
                    p==lst?(q->va+=v):(np->pr=q,0);
                else{
33              node*nq=new node(all,m,q->pr,p->ln+1,p==lst?v:T());
                    nq->tr=q->tr;
                    q->pr=np->pr=nq;
                    if(p==lst)
                        np=nq;
                    for(;p&&p->tr[c]==q;p=p->pr)
                        p->tr[c]=nq;
                }
            }
            return np;
43      }
        void count(){
            vector<int>cnt(all.size());
            vector<node*>tmp=all;
            for(int i=0;i<tmp.size();++i)
                ++cnt[tmp[i]->ln];
            for(int i=1;i<cnt.size();++i)
                cnt[i]+=cnt[i-1];
            for(int i=0;i<tmp.size();++i)
                all[--cnt[tmp[i]->ln]]=tmp[i];
53          for(int i=int(all.size())-1;i>0;--i)
                all[i]->pr->va+=all[i]->va;
        }
        int m;
        node*root;
        vector<node*>all;
    };
```

6.12   Suffix Tree

warning: old style will be replaced ... see Suffix Array (DC3) for new style

---

Suffix Tree.hpp (2296 bytes, 94 lines)

```cpp
 1  #include<bits/stdc++.h>
    using namespace std;
    template<class T,int N,int M,T D>struct SuffixTree{
        struct node;
        struct edge{
            edge():
                l(0),r(0),t(0){
            }
            int length(){
                return r-l;
11          }
            T*l,*r;
            node*t;
        }pe[2*N],*ep=pe;
        edge*newedge(T*l,T*r,node*t){
            ep->l=l;
            ep->r=r;
            ep->t=t;
            return ep++;
        }
21      struct node{
            node():
                s(0),c({0}){
            }
            node*s;
            edge*c[M];
        }pn[2*N+1],*np=pn;
        SuffixTree():
            root(np++),ct(0){
        }
31      void extend(T*s){
            for(;ae&&al>=ae->length();){
                s+=ae->length();
                al-=ae->length();
                an=ae->t;
```

```
                    ae=al?an->c[*s-D]:0;
                }
            }
            bool extend(int c){
                if(ae){
41                  if(*(ae->l+al)-D-c)
                        return true;
                    ++al;
                }else{
                    if(!an->c[c])
                        return true;
                    ae=an->c[c];
                    al=1;
                    if(pr)
                        pr->s=an;
51              }
                extend(ae->l);
                return false;
            }
            void insert(T*s,int n){
                ct+=n;
                an=root;
                ae=al=0;
                for(T*p=s;p!=s+n;++p)
                    for(pr=0;extend(*p-D);){
61                      edge*x=newedge(p,s+n,np++);
                        if(!ae)
                            an->c[*p-D]=x;
                        else{
                            edge*&y=an->c[*ae->l-D];
                            y=newedge(ae->l,ae->l+al,np++);
                            y->t->c[*(ae->l+=al)-D]=ae;
                            y->t->c[*p-D]=x;
                            ae=y;
                        }
71                      if(pr)
                            pr->s=ae?ae->t:an;
                        pr=ae?ae->t:an;
                        int r=1;
                        if(an==root&&!al)
                            break;
```

```
                    if(an==root)
                        --al;
                    else{
                        an=an->s?an->s:root;
81                      r=0;
                    }
                    if(al){
                        T*t=ae->l+(an==root)*r;
                        ae=an->c[*t-D];
                        extend(t);
                    }else
                        ae=0;
                }
        }
91      edge*ae;
        int al,ct;
        node*root,*an,*pr;
    };
```

CHAPTER 7

Utility Tools

7.1   Checker

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Checker.bat (166 bytes, 7 lines)

```
:again
generator > input.txt
program1 < input.txt > output1.txt
program2 < input.txt > output2.txt
fc output1.txt output2.txt
if errorlevel 1 pause
goto again
```

7.2   Date

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Date.hpp (3596 bytes, 145 lines)

```cpp
#include<bits/stdc++.h>
using namespace std;
struct Date{
    int y,m,d,w;
    Date&operator++(){
        return*this=*this+1;
    }
    bool leap(int a)const{
        return a%400==0||(a%4==0&&a%100!=0);
    }
    int month_sum(int a,int b)const{
        if(b==0)
            return 0;
        if(b==1)
            return 31;
        return 59+leap(a)+30*(b−2)+(b+1)/2−1+(b>=8&&b%2==0);
    }
    string month_name(int a)const{
        if(a==1)
            return"January";
```

```
            if(a==2)
                return"February";
23          if(a==3)
                return"March";
            if(a==4)
                return"April";
            if(a==5)
                return"May";
            if(a==6)
                return"June";
            if(a==7)
                return"July";
33          if(a==8)
                return"August";
            if(a==9)
                return"September";
            if(a==10)
                return"October";
            if(a==11)
                return"November";
            if(a==12)
                return"December";
43      }
        string day_name(int a)const{
            if(a==0)
                return"Sunday";
            if(a==1)
                return"Monday";
            if(a==2)
                return"Tuesday";
            if(a==3)
                return"Wednesday";
53          if(a==4)
                return"Thursday";
            if(a==5)
                return"Friday";
            if(a==6)
                return"Saturday";
        }
        operator int()const{
            int t=(y−1)*365+(y−1)/4−(y−1)/100+(y−1)/400+month_sum(y,m−1)+d;
```

```
            if(y==1752&&m>=9&&d>2||y>1752)
63              t-=11;
            t-=min(y-1,1700)/400-min(y-1,1700)/100;
            if(y<=1700&&y%400!=0&&y%100==0&&m>2)
                ++t;
            return t;
        }
        Date(int _y,int _m,int _d):
            y(_y),m(_m),d(_d),w((int(*this)+5)%7){
        }
        Date(int a){
73          int yl=0,yr=1e7;
            while(yl+1<yr){
                int ym=(yl+yr)/2;
                if(int(Date(ym,12,31))<a)
                    yl=ym;
                else
                    yr=ym;
            }
            y=yr;
            int ml=0,mr=12;
83          while(ml+1<mr){
                int mm=(ml+mr)/2,mt;
                if(mm==2){
                    if(y<=1700)
                        mt=28+(y%4==0);
                    else
                        mt=28+(y%4==0&&y%100!=0||y%400==0);
                }else if(mm<=7)
                    mt=30+mm%2;
                else
93                  mt=31-mm%2;
                if(int(Date(y,mm,mt))<a)
                    ml=mm;
                else
                    mr=mm;
            }
            m=mr;
            for(int i=1;;++i){
                if(y==1752&&m==9&&i>2&&i<14)
                    continue;
```

```
103              if(int(Date(y,m,i))==a){
                     d=i;
                     break;
                 }
             }
             w=(5+a)%7;
         }
         operator string()const{
             stringstream s;
             string t;
113          s<<day_name(w)+", "+month_name(m)+" "<<d<<", "<<y;
             getline(s,t);
             return t;
         }
     };
     ostream&operator<<(ostream&s,const Date&a){
         return s<<string(a);
     }
     int operator-(const Date&a,const Date&b){
         return int(a)-int(b);
123  }
     Date operator+(const Date&a,int b){
         return Date(int(a)+b);
     }
     Date operator-(const Date&a,int b){
         return Date(int(a)-b);
     }
     bool operator<(const Date&a,const Date&b){
         if(a.y==b.y&&a.m==b.m)
             return a.d<b.d;
133      if(a.y==b.y)
             return a.m<b.m;
         return a.y<b.y;
     }
     bool operator>(const Date&a,const Date&b){
         return b<a;
     }
     bool operator!=(const Date&a,const Date&b){
         return a.y!=b.y||a.m!=b.m||a.d!=b.d;
     }
143  bool operator==(const Date&a,const Date&b){
```

```
    return !(a!=b);
}
```

7.3   Fast Reader

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Fast Reader.hpp (1251 bytes, 61 lines)

```
#include<bits/stdc++.h>
using namespace std;
struct FastReader{
    FILE*f;
    char*p,*e;
    vector<char>v;
    void ipt(){
        for(int i=1,t;;i<<=1){
            v.resize(v.size()+i);
            if(i!=(t=fread(&v[0]+v.size()−i,1,i,f))){
                p=&v[0],e=p+v.size()−i+t;
                break;
            }
        }
    }
    void ign(){
        while(p!=e&&isspace(*p))
            ++p;
    }
    int isc(){
        return p!=e&&!isspace(*p);
    }
    int isd(){
        return p!=e&&isdigit(*p);
    }
    FastReader(FILE*_f):
        f(_f){
        ipt();
    }
    FastReader(string _f):
        f(fopen(_f.c_str(),"r")){
```

```
            ipt();
        }
        ~FastReader(){
35          fclose(f);
        }
        template<class T>FastReader&operator>>(T&a){
            int n=1;
            ign();
            if(*p=='-')
                n=-1,++p;
            for(a=0;isd();)
                a=a*10+*p++-'0';
            a*=n;
45          return*this;
        }
        FastReader&operator>>(char&a){
            ign();
            a=*p++;
            return*this;
        }
        FastReader&operator>>(char*a){
            for(ign();isc();)
                *a++=*p++;
55          *a=0;
            return*this;
        }
        char get(){
            return*p++;
        }
    };
```

7.4   Fast Writer

warning: old style will be replaced ... see Suffix Array (DC3) for new style

Fast Writer.hpp (866 bytes, 39 lines)

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

```
       FILE*f;
       vector<char>p;
       FastWriter(FILE*_f):
           f(_f){
       }
 9     FastWriter(string _f):
           f(fopen(_f.c_str(),"w")){
       }
       ~FastWriter(){
           if(p.size())
               fwrite(&p[0],1,p.size(),f);
           fclose(f);
       }
       FastWriter&operator<<(char a){
           p.push_back(a);
19         return*this;
       }
       FastWriter&operator<<(const char*a){
           while(*a)
               p.push_back(*a++);
           return*this;
       }
       template<class T>FastWriter&operator<<(T a){
           if(a<0)
               p.push_back('−'),a=−a;
29         static char t[19];
           char*q=t;
           do{
               T b=a/10;
               *q++=a−b*10+'0',a=b;
           }while(a);
           while(q>t)
               p.push_back(*−−q);
           return*this;
       }
39 };
```

7.5   Number Speller

warning: old style will be replaced ... see Suffix Array (DC3) for new style

<div align="center">Number Speller.hpp (2143 bytes, 72 lines)</div>

```cpp
 1  #include<bits/stdc++.h>
    using namespace std;
    namespace NumberSpeller{
        template<class T>string run(T a){
            map<T,string>m;
            m[0]="zero";
            m[1]="one";
            m[2]="two";
            m[3]="three";
            m[4]="four";
11          m[5]="five";
            m[6]="six";
            m[7]="seven";
            m[8]="eight";
            m[9]="nine";
            m[10]="ten";
            m[11]="eleven";
            m[12]="twelve";
            m[13]="thirteen";
            m[14]="fourteen";
21          m[15]="fifteen";
            m[16]="sixteen";
            m[17]="seventeen";
            m[18]="eighteen";
            m[19]="nineteen";
            m[20]="twenty";
            m[30]="thirty";
            m[40]="forty";
            m[50]="fifty";
            m[60]="sixty";
31          m[70]="seventy";
            m[80]="eighty";
            m[90]="ninety";
            if(a<0)
                return"minus "+run(−a);
```

```
          if(m.count(a))
              return m[a];
          if(a<100)
              return run(a/10*10)+"-"+run(a%10);
          if(a<1000&&a%100==0)
41            return run(a/100)+" hundred";
          if(a<1000)
              return run(a/100*100)+" and "+run(a%100);
          vector<string>t;
          t.push_back("thousand");
          t.push_back("million");
          t.push_back("billion");
          t.push_back("trillion");
          t.push_back("quadrillion");
          t.push_back("quintillion");
51        t.push_back("sextillion");
          t.push_back("septillion");
          t.push_back("octillion");
          t.push_back("nonillion");
          t.push_back("decillion");
          t.push_back("undecillion");
          t.push_back("duodecillion");
          t.push_back("tredecillion");
          t.push_back("quattuordecillion");
          t.push_back("quindecillion");
61        string r=a%1000?run(a%1000):"";
          a/=1000;
          for(int i=0;a;++i,a/=1000)
              if(a%1000){
                  if(!i&&r.find("and")==string::npos&&r.find("hundred")==
      string::npos&&r.size())
                      r=run(a%1000)+" "+t[i]+" and "+r;
                  else
                      r=run(a%1000)+" "+t[i]+(r.size()?", ":"")+r;
              }
          return r;
71    }
  }
```