

Algorithms

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CHAPTER 1

Computational Geometry

1.1 Convex Hull

Convex Hull.hpp (1063 bytes, 36 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct ConvexHull{
4      struct point{
5          T x,y;
6          point(T _x,T _y):
7              x(_x),y(_y){
8              }
9          point operator-(point a){
10             return point(x-a.x,y-a.y);
11         }
12         T operator*(point a){
13             return x*a.y-y*a.x;
14         }
15         int operator<(point a){
16             return x==a.x?y<a.y:x<a.x;
17         }
18     };
19     static int check(point a,point b,point c){
20         return (a-c)*(b-c)<=0;
21     }
22     static vector<vector<point> >run(vector<point>a){
23         sort(a.begin(),a.end());
24         vector<point>u,d;
25         for(int i=0;i<a.size();u.push_back(a[i++]))
26             while(u.size()>1&&check(a[i],u.back(),u[u.size()-2]))
27                 u.pop_back();
28         for(int i=int(a.size()-1);i>=0;d.push_back(a[i--]))
29             while(d.size()>1&&check(a[i],d.back(),d[d.size()-2]))
30                 d.pop_back();
31         vector<vector<point> >r;
32         r.push_back(u);
33         r.push_back(d);
34         return r;
35     }
36 };

```


1.2 Delaunay Triangulation

Delaunay Triangulation.hpp (4889 bytes, 159 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct DelaunayTriangulation{
4      const static double E;
5      struct poi{
6          T x,y;
7          poi(T _x=0,T _y=0):
8              x(_x),y(_y){
9              }
10         poi operator-(poi b){
11             return poi(x-b.x,y-b.y);
12         }
13         int operator<(poi b)const{
14             if(fabs(x-b.x)<E)
15                 return y<b.y;
16             return x<b.x;
17         }
18     };
19     int n;
20     vector<pair<poi,int> >pts;
21     vector<vector<int> >egs;
22     T det(poi a,poi b){
23         return a.x*b.y-a.y*b.x;
24     }
25     T dot(poi a,poi b){
26         return a.x*b.x+a.y*b.y;
27     }
28     int dir(poi a,poi b,poi c){
29         T r=det(c-a,b-a);
30         if(r<-E)
31             return -1;
32         return r>E?1:0;
33     }
34     int inc(poi a,poi b,poi c,poi d){
35         a=a-d;
36         b=b-d;
37         c=c-d;

```

```

38     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;
39     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;
40 }
41 int crs(poi a,poi b,poi c,poi d){
42     return dir(a,b,c)*dir(a,b,d)==-1&&dir(c,d,a)*dir(c,d,b)==-1;
43 }
44 DelaunayTriangulation():
45     n(0),pts(1){
46 }
47 void add(T x,T y){
48     poi a;
49     a.x=x;
50     a.y=y;
51     pts.push_back(make_pair(a,++n));
52 }
53 poi&pot(int a){
54     return pts[a].first;
55 }
56 void con(int a,int b){
57     egs[a].push_back(b);
58     egs[b].push_back(a);
59 }
60 void dco(int a,int b){
61     egs[a].erase(find(egs[a].begin(),egs[a].end(),b));
62     egs[b].erase(find(egs[b].begin(),egs[b].end(),a));
63 }
64 void dnc(int l,int r){
65     if(r==l)
66         return;
67     if(r==l+1){
68         con(l,r);
69         return;
70     }
71     if(r==l+2){
72         if(dir(pot(l),pot(l+1),pot(r)))
73             con(l,l+1),con(l+1,r),con(l,r);
74         else{
75             if(dot(pot(l+1)-pot(l),pot(r)-pot(l))<0)
76                 con(l,l+1),con(l,r);
77             else if(dot(pot(l)-pot(l+1),pot(r)-pot(l+1))<0)

```

```

78         con(l,l+1),con(l+1,r);
79     else
80         con(l,r),con(l+1,r);}
81     return;
82 }
83 int m=(l+r)/2,p1=1,pr=r;
84 dnc(l,m);
85 dnc(m+1,r);
86 for(int f=0;;f=0){
87     for(int i=0;i<egs[p1].size();++i){
88         int a=egs[p1][i],d=dir(pot(p1),pot(pr),pot(a));
89         if(d>0||(d==0&&dot(pot(p1)-pot(a),pot(pr)-pot(a))<0)){
90             p1=a;
91             f=1;
92             break;
93         }
94     }
95     for(int i=0;i<egs[pr].size();++i){
96         int a=egs[pr][i],d=dir(pot(p1),pot(pr),pot(a));
97         if(d>0||(d==0&&dot(pot(p1)-pot(a),pot(pr)-pot(a))<0)){
98             pr=a;
99             f=1;
100            break;
101        }
102    }
103    if(!f)
104        break;
105 }
106 con(p1,pr);
107 for(int pn=-1,wh=0;;pn=-1,wh=0){
108     for(int i=0;i<egs[p1].size();++i){
109         int a=egs[p1][i],d=dir(pot(p1),pot(pr),pot(a));
110         if(d<0&&(pn===-1||inc(pot(p1),pot(pr),pot(pn),pot(a))))
111             pn=a;
112     }
113     for(int i=0;i<egs[pr].size();++i){
114         int a=egs[pr][i],d=dir(pot(p1),pot(pr),pot(a));
115         if(d<0&&(pn===-1||inc(pot(p1),pot(pr),pot(pn),pot(a))))
116             pn=a,wh=1;
117     }
118     if(pn===-1)

```

```

119         break;
120     vector<int> ne;
121     if(!wh){
122         for(int i=0;i<egs[p1].size();++i){
123             int a=egs[p1][i];
124             if(!crs(pot(pn),pot(pr),pot(p1),pot(a)))
125                 ne.push_back(a);
126             else
127                 egs[a].erase(find(egs[a].begin(),egs[a].end(),p1));
128         }
129         egs[p1]=ne;
130         con(pr,pn);
131         p1=pn;
132     }else{
133         for(int i=0;i<egs[pr].size();++i){
134             int a=egs[pr][i];
135             if(!crs(pot(pn),pot(p1),pot(pr),pot(a)))
136                 ne.push_back(a);
137             else
138                 egs[a].erase(find(egs[a].begin(),egs[a].end(),pr));
139         }
140         egs[pr]=ne;
141         con(p1,pn);
142         pr=pn;
143     }
144 }
145 }
146 vector<vector<int> >run(){
147     egs.resize(n+1);
148     sort(pts.begin()+1,pts.end());
149     dnc(1,n);
150     vector<vector<int> >res(n+1);
151     for(int u=1;u<=n;++u)
152         for(int i=0;i<egs[u].size();++i){
153             int v=egs[u][i];
154             res[pts[u].second].push_back(pts[v].second);
155         }
156     return res;
157 }
158 };
159 template<class T>const double DelaunayTriangulation<T>::E=1e-8;

```

1.3 Dynamic Convex Hull (Set)

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct DynamicConvexHull{
4      struct point{
5          T x,y;
6          point(T _x=0,T _y=0):
7              x(_x),y(_y){
8              }
9          point operator-(const point&a)const{
10             point p(x-a.x,y-a.y);
11             return p;
12         }
13         T operator*(const point&a)const{
14             return x*a.y-y*a.x;
15         }
16     };
17     struct node{
18         node**nxt;point p;
19         node(node**_n,point _p):
20             nxt(_n),p(_p){
21         }
22         node(const node&a):
23             nxt(new node*(*a.nxt)),p(a.p){
24         }
25         ~node(){
26             delete nxt;
27         }
28         int operator<(const node&a)const{
29             if(ctp)
30                 return p.x==a.p.x?p.y<a.p.y:p.x<a.p.x;
31             point p1,p2;
32             int f=1;
33             if(nxt)
34                 p1=*nxt?(*nxt)->p-p:point(0,-1),p2=a.p;
35             else
36                 f=0,p1=*a.nxt?(*a.nxt)->p-a.p:point(0,-1),p2=p;
37             T x=p1*p2;

```

```

38         return f?x<0:x>0;
39     }
40 };
41 static int ctp;
42 set<node>nds;
43 typedef typename set<node>::iterator P;
44 int check(P a,P b,P c){
45     return (b->p-a->p)*(c->p-b->p)>=0;
46 }
47 void next(P a,P b){
48     *(a->nxt)=(node*)&*b;
49 }
50 void insert(T x,T y){
51     ctp=1;
52     node t(new node*(0),point(x,y));
53     P it=nds.insert(t).first,itl1=it,itl2,ittr1=it,ittr2=it;
54     if(it!=nds.begin())
55         for(next(--itl1,it);itl1!=nds.begin()&&check(--(itl2=itl1),
56 itl1,it);)
57             next(itl2,it),nds.erase(itl1),itl1=itl2;
58     if(++(ittr1=it)!=nds.end())
59         next(it,ittr1);
60     if(itl1!=it&&ittr1!=nds.end()&&check(itl1,it,ittr1)){
61         next(itl1,ittr1);
62         nds.erase(it);
63         return;
64     }
65     if(ittr1!=nds.end())
66         for(++(ittr2=ittr1)!=nds.end()&&check(it,ittr1,ittr2);)
67             next(it,ittr2),nds.erase(ittr1),ittr1=ittr2;
68 }
69 int size(){
70     return nds.size();
71 }
72 pair<T,T>query(T x,T y){
73     ctp=0;
74     node t=*nds.lower_bound(node(0,point(x,y)));
75     return make_pair(t.p.x,t.p.y);
76 }
77 };
78 template<class T>int DynamicConvexHull<T>::ctp=0;

```

1.4 Dynamic Convex Hull (Treap)

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct DynamicConvexHull{
4      struct point{
5          T x,y;
6          point(T _x,T _y):
7              x(_x),y(_y){
8              }
9          point operator-(const point&a)const{
10             point p(x-a.x,y-a.y);
11             return p;
12         }
13         T operator*(const point&a)const{
14             return x*a.y-y*a.x;
15         }
16         int operator<(const point&a)const{
17             return x==a.x?y<a.y:x<a.x;
18         }
19         int operator==(const point&a)const{
20             return x==a.x&&y==a.y;
21         }
22     };
23     struct hull{
24         point*pt;
25         hull*ch[2],*nb[2];
26         int sz,fx;
27         hull(point*_pt):
28             pt(_pt),sz(1),fx(rand()*1.0/RAND_MAX*1e9){
29             ch[0]=ch[1]=nb[0]=nb[1]=0;
30         }
31         T check(point p){
32             return (nb[1]?*nb[1]->pt-*pt:point(0,-1))*p;
33         }
34         void update(){
35             sz=1;
36             for(int i=0;i<2;++i)
37                 if(ch[i])

```

```

38         sz+=ch[i]->sz;
39     }
40 };
41 static int sz(hull*x){
42     return x->sz:0;
43 }
44 static point&pt(hull*x){
45     return*x->pt;
46 }
47 static struct memory{
48     hull*ps,*pp,**ss,**sp;
49     int pm,sm;
50     vector<hull*>ns;
51     memory():
52         ps((hull*)malloc(sizeof(hull))),pp(ps),pm(1),ss((hull**)malloc(
53 sizeof(hull*)),sp(ss),sm(1){
54         ns.push_back(ps);
55     }
56     ~memory(){
57         free(ss);
58         for(int i=0;i<ns.size();++i)
59             free(ns[i]);
60     }
61     hull*create(const hull&x){
62         if(sp!=ss){
63             --sp;
64             **sp=x;
65             return*sp;
66         }
67         if(pp==ps+pm){
68             pp=ps=(hull*)malloc(sizeof(hull)*(pm<=1));
69             ns.push_back(ps);
70         }
71         *pp=x;
72         return pp++;
73     }
74     void destroy(hull*x){
75         if(sp==ss+sm){
76             hull**t=(hull**)malloc(sizeof(hull*)*sm<1);
77             memcpy(t,ss,sm*sizeof(hull*));
78             free(ss);

```



```

78         sp=(ss=t)+sm;
79         sm<=1;}
80     *(sp++)=x;
81 }
82 }me;
83 struct array{
84     hull**ps,**pp;
85     int pm;
86     array():
87         ps((hull**)malloc(sizeof(hull*))),pp(ps),pm(1){
88     }
89     ~array(){
90         free(ps);
91     }
92     int size(){
93         return pp-ps;
94     }
95     hull*operator[](int i){
96         return ps[i];
97     }
98     void push(hull*x){
99         if(pp==ps+pm){
100             hull**t=(hull**)malloc(sizeof(hull*)*pm<1);
101             memcpy(t,ps,pm*sizeof(hull*));
102             free(ps);
103             pp=(ps=t)+pm;
104             pm<=1;
105         }
106         *(pp++)=x;
107     }
108 };
109 static hull*link(hull*x,hull*y,hull*lb,hull*rb,int d,array&ns){
110     hull*r=me.create(*x);
111     if(x==lb||x==rb){
112         r->nb[d]=y;
113         if(y)
114             y->nb[!d]=r;
115     }else
116         r->ch[d]=link(r->ch[d],y,lb,rb,d,ns);
117     r->update();
118     ns.push(r);

```

```

119     return r;
120 }
121 static hull*merge(hull*x,hull*y,hull*lb,hull*rb,array&ns){
122     if(!x)
123         return y;
124     if(!y)
125         return x;
126     int d=x->fx>y->fx;
127     hull*r=me.create(d?*x:*y);
128     r->ch[d]=d?merge(r->ch[1],y,lb,rb,ns):merge(x,y->ch[0],lb,rb,ns);
129     if(d&&x==lb||!d&&y==rb)
130         r->ch[d]=link(r->ch[d],r,lb,rb,!d,ns);
131     r->update();
132     ns.push(r);
133     return r;
134 }
135 static pair<hull*,hull*>split(hull*x,int k,array&ns){
136     if(!x)
137         return make_pair((hull*)0,(hull*)0);
138     int t=sz(x->ch[0])+1;
139     hull*r=me.create(*x);
140     ns.push(r);
141     pair<hull*,hull*>s=split(x->ch[k>=t],k-t*(k>=t),ns);
142     if(k>=t){
143         r->ch[1]=s.first;r->update();
144         return make_pair(r,s.second);
145     }else{
146         r->ch[0]=s.second;r->update();
147         return make_pair(s.first,r);
148     }
149 }
150 static void turn(hull*&x,int d,int&k){
151     k+=(sz((x=x->ch[d])->ch[!d])+1)*(2*d-1);
152 }
153 static pair<T,T>range(hull*x){
154     hull*l=x,*r=x;
155     while(l->ch[0])
156         l=l->ch[0];
157     while(r->ch[1])
158         r=r->ch[1];
159     return make_pair(pt(l).x,pt(r).x);

```

```

160 }
161 static hull*merge(hull*x,hull*y,array&ns){
162     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);
164     int pf=1;
165     hull*p=x,*q=y;
166     if(pr.second==qr.first&&pr.first==pr.second&&p->ch[pf=0])
167         turn(p,0,kp);
168     for(point pq=pt(q)-pt(p);;pq=pt(q)-pt(p)){
169         pd[0]=(p->nb[0]&&(pt(p->nb[0])-pt(p))*pq<=0)*pf;
170         qd[1]=(q->nb[1]&&(pt(q->nb[1])-pt(q))*pq<=0);
171         pd[1]=(p->nb[1]&&(pt(p->nb[1])-pt(p))*pq<0)*pf;
172         qd[0]=(q->nb[0]&&(pt(q->nb[0])-pt(q))*pq<0);
173         if(!(pd[0]+pd[1]+qd[0]+qd[1])){
174             hull*l=split(x,kp,ns).first,*r=split(y,kq-1,ns).second,*lb=
175             1,*rb=r;
176             while(lb->ch[1])
177                 lb=lb->ch[1];
178             while(rb->ch[0])
179                 rb=rb->ch[0];
180             return merge(l,r,lb,rb,ns);
181         }
182         if(!(pd[0]+pd[1]))
183             turn(q,qd[1],kq);
184         if(!(qd[0]+qd[1]))
185             turn(p,pd[1],kp);
186         if(pd[0]&&qd[1])
187             turn(p,0,kp),turn(q,1,kq);
188         if(pd[1]&&qd[1])
189             turn(q,1,kq);
190         if(pd[0]&&qd[0])turn(p,0,kp);
191         if(pd[1]&&qd[0]){
192             point vp=pt(p->nb[1])-pt(p),vq=pt(q->nb[0])-pt(q);
193             if(vp.x==0&&vq.x==0)
194                 turn(p,1,kp),turn(q,0,kq);
195             else if(vp.x==0)
196                 turn(p,1,kp);
197             else if(vq.x==0)
198                 turn(q,0,kq);
199             else{
199                 long double m=pr.second,pb=vp.y*(m-pt(p).x),qb=vq.y*(m-

```

```

pt(q).x);
200         pb=pb/vp.x+pt(p).y;
201         qb=qb/vq.x+pt(q).y;
202         if(qb>pb+1e-8)
203             turn(q,0,kq);
204         else if(pb>qb+1e-8)
205             turn(p,1,kp);
206         else if(pt(q->nb[0]).x+pt(p->nb[1]).x<2*m)
207             turn(q,0,kq);
208         else
209             turn(p,1,kp);
210     }
211 }
212 }
213 }
214 hull*query(hull*x,point p){
215     for(hull*y=0;;){
216         T d=x->check(p);
217         if(d>0)
218             y=x,x=x->ch[0];
219         else if(d<0)
220             x=x->ch[1];
221         else
222             y=x;
223         if(!d||!x)
224             return y;
225     }
226 }
227 struct treap{
228     int fx,ct,sz;
229     point pt;
230     treap*ch[2];
231     struct hull*ip,*hu;
232     array ns;
233     treap(point _pt):
234         fx(rand()*1.0/RAND_MAX*1e9),ct(1),sz(1),pt(_pt),ip(me.create(
hull(&pt))),hu(ip){
235         ch[0]=ch[1]=0;
236     }
237     ~treap(){
238         for(hull**i=ns.ps;i!=ns.pp;++i)

```

```

239         me.destroy(*i);
240     me.destroy(ip);
241 }
242 void update(){
243     for(hull**i=ns.ps;i!=ns.pp;++i)
244         me.destroy(*i);
245     ns.pp=ns.ps;
246     sz=1;
247     hu=ip;
248     if(ch[0])
249         hu=merge(ch[0]->hu,hu,ns),sz+=ch[0]->sz;
250     if(ch[1])
251         hu=merge(hu,ch[1]->hu,ns),sz+=ch[1]->sz;
252 }
253 }*root;
254 void rotate(treap*&x,int d){
255     treap*y=x->ch[d];
256     x->ch[d]=y->ch[!d];
257     y->ch[!d]=x;
258     x=y;
259 }
260 int insert(treap*&x,point p){
261     if(!x)
262         x=new treap(p);
263     else if(p==x->pt){
264         ++x->ct;
265         return 0;
266     }else{
267         int d=x->pt<p;
268         if(!insert(x->ch[d],p))
269             return 0;
270         if(x->ch[d]->fx>x->fx)
271             rotate(x,d),x->ch[!d]->update();
272         x->update();
273     }
274     return 1;
275 }
276 int erase(treap*&x,point p){
277     if(p==x->pt){
278         if(x->ct>1){
279             --x->ct;

```

```

280         return 0;
281     }
282     treap*y=x;
283     if(!x->ch[0])
284         x=x->ch[1], delete y;
285     else if(!x->ch[1])
286         x=x->ch[0], delete y;
287     else{
288         int d=x->ch[0]->fx<x->ch[1]->fx;
289         rotate(x,d);
290         erase(x->ch[!d],p);
291         x->update();
292     }
293     return 1;
294 }
295 if(erase(x->ch[x->pt<p],p)){
296     x->update();
297     return 1;
298 }else{
299     --x->sz;
300     return 0;
301 }
302 }
303 void clear(treap*x){
304     if(x)
305         clear(x->ch[0]), clear(x->ch[1]), delete x;
306 }
307 DynamicConvexHull():
308     root(0){
309 }
310 ~DynamicConvexHull(){
311     clear(root);
312 }
313 int size(){
314     return root?root->sz:0;
315 }
316 void insert(T x,T y){
317     insert(root,point(x,y));
318 }
319 void erase(T x,T y){
320     erase(root,point(x,y));

```

```

321     }
322     pair<T,T>query(T x,T y){
323         point r=pt(query(root->hu,point(x,y)));
324         return make_pair(r.x,r.y);
325     }
326 };
327 template<class T>typename DynamicConvexHull<T>::memory DynamicConvexHull<T>
    >::me;

```

1.5 Geometry 2D

Geometry 2D.hpp (5120 bytes, 164 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace Geometry2D{
4      double eps=1e-8;
5      long double pi=acos((long double)-1);
6      template<class T>T sqr(T a){
7          return a*a;
8      }
9      template<class T>int cmp(T a,T b){
10         if(typeid(T)==typeid(int)||typeid(T)==typeid(long long)){
11             if(a==b)
12                 return 0;
13             return a<b?-1:1;
14         }
15         if(a<b-eps)
16             return -1;
17         if(a>b+eps)
18             return 1;
19         return 0;
20     }
21     template<class T>struct Point{
22         T x,y;
23         Point(T _x=0,T _y=0):
24             x(_x),y(_y){
25         }
26         Point<T>&operator+=(const Point<T>&a){

```

```

27         return*this=*this+a;
28     }
29     Point<T>&operator+=(const Point<T>&a){
30         return*this=*this+a;
31     }
32 };
33 #define Vector Point
34 template<class T>Point<T>operator+(const Point<T>&a,const Point<T>&b){
35     return Point<T>(a.x+b.x,a.y+b.y);
36 }
37 template<class T>Point<T>operator-(const Point<T>&a,const Point<T>&b){
38     return Point<T>(a.x-b.x,a.y-b.y);
39 }
40 template<class T>Point<T>operator*(T a,const Point<T>&b){
41     return Point<T>(b.x*a,b.y*a);
42 }
43 template<class T>Point<T>operator*(const Point<T>&a,T b){
44     return b*a;
45 }
46 template<class T>Point<T>operator/(const Point<T>&a,T b){
47     return Point<T>(a.x/b,a.y/b);
48 }
49 template<class T>bool operator==(const Point<T>&a,const Point<T>&b){
50     return !cmp(a.x,b.x)&&!cmp(a.y,b.y);
51 }
52 template<class T>bool operator!=(const Point<T>&a,const Point<T>&b){
53     return !(a==b);
54 }
55 template<class T>bool operator<(const Point<T>&a,const Point<T>&b){
56     int t=cmp(a.x,b.x);
57     if(t)
58         return t<0;
59     return cmp(a.y,b.y)<0;
60 }
61 template<class T>bool operator>(const Point<T>&a,const Point<T>&b){
62     return b<a;
63 }
64 template<class T>Point<T>NaP(){
65     T t=numeric_limits<T>::max();
66     return Point<T>(t,t);
67 }

```



```

68     template<class T>T det(const Point<T>&a,const Point<T>&b){
69         return a.x*b.y-a.y*b.x;
70     }
71     template<class T>T dot(const Point<T>&a,const Point<T>&b){
72         return a.x*b.x+a.y*b.y;
73     }
74     template<class T>T abs(const Point<T>&a){
75         return sqrt(sqr(a.x)+sqr(a.y));
76     }
77     template<class T>T dis(const Point<T>&a,const Point<T>&b){
78         return abs(a-b);
79     }
80     template<class T>istream&operator>>(istream&s,Point<T>&a){
81         return s>>a.x>>a.y;
82     }
83     template<class T>ostream&operator<<(ostream&s,const Point<T>&a){
84         return s<<a.x<<" "<<a.y;
85     }
86     template<class T>struct Segment;
87     template<class T>struct Line{
88         Point<T>u,v;
89         Line(const Point<T>&_u=Point<T>(),const Point<T>&_v=Point<T>()):
90             u(_u),v(_v){
91         }
92         Line(const Segment<T>&a):
93             u(a.u),v(a.v){
94         }
95     };
96     template<class T>Point<T>nor(const Line<T>&a){
97         Point<T>t=a.v-a.u;
98         return Point<T>(t.y,-t.x);
99     }
100    template<class T>Point<T>dir(const Line<T>&a){
101        return a.v-a.u;
102    }
103    template<class T>int dir(const Line<T>a,const Point<T>b){
104        return cmp(det(b-a.u,a.v-a.u),T(0));
105    }
106    template<class T>Point<T>operator&(const Line<T>&a,const Line<T>&b){
107        T p=det(b.u-a.v,b.v-b.u),q=det(a.u-b.v,b.v-b.u);
108        return (a.u*p+a.v*q)/(p+q);

```

```

109 }
110 template<class T>struct Segment{
111     Point<T>u,v;
112     Segment(const Point<T>&_u=Point<T>(),const Point<T>&_v=Point<T>()):
113         u(_u),v(_v){
114     }
115 };
116 template<class T>Point<T>nor(const Segment<T>&a){
117     Point<T>t=a.v-a.u;
118     return Point<T>(t.y,-t.x);
119 }
120 template<class T>Point<T>dir(const Segment<T>&a){
121     return a.v-a.u;
122 }
123 template<class T>int dir(const Segment<T>a,const Point<T>b){
124     return cmp(b-a.u,a.v-a.u);
125 }
126 template<class T>Point<T>operator&(const Line<T>&a,const Segment<T>&b){
127     if(dir(a,b.u)*dir(a,b.v)<=0)
128         return a&Line<T>(b);
129     return NaP<T>();
130 }
131 template<class T>Point<T>operator&(const Segment<T>&a,const Line<T>&b){
132     return b&a;
133 }
134 template<class T>pair<T,T>dis(const Segment<T>&a,const Point<T>&b){
135     pair<T,T>d(dis(a.u,b),dis(a.v,b));
136     if(d.first>d.second)
137         swap(d.first,d.second);
138     Point<T>t=Line<T>(b,b+nor(a))&a;
139     if(t!=NaP<T>())
140         d.first=dis(t,b);
141     return d;
142 }
143 template<class T>pair<T,T>dis(const Point<T>&a,const Segment<T>&b){
144     return dis(b,a);
145 }
146 template<class T>struct Circle{
147     Point<T>c;
148     T r;
149     Circle(const Point<T>&_c=Point<T>(),T _r=0):

```

```

150         c(_c),r(_r){
151     }
152 };
153 template<class T>T abs(const Circle<T>&a){
154     return pi*sqr(a.r);
155 }
156 template<class T>bool col(const Point<T>&a,const Point<T>&b,const Point
157 <T>&c){
158     return !cmp(det(a-c,b-c),T(0));
159 }
160 template<class T>T read(){
161     T t;
162     cin>>t;
163     return t;
164 }

```

1.6 Half-Plane Intersection

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

```

1 #include<bits/stdc++.h>
2 using namespace std;
3 namespace HalfPlaneIntersection{
4     const double E=1e-8;
5     struct pot{
6         pot(double a=0,double b=0):
7             x(a),y(b){
8         }
9         double x,y;
10    };
11    double ag(pot p){
12        return atan2(double(p.x),double(p.y));
13    }
14    pot operator+(pot p,pot q){
15        return pot(p.x+q.x,p.y+q.y);
16    }
17    pot operator-(pot p,pot q){
18        return pot(p.x-q.x,p.y-q.y);

```

```

19 }
20 pot operator*(pot p,double q){
21     return pot(p.x*q,p.y*q);
22 }
23 pot operator/(pot p,double q){
24     return pot(p.x/q,p.y/q);
25 }
26 double det(pot p,pot q){
27     return p.x*q.y-q.x*p.y;
28 }
29 double dot(pot p,pot q){
30     return p.x*q.x+p.y*q.y;
31 }
32 struct lin{
33     pot p,q;
34     double a;
35     lin(pot a,pot b):
36         p(a),q(b),a(ag(b-a)){
37     }
38 };
39 pot operator*(lin a,lin b){
40     double a1=det(b.p-a.q,b.q-b.p);
41     double a2=det(a.p-b.q,b.q-b.p);
42     return (a.p*a1+a.q*a2)/(a1+a2);
43 }
44 bool cmp(lin a,lin b){
45     if(fabs(a.a-b.a)>E)
46         return a.a<b.a;
47     else
48         return det(a.q-b.p,b.q-b.p)<-E;
49 }
50 bool left(lin a,lin b,lin c){
51     pot t=a*b;
52     return det(t-c.p,c.q-c.p)<-E;
53 }
54 deque<lin>run(vector<lin>lins){
55     deque<lin>ans;
56     sort(lns.begin(),lns.end(),cmp);
57     for(int i=0;i<lns.size();++i){
58         while(ans.size()>1&&!left(ans.back(),ans[ans.size()-2],lns[i]))
59             ans.pop_back();

```

```
60         while(ans.size()>1&&!left(ans[0],ans[1],lns[i]))
61             ans.pop_front();
62         if(ans.empty()||fabs(ans.back().a-lns[i].a)>E)
63             ans.push_back(lns[i]);}
64     while(ans.size()>1&&!left(ans[ans.size()-1],ans[ans.size()-2],ans.
front()))
65         ans.pop_back();
66     if(ans.size()<3)
67         ans.clear();
68     return ans;
69 }
70 }
```


CHAPTER 2

Data Structures

2.1 Binary Heap

BinaryHeap.hpp (1629 bytes, 73 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T, class C> struct BinaryHeap{
4      struct node{
5          node(int _p, T _v):
6              p(_p), v(_v){
7              }
8          int p;
9          T v;
10     };
11     vector<node*> a;
12     BinaryHeap():
13         a(1){
14     }
15     ~BinaryHeap(){
16         clear();
17     }
18     void move(int i, int j){
19         swap(a[i]->p, a[j]->p);
20         swap(a[i], a[j]);
21     }
22     int check(int i, int j){
23         if(!j || j >= a.size() || a[i]->v == a[j]->v)
24             return 0;
25         return a[i]->v < a[j]->v ? -1 : 1;
26     }
27     int up(int i){
28         if(check(i, i >> 1) < 0){
29             move(i, i >> 1);
30             return i >> 1;
31         } else
32             return 0;
33     }
34     int down(int i){
35         if(check(i, i << 1) <= 0 && check(i, i << 1 ^ 1) <= 0)
36             return a.size();
37         if(check(i << 1, i << 1 ^ 1) <= 0){

```



```
38         move(i,i<<1);
39         return i<<1;
40     }else{
41         move(i,i<<1^1);
42         return i<<1^1;
43     }
44 }
45 void maintain(int i){
46     for(int j=up(i);j;i=j,j=up(i));
47     for(int j=down(i);j<a.size();i=j,j=down(i));
48 }
49 void clear(){
50     for(int i=1;i<a.size();++i)
51         delete a[i];
52     a.resize(1);
53 }
54 node*push(T v){
55     a.push_back(new node(a.size(),v));
56     node*r=a.back();
57     maintain(a.size()-1);
58     return r;
59 }
60 T top(){
61     return a[1]->v;
62 }
63 void pop(){
64     move(1,a.size()-1);
65     delete a.back();
66     a.pop_back();
67     maintain(1);
68 }
69 void modify(node*x,T v){
70     x->v=v;
71     maintain(x->p);
72 }
73 };
```

2.2 Dynamic Sequence

Dynamic Sequence.hpp (4119 bytes, 177 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct DynamicSequence{
4      struct node{
5          node(T _i):
6              i(_i),v(_i),s(1),r(0){
7              c[0]=c[1]=0;
8              static int g;
9              w=g=(214013*g+2531011);
10         }
11         T i,v;
12         int s,r,w;
13         node*c[2];
14     }*rt,*sl,*sr;
15     struct pool{
16         node*ps,*pp,**ss,**sp;
17         int pm,sm;
18         vector<node*>ns;
19         pool():
20             ps((node*)malloc(sizeof(node))),pp(ps),pm(1),ss((node**)malloc(
21             sizeof(node*))),sp(ss),sm(1){
22             ns.push_back(ps);
23         }
24         ~pool(){
25             free(ss);
26             for(int i=0;i<ns.size();++i)
27                 free(ns[i]);
28         }
29         node*crt(T a){
30             if(sp!=ss){
31                 --sp;
32                 **sp=node(a);
33                 return*sp;
34             }
35             if(pp==ps+pm){
36                 pp=ps=(node*)malloc(sizeof(node)*(pm<=1));
37                 ns.push_back(ps);

```

```

37     }
38     *pp=node(a);
39     return pp++;
40 }
41 void des(node*x){
42     if(sp==ss+sm){
43         node**t=(node**)malloc(sizeof(node*)*sm<<1);
44         memcpy(t,ss,sm*sizeof(node*));
45         free(ss);
46         sp=(ss=t)+sm;
47         sm<=<=1;
48     }
49     *(sp++)=x;
50 }
51 }me;
52 node*bud(T*a,int l,int r){
53     if(l>r)
54         return 0;
55     int m=l+r>>1;
56     node*t=me.crt(a[m]);
57     t->c[0]=bud(a,l,m-1);
58     t->c[1]=bud(a,m+1,r);
59     pup(t);
60     return t;
61 }
62 void pdw(node*x){
63     for(int d=0;d<2&&(x->i>x->v,1);++d)
64         if(x->c[d])
65             x->i>x->c[d]->i;
66     *x->i;
67     *x->v;
68     if(x->r){
69         -x->i;
70         for(int d=0;d<2;++d)
71             if(x->c[d])
72                 x->c[d]->r^=1;
73         swap(x->c[0],x->c[1]);
74         x->r=0;
75     }
76 }
77 void pup(node*x){

```

```

78     x->i=x->v;
79     x->s=1;
80     for(int d=0;d<2;++d)
81         if(x->c[d])
82             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;
83     }
84     void jon(node*x){
85         rt=jon(jon(sl,x),sr);
86     }
87     node*jon(node*x,node*y){
88         if(!x)
89             return y;
90         if(!y)
91             return x;
92         pdw(x);
93         pdw(y);
94         if(x->w<y->w){
95             x->c[1]=jon(x->c[1],y);
96             pup(x);
97             return x;
98         }else{
99             y->c[0]=jon(x,y->c[0]);
100            pup(y);
101            return y;
102        }
103    }
104    node*spt(int l,int r){
105        spt(rt,l-1);
106        node*t=sl;
107        spt(sr,r-l+1);
108        swap(sl,t);
109        return t;
110    }
111    void spt(node*x,int p){
112        if(!x){
113            sl=sr=0;
114            return;
115        }
116        pdw(x);
117        int t=x->c[0]?x->c[0]->s:0;

```

```

118         if(t<p)
119             spt(x->c[1],p-t-1),x->c[1]=s1,s1=x;
120         else
121             spt(x->c[0],p),x->c[0]=sr,sr=x;
122         pup(x);
123     }
124     void clr(node*x){
125         if(x)
126             clr(x->c[0]),clr(x->c[1]),me.des(x);
127     }
128     DynamicSequence(T*a=0,int n=0){
129         rt=bud(a,1,n);
130     }
131     ~DynamicSequence(){
132         clr(rt);
133     }
134     void clear(){
135         clr(rt);
136         rt=0;
137     }
138     void insert(T a,int p){
139         insert(&a-1,1,p);
140     }
141     void insert(T*a,int n,int p){
142         spt(p+1,p);
143         jon(bud(a,1,n));
144     }
145     void erase(int p){
146         erase(p,p);
147     }
148     void erase(int l,int r){
149         clr(spt(l,r));
150         jon(0);
151     }
152     T query(int p){
153         return query(p,p);
154     }
155     T query(int l,int r){
156         node*t=spt(l,r);
157         T i=t->i;
158         jon(t);

```

```

159     return i;
160 }
161 void modify(T a,int l){
162     modify(a,l,l);
163 }
164 void modify(T a,int l,int r){
165     node*t=spt(l,r);
166     a>t->i;
167     jon(t);
168 }
169 void reverse(int l,int r){
170     node*t=spt(l,r);
171     t->r=1;
172     jon(t);
173 }
174 int length(){
175     return rt?rt->s:0;
176 }
177 };

```

2.3 Fenwick Tree

Fenwick Tree.hpp (529 bytes, 25 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct FenwickTree{
4      FenwickTree(int _n):
5          n(_n),l(log2(n)),a(n+1){
6      }
7      void add(int v,T d){
8          for(;v<=n;v+=v&-v)
9              a[v]+=d;
10     }
11     T sum(int v){
12         T r=0;
13         for(;v>=1;v-=v&-v)
14             r+=a[v];
15         return r;

```

```

16     }
17     int kth(T k,int r=0){
18         for(int i=1<<1;i;i>=1)
19             if(r+i<=n&&a[r+i]<k)
20                 k-=a[r+=i];
21         return r+1;
22     }
23     int n,l;
24     vector<T>a;
25 };

```

2.4 K-D Tree

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct KDTree{
4      struct node{
5          node(int x0,int x1,int d):
6              color(1),cover(0),dir(d){
7              ch[0]=ch[1]=0;
8              x[0]=mi[0]=mx[0]=x0;
9              x[1]=mi[1]=mx[1]=x1;
10         }
11         node*ch[2];
12         int x[2],mi[2],mx[2],color,cover,dir;
13     }*root;
14     KDTree(pair<int,int>*a,int n){
15         root=build(a,1,n,0);
16     }
17     static int direct;
18     static int cmp(pair<int,int>a,pair<int,int>b){
19         if(direct)
20             return make_pair(a.second,a.first)<make_pair(b.second,b.first);
21         return a<b;
22     }
23     node*build(pair<int,int>*a,int l,int r,int d){
24         int m=(r+l)/2;

```

```

25     direct=d;
26     nth_element(a+l,a+m,a+r+1,cmp);
27     node*p=new node((a+m)->first,(a+m)->second,d);
28     if(l!=m)
29         p->ch[0]=build(a,l,m-1,!d);
30     if(r!=m)
31         p->ch[1]=build(a,m+1,r,!d);
32     for(int i=0;i<2;++i)
33         for(int j=0;j<2;++j)
34             if(p->ch[j]){
35                 p->mi[i]=min(p->mi[i],p->ch[j]->mi[i]);
36                 p->mx[i]=max(p->mx[i],p->ch[j]->mx[i]);
37             }
38     return p;
39 }
40 void down(node*a){
41     if(a->cover){
42         for(int i=0;i<2;++i)
43             if(a->ch[i])
44                 a->ch[i]->cover=a->cover;
45         a->color=a->cover;
46         a->cover=0;
47     }
48 }
49 void modify(node*a,int mi0,int mx0,int mi1,int mx1,int c){
50     if(mi0>a->mx[0] || mx0<a->mi[0] || mi1>a->mx[1] || mx1<a->mi[1])
51         return;
52     if(mi0<=a->mi[0]&&mx0>=a->mx[0]&&mi1<=a->mi[1]&&mx1>=a->mx[1]){
53         a->cover=c;
54         return;
55     }
56     down(a);
57     if(mi0<=a->x[0]&&mx0>=a->x[0]&&mi1<=a->x[1]&&mx1>=a->x[1])
58         a->color=c;
59     for(int i=0;i<2;++i)
60         if(a->ch[i])
61             modify(a->ch[i],mi0,mx0,mi1,mx1,c);
62 }
63 void modify(int mi0,int mx0,int mi1,int mx1,int c){
64     modify(root,mi0,mx0,mi1,mx1,c);
65 }

```



```

66     int query(node*a,int x0,int x1){
67         down(a);
68         if(x0==a->x[0]&& x1==a->x[1])
69             return a->color;
70         direct=a->dir;
71         if(cmp(make_pair(x0,x1),make_pair(a->x[0],a->x[1])))
72             return query(a->ch[0],x0,x1);
73         else
74             return query(a->ch[1],x0,x1);
75     }
76     int query(int x0,int x1){
77         return query(root,x0,x1);
78     }
79 };
80 int KDTree::direct=0;

```

2.5 Link-Cut Tree

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct LinkCutTree{
4      struct node{
5          node():
6              ch({0,0}),pr(0),rev(0){
7              }
8          node*ch[2],*pr;
9          T ifo;
10         int rev;
11     }*ptrs;
12     LinkCutTree(int n):
13         ptrs(new node[n]-1){
14     }
15     ~LinkCutTree(){
16         delete ptrs;
17     }
18     int direct(node*x){
19         if(!x->pr)

```

```

20         return 2;
21     if(x==x->pr->ch[0])
22         return 0;
23     if(x==x->pr->ch[1])
24         return 1;
25     return 2;
26 }
27 void down(node*x){
28     if(x->rev){
29         x->ifo.reverse();
30         swap(x->ch[0],x->ch[1]);
31         for(int i=0;i<2;++i)
32             if(x->ch[i])
33                 x->ch[i]->rev^=1;
34         x->rev=0;
35     }
36     x->ifo.down(x->ch[0]?&x->ch[0]->ifo:0,x->ch[1]?&x->ch[1]->ifo:0);
37 }
38 void up(node*x){
39     for(int i=0;i<2;++i)
40         if(x->ch[i])
41             down(x->ch[i]);
42     x->ifo.up(x->ch[0]?&x->ch[0]->ifo:0,x->ch[1]?&x->ch[1]->ifo:0);
43 }
44 void setchild(node*x,node*y,int d){
45     x->ch[d]=y;
46     if(y)
47         y->pr=x;
48     up(x);
49 }
50 void rotate(node*x){
51     node*y=x->pr,*z=y->pr;
52     int d1=direct(x),d2=direct(y);
53     setchild(y,x->ch[!d1],d1);
54     setchild(x,y,!d1);
55     if(d2<2)
56         setchild(z,x,d2);
57     else
58         x->pr=z;
59 }
60 void release(node*x){

```

```

61         if(direct(x)<2)
62             release(x->pr);
63         down(x);
64     }
65     void splay(node*x){
66         for(release(x);direct(x)<2;){
67             node*y=x->pr;
68             if(direct(y)==2)
69                 rotate(x);
70             else if(direct(x)==direct(y))
71                 rotate(y),rotate(x);
72             else
73                 rotate(x),rotate(x);
74         }
75     }
76     node*access(node*x){
77         node*y=0;
78         for(;x;y=x,x=x->pr){
79             splay(x);
80             setchild(x,y,1);
81         }
82         return y;
83     }
84     void evert(node*x){
85         access(x);
86         splay(x);
87         x->rev=1;
88     }
89     void set(int x,T v){
90         ptrs[x].ifo=v;
91     }
92     int linked(int a,int b){
93         access((ptrs+a));
94         node*z=access((ptrs+b));
95         return z==access((ptrs+a));
96     }
97     void link(int a,int b){
98         evert((ptrs+b));
99         (ptrs+b)->pr=(ptrs+a);
100     }
101     void cut(int a,int b){

```

```

102     access((ptrs+b));
103     node*z=access((ptrs+a));
104     if(z==(ptrs+a))
105         splay((ptrs+b)),(ptrs+b)->pr=0;
106     else
107         access((ptrs+b)),splay((ptrs+a)),(ptrs+a)->pr=0;
108 }
109 int root(int a){
110     access((ptrs+a));
111     splay((ptrs+a));
112     node*r=(ptrs+a);
113     while(r->ch[1])
114         r=r->ch[1];
115     return r-ptrs;
116 }
117 void evert(int a){
118     evert((ptrs+a));
119 }
120 int lca(int a,int b){
121     access((ptrs+a));
122     return access((ptrs+b))-ptrs;
123 }
124 T query(int a){
125     splay((ptrs+a));
126     T p=(ptrs+a)->ifo;
127     p.up(0,0);
128     return p;
129 }
130 T query(int a,int b){
131     if((ptrs+a)==(ptrs+b))
132         return query((ptrs+a));
133     access((ptrs+a));
134     node*c=access((ptrs+b));
135     T p=c.ifo;
136     if(c==(ptrs+b)){
137         splay((ptrs+a));
138         T q=(ptrs+a)->ifo;
139         q.reverse();
140         p.up(&q,0);
141         return p;
142     }else if(c==(ptrs+a))

```

```

143         p.up(0,&(ptrs+a)->ch[1]->if0);
144     else{
145         splay((ptrs+a));
146         T q=(ptrs+a)->if0;
147         q.reverse();
148         p.up(&q,&c->ch[1]->if0);
149     }
150     return p;
151 }
152 T equery(int a){
153     return query(a);
154 }
155 T equery(int a,int b){
156     access((ptrs+a));
157     node*c=access((ptrs+b));
158     if(c==(ptrs+b)){
159         splay((ptrs+a));
160         T q=(ptrs+a)->if0;
161         q.reverse();
162         return q;
163     }else if(c==(ptrs+a))
164         return (ptrs+a)->ch[1]->if0;
165     else{
166         splay((ptrs+a));
167         node*t=c->ch[1];
168         while(t->ch[0])
169             t=t->ch[0];
170         splay(t);
171         if(t->ch[1])
172             down(t->ch[1]);
173         T p=t->if0,q=(ptrs+a)->if0;
174         q.reverse();
175         p.up(&q,t->ch[1]?&t->ch[1]->if0:0);
176         return p;
177     }
178 }
179 template<class F>void modify(int a,F f){
180     splay((ptrs+a));
181     f(&(ptrs+a)->if0);
182     up((ptrs+a));
183 }

```

```

184 template<class F>void modify(int a,int b,F f){
185     if((ptrs+a)==(ptrs+b)){
186         splay((ptrs+a));
187         f(0,&(ptrs+a)->ifo,0);
188         up((ptrs+a));
189         return;
190     }
191     access((ptrs+a));
192     node*c=access((ptrs+b));
193     if(c==(ptrs+b))
194         splay((ptrs+a)),f(&(ptrs+a)->ifo,&(ptrs+b)->ifo,0);
195     else if(c==a)
196         f(0,&(ptrs+a)->ifo,&(ptrs+a)->ch[1]->ifo);
197     else
198         splay(a),f(&(ptrs+a)->ifo,&c->ifo,&c->ch[1]->ifo);
199     up(c);
200 }
201 template<class F>void emodify(int a,F f){
202     modify(a,f);
203 }
204 template<class F>void emodify(int a,int b,F f){
205     access((ptrs+a));
206     node*c=access((ptrs+b));
207     if(c==(ptrs+b))
208         splay((ptrs+a)),f(&(ptrs+a)->ifo,0);
209     else if(c==a)
210         f(0,&(ptrs+a)->ch[1]->ifo);
211     else
212         splay(a),f(&(ptrs+a)->ifo,&c->ch[1]->ifo);
213     up(c);
214 }
215 };

```

2.6 Pairing Heap

Pairing Heap.hpp (2226 bytes, 102 lines)

```

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

```

```

3  template<class T, class C> struct PairingHeap{
4      PairingHeap():
5          root(0), siz(0){
6      }
7      ~PairingHeap(){
8          clear(root);
9      }
10     struct node{
11         node(const T& val):
12             val(_val), ch(0), br(0), pr(0){
13         }
14         T val;
15         node*ch, *br, *pr;
16     }*root;
17     int siz;
18     void merge(node*&x, node*&y){
19         if(!x)
20             x=y;
21         else if(y){
22             if(C()(y->val, x->val))
23                 swap(x, y);
24             y->br=x->ch;
25             if(x->ch)
26                 x->ch->pr=y;
27             y->pr=x;
28             x->ch=y;
29         }
30     }
31     void cut(node*&x, node*&y){
32         if(x==y)
33             x=0;
34         else{
35             if(y==y->pr->ch)
36                 y->pr->ch=y->br;
37             else
38                 y->pr->br=y->br;
39             if(y->br)
40                 y->br->pr=y->pr;
41             y->pr=y->br=0;
42         }
43     }

```

```
44 node*split(node*x){
45     vector<node*>t;
46     for(node*i=x->ch;i;i=i->br)
47         t.push_back(i);
48     x->ch=0;
49     node*r=0;
50     for(int i=0;i<t.size();++i)
51         t[i]->pr=t[i]->br=0;
52     for(int i=0;i+1<t.size();i+=2)
53         merge(t[i],t[i+1]);
54     for(int i=0;i<t.size();i+=2)
55         merge(r,t[i]);
56     return r;
57 }
58 void clear(node*x){
59     if(x){
60         clear(x->ch);
61         clear(x->br);
62         delete x;
63     }
64 }
65 void clear(){
66     clear(root);
67     root=0;
68     siz=0;
69 }
70 node*push(T a){
71     node*r=new node(a);
72     merge(root,r);
73     ++siz;
74     return r;
75 }
76 void erase(node*x){
77     cut(root,x);
78     merge(root,split(x));
79     --siz;
80 }
81 T top(){
82     return root->val;
83 }
84 void pop(){
```



```

85     erase(root);
86 }
87 void merge(PairingHeap<T,C>&a){
88     merge(root,a.root);
89     a.root=0;
90     siz+=a.siz;
91     a.siz=0;
92 }
93 void modify(node*x,T v){
94     if(C()(x->val,v))
95         x->val=v,merge(root,split(x));
96     else
97         x->val=v,cut(root,x),merge(root,x);
98 }
99 int size(){
100     return siz;
101 }
102 };

```

2.7 Red-Black Tree

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T,class C>struct RedBlackTree{
4      struct node{
5          node(T _v,node*l,node*r,node*_p,int _b,int _s):
6              v(_v),p(_p),b(_b),s(_s){
7              c[0]=l;
8              c[1]=r;
9          }
10         T v;
11         node*c[2],*p;
12         int b,s;
13     }*root,*nil;
14     void clear(node*x){
15         if(x!=nil){
16             clear(x->c[0]);

```

```

17         clear(x->c[1]);
18         delete x;
19     }
20 }
21 void rotate(node*x,int d){
22     node*y=x->c[!d];
23     x->c[!d]=y->c[d];
24     if(y->c[d]!=nil)
25         y->c[d]->p=x;
26     y->p=x->p;
27     if(x->p==nil)
28         root=y;
29     else
30         x->p->c[x!=x->p->c[0]]=y;
31     y->c[d]=x;
32     x->p=y;
33     y->s=x->s;
34     x->s=x->c[0]->s+x->c[1]->s+1;
35 }
36 void insert_fixup(node*z){
37     while(!z->p->b){
38         int d=z->p==z->p->p->c[0];
39         node*y=z->p->p->c[d];
40         if(!y->b)
41             z->p->b=1,y->b=1,(z=z->p->p)->b=0;
42         else{
43             if(z==z->p->c[d])
44                 rotate(z=z->p,!d);
45             z->p->b=1;
46             z->p->p->b=0;
47             rotate(z->p->p,d);
48         }
49     }
50     root->b=1;
51 }
52 void erase(node*z){
53     node*y;
54     for(y=z;y!=nil;y=y->p)
55         --y->s;
56     if(z->c[0]==nil||z->c[1]==nil)
57         y=z;

```

```

58     else{
59         for(y=z->c[1];y->c[0]!=nil;)
60             y=y->c[0];
61         z->v=y->v;
62         y=z->c[1];
63         while(y->c[0]!=nil)
64             --y->s,y=y->c[0];
65     }
66     node*x=y->c[y->c[0]==nil];
67     x->p=y->p;
68     if(y->p==nil)
69         root=x;
70     else
71         y->p->c[y!=y->p->c[0]]=x;
72     if(y->b)
73         erase_fixup(x);
74     delete y;
75 }
76 void erase_fixup(node*x){
77     while(x!=root&&x->b){
78         int d=x==x->p->c[0];
79         node*w=x->p->c[d];
80         if(!w->b){
81             w->b=1;
82             x->p->b=0;
83             rotate(x->p,!d);
84             w=x->p->c[d];
85         }
86         if(w->c[0]->b&&w->c[1]->b)
87             w->b=0,x=x->p;
88         else{
89             if(w->c[d]->b)
90                 w->c[!d]->b=1,w->b=0,rotate(w,d),w=x->p->c[d];
91             w->b=x->p->b;
92             x->p->b=1;
93             w->c[d]->b=1;
94             rotate(x->p,!d);
95             x=root;
96         }
97     }
98     x->b=1;

```

```

99     }
100 node*clone(node*x,node*y){
101     if(x.size==0)
102         return nil;
103     node*z=new node(*x);
104     z->c[0]=clone(x->c[0],z);
105     z->c[1]=clone(x->c[1],z);
106     z->p=y;
107     return z;
108 }
109 node*precursor(node*x){
110     if(x->c[0]->count){
111         for(x=x->c[0];x->c[1]->count;)
112             x=x->c[1];
113         return x;
114     }else{
115         node*y=x->p;
116         while(y->count&&x==y->c[0])
117             x=y,y=y->p;
118         return y;
119     }
120 }
121 node*successor(node*x){
122     if(x->c[1]->count){
123         for(x=x->c[1];x->c[0]->count;)
124             x=x->c[0];
125         return x;
126     }else{
127         node*y=x->p;
128         while(y->count&&x==y->c[1])
129             x=y,y=y->p;
130         return y;
131     }
132 }
133 RedBlackTree(){
134     root=nil=(node*)malloc(sizeof(node));
135     nil->b=1;
136     nil->s=0;
137 }
138 RedBlackTree(const RedBlackTree&a){
139     nil=new node(*a.nil);

```

```

140     root=clone(a.root,nil);
141 }
142 ~RedBlackTree(){
143     clear(root);
144     free(nil);
145 }
146 RedBlackTree&operator=(const RedBlackTree&a){
147     clear(root);
148     root=clone(a.root,nil);
149     return*this;
150 }
151 node*begin(){
152     node*z=root;
153     while(z!=nil&&z->c[0]!=nil)
154         z=z->c[0];
155     return z;
156 }
157 node*reverse_begin(){
158     node*z=root;
159     while(z!=nil&&z->c[1]!=nil)
160         z=z->c[1];
161     return z;
162 }
163 node*end(){
164     return nil;
165 }
166 node*reverse_end(){
167     return nil;
168 }
169 void clear(){
170     clear(root);
171     root=nil;
172 }
173 void insert(T a){
174     node*y=nil,*x=root;
175     while(x!=nil)
176         y=x,++x->s,x=x->c[C()](x->v,a)];
177     node*z=new node(a,nil,nil,y,0,1);
178     if(y==nil)
179         root=z;
180     else

```

```

181         y->c[C() (y->v, z->v)] = z;
182     insert_fixup(z);
183 }
184 void erase(T a){
185     node*z=root;
186     for(;;)
187         if(C() (a, z->v))
188             z=z->c[0];
189         else if(C() (z->v, a))
190             z=z->c[1];
191         else
192             break;
193     erase(z);
194 }
195 int count(T a){
196     return count_less_equal(a)-count_less(a);
197 }
198 int count_less(T a){
199     int r=0;
200     node*z=root;
201     while(z!=nil)
202         if(C() (z->v, a))
203             r+=z->c[0]->s+1, z=z->c[1];
204         else
205             z=z->c[0];
206     return r;
207 }
208 int count_less_equal(T a){
209     int r=0;
210     node*z=root;
211     while(z!=nil){
212         if(!C() (a, z->v))
213             r+=z->c[0]->s+1, z=z->c[1];
214         else
215             z=z->c[0];
216     }
217     return r;
218 }
219 int count_greater(T a){
220     int r=0;
221     node*z=root;

```

```

222     while(z!=nil)
223         if(C()(a,z->v))
224             r+=z->c[1]->s+1, z=z->c[0];
225         else
226             z=z->c[1];
227     return r;
228 }
229 int count_greater_equal(T a){
230     int r=0;
231     node*z=root;
232     while(z!=nil)
233         if(!C()(z->v,a))
234             r+=z->c[1]->s+1, z=z->c[0];
235         else
236             z=z->c[1];
237     return r;
238 }
239 node*nth_element(int a){
240     node*z=root;
241     for(;;)
242         if(z->c[0]->s>=a)
243             z=z->c[0];
244         else if((z->c[0]->s+1)<a)
245             a-=z->c[0]->s+1, z=z->c[1];
246         else
247             return z;
248 }
249 node*precursor(T a){
250     node*z=root,*r=nil;
251     while(z!=nil)
252         if(C()(z->v,a))
253             r=z, z=z->c[1];
254         else
255             z=z->c[0];
256     return r;
257 }
258 node*successor(T a){
259     node*z=root,*r=nil;
260     while(z!=nil)
261         if(C()(a,z->v))
262             r=z, z=z->c[0];

```

```

263         else
264             z=z->c[1];
265     return r;
266 }
267 node*find(T a){
268     node*z=root,*r=nil;
269     while(z!=nil)
270         if(C()(a,z->v))
271             z=z->c[0];
272         else if(C()(z->v,a))
273             z=z->c[1];
274         else
275             break;
276     return r;
277 }
278 node*lower_bound(T a){
279     node*z=root,*r=nil;
280     while(z!=nil)
281         if(C()(z->v,a))
282             r=z,z=z->c[1];
283         else if(C()(a,z->v))
284             z=z->c[0];
285         else
286             r=z,z=z->c[0];
287     return r;
288 }
289 node*upper_bound(T a){
290     return successor(a);
291 }
292 pair<node*,node*> equal_range(T a){
293     return make_pair(lower_bound(a),upper_bound(a));
294 }
295 int size(){
296     return root->s;
297 }
298 int empty(){
299     return !root->s;
300 }
301 T front(){
302     return*begin();
303 }

```



```

304     T back(){
305         return*reverse_begin();
306     }
307 };

```

2.8 Self-Adjusting Top Tree

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct SelfAdjustingTopTree{
4      const static int inf=~0u>>1;
5      static void gmin(int&a,int b){
6          a=min(a,b);
7      }
8      static void gmax(int&a,int b){
9          a=max(a,b);
10     }
11     struct treap{
12         SelfAdjustingTopTree*tr;
13         treap(struct SelfAdjustingTopTree*a,int n):
14             tr(a),ns(n){
15             }
16         struct node{
17             node(){
18             }
19             node(int a,int b,int c,int d,int e){
20                 ch[0]=ch[1]=0;
21                 val=a;
22                 fix=rand();
23                 add=0;
24                 mi=vmi=b;
25                 mx=vmx=c;
26                 sum=vsum=d;
27                 siz=vsiz=e;
28                 sam=inf;
29             }
30             node*ch[2];

```

```

31         int val,fix,vmi,vmx,vsum,vsiz,mi,mx,sum,siz,add,sam;
32     };
33     vector<node>ns;
34     void down(node*a){
35         if(a->sam!=inf){
36             a->mi=a->mx=a->vmi=a->vmx=a->sam;
37             a->vsum=a->sam*a->vsiz;
38             a->sum=a->sam*a->siz;
39             (&tr->ns[0]+(a-&ns[0]))->viradd=0;
40             (&tr->ns[0]+(a-&ns[0]))->virsam=a->sam;
41             (&tr->ns[0]+(a-&ns[0]))->add=0;
42             (&tr->ns[0]+(a-&ns[0]))->sam=a->sam;
43             for(int i=0;i<=1;++i)
44                 if(a->ch[i])
45                     a->ch[i]->add=0,a->ch[i]->sam=a->sam;
46             a->sam=inf;
47         }
48         if(a->add){
49             a->mi+=a->add;
50             a->mx+=a->add;
51             a->vmi+=a->add;
52             a->vmx+=a->add;
53             a->vsum+=a->add*a->vsiz;
54             a->sum+=a->add*a->siz;
55             (&tr->ns[0]+(a-&ns[0]))->viradd+=a->add;
56             (&tr->ns[0]+(a-&ns[0]))->add+=a->add;
57             for(int i=0;i<=1;++i)
58                 if(a->ch[i])
59                     a->ch[i]->add+=a->add;
60             a->add=0;
61         }
62     }
63     void update(node*a){
64         for(int i=0;i<=1;++i)
65             if(a->ch[i])
66                 down(a->ch[i]);
67         a->mi=a->vmi;
68         for(int i=0;i<=1;++i)
69             if(a->ch[i])
70                 gmin(a->mi,a->ch[i]->mi);
71         a->mx=a->vmx;

```

```

72         for(int i=0;i<=1;++i)
73             if(a->ch[i])
74                 gmax(a->mx,a->ch[i]->mx);
75         a->sum=a->vsum;
76         for(int i=0;i<=1;++i)
77             if(a->ch[i])
78                 a->sum+=a->ch[i]->sum;
79         a->siz=a->vsiz;
80         for(int i=0;i<=1;++i)
81             if(a->ch[i])
82                 a->siz+=a->ch[i]->siz;
83     }
84     void rotate(node*&a,int d){
85         node*b=a->ch[d];
86         a->ch[d]=b->ch[!d];
87         b->ch[!d]=a;
88         update(a);
89         update(b);
90         a=b;
91     }
92     void insert(node*&a,node*b){
93         if(!a)
94             a=b;
95         else{
96             down(a);
97             int d=b->val>a->val;
98             insert(a->ch[d],b);
99             update(a);
100            if(a->ch[d]->fix<a->fix)
101                rotate(a,d);
102        }
103    }
104     void erase(node*&a,int b){
105         down(a);
106         if(a->val==b){
107             if(!a->ch[0])
108                 a=a->ch[1];
109             else if(!a->ch[1])
110                 a=a->ch[0];
111             else{
112                 int d=a->ch[1]->fix<a->ch[0]->fix;

```

```

113         down(a->ch[d]);
114         rotate(a,d);
115         erase(a->ch[!d],b);
116         update(a);
117     }
118     }else{
119         int d=b>a->val;
120         erase(a->ch[d],b);
121         update(a);
122     }
123 }
124 };
125 int n;
126 SelfAdjustingTopTree(int _n,vector<int>*to,int*we,int rt):
127     trp(this,_n+1),ns(_n+1),n(_n){
128     build(to,we,rt);
129 }
130 struct node{
131     node(){}
132     node(int a,node*b){
133         ch[0]=ch[1]=0;
134         pr=b;
135         vir=0;
136         val=a;
137         mi=mx=a;
138         siz=1;
139         rev=virsum=add=0;
140         virmi=inf;
141         virmx=-inf;
142         sam=inf;
143         virsam=inf;
144         virsiz=0;
145         viradd=0;
146     }
147     node*ch[2],*pr;
148     int val,mi,mx,sum,virmi,virmx,virsum,virsam,viradd,virsiz,rev,sam,
149     siz,add;
150     treap::node*vir;
151 };
152 vector<node>ns;
153 treap trp;

```

```

153  int direct(node*a){
154      if(!a->pr)
155          return 3;
156      else if(a==a->pr->ch[0])
157          return 0;
158      else if(a==a->pr->ch[1])
159          return 1;
160      else
161          return 2;
162  }
163  void down(node*a){
164      if(a->rev){
165          swap(a->ch[0],a->ch[1]);
166          for(int i=0;i<=1;++i)
167              if(a->ch[i])
168                  a->ch[i]->rev^=1;
169          a->rev=0;
170      }
171      if(a->sam!=inf){
172          a->val=a->mi=a->mx=a->sam;
173          a->sum=a->sam*a->siz;
174          for(int i=0;i<=1;++i)
175              if(a->ch[i])a->ch[i]->sam=a->sam,a->ch[i]->add=0;
176          a->sam=inf;
177      }
178      if(a->add){
179          a->val+=a->add;
180          a->mi+=a->add;
181          a->mx+=a->add;
182          a->sum+=a->add*a->siz;
183          for(int i=0;i<=1;++i)
184              if(a->ch[i])a->ch[i]->add+=a->add;
185          a->add=0;
186      }
187      if(a->virsam!=inf){
188          if(a->virsiz){
189              a->virmi=a->virmx=a->virsam;
190              a->virsum=a->virsam*a->virsiz;
191              if(a->vir)
192                  a->vir->add=0,a->vir->sam=a->virsam;
193              for(int i=0;i<=1;++i)

```

```

194         if(a->ch[i])
195             a->ch[i]->viradd=0,a->ch[i]->virsam=a->virsam;
196     }
197     a->virsam=inf;
198 }
199 if(a->viradd){
200     if(a->virsiz){
201         a->virmi+=a->viradd;
202         a->virmx+=a->viradd;
203         a->virsum+=a->viradd*a->virsiz;
204         if(a->vir)a->vir->add+=a->viradd;
205         for(int i=0;i<=1;++i)
206             if(a->ch[i])
207                 a->ch[i]->viradd+=a->viradd;
208     }
209     a->viradd=0;
210 }
211 }
212 void update(node*a){
213     for(int i=0;i<=1;++i)
214         if(a->ch[i])
215             down(a->ch[i]);
216     if(a->vir)
217         trp.down(a->vir);
218     a->mi=a->val;
219     for(int i=0;i<=1;++i)
220         if(a->ch[i])
221             gmin(a->mi,a->ch[i]->mi);
222     a->virmi=inf;
223     for(int i=0;i<=1;++i)
224         if(a->ch[i])
225             gmin(a->virmi,a->ch[i]->virmi);
226     if(a->vir)
227         gmin(a->virmi,a->vir->mi);
228     a->mx=a->val;
229     for(int i=0;i<=1;++i)
230         if(a->ch[i])
231             gmax(a->mx,a->ch[i]->mx);
232     a->virmx=-inf;
233     for(int i=0;i<=1;++i)
234         if(a->ch[i])

```

```

235         gmax(a->virmx,a->ch[i]->virmx);
236     if(a->vir)
237         gmax(a->virmx,a->vir->mx);
238     a->sum=a->val;
239     for(int i=0;i<=1;++i)
240         if(a->ch[i])
241             a->sum+=a->ch[i]->sum;
242     a->virsum=0;
243     for(int i=0;i<=1;++i)
244         if(a->ch[i])
245             a->virsum+=a->ch[i]->virsum;
246     if(a->vir)
247         a->virsum+=a->vir->sum;
248     a->siz=1;
249     for(int i=0;i<=1;++i)
250         if(a->ch[i])
251             a->siz+=a->ch[i]->siz;
252     a->virsiz=0;
253     for(int i=0;i<=1;++i)
254         if(a->ch[i])
255             a->virsiz+=a->ch[i]->virsiz;
256     if(a->vir)
257         a->virsiz+=a->vir->siz;
258 }
259 void setchd(node*a,node*b,int d){
260     a->ch[d]=b;
261     if(b)
262         b->pr=a;
263     update(a);
264 }
265 void connect(node*a,node*b){
266     down(a);
267     *(&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);
268     trp.insert(b->vir,&trp.ns[0]+(a-&ns[0]));
269 }
270 void disconnect(node*a,node*b){
271     trp.erase(b->vir,a-&ns[0]);
272 }
273 void rotate(node*a){
274     node*b=a->pr,*c=a->pr->pr;

```

```

275     int d1=direct(a),d2=direct(b);
276     setchd(b,a->ch[!d1],d1);
277     setchd(a,b,!d1);
278     if(d2<2)
279         setchd(c,a,d2);
280     else if(d2==2){
281         disconnect(b,c);
282         connect(a,c);
283         a->pr=c;
284     }else
285         a->pr=0;
286 }
287 void release(node*a){
288     if(direct(a)<2)
289         release(a->pr);
290     else if(a->pr)
291         disconnect(a,a->pr),connect(a,a->pr);
292     down(a);
293 }
294 void splay(node*a){
295     release(a);
296     while(direct(a)<2){
297         node*b=a->pr;
298         if(!b->pr||direct(b)>1)
299             rotate(a);
300         else if(direct(a)==direct(b))
301             rotate(b),rotate(a);
302         else
303             rotate(a),rotate(a);
304     }
305 }
306 node*access(node*a){
307     node*b=0;
308     while(a){
309         splay(a);
310         if(a->ch[1])
311             connect(a->ch[1],a);
312         if(b)
313             disconnect(b,a);
314         setchd(a,b,1);
315         b=a;

```



```

316         a=a->pr;
317     }
318     return b;
319 }
320 void evert(node*a){
321     access(a);
322     splay(a);
323     a->rev=1;
324 }
325 int qchain(node*a,node*b,int d){
326     access(a);
327     node*c=access(b);
328     splay(c);
329     splay(a);
330     int ret=c->val;
331     if(d==1){
332         if(a!=c)
333             gmin(ret,a->mi);
334         if(c->ch[1])
335             down(c->ch[1]),gmin(ret,c->ch[1]->mi);
336     }else if(d==2){
337         if(a!=c)
338             gmax(ret,a->mx);
339         if(c->ch[1])
340             down(c->ch[1]),gmax(ret,c->ch[1]->mx);
341     }else if(d==3){
342         if(a!=c)
343             ret+=a->sum;
344         if(c->ch[1])
345             down(c->ch[1]),ret+=c->ch[1]->sum;
346     }
347     return ret;
348 }
349 void mchain(node*a,node*b,int u,int d){
350     access(a);
351     node*c=access(b);
352     splay(c);
353     splay(a);
354     if(d==1){
355         c->val+=u;
356         if(a!=c)

```

```

357         a->add=u,disconnect(a,c),connect(a,c);
358     if(c->ch[1])
359         down(c->ch[1]),c->ch[1]->add=u;
360 }else if(d==2){
361     c->val=u;
362     if(a!=c)
363         a->sam=u,disconnect(a,c),connect(a,c);
364     if(c->ch[1])
365         down(c->ch[1]),c->ch[1]->sam=u;
366 }
367 update(c);
368 }
369 int qtree(node*a,int d){
370     access(a);
371     splay(a);
372     int ret=a->val;
373     if(d==1){
374         if(a->vir)
375             trp.down(a->vir),gmin(ret,a->vir->mi);
376     }else if(d==2){
377         if(a->vir)
378             trp.down(a->vir),gmax(ret,a->vir->mx);
379     }else if(d==3){
380         if(a->vir)
381             trp.down(a->vir),ret+=a->vir->sum;
382     }
383     return ret;
384 }
385 void mtree(node*a,int u,int d){
386     access(a);
387     splay(a);
388     if(d==1){
389         a->val+=u;
390         if(a->vir)
391             trp.down(a->vir),a->vir->add=u;
392     }else if(d==2){
393         a->val=u;
394         if(a->vir)
395             trp.down(a->vir),a->vir->sam=u;
396     }
397     update(a);

```

```

398     }
399     void stparent(node*a,node*b){
400         access(b);
401         if(access(a)!=a){
402             splay(a);
403             node*c=a->ch[0];
404             down(c);
405             while(c->ch[1])
406                 c=c->ch[1],down(c);
407             splay(c);
408             c->ch[1]=0;
409             update(c);
410             access(b);
411             splay(b);
412             connect(a,b);
413             a->pr=b;
414             update(b);
415         }
416     }
417     void build(vector<int>*to,int*we,int rt){
418         vector<int>pr(n);
419         vector<int>vec;
420         queue<int>qu;
421         qu.push(rt);
422         while(!qu.empty()){
423             int u=qu.front();
424             qu.pop();
425             vec.push_back(u);
426             for(int i=0;i<to[u].size();++i){
427                 int v=to[u][i];
428                 if(v!=pr[u])
429                     qu.push(v),pr[v]=u;
430             }
431         }
432         for(int i=0;i<n;++i){
433             int u=vec[i];
434             ns[u]=node(we[u],pr[u]?&ns[0]+pr[u]:0);
435         }
436         for(int i=n-1;i>=0;--i){
437             int u=vec[i];
438             update(&ns[0]+u);

```

```

439         if(pr[u])
440             connect(&ns[0]+u,&ns[0]+pr[u]);
441     }
442 }
443 };

```

2.9 Skew Heap

Skew Heap.hpp (1220 bytes, 61 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T,class C>struct SkewHeap{
4      SkewHeap():
5          root(0),siz(0){
6      }
7      ~SkewHeap(){
8          clear(root);
9      }
10     struct node{
11         node(T _val):
12             val(_val){
13             ch[0]=ch[1]=0;
14         }
15         T val;
16         node*ch[2];
17     }*root;
18     int siz;
19     node*merge(node*x,node*y){
20         if(!x)
21             return y;
22         if(!y)
23             return x;
24         if(C()(y->val,x->val))
25             swap(x,y);
26         swap(x->ch[0],x->ch[1]=merge(x->ch[1],y));
27         return x;
28     }
29     void clear(node*x){

```

```
30         if(x){
31             clear(x->ch[0]);
32             clear(x->ch[1]);
33             delete x;
34         }
35     }
36     void clear(){
37         clear(root);
38         root=0;
39         siz=0;
40     }
41     void push(T a){
42         root=merge(root,new node(a));
43         ++siz;
44     }
45     T top(){
46         return root->val;
47     }
48     void pop(){
49         root=merge(root->ch[0],root->ch[1]);
50         --siz;
51     }
52     void merge(SkewHeap<T,C>&a){
53         root=merge(root,a.root);
54         a.root=0;
55         siz+=a.siz;
56         a.siz=0;
57     }
58     int size(){
59         return siz;
60     }
61 };
```


CHAPTER 3

Graph Algorithms

3.1 Chordality Test

Chordality Test.hpp (1343 bytes, 42 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct ChordalityTest{
4      int n,ns;
5      vector<vector<int> >to;
6      ChordalityTest(int _n):
7          n(_n),ns(n),to(n+1){
8      }
9      void add(int u,int v){
10         to[u].push_back(v),to[v].push_back(u);
11     }
12     bool run(){
13         vector<int>pos(n+1),idx(n+2),lab(n+1),tab(n+1);
14         vector<list<int>>>qu(n);
15         for(int i=1;i<=n;++i)
16             qu[0].push_back(i);
17         for(int b=0,i=1,u=0;i<=n;++i,u=0){
18             for(;u?++b,0:1;--b)
19                 for(auto j=qu[b].begin();j!=qu[b].end()&&!u;qu[b].erase(j++))
20                     if(!pos[*j]&&lab[*j]==b)
21                         u=*j;
22             pos[u]=ns,idx[ns--]=u;
23             for(int v:to[u])
24                 if(!pos[v])
25                     b=max(b,++lab[v]),qu[lab[v]].push_back(v);}
26         for(int i=1,u=idx[1],v=-1;i<=n;++i,u=idx[i],v=-1){
27             for(int w:to[u])
28                 if(pos[w]>pos[u]&&(v==-1||pos[w]<pos[v]))
29                     v=w;
30             if(v!=-1){
31                 for(int w:to[v])
32                     tab[w]=1;
33                 for(int w:to[u])
34                     if(pos[w]>pos[u]&&w!=v&&!tab[w])
35                         return false;
36                 for(int w:to[v])

```



```

37         tab[w]=0;
38     }
39 }
40 return true;
41 }
42 };

```

3.2 Dominator Tree

Dominator Tree.hpp (2916 bytes, 94 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct DominatorTree{
4      int n,r;
5      vector<vector<int> >to,rto,chd,rsemi;
6      vector<int>dfn,res,prt,rdfn,semi,misemi;
7      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  }
9      int fd(int a){
10         stack<int>stk;
11         for(int b=a;prt[b]!=prt[prt[b]];b=prt[b])
12             stk.push(b);
13         for(int b;stk.empty()?0:(b=stk.top(),stk.pop(),1);){
14             if(dfn[semi[misemi[prt[b]]]]<dfn[semi[misemi[b]]])
15                 misemi[b]=misemi[prt[b]];
16             prt[b]=prt[prt[b]];
17         }
18         return prt[a];
19     }
20     void add(int a,int b){
21         to[a].push_back(b);
22         rto[b].push_back(a);
23     }
24     void dfs(){
25         stack<pair<int,int> >stk;
26         semi[r]=r;
27         for(stk.push(make_pair(r,0));!stk.empty();){

```

```

28         int a=stk.top().first,i=stk.top().second;
29         stk.pop();
30         if(!i)
31             dfn[a]=rdfn.size(),rdfn.push_back(a);
32         if(i<to[a].size()){
33             stk.push(make_pair(a,i+1));
34             int b=to[a][i];
35             if(!semi[b])
36                 semi[b]=a, chd[a].push_back(b),
37                 stk.push(make_pair(b,0));
38         }
39     }
40     semi[r]=0;
41 }
42 void calcsemi(){
43     for(int i=1;i<=n;++i)
44         prt[i]=i, misemi[i]=i;
45     for(int i=rdfn.size()-1;i>=1;--i){
46         int a=rdfn[i];
47         for(int b:rto[a]){
48             if(!dfn[b])
49                 continue;
50             if(dfn[b]<dfn[a]){
51                 if(dfn[b]<dfn[semi[a]])
52                     semi[a]=b;
53             }else{
54                 int c=fd(b);
55                 if(dfn[semi[c]]<dfn[semi[a]])
56                     semi[a]=semi[c];
57                 if(dfn[semi[misemi[b]]]<dfn[semi[a]])
58                     semi[a]=semi[misemi[b]];
59             }
60         }
61         for(int b:chd[a])
62             prt[b]=a;
63     }
64 }
65 void calcres(){
66     for(int i=1;i<=n;++i)
67         prt[i]=i, misemi[i]=i, rsemi[semi[i]].push_back(i);
68     for(int i=rdfn.size()-1;i>=1;--i){

```

```

69         int a=rdfn[i];
70         for(int b:rsemi[a]){
71             fd(b);
72             int c=misemi[b];
73             if(dfn[semi[c]]>dfn[semi[prt[b]]])
74                 c=prt[b];
75             if(semi[c]==semi[b])
76                 res[b]=semi[b];
77             else
78                 res[b]=-c;}
79         for(int b:chd[a])
80             prt[b]=a;
81     }
82     for(int i=1;i<rdfn.size();++i){
83         int a=rdfn[i];
84         if(res[a]<0)
85             res[a]=res[-res[a]];
86     }
87 }
88 vector<int>run(){
89     dfs();
90     calcsemi();
91     calcres();
92     return res;
93 }
94 };

```

3.3 Maximal Clique Count

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<int N>struct MaximalCliqueCount{
4      int n,r;
5      vector<bitset<N> >e,rht,msk;
6      MaximalCliqueCount(int _n):
7          n(_n),e(n),rht(n),msk(n),r(0){
8      }

```

```

9  void add(int u,int v){
10     e[u-1][v-1]=e[v-1][u-1]=1;
11 }
12 void dfs(int u,bitset<N>cur,bitset<N>can){
13     if(cur==can){
14         ++r;
15         return;
16     }
17     for(int v=0;v<u;++v)
18         if(can[v]&&!cur[v]&&(e[v]&rht[u]&can)==(rht[u]&can))
19             return;
20     for(int v=u+1;v<n;++v)
21         if(can[v])
22             dfs(v,cur|msk[v],can&e[v]);
23 }
24 int run(){
25     for(int i=1;i<=n;++i){
26         rht[i-1]=bitset<N>(string(n-i,'1')+string(i,'0'));
27         msk[i-1]=bitset<N>(1)<<i-1;
28         e[i-1]|=msk[i-1];
29     }
30     for(int i=0;i<n;++i)
31         dfs(i,msk[i],e[i]);
32     return r;
33 }
34 };

```

3.4 Maximal Planarity Test

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct MaximalPlanarityTesting{
4      int n,m;
5      vector<set<int> >to2;
6      vector<vector<int> >to;
7      vector<int>dec,rmd,mrk,invc,rt;
8      vector<list<int>::iterator>dpos,pos;

```

```

9      bool order(int v1,int v2,int vn){
10         rt[0]=v1;
11         rt[1]=v2;
12         rt[n-1]=vn;
13         fill(inv.begin(),inv.end(),0);
14         inv[v1]=1;
15         inv[v2]=1;
16         inv[vn]=1;
17         list<int>deg;
18         dpos[vn]=deg.insert(deg.begin(),vn);
19         fill(dec.begin(),dec.end(),0);
20         dec[v1]=2;
21         dec[v2]=2;
22         dec[vn]=2;
23         for(int i=n-1;i>=2;--i){
24             if(deg.empty())
25                 return false;
26             int v=*deg.begin();
27             deg.erase(deg.begin());
28             inv[v]=-1;
29             rt[i]=v;
30             for(int u:to[v]){
31                 if(inv[u]==1){
32                     if(u!=v1&&u!=v2&&dec[u]==2)
33                         deg.erase(dpos[u]);
34                     --dec[u];
35                     if(u!=v1&&u!=v2&&dec[u]==2)
36                         dpos[u]=deg.insert(deg.begin(),u);
37                 }else if(inv[u]==0)
38                     inv[u]=2;
39             }
40             for(int u:to[v])
41                 if(inv[u]==2)
42                     for(int w:to[u])
43                         if(inv[w]==1){
44                             if(w!=v1&&w!=v2&&dec[w]==2)
45                                 deg.erase(dpos[w]);
46                             ++dec[w];
47                             if(w!=v1&&w!=v2&&dec[w]==2)
48                                 dpos[w]=deg.insert(deg.begin(),w);
49                             ++dec[u];

```

```

50         }else if(invc[w]==2)
51             ++dec[u];
52     for(int u:to[v]){
53         if(invc[u]==2){
54             invc[u]=1;
55             if(dec[u]==2)
56                 dpos[u]=deg.insert(deg.begin(),u);
57         }
58     }
59 }
60 return true;
61 }
62 bool embed(){
63     list<int>ext;
64     int mker=0;
65     fill(mrk.begin(),mrk.end(),0);
66     pos[rt[1]]=ext.insert(ext.begin(),rt[1]);
67     pos[rt[2]]=ext.insert(ext.begin(),rt[2]);
68     pos[rt[0]]=ext.insert(ext.begin(),rt[0]);
69     fill(rmd.begin(),rmd.end(),0);
70     rmd[rt[1]]=1;
71     rmd[rt[2]]=1;
72     rmd[rt[0]]=1;
73     for(int i=3;i<n;++i){
74         int v=rt[i];
75         rmd[v]=1;
76         vector<int>can;
77         ++mker;
78         for(int u:to[v])
79             if(rmd[u])
80                 mrk[u]=mker,can.push_back(u);
81         int start=-1,end=-1;
82         for(int u:can){
83             list<int>::iterator it=pos[u];
84             if(it==list<int>::iterator())
85                 return false;
86             if(it==ext.begin()){
87                 if(start!=-1)
88                     return false;
89                 start=u;
90             }else{

```

```

91         list<int>::iterator tmp=it;
92         if(mrk[*(--tmp)]!=mker){
93             if(start!=-1)
94                 return false;
95             start=u;
96         }
97     }
98     list<int>::iterator tmp=it;++tmp;
99     if(tmp==ext.end()){
100         if(end!=-1)
101             return false;
102         end=u;
103     }else{
104         if(mrk[*tmp]!=mker){
105             if(end!=-1)
106                 return false;
107             end=u;
108         }
109     }
110 }
111 if(start==--1 || end==--1)
112     return false;
113 for(int u:can)
114     if(u!=start&&u!=end)
115         ext.erase(pos[u]),pos[u]=list<int>::iterator();
116 pos[v]=ext.insert(pos[end],v);
117 }
118 return true;
119 }
120 bool istri(int u,int v,int w){
121     return to2[u].count(v)&&to2[v].count(w)&&to2[w].count(u);
122 }
123 MaximalPlanarityTesting(int _n):
124     n(_n),to(n),to2(n),m(0),rt(n),invc(n),dec(n),dpos(n),pos(n),rmd(n),
mrk(n){
125 }
126 void add(int u,int v){
127     to[u-1].push_back(v-1);
128     to[v-1].push_back(u-1);
129     to2[u-1].insert(v-1);
130     to2[v-1].insert(u-1);++m;

```

```

131 }
132 bool run(){
133     if(n==1&&m==0)
134         return true;
135     if(n==2&&m==1)
136         return true;
137     if(n==3&&m==3)
138         return true;
139     if(n<=3)
140         return false;
141     if(m!=3*n-6)
142         return false;
143     int v1;
144     for(v1=0;v1<n;++v1)
145         if(to[v1].size()<3)
146             return false;
147     for(v1=0;v1<n;++v1)
148         if(to[v1].size()<=5)
149             break;
150     if(v1>=n)
151         return false;
152     int v2=to[v1].back();
153     for(int i=0;i+1<to[v1].size();++i){
154         int vn=to[v1][i];
155         if(istri(v1,v2,vn)){
156             if(!order(v1,v2,vn))
157                 continue;
158             if(!embed())
159                 continue;
160             return true;
161         }
162     }
163     return false;
164 }
165 };

```

3.5 Maximum Flow

Maximum Flow.hpp (2330 bytes, 80 lines)


```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct MaximumFlow{
4      struct edge{
5          int v;
6          T c,l;
7          edge(int _v,T _c):
8              v(_v),c(_c),l(_c){
9              }
10     };
11     vector<edge>egs;
12     vector<vector<int>> >bge;
13     vector<int>hei,gap,cur,frm;
14     int n,src,snk;
15     MaximumFlow(int _n,int _source,int _sink):
16         bge(_n),hei(_n,_n),gap(_n+1),n(_n),cur(_n),frm(_n),src(_source-1),
17         snk(_sink-1){
18     }
19     void lab(){
20         hei[snk]=0;
21         queue<int>qu;
22         qu.push(snk);
23         for(int u;qu.empty()?0:(u=qu.front(),qu.pop(),1);)
24             for(int i=0;i<bge[u].size();++i){
25                 edge&e=egs[bge[u][i]],&ev=egs[bge[u][i]^1];
26                 if(ev.c>0&&hei[e.v]==n)
27                     hei[e.v]=hei[u]+1,qu.push(e.v);
28             }
29         for(int i=0;i<n;++i)
30             ++gap[hei[i]];
31     }
32     T aug(){
33         T f=0;
34         for(int u=snk;u!=src;u=egs[frm[u]^1].v)
35             if(f<=0||f>egs[frm[u]].c)
36                 f=egs[frm[u]].c;
37         for(int u=snk;u!=src;u=egs[frm[u]^1].v)
38             egs[frm[u]].c-=f,egs[frm[u]^1].c+=f;
39         return f;
40     }

```

```

40 void add(int u,int v,T c){
41     bge[u-1].push_back(egs.size());
42     egs.push_back(edge(v-1,c));
43     bge[v-1].push_back(egs.size());
44     egs.push_back(edge(u-1,0));
45 }
46 T run(){
47     lab();
48     T r=0;
49     int u=src;
50     while(hei[src]!=n){
51         if(u==snk)
52             r+=aug(),u=src;
53         int f=0;
54         for(int i=cur[u];i<bge[u].size();++i){
55             edge&e=egs[bge[u][i]];
56             if(e.c>0&&hei[u]==hei[e.v]+1){
57                 f=1;
58                 frm[e.v]=bge[u][i];
59                 u=e.v;
60                 break;
61             }
62         }
63         if(!f){
64             int mh=n-1;
65             for(int i=0;i<bge[u].size();++i){
66                 edge&e=egs[bge[u][i]];
67                 if(e.c>0&&mh>hei[e.v])
68                     mh=hei[e.v];
69             }
70             if(!--gap[hei[u]])
71                 break;
72             ++gap[hei[u]=mh+1];
73             cur[u]=0;
74             if(u!=src)
75                 u=egs[frm[u]^1].v;
76         }
77     }
78     return r;
79 }
80 };

```

3.6 Maximum Matching

Maximum Matching.hpp (3123 bytes, 112 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct MaximumMatching{
4      int n;
5      vector<int>res,nxt,mrk,vis,top,prt,rnk;
6      vector<vector<int>> >to;
7      queue<int>qu;
8      MaximumMatching(int _n):
9          n(_n),res(n+1),nxt(n+1),mrk(n+1),vis(n+1),top(n+1),to(n+1),prt(n+1)
10         ,rnk(n+1){
11     }
12     int fd(int x){
13         return x==prt[x]?x:prt[x]=fd(prt[x]);
14     }
15     void lk(int x,int y){
16         if(rnk[x=fd(x)]>rnk[y=fd(y)])
17             prt[y]=x;
18         else if(rnk[x]<rnk[y])
19             prt[x]=y;
20         else
21             prt[x]=y,++rnk[y];
22     }
23     int lca(int x,int y){
24         static int t;
25         ++t;
26         for(;;swap(x,y))
27             if(x){
28                 x=top[fd(x)];
29                 if(vis[x]==t)
30                     return x;
31                 vis[x]=t;
32             }
33         if(res[x])
34             x=nxt[res[x]];
35         else
36             x=0;
37     }
38 }
```

```

37 void uni(int x,int p){
38     for(;fd(x)!=fd(p);){
39         int y=res[x],z=nxt[y];
40         if(fd(z)!=fd(p))
41             nxt[z]=y;
42         if(mrk[y]==2)
43             mrk[y]=1,qu.push(y);
44         if(mrk[z]==2)
45             mrk[z]=1,qu.push(z);
46         int t=top[fd(z)];
47         lk(x,y);
48         lk(y,z);
49         top[fd(z)]=t;
50         x=z;
51     }
52 }
53 void aug(int s){
54     for(int i=1;i<=n;++i)
55         nxt[i]=0,mrk[i]=0,top[i]=i,prt[i]=i,rnk[i]=0;
56     mrk[s]=1;
57     qu=queue<int>();
58     for(qu.push(s);!qu.empty();){
59         int x=qu.front();
60         qu.pop();
61         for(int i=0;i<to[x].size();++i){
62             int y=to[x][i];
63             if(res[x]==y||fd(x)==fd(y)||mrk[y]==2)
64                 continue;
65             if(mrk[y]==1){
66                 int z=lca(x,y);
67                 if(fd(x)!=fd(z))
68                     nxt[x]=y;
69                 if(fd(y)!=fd(z))
70                     nxt[y]=x;
71                 uni(x,z);
72                 uni(y,z);
73             }else if(!res[y]){
74                 for(nxt[y]=x;y;){
75                     int z=nxt[y],mz=res[z];
76                     res[z]=y;
77                     res[y]=z;

```

```

78         y=mz;
79     }
80     return;
81 }else{
82     nxt[y]=x;
83     mrk[res[y]]=1;
84     qu.push(res[y]);
85     mrk[y]=2;
86 }
87 }
88 }
89 }
90 void add(int x,int y){
91     to[x].push_back(y);
92     to[y].push_back(x);
93 }
94 int run(){
95     for(int i=1;i<=n;++i)
96         if(!res[i])
97             for(int j=0;j<to[i].size();++j)
98                 if(!res[to[i][j]]){
99                     res[to[i][j]]=i;
100                     res[i]=to[i][j];
101                     break;
102                 }
103     for(int i=1;i<=n;++i)
104         if(!res[i])
105             aug(i);
106     int r=0;
107     for(int i=1;i<=n;++i)
108         if(res[i])
109             ++r;
110     return r/2;
111 }
112 };

```

3.7 Minimum Cost Maximum Flow

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class F=int,class C=int>struct MinimumCostMaximumFlow{
4      struct edge{
5          edge(int _v,F _c,C _w):
6              v(_v),c(_c),w(_w){
7              }
8          int v;
9          F c;
10         C w;
11     };
12     MinimumCostMaximumFlow(int _n,int _src,int _snk,F _all):
13         n(_n),src(_src-1),snk(_snk-1),bg(_n),vis(n),dis(n),all(_all),flow
14         (0),cost(0){}
15     void add(int u,int v,F c,C w){
16         bg[u-1].push_back(eg.size());
17         eg.push_back(edge(v-1,c,w));
18         bg[v-1].push_back(eg.size());
19         eg.push_back(edge(u-1,0,-w));
20     }
21     int spfa(){
22         vector<int>in(n,0);
23         queue<int>qu;
24         fill(vis.begin(),vis.end(),0);
25         dis[src]=0;
26         vis[src]=in[src]=1;
27         qu.push(src);
28         while(!qu.empty()){
29             int u=qu.front();
30             qu.pop();
31             in[u]=0;
32             for(int i=0;i<bg[u].size();++i){
33                 edge&e=eg[bg[u][i]];
34                 if(e.c!=0&&(!vis[e.v]||dis[u]+e.w<dis[e.v])){
35                     dis[e.v]=dis[u]+e.w;
36                     vis[e.v]=1;
37                     if(!in[e.v]){
38                         in[e.v]=1;
39                         qu.push(e.v);
40                     }
41                 }
42             }
43         }
44     }
45 };

```

```

40         }
41     }
42 }
43     return vis[snk]&&dis[snk]<0;
44 }
45 F dfs(int u,F f){
46     if(u==snk)
47         return f;
48     F g=f;
49     vis[u]=1;
50     for(int i=0;i<bg[u].size();++i){
51         edge&e=eg[bg[u][i]],&ev=eg[bg[u][i]^1];
52         if(e.c!=0&&dis[e.v]==dis[u]+e.w&&!vis[e.v]){
53             F t=dfs(e.v,min(g,e.c));
54             g-=t;
55             e.c-=t;
56             ev.c+=t;
57             cost+=t*e.w;
58             if(g==0)
59                 return f;
60         }
61     }
62     return f-g;
63 }
64 pair<F,C>run(){
65     while(all!=0&&spfa()){
66         F t;
67         do{
68             fill(vis.begin(),vis.end(),0);
69             flow+=(t=dfs(src,all));
70             all-=t;
71         }while(t!=0);
72     }
73     return make_pair(flow,cost);
74 }
75 int n,src,snk;
76 vector<vector<int>> >bg;
77 vector<edge>eg;
78 vector<int>vis;
79 vector<C>dis;
80 F all,flow;

```

```

81 |     C cost;
82 | };

```

3.8 Minimum Spanning Arborescence

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct MinimumSpanningArborescence{
4      struct eg{
5          int u,v;
6          T w;
7      };
8      int n,rt;
9      vector<eg>egs;
10     vector<int>vi,in,id;
11     vector<T>inw;
12     MinimumSpanningArborescence(int _n,int _rt):
13         n(_n),rt(_rt),vi(n+1),in(n+1),inw(n+1),id(n+1){
14     }
15     void add(int u,int v,T w){
16         eg e;
17         e.u=u;
18         e.v=v;
19         e.w=w;
20         egs.push_back(e);
21     }
22     T run(){
23         int nv=0;
24         for(T r=0;;n=nv,nv=0,rt=id[rt]){
25             for(int i=1;i<=n;++i)
26                 in[i]=-1;
27             for(int i=0;i<egs.size();++i)
28                 if(egs[i].u!=egs[i].v&&(in[egs[i].v]==-1||egs[i].w<inw[egs[
29 i].v]))
30                     in[egs[i].v]=egs[i].u,inw[egs[i].v]=egs[i].w;
31             for(int i=1;i<=n;++i)
32                 if(i!=rt&&in[i]==-1)

```



```

32         return numeric_limits<T>::max();
33     for(int i=1;i<=n;++i){
34         if(i!=rt)
35             r+=inw[i];
36         id[i]=-1,vi[i]=0;
37     }
38     for(int i=1;i<=n;++i)
39         if(i!=rt&&!vi[i]){
40             int u=i;
41             do{
42                 vi[u]=i;
43                 u=in[u];
44             }while(!vi[u]&&u!=rt);
45             if(u!=rt&&vi[u]==i){
46                 int v=u;
47                 ++nv;
48                 do{
49                     id[v]=nv;
50                     v=in[v];
51                 }while(v!=u);
52             }
53     }
54     if(nv==0)
55         return r;
56     for(int i=1;i<=n;++i)
57         if(id[i]==-1)
58             id[i]=++nv;
59     for(int i=0;i<egs.size();++i)
60         egs[i].w-=inw[egs[i].v],egs[i].u=id[egs[i].u],
61         egs[i].v=id[egs[i].v];
62     }
63 }
64 };

```

3.9 Minimum Spanning Tree

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

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

```

2 using namespace std;
3 template<class T, class C=less<T> > struct MinimumSpanningTree{
4     struct edge{
5         T w;
6         int u,v;
7         int operator<(const edge&b) const{
8             return C()(w,b.w);
9         }
10    };
11    int n;
12    vector<edge>egs;
13    vector<int>pr;
14    MinimumSpanningTree(int _n):
15        n(_n),pr(n+1){
16    }
17    void add(int u,int v,T w){
18        edge e;
19        e.u=u;
20        e.v=v;
21        e.w=w;
22        egs.push_back(e);
23    }
24    int fd(int x){
25        return x==pr[x]?x:pr[x]=fd(pr[x]);
26    }
27    void lk(int x,int y){
28        pr[fd(x)]=y;
29    }
30    pair<T,vector<edge> >run(){
31        vector<edge>ret;
32        T sum=0;
33        sort(egs.begin(),egs.end());
34        for(int i=1;i<=n;++i)
35            pr[i]=i;
36        for(int i=0;i<egs.size();++i){
37            int u=egs[i].u,v=egs[i].v;
38            T w=egs[i].w;
39            if(fd(u)!=fd(v))
40                lk(u,v),ret.push_back(egs[i]),sum+=w;
41        }
42        return make_pair(sum,ret);

```

```

43     }
44 };

```

3.10 Shortest Path

Shortest Path.hpp (1279 bytes, 44 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct ShortestPath{
4      int n,m;
5      vector<vector<int> >to;
6      vector<vector<T> >we;
7      T inf;
8      vector<pair<T,int> >sg;
9      vector<T>di;
10     ShortestPath(int _n):
11         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){
12     }
13     void set(int u,T d){
14         di[u]=d;
15     }
16     void add(int u,int v,T w){
17         to[u].push_back(v);
18         we[u].push_back(w);
19     }
20     int upd(T&a,T b,T c){
21         if(b!=inf&&c!=inf&&b+c<a){
22             a=b+c;
23             return 1;
24         }
25         return 0;
26     }
27     void mod(int u,T d){
28         for(sg[u+m-1]=make_pair(d,u),u=(u+m-1)>>1;u>=1)
29             sg[u]=min(sg[u<<1],sg[u<<1^1]);
30     }
31     vector<T>run(){

```

```

32     for(int i=1;i<=n;++i)
33         sg[i+m-1]=make_pair(di[i],i);
34     for(int i=m-1;i>=1;--i)
35         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)
37         for(int i=0;i<to[u].size();++i){
38             int v=to[u][i];
39             T w=we[u][i];
40             if(upd(di[v],di[u],w))
41                 mod(v,di[v]);}
42     return di;
43 }
44 };

```

3.11 Steiner Tree

Steiner Tree.hpp (1745 bytes, 56 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct SteinerTree{
4      int n,k,z;
5      T inf=numeric_limits<T>::max();
6      vector<vector<T> >wei,dp;
7      vector<int>im;
8      SteinerTree(int _n):
9          n(_n),k(0),wei(n+1,vector<T>(n+1,inf)),im(n+1){
10     }
11     void set(int u){
12         if(!im[u])
13             im[z=u]=++k;
14     }
15     void add(int u,int v,T w){
16         wei[u][v]=wei[v][u]=min(w,wei[u][v]);
17     }
18     int upd(T&a,T b,T c){
19         if(b!=inf&&c!=inf&&b+c<a){
20             a=b+c;

```

```

21         return 1;
22     }
23     return 0;
24 }
25 int ins(int s,int u){
26     return im[u]&&((s>>im[u]-1)&1);
27 }
28 T run(){
29     for(int l=1;l<=n;++l)
30         for(int i=1;i<=n;++i)
31             for(int j=1;j<=n;++j)
32                 upd(wei[i][j],wei[i][l],wei[l][j]);
33     dp=vector<vector<T>>>(1<<k-1,vector<T>(n+1,inf));
34     fill(begin(dp[0]),end(dp[0]),0);
35     for(int s=1;s<(1<<k-1);++s){
36         queue<int>qu;
37         vector<int>in(n+1);
38         for(int u=1;u<=n;++u){
39             if(ins(s,u))
40                 continue;
41             qu.push((u));
42             in[u]=1;
43             for(int t=(s-1)&s;t=(t-1)&s)
44                 upd(dp[s][u],dp[t][u],dp[s^t][u]);
45             for(int v=1;v<=n;++v)
46                 if(ins(s,v))
47                     upd(dp[s][u],dp[s^(1<<im[v]-1)][v],wei[u][v]);
48         }
49         for(int u;qu.empty()?0:(u=qu.front(),qu.pop(),in[u]=0,1);)
50             for(int v=1;v<=n;++v)
51                 if(!ins(s,v)&&upd(dp[s][v],dp[s][u],wei[u][v])&&!in[v])
52                     in[v]=1,qu.push(v);
53     }
54     return k?dp[(1<<k-1)-1][z]:0;
55 }
56 };

```

3.12 Virtual Tree

Virtual Tree.hpp (2375 bytes, 77 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct VirtualTree{
4      int n,r,l;
5      vector<vector<int> >to,vto,up;
6      vector<int>lst,dp,dfn,edf,imp;
7      VirtualTree(int _n,int _r):
8          n(_n),r(_r),l(ceil(log2(n)+1e-8)),to(n+1),vto(n+1),up(n+1,vector<
9          int>(l+1)),dp(n+1),dfn(n+1),edf(n+1),imp(n+1){
10     }
11     void add(int u,int v){
12         to[u].push_back(v);
13         to[v].push_back(u);
14     }
15     void vadd(int u,int v){
16         vto[u].push_back(v);
17     }
18     int lca(int u,int v){
19         if(dp[u]<dp[v])
20             swap(u,v);
21         for(int i=0;i<=l;++i)
22             if(((dp[u]-dp[v])>>i)&1)
23                 u=up[u][i];
24         if(u==v)
25             return u;
26         for(int i=l;i>=0;--i)
27             if(up[u][i]!=up[v][i])
28                 u=up[u][i],v=up[v][i];
29         return up[u][0];
30     }
31     void dfs(int u){
32         dfn[u]=++dfn[0];
33         for(int i=1;i<=l;++i)
34             up[u][i]=up[up[u][i-1]][i-1];
35         for(int i=0;i<to[u].size();++i){
36             int v=to[u][i];
37             if(v!=up[u][0])

```

```

37         up[v][0]=u,dp[v]=dp[u]+1,dfs(v);
38     }
39     edf[u]=dfn[0];
40 }
41 void build(){
42     dfs(r);
43 }
44 void run(int*a,int m){
45     for(int i=0;i<lst.size();++i)
46         imp[lst[i]]=0,vto[lst[i]].clear();
47     vector<pair<int,int> >b(m+1);
48     for(int i=1;i<=m;++i)
49         imp[a[i]]=1,b[i]=make_pair(dfn[a[i]],a[i]);
50     sort(b.begin()+1,b.end());
51     vector<int>st(1,r);
52     lst=st;
53     for(int i=1;i<=m;++i){
54         int u=b[i].second,v=st.back();
55         if(u==r)
56             continue;
57         if(dfn[u]<=edf[v])
58             st.push_back(u);
59         else{
60             int w=lca(u,v);
61             while(st.size()>=2&&dp[st[st.size()-2]]>=dp[w]){
62                 vadd(st[st.size()-2],*st.rbegin());
63                 lst.push_back(*st.rbegin()),st.pop_back();
64             }
65             if(st.size()>=2&&w!=st[st.size()-1]){
66                 vadd(w,*st.rbegin()),lst.push_back(*st.rbegin());
67                 st.pop_back(),st.push_back(w);
68             }
69             st.push_back(u);
70         }
71     }
72     while(st.size()>=2){
73         vadd(st[st.size()-2],*st.rbegin());
74         lst.push_back(*st.rbegin()),st.pop_back();
75     }
76 }
77 };

```


CHAPTER 4

Number Theory

4.1 Discrete Logarithm

DiscreteLogarithm.hpp (1819 bytes, 74 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace DiscreteLogarithm{
4      typedef long long T;
5      int ti[1<<16],va[1<<16],mp[1<<16],nx[1<<16],hd[1<<16],tm,nw;
6      void ins(int x,int v){
7          int y=x&65535;
8          if(ti[y]!=tm)
9              ti[y]=tm,hd[y]=0;
10         for(int i=hd[y];i;i=nx[i])
11             if(va[i]==x){
12                 mp[i]=v;
13                 return;
14             }
15         va[++nw]=x;
16         mp[nw]=v;
17         nx[nw]=hd[y];
18         hd[y]=nw;
19     }
20     int get(int x){
21         int y=x&65535;
22         if(ti[y]!=tm)
23             ti[y]=tm,hd[y]=0;
24         for(int i=hd[y];i;i=nx[i])
25             if(va[i]==x){
26                 return mp[i];
27             }
28         return -1;
29     }
30     T pow(T a,T b,T c){
31         T r=1;
32         for(;b;b&1?r=r*a%c:0,b>>=1,a=a*a%c);
33         return r;
34     }
35     T gcd(T a,T b){
36         return b?gcd(b,a%b):a;
37     }

```

```

38 void exg(T a,T b,T&x,T&y){
39     if(!b)
40         x=1,y=0;
41     else
42         exg(b,a%b,y,x),y-=a/b*x;
43 }
44 T inv(T a,T b){
45     T x,y;
46     exg(a,b,x,y);
47     return x+b;
48 }
49 T bgs(T a,T b,T c){
50     ++tm;
51     nw=0;
52     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)
54         ins(u,i);
55     for(T i=0,u=1,v=inv(pow(a,m,c),c);i*m<=c;++i,u=u*v%c){
56         T t=u*b%c,j;
57         if((j=get(t))!=-1)
58             return i*m+j;
59     }
60     return -1;
61 }
62 T run(T a,T b,T c){
63     T u=1,t=0;
64     a=(a%c+c)%c;
65     b=(b%c+c)%c;
66     for(int i=0;i<32;++i)
67         if(pow(a,i,c)==b)
68             return i;
69     for(T d;(d=gcd(a,c))!=1;++t,u=a/d*u%c,b/=d,c/=d)
70         if(b%d)
71             return -1;
72     return (u=bgs(a,b*inv(u,c)%c,c))<0?-1:u+t;
73 }
74 }

```

4.2 Integer Factorization

Integer Factorization.hpp (2848 bytes, 93 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace IntegerFactorization{
4      template<class T>T mul(T x,T y,T z){
5          if(typeid(T)==typeid(int))
6              return (long long)x*y%z;
7          else if(typeid(T)==typeid(long long))
8              return (x*y-(T)(((long double)x*y+0.5)/z)*z+z)%z;
9          else
10             return x*y%z;
11     }
12     template<class T>T pow(T a,T b,T c){
13         T r=1;
14         for(;b;b&1?r=mul(r,a,c):0,b>>=1,a=mul(a,a,c));
15         return r;
16     }
17     template<class T>int chk(T a,int c=10){
18         if(a==2)
19             return 1;
20         if(a%2==0 || a<2)
21             return 0;
22         static int pi[]={2,7,61},p1
23         []={2,325,9375,28178,450775,9780504,1795265022};
24         if(typeid(T)==typeid(int))
25             c=3;
26         else if(typeid(T)==typeid(long long))
27             c=7;
28         T u=a-1,t=0,p=1;
29         for(;u%2==0;u/=2,++t);
30         for(int i=0;i<c;++i){
31             if(typeid(T)==typeid(int))
32                 p=pi[i]%a;
33             else if(typeid(T)==typeid(long long))
34                 p=p1[i]%a;
35             else
36                 p=(p*29+7)%a;
37             if(!p || p==1 || p==a-1)

```

```

37         continue;
38         T x=pow(p,u,a);
39         if(x==1)
40             continue;
41         for(int j=0;x!=a-1&&j<t;++j){
42             x=mul(x,x,a);
43             if(x==1)
44                 return 0;
45         }
46         if(x==a-1)
47             continue;
48         return 0;
49     }
50     return 1;
51 }
52 template<class T>T gcd(T a,T b){
53     if(a<0)
54         a=-a;
55     if(b<0)
56         b=-b;
57     return b?gcd(b,a%b):a;
58 }
59 template<class T>T rho(T a,T c){
60     T x=double(rand())/RAND_MAX*(a-1),y=x;
61     for(int i=1,k=2;;){
62         x=(mul(x,x,a)+c)%a;
63         T d=gcd(y-x,a);
64         if(d!=1&&d!=a)
65             return d;
66         if(y==x)
67             return a;
68         if(++i==k)
69             y=x,k=2*k;
70     }
71 }
72 template<class T>vector<pair<T,int> >run(T a){
73     if(a==1)
74         return vector<pair<T,int> >();
75     if(chk(a))
76         return vector<pair<T,int> >(1,make_pair(a,1));
77     T b=a;

```

```

78     while((b=rho(b,T(double(rand())/RAND_MAX*(a-1))))==a);
79     vector<pair<T,int> >u=run(b),v=run(a/b),r;
80     for(int pu=0,pv=0;pu<u.size()||pv<v.size();){
81         if(pu==u.size())
82             r.push_back(v[pv++]);
83         else if(pv==v.size())
84             r.push_back(u[pu++]);
85         else if(u[pu].first==v[pv].first)
86             r.push_back(make_pair(u[pu].first,(u[pu].second+v[pv].second
87 ))),++pu,++pv;
88         else if(u[pu].first>v[pv].first)
89             r.push_back(v[pv++]);
90         else
91             r.push_back(u[pu++]);}
92     return r;
93 }

```

4.3 Modular Integer

Modular Integer.hpp (2924 bytes, 96 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T,T P>struct ModularInteger{
4      ModularInteger(T t=0):
5          v(t){
6              if(v<0||v>=P)
7                  v=(v%P+P)%P;
8          }
9      ModularInteger<T,P>&operator=(T a){
10         v=a;
11         if(v<0||v>=P)
12             v%=P;
13         return*this;
14     }
15     ModularInteger<T,P>operator-(){
16         return v?P-v:0;
17     }

```

```

18     ModularInteger<T,P>&operator+=(ModularInteger<T,P>a){
19         return*this=*this+a;
20     }
21     ModularInteger<T,P>&operator--=(ModularInteger<T,P>a){
22         return*this=*this-a;
23     }
24     ModularInteger<T,P>&operator*=(ModularInteger<T,P>a){
25         return*this=*this*a;
26     }
27     ModularInteger<T,P>&operator/=(ModularInteger<T,P>a){
28         return*this=*this/a;
29     }
30     T v;
31 };
32 template<class T,T P>ModularInteger<T,P>pow(ModularInteger<T,P>a,long long
    b){
33     ModularInteger<T,P>r(1);
34     for(;b>=1,a=a*a)
35         if(b&1)
36             r=r*a;
37     return r;
38 }
39 template<class T,T P>ModularInteger<T,P>inv(ModularInteger<T,P>a){
40     return pow(a,P-2);
41 }
42 template<class T,T P>vector<ModularInteger<T,P> >sqrt(ModularInteger<T,P>a)
    {
43     vector<ModularInteger<T,P> >r;
44     if(!a.v)
45         r.push_back(ModularInteger<T,P>(0));
46     else if(pow(a,P-1>>1).v==1){
47         int s=P-1,t=0;
48         ModularInteger<T,P>b=1;
49         for(;pow(b,P-1>>1).v!=P-1;b=rand()*1.0/RAND_MAX*(P-1));
50         for(;s%2==0;++t,s/=2);
51         ModularInteger<T,P>x=pow(a,(s+1)/2),e=pow(a,s);
52         for(int i=1;i<t;++i,e=x*x/a)
53             if(pow(e,1<<t-i-1).v!=1)
54                 x=x*pow(b,(1<<i-1)*s);
55         r.push_back(x);
56         r.push_back(-x);

```

```

57     }
58     return r;
59 }
60 template<class T,T P>ModularInteger<T,P>operator+(ModularInteger<T,P>a,
    ModularInteger<T,P>b){
61     ModularInteger<T,P>c(a.v+b.v);
62     if(c.v>=P)
63         c.v-=P;
64     return c;
65 }
66 template<class T,T P>ModularInteger<T,P>operator-(ModularInteger<T,P>a,
    ModularInteger<T,P>b){
67     ModularInteger<T,P>c(a.v-b.v);
68     if(c.v<0)
69         c.v+=P;
70     return c;
71 }
72 template<class T,T P>ModularInteger<T,P>operator*(ModularInteger<T,P>a,
    ModularInteger<T,P>b){
73     if(typeid(T)!=typeid(int))
74         return ModularInteger<T,P>((a.v*b.v-(long long )(((long double)a.v*
    b.v+0.5)/P)*P+P)%P);
75     else
76         return ModularInteger<T,P>((long long)a.v*b.v%P);
77 }
78 template<class T,T P>ModularInteger<T,P>operator/(ModularInteger<T,P>a,
    ModularInteger<T,P>b){
79     return a*inv(b);
80 }
81 template<class T,T P>bool operator==(ModularInteger<T,P>a,ModularInteger<T,
    P>b){
82     return a.v==b.v;
83 }
84 template<class T,T P>bool operator!=(ModularInteger<T,P>a,ModularInteger<T,
    P>b){
85     return a.v!=b.v;
86 }
87 template<class T,T P>istream&operator>>(istream&s,ModularInteger<T,P>&a){
88     s>>a.v;
89     return s;
90 }

```



```

91 template<class T,T P>ostream&operator<<(ostream&s,ModularInteger<T,P>a){
92     s<<a.v;
93     if(a.v<0||a.v>=P)
94         a.v%=P;
95     return s;
96 }

```

4.4 Möbius Function

Möbius Function.hpp (534 bytes, 21 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace MobiusFunction{
4      vector<int>run(int n){
5          vector<int>p,ntp(n+1),u(n+1);
6          ntp[1]=1;
7          u[1]=1;
8          for(int i=2;i<=n;++i){
9              if(!ntp[i])
10                 p.push_back(i),u[i]=-1;
11                 for(int j=0;j<p.size()&&p[j]*i<=n;++j){
12                     ntp[p[j]*i]=1;
13                     if(i%p[j]==0)
14                         break;
15                     else
16                         u[p[j]*i]=-u[i];
17                 }
18             }
19             return u;
20         }
21     }

```

4.5 Number

Number.hpp (7837 bytes, 345 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>T add(T a,T b,T p){
4      return a+b<p?a+b:a+b-p;
5  }
6  template<class T>T sub(T a,T b,T p){
7      return a-b<0?a-b+p:a-b;
8  }
9  template<class T>T mul(T a,T b,T p){
10     if(typeid(T)==typeid(int))
11         return (long long)a*b%p;
12     else
13         return (a*b-(T)((((long double)a*b+0.5)/p)*p+p)%p;
14 }
15 template<class T>T pow(T a,T b,T p){
16     T r=1;
17     for(;b;b&1?r=mul(r,a,p):0,b>>=1,a=mul(a,a,p));
18     return r;
19 }
20 template<class T>T inv(T a,T p){
21     return pow(a,p-2,p);
22 }
23 template<class T>T div(T a,T b,T p){
24     return mul(a,inv(b,p),p);
25 }
26 template<class T>T gcd(T a,T b){
27     if(a<0)
28         return gcd(-a,b);
29     if(b<0)
30         return gcd(a,-b);
31     return b?gcd(b,a%b):a;
32 }
33 template<class T>pair<T,T>exgcd(T a,T b){
34     if(!b)
35         return make_pair(T(1),T(0));
36     pair<T,T>t=exgcd(b,a%b);
37     swap(t.first,t.second);
38     t.second-=a/b*t.first;
39     return t;
40 }
41 template<class T>vector<T>divisor(T a){

```

```

42     vector<T>t;
43     for(T d=1;d*d<=a;++d)
44         if(a%d==0){
45             t.push_back(d);
46             if(d*d!=a)
47                 t.push_back(a/d);
48         }
49     return t;
50 }
51 template<class T>vector<pair<T,T> >factor(T a){
52     vector<pair<T,T> >t;
53     T b=a;
54     for(T d=2;d*d<=a;++d)
55         if(b%d==0)
56             for(t.push_back(make_pair(d,T(0)));b%d==0;b/=d,++t.back().second
57 );
58     if(b!=1)
59         t.push_back(make_pair(b,T(1)));
60     return t;
61 }
62 template<class T>bool is_prime_number(T a){
63     if(a<2)
64         return false;
65     for(T d=2;d*d<=a;++d)
66         if(a%d==0)
67             return false;
68     return true;
69 }
70 template<class T>bool is_palindromic_number(T a){
71     string b;
72     stringstream s;
73     s<<a;
74     s>>b;
75     for(int i=0;i<b.size();++i)
76         if(b[i]!=b[b.size()-i-1])
77             return false;
78     return true;
79 }
80 template<class T>T pow(T a,T b){
81     T s=1;
82     for(;b/=2,a*=a)

```

```

82         if(b%2)
83             s*=a;
84         return s;
85     }
86     template<class T>T power_sum(T n,T k){
87         T r=0;
88         for(T i=1;i<=n;++i)
89             r+=pow(i,k);
90         return r;
91     }
92     template<class T>T sqr(T a){
93         return a*a;
94     }
95     int nth_prime(int n){
96         int r=1;
97         for(int i=1;i<=n;++i)
98             for(++r;!is_prime_number(r);++r);
99         return r;
100     }
101     vector<vector<int> >pythagorean_triple(int n){
102         vector<vector<int> >t;
103         for(int i=1;i*i<=n;++i)
104             for(int j=1;j<i&& i*i+j*j<=n;++j){
105                 vector<int>u;
106                 u.push_back(i*i-j*j);
107                 u.push_back(2*i*j);
108                 u.push_back(i*i+j*j);
109                 t.push_back(u);
110             }
111         return t;
112     }
113     vector<vector<int> >primitive_pythagorean_triple(int n){
114         vector<vector<int> >t;
115         for(int i=1;i*i<=n;++i)
116             for(int j=1;j<i&& i*i+j*j<=n;++j)
117                 if((i-j)%2&&gcd(i,j)==1){
118                     vector<int>u;
119                     u.push_back(i*i-j*j);
120                     u.push_back(2*i*j);
121                     u.push_back(i*i+j*j);
122                     t.push_back(u);

```

```
123     }
124     return t;
125 }
126 template<class T>nth_triangular_number(T n){
127     if(n%2==0)
128         return n/2*(n+1);
129     else
130         return (n+1)/2*n;
131 }
132 template<class T>nth_pentagonal_number(T n){
133     if(n%2==0)
134         return n/2*(3*n-1);
135     else
136         return (3*n-1)/2*n;
137 }
138 template<class T>nth_hexagonal_number(T n){
139     return n*(2*n-1);
140 }
141 template<class T>vector<T>collatz_sequence(T a){
142     vector<T>t;
143     do{
144         t.push_back(a);
145         if(a==1)
146             return t;
147         if(a%2==0)
148             a/=2;
149         else
150             a=3*a+1;
151     }while(1);
152 }
153 template<class T>T factorial(T n){
154     T r=1;
155     for(T i=1;i<=n;++i)
156         r*=i;
157     return r;
158 }
159 template<class T>T product(T a,T b){
160     T r=1;
161     for(T i=a;i<=b;++i)
162         r*=i;
163     return r;
```

```

164 }
165 template<class T>T C(T n,T k){
166     return factorial(n)/factorial(k)/factorial(n-k);
167 }
168 template<class T>T P(T n,T k){
169     return factorial(n)/factorial(n-k);
170 }
171 vector<int>prime(int n){
172     vector<int>p,ntp(n+1);
173     ntp[1]=1;
174     for(int i=2;i<=n;++i){
175         if(!ntp[i])
176             p.push_back(i);
177         for(int j=0;j<p.size()&&p[j]*i<=n;++j){
178             ntp[p[j]*i]=1;
179             if(i%p[j]==0)
180                 break;
181         }
182     }
183     return p;
184 }
185 template<class T>T digit_sum(T a){
186     T r=0;
187     for(;a;r+=a%10,a/=10);
188     return r;
189 }
190 template<class T>T digit_power_sum(T a,T b){
191     T r=0;
192     for(;a;r+=pow(a%10,b),a/=10);
193     return r;
194 }
195 template<class T>T divisor_sum(T a){
196     vector<T>d=divisor(a);
197     T s=0;
198     for(int i=0;i<d.size();++i)
199         s+=d[i];
200     return s;
201 }
202 template<class T>bool is_perfect(T a){
203     return a*2==divisor_sum(a);
204 }

```

```
205 template<class T>bool is_deficient(T a){
206     return a*2>divisor_sum(a);
207 }
208 template<class T>bool is_abundant(T a){
209     return a*2<divisor_sum(a);
210 }
211 template<class T>set<int>digit_set(T a){
212     set<int>r;
213     for(;a;r.insert(a%10),a/=10);
214     return r;
215 }
216
217 template<class T>multiset<int>digit_multiset(T a){
218     multiset<int>r;
219     for(;a;r.insert(a%10),a/=10);
220     return r;
221 }
222 template<class T>int digit_count(T a){
223     int r=0;
224     if(!a)
225         ++r;
226     for(;a;++r,a/=10);
227     return r;
228 }
229 template<class T>T digit_factorial_sum(T a){
230     T r=0;
231     for(;a;r+=factorial(a%10),a/=10);
232     return r;
233 }
234 template<class T>bool has_distinct_digit(T a){
235     return digit_count(a)==digit_set(a).size();
236 }
237 template<class T>bool has_zero(T a){
238     if(!a)
239         return true;
240     while(a){
241         if(a%10==0)
242             return true;
243         a/=10;
244     }
245     return false;
```

```
246 }
247 template<class T>T right_circular_shift(T a){
248     stringstream ss;
249     ss<<a;
250     string t;
251     ss>>t;
252     t=t.substr(t.size()-1,1)+t.substr(0,t.size()-1);
253     ss<<t;
254     ss>>a;
255     return a;
256 }
257 template<class T>bool is_circular_prime(T a){
258     for(int i=digit_count(a);i-->0,a=right_circular_shift(a))
259         if(!is_prime_number(a))
260             return false;
261     return true;
262 }
263 template<class T>string to_binary(T a){
264     string r;
265     while(a){
266         r.push_back(a%2+'0');
267         a/=2;
268     }
269     reverse(r.begin(),r.end());
270     return r;
271 }
272 template<class T>T digit_reverse(T a){
273     stringstream ss;
274     ss<<a;
275     string t;
276     ss>>t;
277     reverse(t.begin(),t.end());
278     stringstream ss2;
279     ss2<<t;
280     ss2>>a;
281     return a;
282 }
283 template<class T>bool is_truncatable_prime(T a){
284     T b=digit_reverse(a);
285     while(a){
286         if(!is_prime_number(a))
```



```
287         return false;
288     a/=10;
289 }
290 a=b;
291 while(a){
292     if(!is_prime_number(digit_reverse(a)))
293         return false;
294     a/=10;
295 }
296 return true;
297 }
298 template<class T>bool is_triangle_number(T a){
299     if(a<1)
300         return false;
301     T l=1,r=1;
302     while(nth_triangular_number(r)<=a)
303         r*=2;
304     while(l+1<r){
305         T m=l+(r-1)/2;
306         if(nth_triangular_number(m)<=a)
307             l=m;
308         else
309             r=m;
310     }
311     return a==nth_triangular_number(l);
312 }
313 template<class T>bool is_pentagonal_number(T a){
314     if(a<1)
315         return false;
316     T l=1,r=1;
317     while(nth_pentagonal_number(r)<=a)
318         r*=2;
319     while(l+1<r){
320         T m=l+(r-1)/2;
321         if(nth_pentagonal_number(m)<=a)
322             l=m;
323         else
324             r=m;
325     }
326     return a==nth_pentagonal_number(l);
327 }
```

```

328 template<class T>bool is_hexagonal_number(T a){
329     if(a<1)
330         return false;
331     T l=1,r=1;
332     while(nth_hexagonal_number(r)<=a)
333         r*=2;
334     while(l+1<r){
335         T m=l+(r-1)/2;
336         if(nth_hexagonal_number(m)<=a)
337             l=m;
338         else
339             r=m;
340     }
341     return a==nth_hexagonal_number(l);
342 }
343 template<class T>bool is_square_number(T a){
344     return sqr(T(round(sqrt(a))))==a;
345 }

```

4.6 Primality Test

Primality Test.hpp (1509 bytes, 52 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace PrimalityTest{
4      template<class T>T mul(T x,T y,T z){
5          if(typeid(T)==typeid(int))
6              return (long long)x*y%z;
7          else if(typeid(T)==typeid(long long))
8              return (x*y-(T)(((long double)x*y+0.5)/z)*z+z)%z;
9          else
10             return x*y%z;
11     }
12     template<class T>T pow(T a,T b,T c){
13         T r=1;
14         for(;b;b&1?r=mul(r,a,c):0,b>>=1,a=mul(a,a,c));
15         return r;
16     }

```

```

17  template<class T>int run(T a,int c=10){
18      if(a==2)
19          return 1;
20      if(a%2==0 || a<2)
21          return 0;
22      static int pi[]={2,7,61},p1
[]={2,325,9375,28178,450775,9780504,1795265022};
23      if(typeid(T)==typeid(int))
24          c=3;
25      else if(typeid(T)==typeid(long long))
26          c=7;
27      T u=a-1,t=0,p=1;
28      for(;u%2==0;u/=2,++t);
29      for(int i=0;i<c;++i){
30          if(typeid(T)==typeid(int))
31              p=pi[i]%a;
32          else if(typeid(T)==typeid(long long))
33              p=p1[i]%a;
34          else
35              p=(p*29+7)%a;
36          if(!p || p==1 || p==a-1)
37              continue;
38          T x=pow(p,u,a);
39          if(x==1)
40              continue;
41          for(int j=0;x!=a-1&&j<t;++j){
42              x=mul(x,x,a);
43              if(x==1)
44                  return 0;
45          }
46          if(x==a-1)
47              continue;
48          return 0;
49      }
50      return 1;
51  }
52  }

```

4.7 Prime Number

Prime Number.hpp (473 bytes, 18 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace PrimeNumber{
4      pair<vector<int>,vector<int> >run(int n){
5          vector<int>p,ntp(n+1);
6          ntp[1]=1;
7          for(int i=2;i<=n;++i){
8              if(!ntp[i])
9                  p.push_back(i);
10             for(int j=0;j<p.size()&&p[j]*i<=n;++j){
11                 ntp[p[j]*i]=1;
12                 if(i%p[j]==0)
13                     break;
14             }
15         }
16         return make_pair(p,ntp);
17     }
18 }
```

4.8 Primitive Root

Primitive Root.hpp (3256 bytes, 106 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace PrimitiveRoot{
4      template<class T>T mul(T x,T y,T z){
5          if(typeid(T)==typeid(int))
6              return (long long)x*y%z;
7          else
8              return (x*y-(T)((((long double)x*y+0.5)/z)*z+z)%z;
9      }
10     template<class T>T pow(T a,T b,T c){
11         T r=1;
12         for(;b;b&1?r=mul(r,a,c):0,b>>=1,a=mul(a,a,c));
```

```

13     return r;
14 }
15 template<class T>bool chk(T a,int c=10){
16     if(a==1)
17         return false;
18     T u=a-1,t=0;
19     for(;u%2==0;u/=2,++t);
20     for(int i=0;i<c;++i){
21         T x=pow(T(rand()*1.0/RAND_MAX*(a-2)+1),u,a),y;
22         for(int j=0;j<t;++j){
23             y=x;
24             x=mul(x,x,a);
25             if(x==1&&y!=1&&y!=a-1)
26                 return false;
27         }
28         if(x!=1)
29             return false;
30     }
31     return true;
32 }
33 template<class T>T gcd(T a,T b){
34     if(a<0)
35         a=-a;
36     if(b<0)
37         b=-b;
38     return b?gcd(b,a%b):a;
39 }
40 template<class T>T rho(T a,T c){
41     T x=double(rand())/RAND_MAX*(a-1),y=x;
42     for(int i=1,k=2;;){
43         x=(mul(x,x,a)+c)%a;
44         T d=gcd(y-x,a);
45         if(d!=1&&d!=a)
46             return d;
47         if(y==x)
48             return a;
49         if(++i==k)
50             y=x,k=2*k;
51     }
52 }
53 template<class T>vector<pair<T,int> >fac(T a){

```

```

54     if(a==1)
55         return vector<pair<T,int> >();
56     if(chk(a))
57         return vector<pair<T,int> >(1,make_pair(a,1));
58     T b=a;
59     while((b=rho(b,T(double(rand())/RAND_MAX*(a-1))))==a);
60     vector<pair<T,int> >u=fac(b),v=fac(a/b),r;
61     for(int pu=0,pv=0;pu<u.size()||pv<v.size();){
62         if(pu==u.size())
63             r.push_back(v[pv++]);
64         else if(pv==v.size())
65             r.push_back(u[pu++]);
66         else if(u[pu].first==v[pv].first)
67             r.push_back(make_pair(u[pu].first,(u[pu].second+v[pv].second
68 ))),++pu,++pv;
69         else if(u[pu].first>v[pv].first)
70             r.push_back(v[pv++]);
71         else
72             r.push_back(u[pu++]);}
73     return r;
74 }
75 template<class T>void dfs(vector<pair<T,int> >&f,int i,T now,vector<T>&
76 r){
77     if(i==f.size()){
78         r.push_back(now);
79         return;
80     }
81     for(int j=0;j<=f[i].second;++j,now*=f[i].first)
82         dfs(f,i+1,now,r);
83 }
84 template<class T>T run(T a){
85     vector<pair<T,int> >fa=fac(a),fpa;
86     if(fa.size()==0||fa.size()>2)
87         return -1;
88     if(fa.size()==1&&fa[0].first==2&&fa[0].second>2)
89         return -1;
90     if(fa.size()==2&&fa[0]!=make_pair(T(2),1))
91         return -1;
92     T pa=a;
93     for(int i=0;i<fa.size();++i)
94         pa=pa/fa[i].first*(fa[i].first-1);

```

```
93     fpa=fac(pa);
94     vector<T>fs;
95     dfs(fpa,0,1,fs);
96     for(T g=1,f=0;;++g,f=0){
97         for(int i=0;i<fs.size();++i)
98             if(fs[i]!=pa&&pow(g,fs[i],a)==1){
99                 f=1;
100                 break;
101             }
102         if(!f)
103             return g;
104     }
105 }
106 }
```


CHAPTER 5

Numerical Algorithms

5.1 Convolution (Fast Fourier Transform)

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace Convolution{
4      typedef complex<double>T;
5      void fft(vector<T>&a,int n,double s,vector<int>&rev){
6          T im(0,1);
7          double pi=acos(-1);
8          for(int i=0;i<n;++i)
9              if(i<rev[i])
10                 swap(a[i],a[rev[i]]);
11          for(int i=1,m=2;(1<<i)<=n;++i,m<<=1){
12              T wm=exp(s*im*2.0*pi/double(m)),w;
13              for(int j=(w=1,0);j<n;j+=m,w=1)
14                  for(int k=0;k<(m>>1);++k,w*=wm){
15                      T u=a[j+k],v=w*a[j+k+(m>>1)];
16                      a[j+k]=u+v;
17                      a[j+k+(m>>1)]=u-v;
18                  }
19          }
20      }
21      vector<double>run(const vector<double>&a,const vector<double>&b){
22          int l=ceil(log2(a.size()+b.size()-1)),n=1<<l;
23          vector<int>rv;
24          for(int i=(rv.resize(n),0);i<n;++i)
25              rv[i]=(rv[i>>1]>>1)|((i&1)<<(l-1));
26          vector<T>ta(n),tb(n);
27          copy(a.begin(),a.end(),ta.begin());
28          copy(b.begin(),b.end(),tb.begin());
29          fft(ta,n,1,rv);
30          fft(tb,n,1,rv);
31          for(int i=0;i<n;++i)
32              ta[i]*=tb[i];
33          fft(ta,n,-1,rv);
34          vector<double>c(a.size()+b.size()-1);
35          for(int i=0;i<c.size();++i)
36              c[i]=real(ta[i])/n;
37          return c;

```

```

38     }
39 }

```

5.2 Convolution (Karatsuba Algorithm)

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace Convolution{
4      template<class T>void kar(T*a,T*b,int n,int l,T**r){
5          T*r1=r[l],*r11=r[l-1];
6          for(int i=0;i<2*n;++i)
7              *(r1+i)=0;
8          if(n<=30){
9              for(int i=0;i<n;++i)
10                 for(int j=0;j<n;++j)
11                     *(r1+i+j)+=(a+i)**(b+j);
12             return;
13         }
14         kar(a,b,n>>1,l-1,r);
15         for(int i=0;i<n;++i)
16             *(r1+i)+=(r11+i),*(r1+i+(n>>1))+=(r11+i);
17         kar(a+(n>>1),b+(n>>1),n>>1,l-1,r);
18         for(int i=0;i<n;++i)
19             *(r1+i+n)+=(r11+i),*(r1+i+(n>>1))+=(r11+i);
20         for(int i=0;i<(n>>1);++i){
21             *(r1+(n<<1)+i)=(a+(n>>1)+i)-(a+i);
22             *(r1+i+(n>>1)*5)=(b+i)-(b+(n>>1)+i);
23         }
24         kar(r1+(n<<1),r1+(n>>1)*5,n>>1,l-1,r);
25         for(int i=0;i<n;++i)
26             *(r1+i+(n>>1))+=(r11+i);}
27     template<class T>vector<T>run(vector<T>a,vector<T>b){
28         int l=ceil(log2(max(a.size(),b.size()))+1e-8);
29         vector<T>rt(a.size()+b.size()-1);
30         a.resize(1<<l);
31         b.resize(1<<l);
32         T**r=new T*[l+1];

```

```

33     for(int i=0;i<=l;++i)
34         r[i]=new T[(1<<i)*3];
35     kar(&a[0],&b[0],1<<l,1,r);
36     for(int i=0;i<rt.size();++i)
37         rt[i]=*(r[l]+i);
38     for(int i=0;i<=l;++i)
39         delete r[i];
40     delete r;
41     return rt;
42 }
43 }

```

5.3 Convolution (Number Theoretic Transform)

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  namespace Convolution{
4      typedef long long T;
5      T pow(T a,T b,T c){
6          T r=1;
7          for(;b;b&=1)r=r*a%c;0,b>=1,a=a*a%c);
8          return r;
9      }
10 void ntt(vector<T>&a,int n,int s,vector<int>&rev,T p,T g){
11     g=s==1?g:pow(g,p-2,p);
12     vector<T>wm;
13     for(int i=0;1<<i<=n;++i)
14         wm.push_back(pow(g,(p-1)>>i,p));
15     for(int i=0;i<n;++i)
16         if(i<rev[i])
17             swap(a[i],a[rev[i]]);
18     for(int i=1,m=2;1<<i<=n;++i,m<=1){
19         vector<T>wmk(1,1);
20         for(int k=1;k<(m>>1);++k)
21             wmk.push_back(wmk.back()*wm[i]%p);
22         for(int j=0;j<n;j+=m)
23             for(int k=0;k<(m>>1);++k){

```

```

24         T u=a[j+k],v=wmk[k]*a[j+k+(m>>1)]%p;
25         a[j+k]=u+v;
26         a[j+k+(m>>1)]=u-v+p;
27         if(a[j+k]>=p)
28             a[j+k]-=p;
29         if(a[j+k+(m>>1)]>=p)
30             a[j+k+(m>>1)]=-p;
31     }
32 }
33 }
34 vector<T>run(vector<T>a,vector<T>b,T p=15*(1<<27)+1,T g=31){
35     int tn,l=ceil(log2(tn=a.size()+b.size()-1)),n=1<<l;
36     vector<int>rv;
37     for(int i=(rv.resize(n),0);i<n;++i)
38         rv[i]=(rv[i>>1]>>1)|((i&1)<<(l-1));
39     a.resize(n);
40     b.resize(n);
41     ntt(a,n,1,rv,p,g);
42     ntt(b,n,1,rv,p,g);
43     for(int i=0;i<n;++i)
44         a[i]=a[i]*b[i]%p;
45     ntt(a,n,-1,rv,p,g);
46     n=pow(n,p-2,p);
47     for(T&v:a)
48         v=v*n%p;
49     return a.resize(tn),a;
50 }
51 }

```

5.4 Fraction

Fraction.hpp (2217 bytes, 100 lines)

```

1 #include<bits/stdc++.h>
2 using namespace std;
3 template<class T>struct Fraction{
4     T p,q;
5     int s;
6     T gcd(T a,T b){

```

```

7         return b?gcd(b,a%b):a;
8     }
9     void reduce(){
10         T d=gcd(p,q);
11         p/=d;
12         q/=d;
13         if(p==0)
14             s=0;
15     }
16     Fraction(int _s=0,T _p=0,T _q=1):
17         s(_s),p(_p),q(_q){
18         reduce();
19     }
20     Fraction(string a){
21         if(a[0]=='-'){
22             s=-1;
23             a=a.substr(1,a.size()-1);
24         }else if(a[0]=='+'){
25             s=1;
26             a=a.substr(1,a.size()-1);
27         }else
28             s=1;
29         stringstream ss;
30         char tc;
31         ss<<a;
32         ss>>p>>tc>>q;
33         reduce();
34     }
35     Fraction(const char*a){
36         *this=Fraction(string(a));
37     }
38     Fraction<T>&operator=(string a){
39         return*this=Fraction<T>(a);
40     }
41     Fraction<T>&operator=(const char*a){
42         return*this=Fraction<T>(a);
43     }
44 };
45 template<class T>ostream&operator<<(ostream&s,const Fraction<T>&a){
46     if(a.s== -1)
47         s<<'-';

```

```

48     return s<<a.p<<'/'<<a.q;
49 }
50 template<class T>istream&operator>>(istream&s,Fraction<T>&a){
51     string t;
52     s>>t;
53     a=t;
54     return s;
55 }
56 template<class T>vector<string>real(const Fraction<T>&a){
57     vector<string>r;
58     stringstream ss;
59     string st;
60     if(a.s<0)
61         r.push_back("-");
62     else
63         r.push_back("+");
64     T p=a.p,q=a.q;
65     ss<<p/q;
66     ss>>st;
67     r.push_back(st);
68     p%=q;
69     st.clear();
70     map<T,int>mp;
71     while(true){
72         if(p==0){
73             r.push_back(st);
74             r.push_back("");
75             return r;
76         }
77         if(mp.count(p)){
78             r.push_back(st.substr(0,mp[p]));
79             r.push_back(st.substr(mp[p],st.size()-mp[p]));
80             return r;
81         }
82         p*=10;
83         mp[p/10]=st.size();
84         st.push_back('0'+p/q);
85         p%=q;
86     }
87     return r;
88 }

```

```

89 template<class T>string decimal(const Fraction<T>&a){
90     string r;
91     vector<string>t=real(a);
92     if(t[0]=="-")
93         r.push_back('-');
94     r+=t[1];
95     if(t[2].size()||t[3].size())
96         r+="."+t[2];
97     if(t[3].size())
98         r+="("+t[3]+")";
99     return r;
100 }

```

5.5 Integer

Integer.hpp (6378 bytes, 269 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct Integer operator+(Integer a,Integer b);
4  Integer operator+(Integer a,int b);
5  Integer operator-(Integer a,Integer b);
6  Integer operator*(Integer a,Integer b);
7  Integer operator*(Integer a,Integer b);
8  Integer operator/(Integer a,Integer b);
9  Integer operator%(Integer a,Integer b);
10 Integer operator%(Integer a,int b);
11 Integer operator%(Integer a,long long b);
12 bool operator!=(Integer a,int b);
13 bool operator<=(Integer a,int b);
14 struct Integer{
15     operator bool(){
16         return *this!=0;
17     }
18     Integer(long long a=0){
19         if(a<0){
20             s=-1;
21             a=-a;
22         }else

```



```

23         s=a!=0;
24     do{
25         d.push_back(a%B);
26         a/=B;
27     }while(a);
28 }
29 Integer(string a){
30     s=(a[0]=='-')?-1:(a!="0");
31     for(int i=a.size()-1;i>=(a[0]=='-');i-=L){
32         int t=0,j=max(i-L+1,int(a[0]=='-'));
33         for(int k=j;k<=i;++k)
34             t=t*10+a[k]-'0';
35         d.push_back(t);
36     }
37 }
38 Integer(const Integer&a){
39     d=a.d;
40     s=a.s;
41 }
42 Integer&operator=(long long a){
43     return*this=Integer(a);
44 }
45 Integer&operator+=(Integer a){
46     return*this=*this+a;
47 }
48 Integer&operator-=(Integer a){
49     return*this=*this-a;
50 }
51 Integer&operator*=(Integer a){
52     return*this=*this*a;
53 }
54 Integer&operator/=(Integer a){
55     return*this=*this/a;
56 }
57 Integer&operator%=(Integer a){
58     return*this=*this%a;
59 }
60 Integer&operator++(){
61     return*this=*this+1;
62 }
63 operator string()const{

```

```

64     string r;
65     for(int i=0;i<d.size();++i){
66         stringstream ts;
67         ts<<d[i];
68         string tt;
69         ts>>tt;
70         reverse(tt.begin(),tt.end());
71         while(i+1!=d.size()&&tt.size()<L)
72             tt.push_back('0');
73         r+=tt;
74     }
75     reverse(r.begin(),r.end());
76     return r;
77 }
78 int s;
79 vector<int>d;
80 static const int B=1e8,L=8;
81 };
82 string str(const Integer&a){
83     return string(a);
84 }
85 bool operator<(Integer a,Integer b){
86     if(a.s!=b.s)
87         return a.s<b.s;
88     if(a.d.size()!=b.d.size())
89         return (a.s!=1)^(a.d.size()<b.d.size());
90     for(int i=a.d.size()-1;i>=0;--i)
91         if(a.d[i]!=b.d[i])
92             return (a.s!=1)^(a.d[i]<b.d[i]);
93     return false;
94 }
95 bool operator>(Integer a,Integer b){
96     return b<a;
97 }
98 bool operator<=(Integer a,Integer b){
99     return !(a>b);
100 }
101 bool operator>=(Integer a,Integer b){
102     return !(a<b);
103 }
104 bool operator==(Integer a,Integer b){

```

```

105     return !(a<b)&&!(a>b);
106 }
107 bool operator!=(Integer a,Integer b){
108     return !(a==b);
109 }
110 istream&operator>>(istream&s,Integer&a){
111     string t;
112     s>>t;
113     a=Integer(t);
114     return s;
115 }
116 ostream&operator<<(ostream&s,Integer a){
117     if(a.s== -1)
118         s<<"-";
119     for(int i=a.d.size()-1;i>=0;--i){
120         if(i!=a.d.size()-1)
121             s<<setw(Integer::L)<<setfill('0');
122         s<<a.d[i];
123     }
124     s<<setw(0)<<setfill(' ');
125     return s;
126 }
127 void dzero(Integer&a){
128     while(a.d.size()>1&&a.d.back()==0)
129         a.d.pop_back();
130 }
131 Integer operator-(Integer a){
132     a.s*=-1;
133     if(a.d.size()==1&&a.d[0]==0)
134         a.s=1;
135     return a;
136 }
137 Integer operator+(Integer a,int b){
138     return a+Integer(b);
139 }
140 Integer operator*(Integer a,int b){
141     return a*Integer(b);
142 }
143 Integer operator%(Integer a,int b){
144     return a%Integer(b);
145 }

```

```

146 Integer operator%(Integer a,long long b){
147     return a%Integer(b);
148 }
149 bool operator!=(Integer a,int b){
150     return a!=Integer(b);
151 }
152 bool operator<=(Integer a,int b){
153     return a<=Integer(b);
154 }
155 Integer operator+(Integer a,Integer b){
156     if(a.s*b.s!=-1){
157         Integer c;c.s=a.s?a.s:b.s;
158         c.d.resize(max(a.d.size(),b.d.size()+1));
159         for(int i=0;i<c.d.size()-1;++i){
160             if(i<a.d.size())
161                 c.d[i]+=a.d[i];
162             if(i<b.d.size())
163                 c.d[i]+=b.d[i];
164             if(c.d[i]>=Integer::B){
165                 c.d[i]-=Integer::B;
166                 ++c.d[i+1];
167             }
168         }
169         dzero(c);
170         return c;
171     }
172     return a-(-b);
173 }
174 Integer operator-(Integer a,Integer b){
175     if(a.s*b.s==1){
176         if(a.s==-1)
177             return (-b)-(-a);
178         if(a<b)
179             return -(b-a);
180         if(a==b)
181             return 0;
182         for(int i=0;i<b.d.size();++i){
183             a.d[i]-=b.d[i];
184             if(a.d[i]<0){
185                 a.d[i]+=Integer::B;
186                 --a.d[i+1];

```

```

187         }
188     }
189     dzero(a);
190     return a;
191 }
192 return a+(-b);
193 }
194 Integer operator*(Integer a,Integer b){
195     vector<long long>t(a.d.size()+b.d.size());
196     for(int i=0;i<a.d.size();++i)
197         for(int j=0;j<b.d.size();++j)
198             t[i+j]+=(long long)a.d[i]*b.d[j];
199     for(int i=0;i<t.size()-1;++i){
200         t[i+1]+=t[i]/Integer::B;
201         t[i]%=Integer::B;
202     }
203     Integer c;
204     c.s=a.s*b.s;c.d.resize(t.size());
205     copy(t.begin(),t.end(),c.d.begin());
206     dzero(c);
207     return c;
208 }
209 Integer div2(Integer a){
210     for(int i=a.d.size()-1;i>=0;--i){
211         if(i)
212             a.d[i-1]+=(a.d[i]&1)*Integer::B;
213         a.d[i]>>=1;
214     }
215     dzero(a);
216     if(a.d.size()==1&&a.d[0]==0)
217         a.s=0;
218     return a;
219 }
220 Integer operator/(Integer a,Integer b){
221     if(!a.s)
222         return 0;
223     if(a.s<0)
224         return -((-a)/b);
225     if(a<b)
226         return 0;
227     Integer l=1,r=1;

```

```

228     while(r*b<=a)
229         r=r*2;
230     while(l+1<r){
231         Integer m=div2(l+r);
232         if(m*b>a)
233             r=m;
234         else
235             l=m;
236     }
237     return l;
238 }
239 Integer operator%(Integer a,Integer b){
240     return a-a/b*b;
241 }
242 Integer gcd(Integer a,Integer b){
243     Integer r=1;
244     while(a!=0&&b!=0){
245         if(!(a.d[0]&1)&&!(b.d[0]&1)){
246             a=div2(a);
247             b=div2(b);
248             r=r*2;
249         }else if(!(a.d[0]&1))
250             a=div2(a);
251         else if(!(b.d[0]&1))
252             b=div2(b);
253         else{
254             if(a<b)
255                 swap(a,b);
256             a=div2(a-b);
257         }
258     }
259     if(a!=0)
260         return r*a;
261     return r*b;
262 }
263 int length(Integer a){
264     a.s=1;
265     return string(a).size();
266 }
267 int len(Integer a){
268     return length(a);

```

269 | }

5.6 Linear Programming

Linear Programming.hpp (2522 bytes, 89 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct LinearProgramming{
4      const double E;
5      int n,m,p;
6      vector<int>mp,ma,md;
7      vector<vector<double> >a;
8      vector<double>res;
9      LinearProgramming(int _n,int _m):
10         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     }
12     void piv(int l,int e){
13         swap(mp[l],md[e]);
14         ma[mp[l]]=1;
15         ma[md[e]]=-1;
16         double t=-a[l][e];
17         a[l][e]=-1;
18         vector<int>qu;
19         for(int i=0;i<=m+1;++i)
20             if(fabs(a[l][i]/t)>E)
21                 qu.push_back(i);
22         for(int i=0;i<=n+1;++i)
23             if(i!=l&&fabs(a[i][e])>E){
24                 t=a[i][e];
25                 a[i][e]=0;
26                 for(int j=0;j<qu.size();++j)
27                     a[i][qu[j]]+=a[l][qu[j]]*t;
28             }
29         if(-p==1)
30             p=e;
31         else if(p==e)
32             p=-l;

```

```

33     }
34     int opt(int d){
35         for(int l=-1,e=-1;;piv(l,e),l=-1,e=-1){
36             for(int i=1;i<=m+1;++i)
37                 if(a[d][i]>E){
38                     e=i;
39                     break;
40                 }
41             if(e==-1)
42                 return 1;
43             double t;
44             for(int i=1;i<=n;++i)
45                 if(a[i][e]<-E&&(l==-1||a[i][0]/-a[i][e]<t))
46                     t=a[i][0]/-a[i][e],l=i;
47             if(l==-1)
48                 return 0;
49         }
50     }
51     double&at(int x,int y){
52         return a[x][y];
53     }
54     vector<double>run(){
55         for(int i=1;i<=m+1;++i)
56             ma[i]=-1,md[i]=i;
57         for(int i=m+2;i<=m+n+1;++i)
58             ma[i]=i-(m+1),mp[i-(m+1)]=i;
59         double t;
60         int l=-1;
61         for(int i=1;i<=n;++i)
62             if(l==-1||a[i][0]<t)
63                 t=a[i][0],l=i;
64         if(t<-E){
65             for(int i=1;i<=n;++i)
66                 a[i][m+1]=1;
67             a[n+1][m+1]=-1;
68             p=m+1;
69             piv(l,m+1);
70             if(!opt(n+1)||fabs(a[n+1][0])>E)
71                 return vector<double>();
72             if(p<0)
73                 for(int i=1;i<=m;++i)

```



```

74         if(fabs(a[-p][i])>E){
75             piv(-p,i);
76             break;
77         }
78         for(int i=0;i<=n;++i)
79             a[i][p]=0;
80     }
81     if(!opt(0))
82         return vector<double>();
83     res[0]=a[0][0];
84     for(int i=1;i<=m;++i)
85         if(ma[i]!=-1)
86             res[i]=a[ma[i]][0];
87     return res;
88 }
89 };

```

5.7 Linear System

Linear System.hpp (1477 bytes, 56 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct LinearSystem{
4      int n;
5      vector<vector<T> >a;
6      vector<int>main,pos;
7      vector<T>ans;
8      int cmp(T a){
9          if(typeid(T)==typeid(double)||typeid(T)==typeid(long double)||
10             typeid(T)==typeid(float)){
11              if(a<-1e-8)
12                  return -1;
13              if(a>1e-8)
14                  return 1;
15              return 0;
16          }
17          if(a<0)
18              return -1;

```

```

18     if(a>0)
19         return 1;
20     return 0;
21 }
22 T&at(int i,int j){
23     return a[i][j];
24 }
25 vector<T>&at(int i){
26     return a[i];
27 }
28 LinearSystem(int _n):
29     n(_n),a(n+1,vector<T>(n+1)),main(n+1),pos(n+1),ans(n){
30 }
31 vector<T>run(){
32     for(int i=1;i<=n;++i){
33         int j=1;
34         for(;j<=n&&!cmp(a[i][j]);++j);
35         if(j<=n){
36             main[i]=j;
37             pos[j]=i;
38             T t=a[i][j];
39             for(int k=0;k<=n;++k)
40                 a[i][k]/=t;
41             for(int k=1;k<=n;++k)
42                 if(k!=i&&cmp(a[k][j])){
43                     t=a[k][j];
44                     for(int l=0;l<=n;++l)
45                         a[k][l]-=a[i][l]*t;
46                 }
47         }
48     }
49     for(int i=1;i<=n;++i){
50         if(!pos[i])
51             return vector<T>();
52         ans[i-1]=a[pos[i]][0];
53     }
54     return ans;
55 }
56 };

```

5.8 Polynomial Interpolation

Polynomial Interpolation.hpp (372 bytes, 15 lines)

```
1 #include<bits/stdc++.h>
2 using namespace std;
3 template<class T>T PolynomialInterpolation(vector<T>x,vector<T>y,T x0){
4     T r=0;
5     for(int i=0;i<x.size();++i){
6         T p=1,q=1;
7         for(int j=0;j<x.size();++j)
8             if(j!=i){
9                 p*=(x0-x[j]);
10                q*=(x[i]-x[j]);
11            }
12        r+=p/q*y[i];
13    }
14    return r;
15 }
```


CHAPTER 6

String Algorithms

6.1 Aho-Corasick Automaton

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct AhoCorasickAutomaton{
4      struct node{
5          node(int m):
6              tr(m),fail(0),cnt(0){
7              }
8          vector<node*>tr;
9          node*fail;
10         int cnt;
11     };
12     int m;
13     node*root;
14     vector<node*>all;
15     AhoCorasickAutomaton(int _m):
16         m(_m),root(new node(m)),all(1,root){
17     }
18     ~AhoCorasickAutomaton(){
19         for(int i=0;i<all.size();++i)
20             delete all[i];
21     }
22     node*insert(int*s){
23         node*p;
24         for(p=root;*s!=-1;p=p->tr[*s++])
25             if(!p->tr[*s])
26                 p->tr[*s]=new node(m);
27         return p;
28     }
29     void build(){
30         queue<node*>qu;
31         for(int i=0;i<m;++i)
32             if(!root->tr[i])
33                 root->tr[i]=root;
34             else
35                 root->tr[i]->fail=root,qu.push(root->tr[i]);
36         for(node*u;qu.size();(u=qu.front(),qu.pop(),all.push_back(u),1):0;)
37             for(int i=0;i<m;++i)

```

```

38         if(!u->tr[i])
39             u->tr[i]=u->fail->tr[i];
40         else
41             u->tr[i]->fail=u->fail->tr[i],qu.push(u->tr[i]);
42     }
43     void run(int*s){
44         for(node*p=root;*s!=-1;++(p=p->tr[*s]))->cnt);
45     }
46     void count(){
47         for(int i=all.size()-1;i>=1;--i)
48             all[i]->fail->cnt+=all[i]->cnt;
49     }
50 };

```

6.2 Factor Oracle

Factor Oracle.hpp (705 bytes, 21 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T,int N,int M,T D>struct FactorOracle{
4      FactorOracle(){
5          memset(tr,(lrs[0]=0,sp[0]=-1),4*M);
6      }
7      void insert(const T*s,int n){
8          for(int i=0,c=s[i]-D;i<n;c=s[++i]-D){
9              memset(tr+i+1,(lrs[i+1]=0)-1,4*M);
10             int j=sp[i],p1=(tr[i][c]=i+1)-1;
11             for(;j>-1&&tr[j][c]<0;tr[j][c]=i+1,j=sp[p1=j]);
12             sp[i+1]=j<0?0:tr[j][c];
13             if(sp[i+1]){
14                 int p2=sp[i+1]-1==sp[p1]?p1:sp[i+1]-1;
15                 for(;sp[p1]!=sp[p2];p2=sp[p2]);
16                 lrs[i+1]=min(lrs[p1],lrs[p2])+1;
17             }
18         }
19     }
20     int sp[N+1],lrs[N+1],tr[N+1][M];
21 };

```

6.3 Palindromic Tree

Palindromic Tree.hpp (1327 bytes, 50 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct PalindromicTree{
4      struct node{
5          node(int m,node*f,int l):
6              nxt(m),fail(f),len(l){
7              }
8          vector<node*>nxt;
9          node*fail;
10         T val;
11         int len;
12     }*root;
13     int m;
14     vector<int>str;
15     vector<node*>all;
16     PalindromicTree(int _m):
17         m(_m){
18         node*n0=new node(m,0,-2),*n1=new node(m,n0,-1),*n2=new node(m,n1,0)
19         ;
20         all.push_back(n0);
21         all.push_back(n1);
22         all.push_back(n2);
23         fill(n0->nxt.begin(),n0->nxt.end(),n2);
24         root=n1;
25     }
26     ~PalindromicTree(){
27         for(int i=0;i<all.size();++i)
28             delete all[i];
29     }
30     node*find(node*x){
31         while(x->fail&&str[str.size()-x->len-2]!=str[str.size()-1])
32             x=x->fail;
33         return x;
34     }
35     node*insert(node*p,int c,T v){
36         if(p==root)
37             str=vector<int>(1,-1);

```



```

37     str.push_back(c);
38     p=find(p);
39     if(!p->nxt[c]){
40         node*np=(p->nxt[c]=new node(m,find(p->fail)->nxt[c],p->len+2))
41     ;
42         all.push_back(np);
43     }
44     p->nxt[c]->val+=v;
45     return p->nxt[c];
46 }
47 void count(){
48     for(int i=all.size()-1;i>=1;--i)
49         all[i]->fail->val+=all[i]->val;
50 };

```

6.4 String Searching

String Searching.hpp (682 bytes, 25 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct StringSearching{
4      StringSearching(T*a):
5          b(2,a[1]),f(2),l(2){
6          for(int i=0;a[1]?1:(-1,0);b.push_back(a[l++])){
7              for(;i&&a[i+1]!=a[l];i=f[i]);
8              f.push_back(i=i+(a[i+1]==a[l]));
9          }
10         for(int i=2;i<l;++i)
11             if(a[f[i]+1]==a[i+1])
12                 f[i]=f[f[i]];
13     }
14     int run(T*a,int p){
15         for(int i=p?p+1:1,j=p?f[l]:0;a[i];++i){
16             for(;j&&b[j+1]!=a[i];j=f[j]);
17             if((j+=b[j+1]==a[i])==1)
18                 return i-l+1;
19         }

```

```
20     return 0;
21 }
22 int l;
23 vector<T>b;
24 vector<int>f;
25 };
```

6.5 String

String.hpp (987 bytes, 45 lines)

```
1 #include<bits/stdc++.h>
2 using namespace std;
3 string read_all(){
4     string t;
5     getline(cin,t,char(EOF));
6     return t;
7 }
8 string delete_all(string a,char b){
9     string r;
10    for(int i=0;i<a.size();++i)
11        if(a[i]!=b)
12            r.push_back(a[i]);
13    return r;
14 }
15 string substr(string a,int l,int r){
16    return a.substr(l,r-l+1);
17 }
18 vector<string>split(string a,char b){
19    vector<string>r;
20    string t;
21    for(int i=0;i<a.size();++i)
22        if(a[i]!=b)
23            t.push_back(a[i]);
24        else{
25            r.push_back(t);
26            t="";
27        }
28    r.push_back(t);
```

```

29     return r;
30 }
31 int letter_order(char a){
32     return a>='a'&&a<='z'?a-'a'+1:a-'A'+1;
33 }
34 int letter_sum(string a){
35     int r=0;
36     for(int i=0;i<a.size();++i)
37         r+=letter_order(a[i]);
38     return r;
39 }
40 bool is_palindromic_string(string a){
41     for(int i=0;i<a.size();++i)
42         if(a[i]!=a[a.size()-i-1])
43             return false;
44     return true;
45 }

```

6.6 Suffix Array (DC3 Algorithm)

Suffix Array (DC3 Algorithm).hpp (2952 bytes, 107 lines)

```

1 #include<bits/stdc++.h>
2 using namespace std;
3 struct SuffixArray{
4     int*sa,*ht,*rk,*ts,*ct,ln;
5     SuffixArray(int*s){
6         int m=0;
7         for(ln=0;s[ln+1];)
8             m=max(m,s[++ln]);
9         crt(sa,ln);
10        crt(ht,ln);
11        crt(rk,ln);
12        crt(ts,ln);
13        crt(ct,max(ln,m));
14        dc3(s,ln,m,sa,rk);
15        for(int i=1;i<=ln;++i){
16            if(rk[i]==1){
17                ht[1]=0;

```

```

18         continue;
19     }
20     int&d=ht[rk[i]]=max(i==1?0:ht[rk[i-1]]-1,0);
21     for(;i+d<=ln&&sa[rk[i]-1]+d<=ln&&s[i+d]==s[sa[rk[i]-1]+d];++d);
22 }
23 }
24 ~SuffixArray(){
25     del(sa);
26     del(ht);
27     del(rk);
28     del(ts);
29     del(ct);
30 }
31 void crt(int*&a,int n){
32     a=new int[n+1];
33 }
34 void del(int*a){
35     delete a;
36 }
37 #define fc(i)(p0[i]+d>n||!p0[i]?0:s[p0[i]+d])
38 int cmp(int*p0,int i,int*s,int n){
39     for(int d=0;d<3;++d)
40         if(fc(i)!=fc(i-1))
41             return 1;
42     return 0;
43 }
44 void sot(int*p0,int n0,int*s,int n,int m,int d){
45     memset(ct,0,(m+1)*4);
46     for(int i=1;i<=n0;++i)
47         ++ct[fc(i)];
48     for(int i=1;i<=m;++i)
49         ct[i]+=ct[i-1];
50     for(int i=n0;i>=1;--i)
51         ts[ct[fc(i)]--]=p0[i];
52     memcpy(p0+1,ts+1,n0*4);
53 }
54 #define fc(d)if(s[i+d]!=s[j+d])return s[i+d]<s[j+d];if(i==n-d||j==n-d)
55 return i==n-d;
56 bool cmp(int*s,int n,int*r,int i,int j){
57     fc(0)
58     if(j%3==1)

```

```

58         return r[i+1]<r[j+1];
59     fc(1)
60     return r[i+2]<r[j+2];
61 }
62 #undef fc
63 void dc3(int*s,int n,int m,int*a,int*r){
64     int n0=n-(n/3)+1,*a0,*s0,i,j=0,k=n/3+bool(n%3)+1,1;
65     crt(s0,n0);
66     s0[k]=1;
67     crt(a0,n0+1);
68     a0[k]=0;
69     for(i=1;i<=n;i+=3)
70         a0[++j]=i,a0[j+k]=i+1;
71     for(i=2;i>=0;--i)
72         sot(a0,n0,s,n,m,i);
73     r[a0[1]]=1;
74     for(i=2;i<=n0;++i)
75         r[a0[i]]=r[a0[i-1]]+cmp(a0,i,s,n);
76     for(i=1,j=0;i<=n;i+=3)
77         s0[++j]=r[i],s0[j+k]=r[i+1];
78     if(r[a0[n0]]==n0){
79         memcpy(r+1,s0+1,n0*4);
80         for(i=1;i<=n0;++i)
81             a0[a[i]=r[i]]=i;
82     }else
83         dc3(s0,n0,r[a0[n0]],a0,a);
84     for(i=1,j=0;i<=n;i+=3)
85         r[i]=a[++j],r[i+1]=a[j+k];
86     j=0;
87     if(n%3==0)
88         s0[++j]=n;
89     for(i=1;i<=n0;++i)
90         if(a0[i]<k){
91             a0[i]=3*a0[i]-2;
92             if(a0[i]!=1)
93                 s0[++j]=a0[i]-1;
94         }else
95             a0[i]=(a0[i]-k)*3-1;
96     sot(s0,j,s,n,m,0);
97     for(i=1,k=2,l=0;i<=j||k<=n0;)
98         if(k>n0||i<=j&&cmp(s,n,r,s0[i],a0[k]))

```

```

99         a[++l]=s0[i++];
100     else
101         a[++l]=a0[k++];
102     for(i=1;i<=n;++i)
103         r[a[i]]=i;
104     del(a0);
105     del(s0);
106 }
107 };

```

6.7 Suffix Array (Prefix-Doubling Algorithm)

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

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct SuffixArray{
4      int*a,*h,*r,*t,*c,n,m;
5      #define lp(u,v)for(int i=u;i<=v;++i)
6      #define rp(u,v)for(int i=u;i>=v;--i)
7      void sort(){
8          memset(c+1,0,m*4);
9          lp(1,n)
10             ++c[r[t[i]]];
11          lp(2,m)
12             c[i]+=c[i-1];
13          rp(n,1)
14             a[c[r[t[i]]]--]=t[i];
15     }
16     SuffixArray(int*s){
17         for(n=m=0;s[n+1];m=max(m,s[+n]));
18         a=new int[4*n+max(n,m)+3];
19         h=a+n;
20         r=h+n+1;
21         t=r+n+1;
22         c=t+n;
23         lp(1,n)
24             t[i]=i,r[i]=s[i];
25         sort();

```

```

26     for(int l=1;l<=n;l<=1,r[a[n]]==n?l=n+1:m=r[a[n]]){
27         t[0]=0;
28         lp(n-l+1,n)
29         t[++t[0]]=i;
30         lp(1,n)
31         if(a[i]>l)
32             t[++t[0]]=a[i]-1;
33         sort();
34         swap(r,t);
35         r[a[1]]=1;
36         lp(2,n)
37         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]+1]!=t[a[i-1]+1]);
38     }
39     int l=0;
40     a[0]=n+1;
41     lp(1,n){
42         if(r[i]==1)
43             l=0;
44             l--=(l>0);
45         int j=a[r[i]-1];
46         for(;s[i+1]==s[j+1];++l);
47         h[r[i]]=l;
48     }
49 }
50 #undef lp
51 #undef rp
52 ~SuffixArray(){
53     delete a;
54 }
55 };

```

6.8 Suffix Array (Treap)

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

```

1 #include<bits/stdc++.h>
2 using namespace std;
3 template<class T>struct SuffixArray{

```

```

4  struct node{
5      node*c[2],*p;
6      T v;
7      int f,s,l,h,m;
8      double t;
9      node(node*_p,T _v,int _l):
10         f(rand()*1.0/RAND_MAX*1e9),p(_p),v(_v),s(1),l(_l),h(0),m(0),t(5
e8){
11         c[0]=c[1]=0;
12     }
13 }*root;
14 vector<T>a;
15 SuffixArray():
16     root(new node(0,0,0)),a(1){
17 }
18 ~SuffixArray(){
19     clear(root);
20 }
21 void relabel(node*x,double l,double r){
22     x->t=(l+r)/2;
23     if(x->c[0])
24         relabel(x->c[0],l,x->t);
25     if(x->c[1])
26         relabel(x->c[1],x->t,r);
27 }
28 void update(node*x){
29     x->s=1;
30     x->m=x->h;
31     for(int i=0;i<2;++i)
32         if(x->c[i])
33             x->s+=x->c[i]->s,x->m=min(x->m,x->c[i]->m);
34 }
35 void rotate(node*&x,int d){
36     node*y=x->c[d];
37     x->c[d]=y->c[!d];
38     y->c[!d]=x;
39     y->s=x->s;
40     y->m=x->m;
41     update(x);
42     x=y;
43 }

```



```

44 void clear(node*x){
45     if(!x)
46         return;
47     clear(x->c[0]);
48     clear(x->c[1]);
49     delete x;
50 }
51 node*insert(node*&x,node*p,T v,node*l,node*r){
52     int d=x->v!=v?x->v<v:x->p->t<p->t;
53     double tl=l?l->t:0,tr=r?r->t:1e9;
54     node*y;
55     if(d)
56         l=x;
57     else
58         r=x;
59     if(!x->c[d]){
60         y=new node(p,v,p->l+1);
61         y->t=((l?l->t:0)+(r?r->t:1e9))/2;
62         y->m=y->h=l->v==y->v?lcp(l->p,y->p)+1:0;
63         if(r)
64             r->h=r->v==y->v?lcp(r->p,y->p)+1:0;
65         x->c[d]=y;
66     }else
67         y=insert(x->c[d],p,v,l,r);
68     update(x);
69     if(x->c[d]->f>x->f)
70         rotate(x,d),relabel(x,tl,tr);
71     return y;
72 }
73 node*insert(node*p,T v){
74     a.push_back(v);
75     return insert(root,p,v,0,0);
76 }
77 void erase(node*&x,node*y){
78     if(x==y){
79         if(!x->c[0]){
80             x=x->c[1];
81             delete y;
82         }else if(!x->c[1]){
83             x=x->c[0];
84             delete y;

```

```

85         }else{
86             int d=x->c[0]->f<x->c[1]->f;
87             rotate(x,d);
88             erase(x->c[!d],y);
89             --x->s;
90         }
91     }else
92         erase(x->c[x->t<y->t],y),update(x);
93 }
94 void erase(node*y){
95     erase(root,y);
96     a.pop_back();
97 }
98 bool check(node*x,T*y,node*&p,int&l){
99     if(p){
100         int t=x->c[p->t>x->t]?x->c[p->t>x->t]->m:~0u>>1;
101         if(p->t>x->t)
102             t=min(t,p->h);
103         else
104             t=min(t,x->h);
105         if(t<l)
106             return x->t<p->t;
107     }
108     for(p=x;l+1<=x->l&&y[l+1];++l)
109         if(a[x->l-1]!=y[l+1])
110             return a[x->l-1]<y[l+1];
111     return y[l+1]!=0;
112 }
113 int count(node*x,T*y){
114     int r=0,l=0;
115     for(node*p=0;x;)
116         if(check(x,y,p,l))
117             r+=(x->c[0]?x->c[0]->s:0)+1,x=x->c[1];
118         else
119             x=x->c[0];
120     return r;
121 }
122 int count(T*y){
123     T*t=y;
124     while(*(t+1))
125         ++t;

```

```

126     int r=-count(root,y);
127     ++*t;
128     r+=count(root,y);
129     --*t;
130     return r;
131 }
132 int lcp(node*x,double u,double v,double l,double r){
133     if(v<l||u>r||!x)
134         return ~0u>>1;
135     if(u<l&&v>=r)
136         return x->m;
137     int t=u<x->t&&v>=x->t?x->h:~0u>>1;
138     t=min(t,lcp(x->c[0],u,v,l,x->t));
139     t=min(t,lcp(x->c[1],u,v,x->t,r));
140     return t;
141 }
142 int lcp(node*x,node*y){
143     if(x->t>y->t)
144         swap(x,y);
145     return lcp(root,x->t,y->t,0,1e9);
146 }
147 };

```

6.9 Suffix Automaton

Suffix Automaton.hpp (1694 bytes, 59 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T>struct SuffixAutomaton{
4      struct node{
5          node(vector<node*>&all,int m,node*_pr=0,int _ln=0,T _va=T()):
6              pr(_pr),tr(m),ln(_ln),va(_va){
7              all.push_back(this);
8          }
9          T va;
10         int ln;
11         node*pr;
12         vector<node*>tr;

```

```

13     };
14     SuffixAutomaton(int _m):
15         root(new node(all,m)),m(_m){
16     }
17     ~SuffixAutomaton(){
18         for(int i=0;i<all.size();++i)
19             delete all[i];
20     }
21     node*insert(node*lst,int c,T v){
22         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)
24             p->tr[c]=np;
25         if(!p)np->pr=root;
26         else{
27             node*q=p->tr[c];
28             if(p==lst)
29                 np=q;
30             if(q->ln==p->ln+1)
31                 p==lst?(q->va+=v):(np->pr=q,0);
32             else{
33                 node*nq=new node(all,m,q->pr,p->ln+1,p==lst?v:T());
34                 nq->tr=q->tr;
35                 q->pr=np->pr=nq;
36                 if(p==lst)
37                     np=nq;
38                 for(;p&&p->tr[c]==q;p=p->pr)
39                     p->tr[c]=nq;
40             }
41         }
42         return np;
43     }
44     void count(){
45         vector<int>cnt(all.size());
46         vector<node*>tmp=all;
47         for(int i=0;i<tmp.size();++i)
48             ++cnt[tmp[i]->ln];
49         for(int i=1;i<cnt.size();++i)
50             cnt[i]+=cnt[i-1];
51         for(int i=0;i<tmp.size();++i)
52             all[--cnt[tmp[i]->ln]]=tmp[i];
53         for(int i=int(all.size())-1;i>0;--i)

```

```

54         all[i]→pr→va+=all[i]→va;
55     }
56     int m;
57     node*root;
58     vector<node*>all;
59 };

```

6.10 Suffix Tree

Suffix Tree.hpp (2899 bytes, 116 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  template<class T=char,int N=int(1e5),int M=27,T D='a'-1>struct SuffixTree{
4      struct node;
5      struct edge{
6          edge():
7              l(0),r(0),t(0){
8              }
9          int length(){
10             return r-l;
11         }
12         T*l,*r;
13         node*t;
14     }pe[2*N],*ep=pe;
15     edge*newedge(T*l,T*r,node*t){
16         ep→l=l;
17         ep→r=r;
18         ep→t=t;
19         return ep++;
20     }
21     struct node{
22         node():
23             s(0),c({0}){
24         }
25         node*s;
26         edge*c[M];
27     }pn[2*N+1],*np=pn;
28     SuffixTree():

```

```

29     root(np++),ct(0){
30 }
31 void extend(T*s){
32     for(;ae&&al>=ae->length();){
33         s+=ae->length();
34         al-=ae->length();
35         an=ae->t;
36         ae=al?an->c[*s-D]:0;
37     }
38 }
39 bool extend(int c){
40     if(ae){
41         if(*(ae->l+al)-D-c)
42             return true;
43         ++al;
44     }else{
45         if(!an->c[c])
46             return true;
47         ae=an->c[c];
48         al=1;
49         if(pr)
50             pr->s=an;
51     }
52     extend(ae->l);
53     return false;
54 }
55 void insert(T*s,int n){
56     ct+=n;
57     an=root;
58     ae=0;
59     al=0;
60     for(T*p=s;p!=s+n;++p)
61         for(pr=0;extend(*p-D);){
62             edge*x=newedge(p,s+n,np++);
63             if(!ae)
64                 an->c[*p-D]=x;
65             else{
66                 edge*&y=an->c[*ae->l-D];
67                 y=newedge(ae->l,ae->l+al,np++);
68                 y->t->c[* (ae->l+al)-D]=ae;
69                 y->t->c[*p-D]=x;

```

```

70         ae=y;
71     }
72     if(pr)
73         pr->s=ae?ae->t:an;
74     pr=ae?ae->t:an;
75     int r=1;
76     if(an==root&&!a1)
77         break;
78     if(an==root)
79         --a1;
80     else{
81         an=an->s?an->s:root;
82         r=0;
83     }
84     if(a1){
85         T*t=ae->l+(an==root)*r;
86         ae=an->c[*t-D];
87         extend(t);
88     }else
89         ae=0;
90 }
91 }
92 void build(node*u=0,int d=0){
93     if(!u)
94         u=root;
95     int t=0,s=0;
96     for(int i=0;i<M;++i)
97         if(u->c[i]){
98             if(!t)
99                 t=1;
100             else if(!s){
101                 s=1;
102                 *sp++=d;
103             }
104             build(u->c[i]->t,d+u->c[i]->length());
105         }
106     if(s)
107         --sp;
108     else if(!t&&sp!=sk){
109         *hp++=(sp-1);
110         *fp++=ct-d+1;

```

```
111     }
112   }
113   edge*ae;
114   node*root,*an,*pr;
115   int al,ct,sk[N],*sp=sk,height[N],*hp=height,suffix[N],*fp=suffix;
116 };
```


CHAPTER 7

Utility Tools

7.1 Checker

Checker.bat (113 bytes, 7 lines)

```
1 :ag
2 gen > in.txt
3 p1 < in.txt > p1.txt
4 p2 < in.txt > p2.txt
5 fc p1.txt p2.txt
6 if errorlevel 1 pause
7 goto ag
```

7.2 Date

Date.hpp (3596 bytes, 145 lines)

```
1 #include<bits/stdc++.h>
2 using namespace std;
3 struct Date{
4     int y,m,d,w;
5     Date&operator++(){
6         return*this=*this+1;
7     }
8     bool leap(int a)const{
9         return a%400==0|| (a%4==0&&a%100!=0);
10    }
11    int month_sum(int a,int b)const{
12        if(b==0)
13            return 0;
14        if(b==1)
15            return 31;
16        return 59+leap(a)+30*(b-2)+(b+1)/2-1+(b>=8&&b%2==0);
17    }
18    string month_name(int a)const{
19        if(a==1)
20            return"January";
21        if(a==2)
22            return"February";
23        if(a==3)
```

```
24         return "March";
25     if(a==4)
26         return "April";
27     if(a==5)
28         return "May";
29     if(a==6)
30         return "June";
31     if(a==7)
32         return "July";
33     if(a==8)
34         return "August";
35     if(a==9)
36         return "September";
37     if(a==10)
38         return "October";
39     if(a==11)
40         return "November";
41     if(a==12)
42         return "December";
43 }
44 string day_name(int a) const {
45     if(a==0)
46         return "Sunday";
47     if(a==1)
48         return "Monday";
49     if(a==2)
50         return "Tuesday";
51     if(a==3)
52         return "Wednesday";
53     if(a==4)
54         return "Thursday";
55     if(a==5)
56         return "Friday";
57     if(a==6)
58         return "Saturday";
59 }
60 operator int() const {
61     int t=(y-1)*365+(y-1)/4-(y-1)/100+(y-1)/400+month_sum(y,m-1)+d;
62     if(y==1752&&m>=9&&d>2||y>1752)
63         t-=11;
64     t-=min(y-1,1700)/400-min(y-1,1700)/100;
```

```

65         if(y<=1700&&y%400!=0&&y%100==0&&m>2)
66             ++t;
67         return t;
68     }
69     Date(int _y,int _m,int _d):
70         y(_y),m(_m),d(_d),w((int)(*this)+5)%7){
71     }
72     Date(int a){
73         int y1=0,yr=1e7;
74         while(y1+1<yr){
75             int ym=(y1+yr)/2;
76             if(int(Date(ym,12,31))<a)
77                 y1=ym;
78             else
79                 yr=ym;
80         }
81         y=yr;
82         int m1=0,mr=12;
83         while(m1+1<mr){
84             int mm=(m1+mr)/2,mt;
85             if(mm==2){
86                 if(y<=1700)
87                     mt=28+(y%4==0);
88                 else
89                     mt=28+(y%4==0&&y%100!=0 | y%400==0);
90             }else if(mm<=7)
91                 mt=30+mm%2;
92             else
93                 mt=31-mm%2;
94             if(int(Date(y,mm,mt))<a)
95                 m1=mm;
96             else
97                 mr=mm;
98         }
99         m=mr;
100         for(int i=1; ; ++i){
101             if(y==1752&&m==9&&i>2&&i<14)
102                 continue;
103             if(int(Date(y,m,i))==a){
104                 d=i;
105                 break;

```

```
106         }
107     }
108     w=(5+a)%7;
109 }
110 operator string()const{
111     stringstream s;
112     string t;
113     s<<day_name(w)+", "+month_name(m)+" "<<d<<"", "<<y;
114     getline(s,t);
115     return t;
116 }
117 };
118 ostream&operator<<(ostream&s,const Date&a){
119     return s<<string(a);
120 }
121 int operator-(const Date&a,const Date&b){
122     return int(a)-int(b);
123 }
124 Date operator+(const Date&a,int b){
125     return Date(int(a)+b);
126 }
127 Date operator-(const Date&a,int b){
128     return Date(int(a)-b);
129 }
130 bool operator<(const Date&a,const Date&b){
131     if(a.y==b.y&&a.m==b.m)
132         return a.d<b.d;
133     if(a.y==b.y)
134         return a.m<b.m;
135     return a.y<b.y;
136 }
137 bool operator>(const Date&a,const Date&b){
138     return b<a;
139 }
140 bool operator!=(const Date&a,const Date&b){
141     return a.y!=b.y||a.m!=b.m||a.d!=b.d;
142 }
143 bool operator==(const Date&a,const Date&b){
144     return !(a!=b);
145 }
```

7.3 Fast Reader

Fast Reader.hpp (1251 bytes, 61 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct FastReader{
4      FILE*f;
5      char*p,*e;
6      vector<char>v;
7      void ipt(){
8          for(int i=1,t;;i<=1){
9              v.resize(v.size()+i);
10             if(i!=(t=fread(&v[0]+v.size()-i,1,i,f))){
11                 p=&v[0],e=p+v.size()-i+t;
12                 break;
13             }
14         }
15     }
16     void ign(){
17         while(p!=e&&isspace(*p))
18             ++p;
19     }
20     int isc(){
21         return p!=e&&!isspace(*p);
22     }
23     int isd(){
24         return p!=e&&isdigit(*p);
25     }
26     FastReader(FILE*_f):
27         f(_f){
28             ipt();
29         }
30     FastReader(string _f):
31         f(fopen(_f.c_str(),"r")){
32             ipt();
33         }
34     ~FastReader(){
35         fclose(f);
36     }
37     template<class T>FastReader&operator>>(T&a){

```

```

38     int n=1;
39     ign();
40     if(*p=='-')
41         n=-1,++p;
42     for(a=0;isd();)
43         a=a*10+*p++-'0';
44     a*=n;
45     return*this;
46 }
47 FastReader&operator>>(char&a){
48     ign();
49     a=*p++;
50     return*this;
51 }
52 FastReader&operator>>(char*a){
53     for(ign();isc();)
54         *a++=*p++;
55     *a=0;
56     return*this;
57 }
58 char get(){
59     return*p++;
60 }
61 };

```

7.4 Fast Writer

Fast Writer.hpp (866 bytes, 39 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  struct FastWriter{
4      FILE*f;
5      vector<char>p;
6      FastWriter(FILE*_f):
7          f(_f){
8      }
9      FastWriter(string _f):
10         f(fopen(_f.c_str(),"w")){

```

```

11     }
12     ~FastWriter(){
13         if(p.size())
14             fwrite(&p[0],1,p.size(),f);
15         fclose(f);
16     }
17     FastWriter&operator<<(char a){
18         p.push_back(a);
19         return*this;
20     }
21     FastWriter&operator<<(const char*a){
22         while(*a)
23             p.push_back(*a++);
24         return*this;
25     }
26     template<class T>FastWriter&operator<<(T a){
27         if(a<0)
28             p.push_back('-'),a=-a;
29         static char t[19];
30         char*q=t;
31         do{
32             T b=a/10;
33             *q++=a-b*10+'0',a=b;
34         }while(a);
35         while(q>t)
36             p.push_back(*--q);
37         return*this;
38     }
39 };

```

7.5 Number Speller

Number Speller.hpp (2143 bytes, 72 lines)

```

1 #include<bits/stdc++.h>
2 using namespace std;
3 namespace NumberSpeller{
4     template<class T>string run(T a){
5         map<T,string>m;

```



```
6      m[0]="zero";
7      m[1]="one";
8      m[2]="two";
9      m[3]="three";
10     m[4]="four";
11     m[5]="five";
12     m[6]="six";
13     m[7]="seven";
14     m[8]="eight";
15     m[9]="nine";
16     m[10]="ten";
17     m[11]="eleven";
18     m[12]="twelve";
19     m[13]="thirteen";
20     m[14]="fourteen";
21     m[15]="fifteen";
22     m[16]="sixteen";
23     m[17]="seventeen";
24     m[18]="eighteen";
25     m[19]="nineteen";
26     m[20]="twenty";
27     m[30]="thirty";
28     m[40]="forty";
29     m[50]="fifty";
30     m[60]="sixty";
31     m[70]="seventy";
32     m[80]="eighty";
33     m[90]="ninety";
34     if(a<0)
35         return"minus "+run(-a);
36     if(m.count(a))
37         return m[a];
38     if(a<100)
39         return run(a/10*10)+"-"+run(a%10);
40     if(a<1000&&a%100==0)
41         return run(a/100)+" hundred";
42     if(a<1000)
43         return run(a/100*100)+" and "+run(a%100);
44     vector<string>t;
45     t.push_back("thousand");
46     t.push_back("million");
```

```

47     t.push_back("billion");
48     t.push_back("trillion");
49     t.push_back("quadrillion");
50     t.push_back("quintillion");
51     t.push_back("sextillion");
52     t.push_back("septillion");
53     t.push_back("octillion");
54     t.push_back("nonillion");
55     t.push_back("decillion");
56     t.push_back("undecillion");
57     t.push_back("duodecillion");
58     t.push_back("tredecillion");
59     t.push_back("quattuordecillion");
60     t.push_back("quindecillion");
61     string r=a%1000?run(a%1000):"";
62     a/=1000;
63     for(int i=0;a;++i,a/=1000)
64         if(a%1000){
65             if(!i&&r.find("and")==string::npos&&r.find("hundred")==
string::npos&&r.size())
66                 r=run(a%1000)+" "+t[i]+" and "+r;
67             else
68                 r=run(a%1000)+" "+t[i]+(r.size()?"," : "")+r;
69         }
70     return r;
71 }
72 }

```

7.6 Utility

Utility.hpp (4146 bytes, 167 lines)

```

1  #include<bits/stdc++.h>
2  using namespace std;
3  typedef long long ll;
4  typedef long double ld;
5  #define lp(i,a,b)for(auto i=a;i<=b;++i)
6  void set_read(string a){
7      freopen(a.c_str(),"r",stdin);

```

```

8 }
9 void set_write(string a){
10     freopen(a.c_str(),"w",stdout);
11 }
12 template<class T>void write(T a){
13     cout<<a;
14 }
15 template<class T>void writeln(T a){
16     cout<<a<<endl;
17 }
18 template<class T>T read(){
19     T a;
20     cin>>a;
21     return a;
22 }
23 void sync(int t){
24     ios::sync_with_stdio(t);
25 }
26 template<class T1,class T2>T2 convert(T1 a){
27     stringstream s;
28     s<<a;
29     T2 t;
30     s>>t;
31     return t;
32 }
33
34 template<class T1,class T2>ostream&operator<<(ostream&s,const pair<T1,T2>&a
35 ){
36     return s<<a.first<<" "<<a.second;
37 }
38 template<class T1,class T2,class T3>struct triple{
39     triple(T1 a,T2 b,T3 c):
40         first(a),second(b),third(c){
41     }
42     T1 first;
43     T2 second;
44     T3 third;
45 };
46 template<class T1,class T2,class T3>ostream&operator<<(ostream&s,const
47     triple<T1,T2,T3>&a){
48     return s<<a.first<<" "<<a.second<<" "<<a.third;

```

```

47 }
48 template<class T1,class T2,class T3>triple<T1,T2,T3>make_triple(T1 a,T2 b,
    T3 c){
49     return triple<T1,T2,T3>(a,b,c);
50 }
51 template<class T>T sum(triple<T,T,T>a){
52     return a.first+a.second+a.third;
53 }
54 template<class T>T product(triple<T,T,T>a){
55     return a.first*a.second*a.third;
56 }
57 template<class T>vector<T>sort(vector<T>a){
58     sort(a.begin(),a.end());
59     return a;
60 }
61 template<class T,class F>vector<T>foreach(vector<T>a,F f){
62     for(int i=0;i<a.size();++i)
63         f(a[i]);
64     return a;
65 }
66 template<class T>T sum(const vector<T>&a){
67     T r=0;
68     for(int i=0;i<a.size();++i)
69         r+=a[i];
70     return r;
71 }
72 template<class T>T sum(const set<T>&a){
73     T r=0;
74     for(typename set<T>::iterator i=a.begin();i!=a.end();++i)
75         r+=*i;
76     return r;
77 }
78 template<class T>ostream&operator<<(ostream&s,const vector<T>&a){
79     for(int i=0;i<a.size();++i){
80         if(i)
81             cout<<' ';
82         cout<<a[i];
83     }
84     return s;
85 }
86 template<class T>vector<T>unique(vector<T>a){

```

```
87     sort(a.begin(),a.end());
88     a.erase(unique(a.begin(),a.end()),a.end());
89     return a;
90 }
91 template<class T>vector<T>combination(T a){
92     vector<T>r;
93     for(int i=0;i<(1<<a.size());++i){
94         T t;
95         for(int j=0;j<a.size();++j)
96             if((i>>j)&1)
97                 t.push_back(a[j]);
98         r.push_back(t);
99     }
100    return r;
101 }
102 template<class T>vector<T>permutation(T a){
103     sort(a.begin(),a.end());
104     vector<T>r;
105     for(int i=0;i<(1<<a.size());++i){
106         T t;
107         for(int j=0;j<a.size();++j)
108             if((i>>j)&1)
109                 t.push_back(a[j]);
110         do{
111             r.push_back(t);
112         }while(next_permutation(t.begin(),t.end()));
113     }
114     return r;
115 }
116 template<class T>vector<T>permutation(T a,int b){
117     sort(a.begin(),a.end());
118     vector<T>r;
119     for(int i=0;i<(1<<a.size());++i){
120         T t;
121         for(int j=0;j<a.size();++j)
122             if((i>>j)&1)
123                 t.push_back(a[j]);
124         if(t.size()!=b)
125             continue;
126         do{
127             r.push_back(t);
```

```

128         }while(next_permutation(t.begin(),t.end()));
129     }
130     return r;
131 }
132 template<class T>set<T>operator+(set<T>a,set<T>b){
133     for(typename set<T>::iterator i=a.begin();i!=a.end();++i)
134         b.insert(*i);
135     return b;
136 }
137 template<class T>vector<T>operator+(vector<T>a,vector<T>b){
138     for(int i=0;i<b.size();++i)
139         a.push_back(b[i]);
140     return a;
141 }
142 template<class T>set<T>operator&(set<T>a,set<T>b){
143     set<T>c;
144     for(typename set<T>::iterator i=a.begin();i!=a.end();++i)
145         if(b.count(*i))
146             c.insert(*i);
147     return c;
148 }
149 string str(int a){
150     return convert<int,string>(a);
151 }
152 string str(ll a){
153     return convert<ll,string>(a);
154 }
155 int to_int(string a){
156     return convert<string,int>(a);
157 }
158 ll to_ll(string a){
159     return convert<string,ll>(a);
160 }
161 template<class T,class F>vector<T>delete_if(vector<T>a,F b){
162     vector<T>c;
163     for(int i=0;i<a.size();++i)
164         if(!b(a[i]))
165             c.push_back(a[i]);
166     return c;
167 }

```