

Algorithm Library

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头文件

DEBUG 头

```
1  #include <bits/stdc++.h>
2  using namespace std;
3  using i64=long long;
4  using i128=__int128;
5
6  namespace DBG
7  {
8      template <class T>
9      void _dbg(const char *f,T t) { cerr<<f<<'\n'; }
10
11     template <class A,class... B>
12     void _dbg(const char *f,A a,B... b)
13     {
14         while (*f!=',') cerr<<*f++;
15         cerr<<'\n';
16         _dbg(f+1,b...);
17     }
18
19     template <class T>
20     ostream& operator << (ostream& os,const vector<T> &v)
21     {
22         os<<"[ ";
23         for (const auto &x:v) os<<x<<", ";
24         os<<"]";
25         return os;
26     }
27
28     #define dbg(...) _dbg(#__VA_ARGS__, __VA_ARGS__)
29 }
30
31 using namespace DBG;
```

__int128 输出流

```
1  ostream &operator << (ostream &os,i128 n)
2  {
3      string s;
4      bool neg=n<0;
5      if (neg) n=-n;
6      while (n)
7      {
8          s+='0'+n%10;
9          n/=10;
10     }
11     if (neg) s+='-';
12     reverse(s.begin(),s.end());
13     if (s.empty()) s+='0';
14     return os<<s;
15 }
```

常用数学函数

```
1  i64 ceilDiv(i64 n,i64 m)
2  {
3      if (n>=0) return (n+m-1)/m;
4      else return n/m;
5  }
6
7  i64 floorDiv(i64 n,i64 m)
8  {
9      if (n>=0) return n/m;
10     else return (n-m+1)/m;
11 }
12
13 i128 gcd(i128 a,i128 b)
14 {
```

```

15     return b?gcd(b,a%b):a;
16 }

```

数学

欧拉筛

```

1  vector<int> minp,primes;
2
3  void sieve(int n)
4  {
5      minp.assign(n+1,0);
6      primes.clear();
7      for (int i=2;i<=n;i++)
8      {
9          if (!minp[i])
10             {
11                 minp[i]=i;
12                 primes.push_back(i);
13             }
14             for (auto p:primes)
15             {
16                 if (i*p>n) break;
17                 minp[i*p]=p;
18                 if (p==minp[i]) break;
19             }
20     }
21 }

```

取模类 (MInt)

```

1  template <class T>
2  constexpr T power(T a,i64 b)
3  {
4      T res=1;
5      for (;b>=1,a*=a)
6          if (b&1) res*=a;
7      return res;
8  }
9
10 template <int P>
11 struct MInt
12 {
13     int x;
14     constexpr MInt():x{} {}
15     constexpr MInt(i64 x):x{norm(x%getMod())} {}
16
17     static int Mod;
18     constexpr static int getMod()
19     {
20         if (P>0) return P;
21         else return Mod;
22     }
23
24     constexpr static void setMod(int Mod_) { Mod=Mod_; }
25
26     constexpr int norm(int x) const
27     {
28         if (x<0) x+=getMod();
29         if (x>=getMod()) x-=getMod();
30         return x;
31     }
32
33     constexpr int val() const { return x; }
34
35     explicit constexpr operator int () const { return x; }
36
37     constexpr MInt operator - () const
38     {

```

```

39     MInt res;
40     res.x=norm(getMod()-x);
41     return res;
42 }
43
44 constexpr MInt inv() const
45 {
46     assert(x!=0);
47     return power(*this,getMod()-2);
48 }
49
50 constexpr MInt &operator *= (MInt rhs) &
51 {
52     x=1ll*x*rhs.x%getMod();
53     return *this;
54 }
55
56 constexpr MInt &operator += (MInt rhs) &
57 {
58     x=norm(x+rhs.x);
59     return *this;
60 }
61
62 constexpr MInt &operator -= (MInt rhs) &
63 {
64     x=norm(x-rhs.x);
65     return *this;
66 }
67
68 constexpr MInt &operator /= (MInt rhs) &
69 {
70     return *this*=rhs.inv();
71 }
72
73 friend constexpr MInt operator * (MInt lhs,MInt rhs)
74 {
75     MInt res=lhs;
76     res*=rhs;
77     return res;
78 }
79
80 friend constexpr MInt operator + (MInt lhs,MInt rhs)
81 {
82     MInt res=lhs;
83     res+=rhs;
84     return res;
85 }
86
87 friend constexpr MInt operator - (MInt lhs,MInt rhs)
88 {
89     MInt res=lhs;
90     res-=rhs;
91     return res;
92 }
93
94 friend constexpr MInt operator / (MInt lhs,MInt rhs)
95 {
96     MInt res=lhs;
97     res/=rhs;
98     return res;
99 }
100
101 friend constexpr istream &operator >> (istream &is,MInt &a)
102 {
103     i64 v;
104     is>>v;
105     a=MInt(v);
106     return is;
107 }
108
109 friend constexpr ostream &operator << (ostream &os,const MInt &a) { return os<<a.val(); }

```

```

110
111     friend constexpr bool operator == (MInt lhs, MInt rhs) { return lhs.val() == rhs.val(); }
112
113     friend constexpr bool operator != (MInt lhs, MInt rhs) { return lhs.val() != rhs.val(); }
114 };
115
116 template<>
117 int MInt<0>::Mod=1;
118
119 template<int V, int P>
120 constexpr MInt<P> CInv=MInt<P>(V).inv();

```

组合数

```

1  struct Comb
2  {
3      int n;
4      vector<Z> _fac, _inv, _finv;
5
6      Comb():n{0}, _fac{1}, _inv{0}, _finv{1}{}
7      Comb(int n):Comb() { init(n); }
8
9      void init(int m)
10     {
11         m=min(m, Z::getMod()-1);
12         if (m<=n) return;
13         _fac.resize(m+1);
14         _inv.resize(m+1);
15         _finv.resize(m+1);
16
17         for (int i=n+1; i<=m; i++)
18             _fac[i]=_fac[i-1]*i;
19         _finv[m]=_fac[m].inv();
20         for (int i=m; i>n; i--)
21         {
22             _finv[i-1]=_finv[i]*i;
23             _inv[i]=_finv[i]*_fac[i-1];
24         }
25         n=m;
26     }
27
28     Z fac(int m)
29     {
30         if (m>n) init(m<<1);
31         return _fac[m];
32     }
33
34     Z finv(int m)
35     {
36         if (m>n) init(m<<1);
37         return _finv[m];
38     }
39
40     Z inv(int m)
41     {
42         if (m>n) init(m<<1);
43         return _inv[m];
44     }
45
46     Z binom(int n, int m)
47     {
48         if (n<m || m<0) return 0;
49         return fac(n)*finv(m)*finv(n-m);
50     }
51 } comb;

```

多项式

```

1  vector<int> rev;
2  vector<Z> roots{0,1};

```

```

3
4 void dft(vector<Z> &a)
5 {
6     int n=a.size();
7     if (int(rev.size())!=n)
8     {
9         int k=__builtin_ctz(n)-1;
10        rev.resize(n);
11        for (int i=0;i<n;i++)
12            rev[i]=rev[i>>1]>>1|(i&1)<<k;
13    }
14    for (int i=0;i<n;i++)
15        if (rev[i]<i)
16            swap(a[i],a[rev[i]]);
17    if (int(roots.size())<n)
18    {
19        int k=__builtin_ctz(roots.size());
20        roots.resize(n);
21        while ((1<<k)<n)
22        {
23            Z e=power(Z(3),(P-1)>>(k+1));
24            for (int i=1<<(k-1);i<(1<<k);i++)
25            {
26                roots[i<<1]=roots[i];
27                roots[i<<1|1]=roots[i]*e;
28            }
29            k++;
30        }
31    }
32    for (int k=1;k<n;k<<=1)
33        for (int i=0;i<n;i+=k*2)
34            for (int j=0;j<k;j++)
35            {
36                Z u=a[i+j],v=a[i+j+k]*roots[j+k];
37                a[i+j]=u+v;
38                a[i+j+k]=u-v;
39            }
40 }
41
42 void idft(vector<Z> &a)
43 {
44     int n=a.size();
45     reverse(a.begin()+1,a.end());
46     dft(a);
47     Z inv=(1-P)/n;
48     for (int i=0;i<n;i++) a[i]*=inv;
49 }
50
51 struct Poly
52 {
53     vector<Z> a;
54
55     Poly(){}
56     explicit Poly(int size,function<Z(int)>f=[](int) { return 0; }):a(size)
57     { for (int i=0;i<size;i++) a[i]=f(i); }
58     Poly(const vector<Z> &a):a(a){}
59     Poly(const initializer_list<Z> &a):a(a){}
60
61     int size() const { return a.size(); }
62
63     void resize(int n) { a.resize(n); }
64
65     Z operator [] (int idx) const
66     {
67         if (idx<size()) return a[idx];
68         else return 0;
69     }
70
71     Z &operator [] (int idx) { return a[idx]; }
72
73     Poly mulxk(int k) const

```

```

74 {
75     auto b=a;
76     b.insert(b.begin(),k,0);
77     return Poly(b);
78 }
79
80 Poly modxk(int k) const
81 {
82     k=min(k,size());
83     return Poly(vector<Z>(a.begin(),a.begin()+k));
84 }
85
86 Poly divxk(int k) const
87 {
88     if (size()<=k) return Poly();
89     return Poly(vector<Z>(a.begin()+k,a.end()));
90 }
91
92 friend Poly operator + (const Poly &a,const Poly &b)
93 {
94     vector<Z> res(max(a.size(),b.size()));
95     for (int i=0;i<int(res.size());i++)
96         res[i]=a[i]+b[i];
97     return Poly(res);
98 }
99
100 friend Poly operator - (const Poly &a,const Poly &b)
101 {
102     vector<Z> res(max(a.size(),b.size()));
103     for (int i=0;i<int(res.size());i++)
104         res[i]=a[i]-b[i];
105     return Poly(res);
106 }
107
108 friend Poly operator - (const Poly &a)
109 {
110     vector<Z> res(a.size());
111     for (int i=0;i<int(res.size());i++)
112         res[i]=-a[i];
113     return Poly(res);
114 }
115
116 friend Poly operator * (Poly a,Poly b)
117 {
118     if (!a.size()||!b.size()) return Poly();
119     if (a.size()<b.size()) swap(a,b);
120     if (b.size()<128)
121     {
122         Poly c(a.size()+b.size()-1);
123         for (int i=0;i<a.size();i++)
124             for (int j=0;j<b.size();j++)
125                 c[i+j]+=a[i]*b[j];
126         return c;
127     }
128     int sz=1,tot=a.size()+b.size()-1;
129     while (sz<tot) sz<<=1;
130     a.a.resize(sz);
131     b.a.resize(sz);
132     dft(a.a);
133     dft(b.a);
134     for (int i=0;i<sz;i++)
135         a.a[i]=a[i]*b[i];
136     idft(a.a);
137     a.a.resize(tot);
138     return a;
139 }
140
141 friend Poly operator * (Z a,Poly b)
142 {
143     for (int i=0;i<int(b.size());i++) b[i]*=a;
144     return b;

```



```

145     }
146
147     friend Poly operator * (Poly a,Z b)
148     {
149         for (int i=0;i<int(a.size());i++) a[i]*=b;
150         return a;
151     }
152
153     Poly &operator += (Poly b) { return (*this)=(*this)+b; }
154     Poly &operator -= (Poly b) { return (*this)=(*this)-b; }
155     Poly &operator *= (Poly b) { return (*this)=(*this)*b; }
156     Poly &operator *= (Z b) { return (*this)=(*this)*b; }
157
158     Poly deriv() const
159     {
160         if (a.empty()) return Poly();
161         vector<Z> res(size()-1);
162         for (int i=0;i<size()-1;i++)
163             res[i]=(i+1)*a[i+1];
164         return Poly(res);
165     }
166
167     Poly integr() const
168     {
169         vector<Z> res(size()+1);
170         for (int i=0;i<size();i++)
171             res[i+1]=a[i]/(i+1);
172         return Poly(res);
173     }
174
175     Poly inv(int m) const
176     {
177         Poly x{a[0].inv()};
178         int k=1;
179         while (k<m)
180         {
181             k<<=1;
182             x=(x*(Poly{2}-modxk(k)*x)).modxk(k);
183         }
184         return x.modxk(m);
185     }
186
187     Poly ln(int m) const { return (deriv()*inv(m)).integr().modxk(m); }
188
189     Poly exp(int m) const
190     {
191         Poly x{1};
192         int k=1;
193         while (k<m)
194         {
195             k<<=1;
196             x=(x*(Poly{1}-x.ln(k)+modxk(k))).modxk(k);
197         }
198         return x.modxk(m);
199     }
200
201     Poly pow(int k,int m) const
202     {
203         int i=0;
204         while (i<size()&&a[i].val()==0) i++;
205         if (i==size()||1ll*i*k>=m) return Poly(vector<Z>(m));
206         Z v=a[i];
207         auto f=divxk(i)*v.inv();
208         return (f.ln(m-i*k)*k).exp(m-i*k).mulxk(i*k)*power(v,k);
209     }
210
211     Poly sqrt(int m) const
212     {
213         Poly x{1};
214         int k=1;
215         while (k<m)

```

```

216     {
217         k<=1;
218         x=(x+(modxk(k)*x.inv(k)).modxk(k))*((P+1)/2);
219     }
220     return x.modxk(m);
221 }
222 Poly mult(Poly b) const
223 {
224     if (b.size()==0) return Poly();
225     int n=b.size();
226     reverse(b.a.begin(),b.a.end());
227     return ((*this)*b).divxk(n-1);
228 }
229
230 vector<Z> eval(vector<Z> x) const
231 {
232     if (size()==0) return vector<Z>(x.size(),0);
233     const int n=max(int(x.size()),size());
234     vector<Poly> q(n<<2);
235     vector<Z> ans(x.size());
236     x.resize(n);
237     function<void(int,int,int)> build=[&](int p,int l,int r)
238     {
239         if (r-l==1) q[p]=Poly{1,-x[l]};
240         else
241         {
242             int m=(l+r)>>1;
243             build(p<<1,l,m);
244             build(p<<1|1,m,r);
245             q[p]=q[p<<1]*q[p<<1|1];
246         }
247     };
248     function<void(int,int,int,const Poly&)> work=[&](int p,int l,int r,const Poly &num)
249     {
250         if (r-l==1)
251         {
252             if (l<int(ans.size())) ans[l]=num[0];
253         }
254         else
255         {
256             int m=(l+r)>>1;
257             work(p<<1,l,m,num.mult(q[p<<1|1]).modxk(m-l));
258             work(p<<1|1,m,r,num.mult(q[p<<1]).modxk(r-m));
259         }
260     };
261     build(1,0,n);
262     work(1,0,n,mult(q[1].inv(n)));
263     return ans;
264 }
265 };

```

线性基

```

1  struct LB
2  {
3      static constexpr int L=60;
4      array<i64,L+1> a{};
5
6      LB(){}
7
8      LB(const vector<i64> &v) { init(v); }
9
10     bool insert(i64 t)
11     {
12         for (int i=L;i>=0;i--)
13             if (t&(1ll<<i))
14             {
15                 if (!a[i])
16                 {
17                     a[i]=t;
18                     return 1;

```

```

19         }
20         else t^=a[i];
21     }
22     return 0;
23 }
24
25 void init(const vector<i64> &v) { for (auto x:v) insert(x); }
26
27 bool check(i64 t)
28 {
29     for (int i=L;i>=0;i--)
30         if (t&(1ll<<i))
31             if (!a[i]) return 0;
32             else t^=a[i];
33     return 1;
34 }
35
36 i64 QueryMax()
37 {
38     i64 res=0;
39     for (int i=L;i>=0;i--)
40         res=max(res,res^a[i]);
41     return res;
42 }
43
44 i64 QueryMin()
45 {
46     for (int i=0;i<=L;i++)
47         if (a[i]) return a[i];
48     return 0;
49 }
50
51 i64 QueryKth(int k)
52 {
53     i64 res=0;
54     int cnt=0;
55     array<i64,L+1> tmp{};
56     for (int i=0;i<=L;i++)
57     {
58         for (int j=i-1;j>=0;j--)
59             if (a[i]&(1ll<<j)) a[i]^=a[j];
60         if (a[i]) tmp[cnt++]=a[i];
61     }
62     if (k>=(1ll<<cnt)) return -1;
63     for (int i=0;i<cnt;i++)
64         if (k&(1ll<<i)) res^=tmp[i];
65     return res;
66 }
67 };

```

原根表

1	prime	r	k	g
2	3	1	1	2
3	5	1	2	2
4	17	1	4	3
5	97	3	5	5
6	193	3	6	5
7	257	1	8	3
8	7681	15	9	17
9	12289	3	12	11
10	40961	5	13	3
11	65537	1	16	3
12	786433	3	18	10
13	5767169	11	19	3
14	7340033	7	20	3
15	23068673	11	21	3
16	104857601	25	22	3
17	167772161	5	25	3
18	469762049	7	26	3
19	1004535809	479	21	3

```

20 2013265921      15 27 31
21 2281701377      17 27 3
22 3221225473      3 30 5
23 75161927681     35 31 3
24 77309411329     9 33 7
25 206158430209    3 36 22
26 2061584302081   15 37 7
27 2748779069441   5 39 3
28 6597069766657   3 41 5
29 39582418599937   9 42 5
30 79164837199873   9 43 5
31 263882790666241 15 44 7
32 1231453023109121 35 45 3
33 1337006139375617 19 46 3
34 3799912185593857 27 47 5
35 4222124650659841 15 48 19
36 7881299347898369 7 50 6
37 31525197391593473 7 52 3
38 180143985094819841 5 55 6
39 1945555039024054273 27 56 5
40 4179340454199820289 29 57 3
41

```

数据结构

并查集（启发式合并 + 带撤销）

```

1 struct DSU
2 {
3     int n=0;
4     vector<int> fa,siz;
5     stack<int> s;
6
7     DSU(int n) { init(n); }
8
9     void init(int n)
10    {
11        fa.resize(n);
12        iota(fa.begin(),fa.end(),0);
13        siz.assign(n,1);
14        while (!s.empty()) s.pop();
15    }
16
17    int get(int x) { return fa[x]==x?x:get(fa[x]); }
18
19    void merge(int x,int y)
20    {
21        x=get(x),y=get(y);
22        if (x==y) return;
23        if (siz[x]<siz[y]) swap(x,y);
24        s.push(y),fa[y]=x,siz[x]+=siz[y];
25    }
26
27    void undo()
28    {
29        if (s.empty()) return;
30        int y=s.top();
31        s.pop();
32        siz[fa[y]]-=siz[y];
33        fa[y]=y;
34    }
35
36    void back(int t=0) { while (s.size()>t) undo(); }
37 };

```

状压 RMQ

```

1 template <class T,class Cmp=less<T>>
2 struct RMQ

```

```

3 {
4     const Cmp cmp=Cmp();
5     static constexpr unsigned B=64;
6     using u64=unsigned long long;
7     int n;
8     vector<vector<T>> > a;
9     vector<T> pre,suf,ini;
10    vector<u64> stk;
11
12    RMQ() {}
13    RMQ(const vector<T> &v) { init(v); }
14
15    void init(const vector<T> &v)
16    {
17        n=v.size();
18        pre=suf=ini=v;
19        stk.resize(n);
20        if (!n) return;
21        const int M=(n-1)/B+1;
22        const int lg=__lg(M);
23        a.assign(lg+1,vector<T>(M));
24        for (int i=0;i<M;i++)
25        {
26            a[0][i]=v[i*B];
27            for (int j=1;j<B&& i*B+j<n;j++)
28                a[0][i]=min(a[0][i],v[i*B+j],cmp);
29        }
30        for (int i=1;i<n;i++)
31            if (i%B) pre[i]=min(pre[i],pre[i-1],cmp);
32        for (int i=n-2;i>=0;i--)
33            if (i%B!=B-1) suf[i]=min(suf[i],suf[i+1],cmp);
34        for (int j=0;j<lg;j++)
35            for (int i=0;i+(2<<j)<=M;i++)
36                a[j+1][i]=min(a[j][i],a[j][i+(1<<j)],cmp);
37        for (int i=0;i<M;i++)
38        {
39            const int l=i*B;
40            const int r=min(1U*n,l+B);
41            u64 s=0;
42            for (int j=l;j<r;j++)
43            {
44                while (s&&cmp(v[j],v[__lg(s)+l])) s|=1ULL<<__lg(s);
45                s|=1ULL<<(j-l);
46                stk[j]=s;
47            }
48        }
49    }
50
51    //查询区间 [l,r) 的 RMQ
52    T operator()(int l,int r)
53    {
54        if (l/B!=(r-1)/B)
55        {
56            T ans=min(suf[l],pre[r-1],cmp);
57            l=l/B+1,r=r/B;
58            if (l<r)
59            {
60                int k=__lg(r-l);
61                ans=min({ans,a[k][l],a[k][r-(1<<k)]},cmp);
62            }
63            return ans;
64        }
65        else
66        {
67            int x=B*(l/B);
68            return ini[__builtin_ctzll(stk[r-1]>>(l-x))+l];
69        }
70    }
71 };

```

树状数组

```
1  template <class T>
2  struct BIT
3  {
4      int n;
5      vector<T> a;
6
7      BIT(int n_=0) { init(n_); }
8
9      void init(int n_)
10     {
11         n=n_;
12         a.assign(n,T{});
13     }
14
15     void add(int x,const T &v)
16     {
17         for (int i=x+1;i<=n;i+=i&-i)
18             a[i-1]=a[i-1]+v;
19     }
20
21     //查询区间 [0,x)
22     T sum(int x)
23     {
24         T ans{};
25         for (int i=x;i>0;i-=i&-i)
26             ans=ans+a[i-1];
27         return ans;
28     }
29
30     //查询区间 [l,r)
31     T rangeSum(int l,int r) { return sum(r)-sum(l); }
32
33     int select(const T &k)
34     {
35         int x=0;
36         T cur{};
37         for (int i=1<<__lg(n);i;i>>=1)
38         {
39             if (x+i<=n&&cur+a[x+i-1]<=k)
40             {
41                 x+=i;
42                 cur=cur+a[x-1];
43             }
44         }
45         return x;
46     }
47 };
```

线段树

```
1  template <class Info,class Tag>
2  struct SGT
3  {
4      int n;
5      vector<Info> info;
6      vector<Tag> tag;
7
8      SGT():n(0) {}
9      SGT(int n_,Info v_=Info()) { init(n_,v_); }
10
11     template <class T>
12     SGT(vector<T> init_) { init(init_); }
13
14     void init(int n_,Info v_=Info()) { init(vector(n_,v_)); }
15
16     template <class T>
17     void init(vector<T> init_)
18     {
19         n=init_.size();
```

```

20     info.assign(4<<__lg(n),Info());
21     tag.assign(4<<__lg(n),Tag());
22     function<void(int,int,int)> build=[&](int p,int l,int r)
23     {
24         if (r-l==1)
25         {
26             info[p]=init_[l];
27             return;
28         }
29         int m=(l+r)>>1;
30         build(p<<1,l,m);
31         build(p<<1|1,m,r);
32         pushup(p);
33     };
34     build(1,0,n);
35 }
36
37 void pushup(int p) { info[p]=info[p<<1]+info[p<<1|1]; }
38
39 void apply(int p,const Tag &v)
40 {
41     info[p].apply(v);
42     tag[p].apply(v);
43 }
44
45 void pushdown(int p)
46 {
47     apply(p<<1,tag[p]);
48     apply(p<<1|1,tag[p]);
49     tag[p]=Tag();
50 }
51
52 void modify(int p,int l,int r,int x,const Info &v)
53 {
54     if (r-l==1)
55     {
56         info[p]=v;
57         return;
58     }
59     int m=(l+r)>>1;
60     pushdown(p);
61     if (x<m) modify(p<<1,l,m,x,v);
62     else modify(p<<1|1,m,r,x,v);
63     pushup(p);
64 }
65
66 //O(log n) 单点修改
67 void modify(int p,const Info &v) { modify(1,0,n,p,v); }
68
69 Info rangeQuery(int p,int l,int r,int x,int y)
70 {
71     if (l>=y||r<=x) return Info();
72     if (l>=x&&r<=y) return info[p];
73     int m=(l+r)>>1;
74     pushdown(p);
75     return rangeQuery(p<<1,l,m,x,y)+rangeQuery(p<<1|1,m,r,x,y);
76 }
77
78 //O(log n) 区间查询 [l,r)
79 Info rangeQuery(int l,int r) { rangeQuery(1,0,n,l,r); }
80
81 void rangeApply(int p,int l,int r,int x,int y,const Tag &v)
82 {
83     if (l>=y||r<=x) return;
84     if (l>=x&&r<=y)
85     {
86         apply(p,v);
87         return;
88     }
89     int m=(l+r)>>1;
90     pushdown(p);

```

```

91     rangeApply(p<<1,l,m,x,y,v);
92     rangeApply(p<<1|1,m,r,x,y,v);
93     pushup(p);
94 }
95
96 //O(log n) 区间操作 [l,r)
97 void rangeApply(int l,int r,const Tag &v) { rangeApply(1,0,n,l,r,v); }
98
99 //O(log n) 区间 [l,r) 内查找第一个合法位置
100 template <class F>
101 int findFirst(int p,int l,int r,int x,int y,F pred)
102 {
103     if (l>=y||r<=x||!pred(info[p])) return -1;
104     if (r-l==1) return l;
105     int m=(l+r)>>1;
106     pushdown(p);
107     int res=findFirst(p<<1,l,m,x,y,pred);
108     if (res==-1) res=findFirst(p<<1|1,m,r,x,y,pred);
109     return res;
110 }
111
112 template <class F>
113 int findFirst(int l,int r,F pred) { return findFirst(1,0,n,l,r,pred); }
114
115 template <class F>
116 int findLast(int p,int l,int r,int x,int y,F pred)
117 {
118     if (l>=y||r<=x||!pred(info[p])) return -1;
119     if (r-l==1) return l;
120     int m=(l+r)>>1;
121     pushdown(p);
122     int res=findFirst(p<<1|1,m,r,x,y,pred);
123     if (res==-1) res=findFirst(p<<1,l,m,x,y,pred);
124     return res;
125 }
126
127 template <class F>
128 int findLast(int l,int r,F pred) { return findLast(1,0,n,l,r,pred); }
129 };
130
131 //这里默认乘法优先 (x*a+b)*c+d=x*(a*c)+(b*c+d)
132 struct Tag
133 {
134     i64 a=1,b=0;
135     void apply(Tag t)
136     {
137         a*=t.a;
138         b=b*t.a+t.b;
139     }
140 };
141
142 struct Info
143 {
144     i64 x=0,l=0,r=0;
145     void apply(Tag t)
146     {
147         int len=r-l+1;
148         x=x*t.a+len*t.b;
149     }
150 };
151
152 Info operator + (Info a,Info b)
153 {
154     return {a.x+b.x,min(a.l,b.l),max(a.r,b.r)};
155 }

```


字符串

字符串哈希（随机模数）

```
1 bool isPrime(int n)
2 {
3     if (n<=1) return 0;
4     for (int i=2;i*i<=n;i++)
5         if (n%i==0) return 0;
6     return 1;
7 }
8
9 int findPrime(int n)
10 {
11     while (!isPrime(n)) n++;
12     return n;
13 }
14
15 mt19937 rng(time(0));
16 const int P=findPrime(rng()%9000000000+1000000000);
17 struct StrHash
18 {
19     int n;
20     vector<int> h,p;
21
22     StrHash(const string &s){ init(s); }
23
24     void init(const string &s)
25     {
26         n=s.size();
27         h.resize(n+1);
28         p.resize(n+1);
29         p[0]=1;
30         for (int i=0;i<n;i++) h[i+1]=(10ll*h[i]+s[i]-'a')%P;
31         for (int i=0;i<n;i++) p[i+1]=10ll*p[i]%P;
32     }
33
34     //查询 [l,r) 的区间哈希
35     int get(int l,int r) { return (h[r]+1ll*(P-h[l])*p[r-l])%P; }
36 };
```

KMP

```
1 vector<int> KMP(const string &s)
2 {
3     int now=0;
4     vector<int> pre(s.size(),0);
5     for (int i=1;i<s.size();i++)
6     {
7         while (now&& s[i]!=s[now]) now=pre[now-1];
8         if (s[i]==s[now]) now++;
9         pre[i]=now;
10    }
11    return pre;
12 }
```

Z函数

```
1 vector<int> zFunction(string s)
2 {
3     int n=s.size();
4     vector<int> z(n);
5     z[0]=n;
6     for (int i=1,j=1;i<n;i++)
7     {
8         z[i]=max(0,min(j+z[j]-i,z[i-j]));
9         while (i+z[i]<n&& s[z[i]]==s[i+z[i]]) z[i]++;
10        if (i+z[i]>j+z[j]) j=i;
11    }
```

```

12     return z;
13 }

```

AC 自动机

```

1  struct ACAM
2  {
3      static constexpr int ALPHABET=26;
4      struct Node
5      {
6          int len;
7          int link;
8          array<int,ALPHABET> next;
9          Node():len{0},link{0},next{}{}
10     };
11
12     vector<Node> t;
13
14     ACAM() { init(); }
15
16     void init()
17     {
18         t.assign(2,Node());
19         t[0].next.fill(1);
20         t[0].len=-1;
21     }
22
23     int newNode()
24     {
25         t.emplace_back();
26         return t.size()-1;
27     }
28
29     int add(const string &a)
30     {
31         int p=1;
32         for (auto c:a)
33         {
34             int x=c-'a';
35             if (t[p].next[x]==0)
36             {
37                 t[p].next[x]=newNode();
38                 t[t[p].next[x]].len=t[p].len+1;
39             }
40             p=t[p].next[x];
41         }
42         return p;
43     }
44
45     void work()
46     {
47         queue<int> q;
48         q.push(1);
49         while (!q.empty())
50         {
51             int x=q.front();
52             q.pop();
53             for (int i=0;i<ALPHABET;i++)
54             {
55                 if (t[x].next[i]==0) t[x].next[i]=t[t[x].link].next[i];
56                 else
57                 {
58                     t[t[x].next[i]].link=t[t[x].link].next[i];
59                     q.push(t[x].next[i]);
60                 }
61             }
62         }
63     }
64
65     int next(int p,int x) { return t[p].next[x]; }
66

```

```

67     int link(int p) { return t[p].link; }
68
69     int size() { return t.size(); }
70 };

```

后缀数组

```

1  struct SA
2  {
3      int n;
4      vector<int> sa,rk,lc;
5      SA(const string &s)
6      {
7          n=s.length();
8          sa.resize(n);
9          rk.resize(n);
10         lc.resize(n-1);
11         iota(sa.begin(),sa.end(),0);
12         sort(sa.begin(),sa.end(),[&](int a,int b){ return s[a]<s[b]; });
13         rk[sa[0]]=0;
14         for (int i=1;i<n;i++) rk[sa[i]]=rk[sa[i-1]]+(s[sa[i]]!=s[sa[i-1]]);
15         int k=1;
16         vector<int> tmp,cnt(n);
17         tmp.reserve(n);
18         while (rk[sa[n-1]]<n-1)
19         {
20             tmp.clear();
21             for (int i=0;i<k;i++) tmp.push_back(n-k+i);
22             for (auto i:sa)
23                 if (i>=k) tmp.push_back(i-k);
24             fill(cnt.begin(),cnt.end(),0);
25             for (int i=0;i<n;i++) cnt[rk[i]]++;
26             for (int i=1;i<n;i++) cnt[i]+=cnt[i-1];
27             for (int i=n-1;i>=0;i--) sa[--cnt[rk[tmp[i]]]]=tmp[i];
28             swap(rk,tmp);
29             rk[sa[0]]=0;
30             for (int i=1;i<n;i++)
31                 rk[sa[i]]=rk[sa[i-1]]+(tmp[sa[i-1]]<tmp[sa[i]] || sa[i-1]+k==n || tmp[sa[i-1]+k]<tmp[sa[i]+k]);
32             k<=1;
33         }
34         for (int i=0,j=0;i<n;i++)
35         {
36             if (rk[i]==0) j=0;
37             else
38             {
39                 for (j=j>0;i+j<n&&sa[rk[i]-1]+j<n&&s[i+j]==s[sa[rk[i]-1]+j];) j++;
40                 lc[rk[i]-1]=j;
41                 //lc[i]:lcp(sa[i],sa[i+1]),lcp(sa[i],sa[j])=min{lc[i...j-1]}
42             }
43         }
44 };

```

(广义) 后缀自动机

```

1  struct SAM
2  {
3      static constexpr int ALPHABET=26;
4      struct Node
5      {
6          int len;
7          int link;
8          array<int,ALPHABET> next;
9          Node():len{},link{},next{} {}
10     };
11
12     vector<Node> t;
13
14     SAM() { init(); }
15
16     void init()

```

```

17     {
18         t.assign(2,Node());
19         t[0].next.fill(1);
20         t[0].len=-1;
21     }
22
23     int newNode()
24     {
25         t.emplace_back();
26         return t.size()-1;
27     }
28
29     int extend(int lst,int c)
30     {
31         if (t[lst].next[c]&& t[t[lst].next[c]].len==t[lst].len+1)
32             return t[lst].next[c];
33         int p=lst,np=newNode(),flag=0;
34         t[np].len=t[p].len+1;
35         while (!t[p].next[c])
36         {
37             t[p].next[c]=np;
38             p=t[p].link;
39         }
40         if (!p)
41         {
42             t[np].link=1;
43             return np;
44         }
45         int q=t[p].next[c];
46         if (t[q].len==t[p].len+1)
47         {
48             t[np].link=q;
49             return np;
50         }
51         if (p==lst) flag=1,np=0,t.pop_back();
52         int nq=newNode();
53         t[nq].link=t[q].link;
54         t[nq].next=t[q].next;
55         t[nq].len=t[p].len+1;
56         t[q].link=t[np].link=nq;
57         while (p&& t[p].next[c]==q)
58         {
59             t[p].next[c]=nq;
60             p=t[p].link;
61         }
62         return flag?nq:np;
63     }
64
65     int add(const string &a)
66     {
67         int p=1;
68         for (auto c:a) p=extend(p,c-'a');
69         return p;
70     }
71
72     int next(int p,int x) { return t[p].next[x]; }
73
74     int link(int p) { return t[p].link; }
75
76     int len(int p) { return t[p].len; }
77
78     int size() { return t.size(); }
79 };

```

Manacher

```

1 vector<int> manacher(vector<int> s)
2 {
3     vector<int> t{0};
4     for (auto c:s)
5     {

```

```

6         t.push_back(c);
7         t.push_back(0);
8     }
9     int n=t.size();
10    vector<int> r(n);
11    for (int i=0,j=0;i<n;i++)
12    {
13        if (j*2-i>=0&&j+r[j]>i) r[i]=min(r[j*2-i],j+r[j]-i);
14        while (i-r[i]>=0&&i+r[i]<n&&t[i-r[i]]==t[i+r[i]]) r[i]++;
15        if (i+r[i]>j+r[j]) j=i;
16    }
17    return r;
18 }

```

回文自动机

```

1  struct PAM
2  {
3      static constexpr int ALPHABET_SIZE=28;
4      struct Node
5      {
6          int len,link,cnt;
7          array<int,ALPHABET_SIZE> next;
8          Node():len{},link{},cnt{},next{}{}
9      };
10     vector<Node> t;
11     int suff;
12     string s;
13
14     PAM() { init(); }
15
16     void init()
17     {
18         t.assign(2,Node());
19         t[0].len=-1;
20         suff=1;
21         s.clear();
22     }
23
24     int newNode()
25     {
26         t.emplace_back();
27         return t.size()-1;
28     }
29
30     bool add(char c,char offset='a')
31     {
32         int pos=s.size();
33         s+=c;
34         int let=c-offset;
35         int cur=suff,curlen=0;
36         while (1)
37         {
38             curlen=t[cur].len;
39             if (pos-curlen-1>=0&&s[pos-curlen-1]==s[pos]) break;
40             cur=t[cur].link;
41         }
42         if (t[cur].next[let])
43         {
44             suff=t[cur].next[let];
45             return 0;
46         }
47         int num=newNode();
48         suff=num;
49         t[num].len=t[cur].len+2;
50         t[cur].next[let]=num;
51         if (t[num].len==1)
52         {
53             t[num].link=t[num].cnt=1;
54             return 1;
55         }

```

```

56     while (1)
57     {
58         cur=t[cur].link;
59         curlen=t[cur].len;
60         if (pos-curlen-1>=0&&s[pos-curlen-1]==s[pos])
61         {
62             t[num].link=t[cur].next[let];
63             break;
64         }
65     }
66     t[num].cnt=t[t[num].link].cnt+1;
67     return 1;
68 }
69 };

```

图论

强连通分量

```

1  struct SCC
2  {
3      int n,cur,cnt;
4      vector<vector<int>> adj;
5      vector<int> stk,dfn,low,bel;
6
7      SCC() {}
8      SCC(int n) { init(n); }
9
10     void init(int n)
11     {
12         this->n=n;
13         adj.assign(n,{});
14         stk.clear();
15         dfn.assign(n,-1);
16         low.resize(n);
17         bel.assign(n,-1);
18         cur=cnt=0;
19     }
20
21     void add(int u,int v) { adj[u].push_back(v); }
22
23     void dfs(int x)
24     {
25         dfn[x]=low[x]=cur++;
26         stk.push_back(x);
27         for (auto y:adj[x])
28         {
29             if (dfn[y]==-1)
30             {
31                 dfs(y);
32                 low[x]=min(low[x],low[y]);
33             }
34             else if (bel[y]==-1) low[x]=min(low[x],dfn[y]);
35         }
36         if (dfn[x]==low[x])
37         {
38             int y;
39             do
40             {
41                 y=stk.back();
42                 bel[y]=cnt;
43                 stk.pop_back();
44             } while (y!=x);
45             cnt++;
46         }
47     }
48
49     vector<int> work()
50     {
51         for (int i=0;i<n;i++)

```

```

52         if (dfn[i]==-1) dfs(i);
53         return bel;
54     }
55
56     struct Graph
57     {
58         int n;
59         vector<pair<int,int>> edges;
60         vector<int> siz,cnt;
61     };
62
63     Graph compress()
64     {
65         Graph G;
66         G.n=cnt;
67         G.siz.resize(cnt);
68         G.cnt.resize(cnt);
69         for (int i=0;i<n;i++)
70         {
71             G.siz[bel[i]]++;
72             for (auto j:adj[i])
73                 if (bel[i]!=bel[j])
74                     G.edges.emplace_back(bel[j],bel[i]);
75         }
76         return G;
77     };
78 };

```

边双连通分量

```

1  struct EBCC
2  {
3      int n;
4      vector<vector<int>> adj;
5      vector<int> stk,dfn,low,bel;
6      int cur,cnt;
7
8      EBCC() {}
9      EBCC(int n) { init(n); }
10
11     void init(int n)
12     {
13         this->n=n;
14         adj.assign(n,{});
15         dfn.assign(n,-1);
16         low.resize(n);
17         bel.assign(n,-1);
18         stk.clear();
19         cur=cnt=0;
20     }
21
22     void add(int u,int v)
23     {
24         adj[u].push_back(v);
25         adj[v].push_back(u);
26     }
27
28     void dfs(int x,int p)
29     {
30         dfn[x]=low[x]=cur++;
31         stk.push_back(x);
32         for (auto y:adj[x])
33         {
34             if (y==p) continue;
35             if (dfn[y]==-1)
36             {
37                 dfs(y,x);
38                 low[x]=min(low[x],low[y]);
39             }
40             else if (bel[y]==-1&&dfn[y]<dfn[x]) low[x]=min(low[x],dfn[y]);
41         }

```

```

42         if (dfn[x]==low[x])
43         {
44             int y;
45             do
46             {
47                 y=stk.back();
48                 bel[y]=cnt;
49                 stk.pop_back();
50             } while (y!=x);
51             cnt++;
52         }
53     }
54
55     vector<int> work()
56     {
57         dfs(0,-1);
58         return bel;
59     }
60
61     struct Graph
62     {
63         int n;
64         vector<pair<int,int>> edges;
65         vector<int> siz,cnt;
66     };
67
68     Graph compress()
69     {
70         Graph G;
71         G.n=cnt;
72         G.siz.resize(cnt);
73         G.cnt.resize(cnt);
74         for (int i=0;i<n;i++)
75         {
76             G.siz[bel[i]]++;
77             for (auto j:adj[i])
78             {
79                 if (bel[i]<bel[j]) G.edges.emplace_back(bel[i],bel[j]);
80                 else if (i<j) G.cnt[bel[i]]++;
81             }
82         }
83         return G;
84     };
85 };

```

轻重链剖分

```

1  struct HLD
2  {
3      int n;
4      vector<int> siz,top,dep,pa,in,out,seq;
5      vector<vector<int>> adj;
6      int cur;
7
8      HLD(){}
9      HLD(int n) { init(n); }
10
11     void init(int n)
12     {
13         this->n=n;
14         siz.resize(n);
15         top.resize(n);
16         dep.resize(n);
17         pa.resize(n);
18         in.resize(n);
19         out.resize(n);
20         seq.resize(n);
21         cur=0;
22         adj.assign(n,{});
23     }
24

```



```

25 void addEdge(int u,int v)
26 {
27     adj[u].push_back(v);
28     adj[v].push_back(u);
29 }
30
31 void work(int rt=0)
32 {
33     top[rt]=rt;
34     dep[rt]=0;
35     pa[rt]=-1;
36     dfs1(rt);
37     dfs2(rt);
38 }
39
40 void dfs1(int u)
41 {
42     if (pa[u]!=-1) adj[u].erase(find(adj[u].begin(),adj[u].end(),pa[u]));
43     siz[u]=1;
44     for (auto &v:adj[u])
45     {
46         pa[v]=u;
47         dep[v]=dep[u]+1;
48         dfs1(v);
49         siz[u]+=siz[v];
50         if (siz[v]>siz[adj[u][0]])
51             swap(v,adj[u][0]);
52     }
53 }
54
55 void dfs2(int u)
56 {
57     in[u]=cur++;
58     seq[in[u]]=u;
59     for (auto v:adj[u])
60     {
61         top[v]=(v==adj[u][0])?top[u]:v;
62         dfs2(v);
63     }
64     out[u]=cur;
65 }
66
67 int lca(int u,int v)
68 {
69     while (top[u]!=top[v])
70     {
71         if (dep[top[u]]>dep[top[v]]) u=pa[top[u]];
72         else v=pa[top[v]];
73     }
74     return dep[u]<dep[v]?u:v;
75 }
76
77 int dist(int u,int v) { return dep[u]+dep[v]-(dep[lca(u,v)]<<1); }
78
79 int jump(int u,int k)
80 {
81     if (dep[u]<k) return -1;
82     int d=dep[u]-k;
83     while (dep[top[u]]>d) u=pa[top[u]];
84     return seq[in[u]-dep[u]+d];
85 }
86
87 bool isAncestor(int u,int v) { return in[u]<=in[v]&&in[v]<out[u]; }
88
89 int rootedParent(int u,int v)//u->root,v->point
90 {
91     if (u==v) return u;
92     if (!isAncestor(v,u)) return pa[v];
93     auto it=upper_bound(adj[v].begin(),adj[v].end(),u,[&](int x,int y){ return in[x]<in[y]; })-1;
94     return *it;
95 }

```

```

96
97     int rootedSize(int u,int v)//same as rootedParent
98     {
99         if (u==v) return n;
100        if (!isAncestor(v,u)) return siz[v];
101        return n-siz[rootedParent(u,v)];
102    }
103
104    int rootedLca(int a,int b,int c) { return lca(a,b)^lca(b,c)^lca(c,a); }
105 };

```

2-SAT

```

1  struct TwoSat
2  {
3      int n;
4      vector<vector<int>> e;
5      vector<bool> ans;
6
7      TwoSat(int n):n(n),e(n<<1),ans(n){}
8
9      void addClause(int u,bool f,int v,bool g)
10     {
11         e[u*2+!f].push_back(v*2+g);
12         e[v*2+!g].push_back(u*2+f);
13     }
14
15     bool satisfiable()
16     {
17         vector<int> id(n*2,-1),dfn(n*2,-1),low(n*2,-1),stk;
18         int now=0,cnt=0;
19         function<void(int)> tarjan=[&](int u)
20         {
21             stk.push_back(u);
22             dfn[u]=low[u]=now++;
23             for (auto v:e[u])
24             {
25                 if (dfn[v]==-1)
26                 {
27                     tarjan(v);
28                     low[u]=min(low[u],low[v]);
29                 }
30                 else if (id[v]==-1)
31                     low[u]=min(low[u],dfn[v]);
32             }
33             if (dfn[u]==low[u])
34             {
35                 int v;
36                 do
37                 {
38                     v=stk.back();
39                     stk.pop_back();
40                     id[v]=cnt;
41                 } while (v!=u);
42                 cnt++;
43             }
44         };
45         for (int i=0;i<n*2;i++)
46             if (dfn[i]==-1)
47                 tarjan(i);
48         for (int i=0;i<n;i++)
49         {
50             if (id[i*2]==id[i*2+1]) return 0;
51             ans[i]=id[i*2]>id[i*2+1];
52         }
53         return 1;
54     }
55     vector<bool> answer() { return ans; }
56 };

```

计算几何

EPS

```
1  const double eps=1e-8;
2  int sgn(double x)
3  {
4      if (fabs(x)<eps) return 0;
5      if (x>0) return 1;
6      return -1;
7  }
```

Point

```
1  template <class T>
2  struct Point
3  {
4      T x,y;
5      Point(T x_=0,T y_=0):x(x_),y(y_) {}
6
7      Point &operator += (Point p) &
8      {
9          x+=p.x;
10         y+=p.y;
11         return *this;
12     }
13
14     Point &operator -= (Point p) &
15     {
16         x-=p.x;
17         y-=p.y;
18         return *this;
19     }
20
21     Point &operator *= (T v) &
22     {
23         x*=v;
24         y*=v;
25         return *this;
26     }
27
28     Point operator - () const { return Point(-x,-y); }
29
30     friend Point operator + (Point a,Point b) { return a+=b; }
31     friend Point operator - (Point a,Point b) { return a-=b; }
32     friend Point operator * (Point a,T b) { return a*=b; }
33     friend Point operator * (T a,Point b) { return b*=a; }
34
35     friend bool operator == (Point a,Point b) { return a.x==b.x&& a.y==b.y; }
36
37     friend istream &operator >> (istream &is,Point &p) { return is>>p.x>>p.y; }
38
39     friend ostream &operator << (ostream &os,Point p) { return os<<'('<<p.x<<','<<p.y<<')'; }
40 };
41
42 template <class T>
43 T dot(Point<T> a,Point<T> b) { return a.x*b.x+a.y*b.y; }
44
45 template <class T>
46 T cross(Point<T> a,Point<T> b) { return a.x*b.y-a.y*b.x; }
47
48 template <class T>
49 T square(Point<T> p) { return dot(p,p); }
50
51 template <class T>
52 double length(Point<T> p) { return sqrt(double(square(p))); }
53
54 long double length(Point<long double> p) { return sqrt(square(p)); }
```

Line

```
1  template <class T>
2  struct Line
3  {
4      Point<T> a,b;
5      Line(Point<T> a_=Point<T>(),Point<T> b_=Point<T>()):a(a_),b(b_) {}
6  };
```

距离

```
1  template <class T>
2  double dis_PP(Point<T> a,Point<T> b) { return length(a-b); }
3
4  template <class T>
5  double dis_PL(Point<T> a,Line<T> l) { return fabs(cross(a-l.a,a-l.b))/dis_PP(l.a,l.b); }
6
7  template <class T>
8  double dis_PS(Point<T> a,Line<T> l)
9  {
10     if (dot(a-l.a,l.b-l.a)<0) return dis_PP(a,l.a);
11     if (dot(a-l.b,l.a-l.b)<0) return dis_PP(a,l.b);
12     return dis_PL(a,l);
13 }
```

点绕中心旋转

```
1  template <class T>
2  Point<T> rotate(Point<T> a,double alpha)
3  { return Point<T>(a.x*cos(alpha)-a.y*sin(alpha),a.x*sin(alpha)+a.y*cos(alpha)); }
```

关于线的对称点

```
1  template <class T>
2  Point<T> lineRoot(Point<T> a,Line<T> l)
3  {
4      Point<T> v=l.b-l.a;
5      return l.a+v*(dot(a-l.a,v)/dot(v,v));
6  }
7
8  template <class T>
9  Point<T> symmetry_PL(Point<T> a,Line<T> l) { return a+(lineRoot(a,l)-a)*2; }
```

位置关系判断

```
1  template <class T>
2  bool pointOnSegment(Point<T> a,Line<T> l)
3  { return (sgn(cross(a-l.a,a-l.b))==0)&&(sgn(dot(a-l.a,a-l.b))<=0); }
4
5  template <class T>
6  bool lineCrossLine(Line<T> a,Line<T> b)
7  {
8      double f1=cross(b.a-a.a,a.b-a.a),f2=cross(b.b-a.a,a.b-a.a);
9      double g1=cross(a.a-b.a,b.b-b.a),g2=cross(a.b-b.a,b.b-b.a);
10     return ((f1<0)^(f2<0))&&((g1<0)^(g2<0));
11 }
12
13 template <class T>
14 bool pointOnLineLeft(Point<T> a,Line<T> l) { return cross(l.b-l.a,a-l.a)>0; }
15
16 //适用任意多边形, O(n)
17 template <class T>
18 bool pointInPolygon(Point<T> a,const vector<Point<T>> &p)
19 {
20     int n=p.size();
21     for (int i=0;i<n;i++)
22         if (pointOnSegment(a,Line<T>(p[i],p[(i+1)%n])))
23             return 1;
24     bool t=0;
```

```

25     for (int i=0;i<n;i++)
26     {
27         Point<T> u=p[i],v=p[(i+1)%n];
28         if (u.x<a.x&&v.x>=a.x&&pointOnLineLeft(a,Line<T>(v,u))) t^=1;
29         if (u.x>=a.x&&v.x<a.x&&pointOnLineLeft(a,Line<T>(u,v))) t^=1;
30     }
31     return t;
32 }
33
34 //适用凸多边形,  $O(\log n)$ 
35 template <class T>
36 bool pointInPolygon_(Point<T> a,const vector<Point<T>> &p)
37 {
38     int n=p.size();
39     if (cross(a-p[0],p[1]-p[0])<0||cross(a-p[0],p[n-1]-p[0])>0) return 0;
40     if (pointOnSegment(a,Line<T>(p[0],p[1]))||pointOnSegment(a,Line<T>(p[n-1],p[0]))) return 1;
41     int l=1,r=n-1;
42     while (l+1<r)
43     {
44         int mid=(l+r)>>1;
45         if (cross(a-p[l],p[mid]-p[l])<0) l=mid;
46         else r=mid;
47     }
48     if (cross(a-p[l],p[r]-p[l])>0) return 0;
49     if (pointOnSegment(a,Line<T>(p[l],p[r]))) return 1;
50     return 1;
51 }

```

线段交点

```

1 //小心平行
2 template <class T>
3 Point<T> lineIntersection(Line<T> a,Line<T> b)
4 {
5     Point<T> u=a.a-b.a,v=a.b-a.a,w=b.b-b.a;
6     double t=cross(u,w)/cross(w,v);
7     return a.a+t*v;
8 }

```

过定点做圆的切线

```

1 template <class T>
2 vector<Line<T>> tan_PC(Point<T> a,Point<T> c,T r)
3 {
4     Point<T> v=c-a;
5     vector<Line<T>> res;
6     int dis=dis_PP(a,c);
7     if (sgn(dis-r)==0) res.push_back(rotate(v,acos(-1)/2));
8     else if (dis>r)
9     {
10         double alpha=asin(r/dis);
11         res.push_back(rotate(v,alpha));
12         res.push_back(rotate(v,-alpha));
13     }
14     return res;
15 }

```

两圆交点

```

1 template <class T>
2 vector<Point<T>> circleIntersection(Point<T> c1,T r1,Point<T> c2,T r2)
3 {
4     auto get=[&](Point<T> c,T r,double alpha)->Point<T>
5     { return Point<T>(c.x+cos(alpha)*r,c.y+sin(alpha)*r); };
6
7     auto angle=[&](Point<T> a)->double { return atan2(a.x,a.y); };
8
9     vector<Point<T>> res;
10    double d=dis_PP(c1,c2);

```

```

11     if (sgn(d)==0) return res;
12     if (sgn(r1+r2-d)<0) return res;
13     if (sgn(fabs(r1-r2)-d)>0) return res;
14     double alpha=angle(c2-c1);
15     double beta=acos((r1*r1-r2*r2+d*d)/(r1*d*2));
16     Point<T> p1=get(c1,r1,alpha-beta),p2=get(c1,r1,alpha+beta);
17     res.push_back(p1);
18     if (p1!=p2) res.push_back(p2);
19     return res;
20 }

```

多边形面积

```

1 template <class T>
2 double polygonArea(const vector<Point<T>> &p)
3 {
4     int n=p.size();
5     double res=0;
6     for (int i=1;i<n-1;i++) res+=cross(p[i]-p[0],p[i+1]-p[0]);
7     return fabs(res/2);
8 }

```

自适应辛普森法

```

1 //注意边界函数值不能小于 eps
2 double f(double x) { return pow(x,0.5); }
3 double calc(double l,double r)
4 {
5     double mid=(l+r)/2.0;
6     return (r-l)*(f(l)+f(r)+f(mid)*4.0)/6.0;
7 }
8 double simpson(double l,double r,double lst)
9 {
10     double mid=(l+r)/2.0;
11     double fl=calc(l,mid),fr=calc(mid,r);
12     if (sgn(fl+fr-lst)==0) return fl+fr;
13     else return simpson(l,mid,fl)+simpson(mid,r,fr);
14 }

```

静态凸包

```

1 template <class T>
2 vector<Point<T>> getHull(vector<Point<T>> p)
3 {
4     vector<Point<T>> h,l;
5     sort(p.begin(),p.end(),[&](auto a,auto b)
6     {
7         if (a.x!=b.x) return a.x<b.x;
8         else return a.y<b.y;
9     });
10    p.erase(unique(p.begin(),p.end()),p.end());
11    if (p.size()<=1) return p;
12    for (auto a:p)
13    {
14        while (h.size()>1&&sgn(cross(a-h.back(),a-h[h.size()-2]))<=0) h.pop_back();
15        while (l.size()>1&&sgn(cross(a-l.back(),a-l[l.size()-2]))>=0) l.pop_back();
16        l.push_back(a);
17        h.push_back(a);
18    }
19    l.pop_back();
20    reverse(h.begin(),h.end());
21    h.pop_back();
22    l.insert(l.end(),h.begin(),h.end());
23    return l;
24 }

```

旋转卡壳求直径

```
1  template <class T>
2  double getDiameter(vector<Point<T>> p)
3  {
4      double res=0;
5      if (p.size()==2) return dis_PP(p[0],p[1]);
6      int n=p.size();
7      p.push_back(p.front());
8      int j=2;
9      for (int i=0;i<n;i++)
10     {
11         while (sgn(cross(p[i+1]-p[i],p[j]-p[i])-cross(p[i+1]-p[i],p[j+1]-p[i]))<0)
12             j=(j+1)%n;
13         res=max({res,dis_PP(p[i],p[j]),dis_PP(p[i+1],p[j])});
14     }
15     return res;
16 }
```