

Algorithm Library

`magic::team.getname()`

South China Normal University

September 7, 2024

Contents

头文件	2
DEBUG 头	2
__int128 输出流	2
常用数学函数	2
数学	3
欧拉筛	3
取模类 (MInt)	3
多项式	5
杜教筛	7
Min_25 筛	7
线性基	8
数据结构	9
并查集 (启发式合并 + 带撤销)	9
状压 RMQ	10
树状数组	11
线段树	12
字符串	14
字符串哈希 (随机模数)	14
KMP	14
Z 函数	15
AC 自动机	15
后缀数组	16
(广义) 后缀自动机	17
Manacher	18
回文自动机	18
图论	19
强连通分量	19
边双连通分量	20
轻重链剖分	21
最大流	23
最大流条件下最小费用 (费用流)	24

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();

```

多项式

```

1 namespace polygone{
2     //慎用!!!
3     //需要根据实际情况来调整 函数 poly operator * (poly f,poly g)
4     //和 数据类型 (变为 int) 因为取模频繁 而且我这一块处理的不好导致常数很大
5     //涵盖了 多项式 求导, 积分, 加减乘, 快速幂, ln, exp, 开根
6     //没有涵盖 除法 多点求值 复合运算 等复杂部分 (学艺不精呜呜呜)
7     //带有模数 没有支持无模
8     #define N 3000006
9     #define ll long long
10    long long read(){
11        ll f=1,s=0;char ch=getchar();
12        while(ch<'0' || ch>'9'){if(ch=='-')f=-1;ch=getchar();}
13        while(ch>='0'&&ch<='9')s=(s<<1)+(s<<3)+ch-'0',ch=getchar();
14        return s*f;
15    }
16
17    long long reading(ll mod){
18        ll f=1,s=0;char ch=getchar();
19        while(ch<'0' || ch>'9'){if(ch=='-')f=-1;ch=getchar();}
20        while(ch>='0'&&ch<='9')s=(s<<1)+(s<<3)+ch-'0',s%=mod,ch=getchar();
21        return s*f;
22    }
23    const double pi=acos(-1.0);
24    const long long mod = 998244353, g = 3, g1 = 332748118;
25    ll add(ll x,ll y){x+=y;return x>=mod?x-mod:x;}
26    ll rdu(ll x,ll y){x-=y;return x<0?x+mod:x;}
27    ll mul(ll x,ll y){return 1ll*x*y%mod;}
28
29    #define poly vector<ll>
30    #define plen(x) ((int)x.size())
31
32    ll finv[N],r[N],lim,lg;
33
34    ll qpow(ll x,ll y){
35        if(y==1) return x;
36        ll res=qpow(x,y>>1);
37        if(y&1) return ((res*res)%mod)*x)%mod;
38        return (res*res)%mod;
39    }ll ginv(ll x){return qpow(x,mod-2);}
40
41    void init(ll n){
42        for(lim=1,lg=0;lim<=n;lim<=1,lg++);
43        for(int i=0;i<lim;i++) r[i]=((r[i>>1]>>1)|((i&1)<<(lg-1)));
44    }
45
46    void cinv(ll n){
47        finv[1]=1;
48        for(int i=2;i<=n;i++) finv[i]=mul(mod-mod/i,finv[mod%i]);
49    }
50
51    poly operator - (ll x,poly f){ll len=plen(f);for(int i=0;i<len;i++) f[i]=mod-f[i];f[0]=add(f[0],x);return f;}
52    poly operator - (poly f,ll x){f[0]=rdu(f[0],x);return f;}
53    poly operator - (poly f,poly g){ll n=max(plen(f),plen(g));f.resize(n);g.resize(n);for(int i=0;i<n;i++)
    ↪ f[i]=rdu(f[i],g[i]);return f;}
54    poly operator * (poly f,ll x){ll len=plen(f);for(int i=0;i<len;i++) f[i]=mul(f[i],x);return f;}
55    poly operator + (poly f,poly g){ll n=max(plen(f),plen(g));f.resize(n);g.resize(n);for(int i=0;i<n;i++)
    ↪ f[i]=add(f[i],g[i]);return f;}

```

```

56
57 void ntt(poly &f,int op){
58     for(int i=0;i<lim;i++) if(i<r[i]) swap(f[i],f[r[i]]);
59     for(int mid=1;mid<lim;mid<=<1){
60         ll wn=qpow(op==1?g:g1,(mod-1)/(mid<=<1));
61         for(int j=0;j<lim;j+=(mid<=<1)){
62             ll w=1;
63             for(int k=0;k<mid;k++,w=(w*wn)%mod){
64                 ll x=f[j+k],y=w*f[j+k+mid]%mod;
65                 f[j+k]=(x+y)%mod;
66                 f[j+k+mid]=(x-y+mod)%mod;
67             }
68         }
69     }
70     if(op==1) return;
71     ll inv=qpow(lim,mod-2);
72     for(int i=0;i<lim;i++) f[i]=1ll*f[i]*inv%mod;
73 }
74
75 poly operator * (poly f,poly g){
76     ll n=plen(f)+plen(g)-1;
77     init(n);
78     f.resize(lim);g.resize(lim);
79     ntt(f,1);ntt(g,1);
80     for(int i=0;i<lim;i++) f[i]=mul(f[i],g[i]);
81     ntt(f,-1);
82     f.resize(min(n,1ll*1000000));
83     return f;
84 }
85
86 poly inv(poly f){
87     poly g=poly(1,ginv(f[0]));
88     ll len=plen(f);
89     for(int i=2;i<(len<=<1);i<=<1){
90         poly A=f;
91         A.resize(i);
92         g=g*(2-(g*A));
93     }
94     g.resize(len);
95     return g;
96 }
97
98 poly qiudao(poly f){
99     ll len=plen(f);
100     for(int i=0;i<len-1;i++) f[i]=mul(i+1,f[i+1]);
101     f.resize(len-1);
102     return f;
103 }
104
105 poly jifen(poly f){
106     ll len=plen(f);
107     f.resize(len+1);
108     for(int i=len-1;i>=1;i--) f[i]=mul(f[i-1],finv[i]);
109     f[0]=0;
110     return f;
111 }
112
113 poly ln(poly f){
114     poly g=jifen(qiudao(f)*inv(f));
115     g.resize(plen(f));
116     return g;
117 }
118
119 poly exp(poly f){
120     poly g=poly(1,1);
121     ll len=plen(f);
122     for(int i=2;i<(len<=<2);i<=<1){
123         poly A=f;
124         A.resize(i);
125         g=g*((1-ln(g))+A);
126     }

```

```

127         g.resize(len);
128         return g;
129     }
130
131     poly Pow(poly f, ll k){
132         f=ln(f); f=f*k; f=exp(f);
133         return f;
134     }
135
136     poly sqrt(poly f){
137         poly g=poly(1,1);
138         ll len=len(f);
139         ll inv2=ginv(2);
140         for(int i=2; i<(len<2); i<=1){
141             poly A=f;
142             A.resize(i);
143             g=(g+(A*inv(g)))*inv2;
144         }
145         g.resize(len);
146         return g;
147     }
148 }
149 using namespace polygone;

```

杜教筛

```

1 void prime(){
2     u[1]=1; v[1]=1; phi[1]=1;
3     for(ll i=2; i<=N; i++){
4         if(!v[i]) {u[i]=-1; p[++cnt]=i; phi[i]=i-1;}
5         for(ll j=1; j<=cnt&&p[j]*i<=N; j++){
6             v[p[j]*i]=1;
7             if(!(i%p[j])) {phi[i*p[j]]=phi[i]*p[j]; break;}
8             else u[i*p[j]]=-u[i], phi[i*p[j]]=phi[i]*phi[p[j]];
9         }
10    }
11    for(ll i=1; i<=N; i++) u[i]+=u[i-1], phi[i]+=phi[i-1];
12 }
13
14 ll sumu(ll n) {
15     if(n<=N) return u[n];
16     if(M[n]) return M[n];
17     ll res=1;
18     for(ll l=2, r=0; l<=n; l=r+1){
19         r=n/(n/l);
20         res-=1ll*sumu(n/l)*(r-l+1);
21     }
22     M[n]=res;
23     return M[n];
24 }

```

Min_25 筛

```

1 void prime(ll n){
2     for(ll i=2; i<=n; i++){
3         if(!vis[i]) p[++cnt]=i;
4         for(ll j=1; j<=cnt&&p[j]<=n/i; j++){
5             vis[i*p[j]]=1;
6             if(i%p[j]==0) break;
7         }
8     }
9 }
10
11 ll qz1(ll x){return x%mod, x*(x+1)%mod*inv2%mod;}
12 ll qz2(ll x){return x%mod, x*(x+1)%mod*(2*x+1)%mod*inv6%mod;}
13 ll get(ll x){return x<N?id1[x]:id2[n/x];}
14 ll sq(ll x){return x%mod, x*x%mod;}
15 ll F(ll x){return x%mod, (sq(x)+mod-x)%mod;}
16
17 void getg(){

```



```

18     for(ll l=1,r;l<=n;l=r+1){
19         r=n/(n/l);
20         v[++m]=n/l;
21         if(v[m]<N) id1[v[m]]=m;
22         else id2[n/v[m]]=m;
23         g1[m]=(qz1(v[m])-1+mod)%mod;
24         g2[m]=(qz2(v[m])-1+mod)%mod;
25     }
26     for(ll j=1;j<=cnt;j++){
27         for(ll i=1;i<=m&&p[j]<=v[i]/p[j];i++){
28             g1[i]=(g1[i]-p[j]*(g1[get(v[i]/p[j]])-g1[get(p[j-1]]))%mod+mod)%mod;
29             g1[i]=(g1[i]+mod)%mod;
30             g2[i]=(g2[i]-sq(p[j])*(g2[get(v[i]/p[j]])-g2[get(p[j-1]]))%mod+mod)%mod;
31             g2[i]=(g2[i]+mod)%mod;
32         }
33     }
34 }
35
36 ll S(ll x,ll y){
37     if(p[y]>=x) return 0;
38     ll res=(g2[get(x)]-g1[get(x)]-g2[get(p[y]]+g1[get(p[y]])+mod)%mod;//g(n);
39     for(ll i=y+1;i<=cnt&&p[i]<=x/p[i];i++){
40         ll P=p[i];
41         for(ll j=1;P<=x/p[i];j++,P*=p[i]){//p^e
42             res=(res+F(P)*S(x/P,i)%mod+F(P*p[i]))%mod;
43         }
44     }
45     return res;
46 }
47
48 ll qpow(ll x,ll y){
49     if(y==1) return x;
50     ll res=qpow(x,y>>1);
51     if(y&1) return ((res*res)%mod*x)%mod;
52     return (res*res)%mod;
53 }ll inv(ll x){return qpow(x,mod-2);}
54
55 int main(){
56     inv2=inv(2),inv6=inv(6);
57     n=read();
58     ll T=sqrt(n)+1;
59     prime(T);
60     getg();
61     ll ans=(S(n,0)+1+mod)%mod;
62     cout<<ans;
63     return 0;
64 }

```

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 };

```

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>=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()%900000000+100000000);
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    }
```

```

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 };

```

最大流

```

1  bool bfs(ll s,ll t){
2      queue<ll>q;
3      for(int i=1;i<=n;i++) dis[i]=-1;dis[s]=0;
4      for(int i=1;i<=n;i++) cur[i]=frm[i];
5      q.push(s);
6      while(!q.empty()){
7          ll x=q.front();q.pop();
8          for(int i=frm[x];i;i=e[i].net){
9              ll v=e[i].to;
10             if(dis[v]==-1&&e[i].val) dis[v]=dis[x]+1,q.push(v);
11         }
12     }
13     return dis[t]!=-1;
14 }
15
16 ll dfs(ll s,ll flow){
17     if(s==t||!flow) return flow;
18     if(dis[s]>dis[t]) return 0;
19     ll now=0,res=0;
20     for(int i=cur[s];i;i=e[i].net){
21         ll x=e[i].to;
22         if(dis[x]==dis[s]+1&&e[i].val){
23             res=dfs(x,min(flow-now,e[i].val));
24             if(!res) continue;
25             e[i].val-=res;e[i^1].val+=res;now+=res;flow-=res;
26             cur[s]=i;
27             if(!flow) break;
28         }
29     }
30     if(!now) return (dis[s]=0);
31     return now;
32 }
33
34 void dinic(ll s,ll t){
35     while(bfs(s,t)){
36         ll last=dfs(s,1e18);
37         while(last) ans+=last,last=dfs(s,1e18);
38     }
39 }

```


最大流条件下最小费用（费用流）

```
1  bool bfs(ll s,ll t){
2      queue<ll>q;
3      memset(dis,127,sizeof dis);memset(vis,0,sizeof vis);memset(pre,-1,sizeof pre);
4      ll inf=dis[0];dis[s]=0;vis[s]=1;
5      dis[s]=pre[s]=0;flow[s]=inf;q.push(s);
6      while(!q.empty()){
7          ll x=q.front();q.pop();vis[x]=0;
8          for(int i=frm[x];i;i=e[i].net){
9              ll v=e[i].to;
10             if(dis[v]>dis[x]+e[i].cost&&e[i].val){
11                 dis[v]=dis[x]+e[i].cost;
12                 xb[v]=i;pre[v]=x;flow[v]=min(flow[x],e[i].val);
13                 if(!vis[v]) q.push(v),vis[v]=1;
14             }
15         }
16     }
17     if(dis[t]==inf) return 0;
18     return 1;
19 }
20
21 void EK(ll s,ll t){
22     while(bfs(s,t)){
23         ll k=t;
24         while(s!=k){
25             e[xb[k]].val-=flow[t];e[xb[k]^1].val+=flow[t];
26             k=pre[k];
27         }
28         maxflow+=flow[t];mincost+=flow[t]*dis[t];
29     }
30 }
31 //add(x,y,v,c);add(x,y,0,-c);
```