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1 Basic

1.1 vimrc

```
se is nu rnu bs=2 ru mouse=a encoding=utf-8
se cin et ts=4 sw=4 sts=4 t_Co=256
syn on
colorscheme ron
filetype indent on
map <F8> <ESC>:w<CR>:!clear && g++ "%" -o "%<" -
    fsanitize=address -fsanitize=undefined -g && echo
    success<CR>
map <F9> <ESC>:w<CR>:!clear && g++ "%" -o "%<" -O2 &&
    echo success<CR>
map <F10> <ESC>:!. / "%<" <CR>
```

1.2 Increase Stack

```
const int size = 256 << 20;
register long rsp asm("rsp");
char *p = (char*)malloc(size)+size, *bak = (char*)rsp;
__asm__("movq %0, %%rsp\n": "r"(p));
// main
__asm__("movq %0, %%rsp\n": "r"(bak));
```

1.3 Pragma Optimization

```
#pragma GCC optimize("Ofast,no-stack-protector")
#pragma GCC optimize("no-math-errno,unroll-loops")
#pragma GCC target("sse,sse2,sse3,ssse3,sse4")
#pragma GCC target("popcnt,abm,mmx,avx,tune=native")
```

1.4 IO Optimization

```
static inline int gc() {
    static char buf[ 1 << 20 ], *p = buf, *end = buf;
    if ( p == end ) {
        end = buf + fread( buf, 1, 1 << 20, stdin );
        if ( end == buf ) return EOF;
        p = buf;
    }
    return *p++;
}

template < typename T >
static inline bool gn( T &_ ) {
    register int c = gc(); register T _ = 1; _ = 0;
    while(( '0' < c && c <= '9' ) && c != EOF && c != '-' ) c = gc();
    if(c == '-') { _ = -1; c = gc(); }
    if(c == EOF) return false;
    while('0' <= c && c <= '9') _ = _ * 10 + c - '0', c = gc();
    _ *= _;
    return true;
}

template < typename T, typename ...Args >
static inline bool gn( T &x, Args &...args )
{ return gn(x) && gn(args...); }
```

2 Data Structure

2.1 BigInt

```
class BigInt{
private:
    using lld = int_fast64_t;
#define PRINTF_ARG PRIuFAST64
#define LOG_BASE_STR "9"
    static constexpr lld BASE = 1000000000;
    static constexpr int LOG_BASE = 9;
    vector<lld> dig; bool neg;
    inline int len() const { return (int) dig.size(); }
    inline int cmp_minus(const BigInt& a) const {
        if(len() == 0 && a.len() == 0) return 0;
        if(neg ^ a.neg) return a.neg ^ 1;
        if(len() != a.len())
            return neg?a.len()-len():len()-a.len();
        for(int i=len()-1; i>=0; i--) if(dig[i] != a.dig[i])
            return neg?a.dig[i]-dig[i]:dig[i]-a.dig[i];
        return 0;
    }
    inline void trim(){
        while(!dig.empty() && !dig.back()) dig.pop_back();
        if(dig.empty()) neg = false;
    }
public:
    BigInt(): dig(vector<lld>()), neg(false){}
    BigInt(lld a): dig(vector<lld>()){
        neg = a<0; dig.push_back(abs(a));
        trim();
    }
    BigInt(const string& a): dig(vector<lld>()){
        assert(!a.empty()); neg = (a[0]=='-');
        for(int i=((int)a.size()-1; i>=neg; i-=LOG_BASE){
            lld cur = 0;
            for(int j=min(LOG_BASE-1, i-neg); j>=0; j--){
                cur = cur*10+a[i-j]-'0';
                dig.push_back(cur);
            } trim();
        }
    }
    inline bool operator<(const BigInt& a) const {
        return cmp_minus(a)<0;
    }
    inline bool operator<=(const BigInt& a) const {
        return cmp_minus(a)<=0;
    }
    inline bool operator==(const BigInt& a) const {
        return cmp_minus(a)==0;
    }
    inline bool operator!=(const BigInt& a) const {
        return cmp_minus(a)!=0;
    }
    inline bool operator>(const BigInt& a) const {
        return cmp_minus(a)>0;
    }
    inline bool operator>=(const BigInt& a) const {
        return cmp_minus(a)>=0;
    }
    BigInt operator-() const {
        BigInt ret = *this;
        ret.neg ^= 1; return ret;
    }
    BigInt operator+(const BigInt& a) const {
        if(neg) return -(-( *this ) + (-a));
        if(a.neg) return ( *this ) - (-a);
        int n = max(a.len(), len());
        BigInt ret; ret.dig.resize(n);
        lld pro = 0;
        for(int i=0; i<n; i++) {
            ret.dig[i] = pro;
            if(i < a.len()) ret.dig[i] += a.dig[i];
            if(i < len()) ret.dig[i] += dig[i];
            pro = 0;
            if(ret.dig[i] >= BASE) pro = ret.dig[i]/BASE;
            ret.dig[i] -= BASE*pro;
        }
        if(pro != 0) ret.dig.push_back(pro);
        return ret;
    }
    BigInt operator-(const BigInt& a) const {
        if(neg) return -(-( *this ) - (-a));
        if(a.neg) return ( *this ) + (-a);
        int diff = cmp_minus(a);
        if(diff < 0) return -(a - ( *this ));
        if(diff == 0) return 0;
        BigInt ret; ret.dig.resize(len(), 0);
        for(int i=0; i<len(); i++) {
            ret.dig[i] += dig[i];

```

```

            if(i < a.len()) ret.dig[i] -= a.dig[i];
            if(ret.dig[i] < 0){
                ret.dig[i] += BASE;
                ret.dig[i+1]--;
            }
        }
        ret.trim(); return ret;
    }
    BigInt operator*(const BigInt& a) const {
        if(!len() || !a.len()) return 0;
        BigInt ret; ret.dig.resize(len()+a.len()+1);
        ret.neg = neg ^ a.neg;
        for(int i=0; i<len(); i++){
            for(int j=0; j<a.len(); j++){
                ret.dig[i+j] += dig[i] * a.dig[j];
                if(ret.dig[i+j] >= BASE) {
                    lld x = ret.dig[i+j] / BASE;
                    ret.dig[i+j+1] += x;
                    ret.dig[i+j] -= x * BASE;
                }
            }
        }
        ret.trim(); return ret;
    }
    BigInt operator/(const BigInt& a) const {
        assert(a.len());
        if(len() < a.len()) return 0;
        BigInt ret; ret.dig.resize(len()-a.len()+1);
        ret.neg = a.neg;
        for(int i=len()-a.len(); i>=0; i--){
            lld l = 0, r = BASE;
            while(r-l > 1){
                lld mid = (l+r)>>1;
                ret.dig[i] = mid;
                if(ret*a <= (neg?-( *this ):( *this ))) l = mid;
                else r = mid;
            }
            ret.dig[i] = 1;
        }
        ret.neg ^= neg; ret.trim();
        return ret;
    }
    BigInt operator%(const BigInt& a) const {
        return ( *this ) - ( *this ) / a * a;
    }
    friend BigInt abs(BigInt a) { a.neg = 0; return a; }
    friend void swap(BigInt& a, BigInt& b){
        swap(a.dig, b.dig); swap(a.neg, b.neg);
    }
    friend istream& operator>>(istream& ss, BigInt& a){
        string s; ss >> s; a = s; return ss;
    }
    friend ostream& operator<<(ostream& o, const BigInt& a){
        if(a.len() == 0) return o << '0';
        if(a.neg) o << '-';
        ss << o.dig.back();
        for(int i=a.len()-2; i>=0; i--){
            o << setw(LOG_BASE)<< setfill('0')<< a.dig[i];
            return o;
        }
    }
    inline void print() const {
        if(len() == 0){ putchar('0'); return; }
        if(neg) putchar('-');
        printf("%" PRINTF_ARG, dig.back());
        for(int i=len()-2; i>=0; i--){
            printf("%0" LOG_BASE_STR PRINTF_ARG, dig[i]);
        }
    }
#undef PRINTF_ARG
#undef LOG_BASE_STR
};

```

2.2 Dark Magic

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/priority_queue.hpp>
using __gnu_pbds::pairing_heap_tag;
using __gnu_pbds::binary_heap_tag;
using __gnu_pbds::binomial_heap_tag;
using __gnu_pbds::rc_binomial_heap_tag;
using __gnu_pbds::thin_heap_tag;
template<typename T>
using pbds_heap = __gnu_pbds::prioity_queue<T, less<T>, \
    pairing_heap_tag>;
// a.join(b), pq.modify(pq.push(10), 87)

```

```
using __gnu_pbds::rb_tree_tag;
using __gnu_pbds::ov_tree_tag;
using __gnu_pbds::splay_tree_tag;
template<typename T>
using ordered_set = __gnu_pbds::tree<T,\
__gnu_pbds::null_type,less<T>,rb_tree_tag,\
__gnu_pbds::tree_order_statistics_node_update>;
// find_by_order, order_of_key
template<typename A,typename B>
using hTable1=__gnu_pbds::cc_hash_table<A,B>;
template<typename A,typename B>
using hTable2=__gnu_pbds::gp_hash_table<A,B>;
```

2.3 Disjoint Set

```
class DJS {
private:
    vector< int > fa, sz, sv;
    vector< pair< int*, int > > opt;
    void assign( int *k, int v ) {
        opt.emplace_back( k, *k );
        *k = v;
    }
public:
    void init( int n ) {
        fa.resize( n ); iota( fa.begin(), fa.end(), 0 );
        sz.resize( n ); fill( sz.begin(), sz.end(), 1 );
        opt.clear();
    }
    int query(int x) {return fa[x] == x?x:query(fa[x]);}
    void merge( int a, int b ) {
        int af = query( a ), bf = query( b );
        if( af == bf ) return;
        if( sz[ af ] < sz[ bf ] ) swap( af, bf );
        assign( &fa[ bf ], fa[ af ] );
        assign( &sz[ af ], sz[ af ] + sz[ bf ] );
    }
    void save() { sv.push_back( (int) opt.size() ); }
    void undo() {
        int ls = sv.back(); sv.pop_back();
        while ( ( int ) opt.size() > ls ) {
            pair< int*, int > cur = opt.back();
            *cur.first = cur.second;
            opt.pop_back();
        }
    }
};
```

2.4 Link-Cut Tree

```
struct Node{
    Node *par,*ch[2];
    int xor_sum,v;
    bool is_rev;
    Node(int _v){
        v=xor_sum=_v;is_rev=false;
        par=ch[0]=ch[1]=nullptr;
    }
    inline void set_rev(){is_rev^=1;swap(ch[0],ch[1]);}
    inline void down(){
        if(is_rev){
            if(ch[0]!=nullptr) ch[0]->set_rev();
            if(ch[1]!=nullptr) ch[1]->set_rev();
            is_rev=false;
        }
    }
    inline void up(){
        xor_sum=v;
        if(ch[0]!=nullptr){
            xor_sum^=ch[0]->xor_sum;
            ch[0]->par=this;
        }
        if(ch[1]!=nullptr){
            xor_sum^=ch[1]->xor_sum;
            ch[1]->par=this;
        }
    }
    inline bool is_root(){
        return par==nullptr ||\
            (par->ch[0]!=this && par->ch[1]!=this);
    }
    bool is_rch(){return !is_root() && par->ch[1]==this;}
} *node[maxn],*stk[maxn];
int top;
```

```
void to_child(Node* p,Node* c,bool dir){
    p->ch[dir]=c;
    p->up();
}
inline void rotate(Node* node){
    Node* par=node->par;
    Node* par_par=par->par;
    bool dir=node->is_rch();
    bool par_dir=par->is_rch();
    to_child(par,node->ch[!dir],dir);
    to_child(node,par,!dir);
    if(par_par!=nullptr && par_par->ch[par_dir]==par)
        to_child(par_par,node,par_dir);
    else node->par=par_par;
}
inline void splay(Node* node){
    Node* tmp=node;
    stk[top++]=node;
    while(!tmp->is_root()){
        tmp=tmp->par;
        stk[top++]=tmp;
    }
    while(top) stk[--top]->down();
    for(Node *fa=node->par;
        !node->is_root();
        rotate(node),fa=node->par)
        if(!fa->is_root())
            rotate(fa->is_rch()==node->is_rch()?fa:node);
}
inline void access(Node* node){
    Node* last=nullptr;
    while(node!=nullptr){
        splay(node);
        to_child(node,last,true);
        last=node;
        node=node->par;
    }
}
inline void change_root(Node* node){
    access(node);splay(node);node->set_rev();
}
inline void link(Node* x,Node* y){
    change_root(x);splay(x);x->par=y;
}
inline void split(Node* x,Node* y){
    change_root(x);access(y);splay(x);
    to_child(x,nullptr,true);y->par=nullptr;
}
inline void change_val(Node* node,int v){
    access(node);splay(node);node->v=v;node->up();
}
inline int query(Node* x,Node* y){
    change_root(x);access(y);splay(y);
    return y->xor_sum;
}
inline Node* find_root(Node* node){
    access(node);splay(node);
    Node* last=nullptr;
    while(node!=nullptr){
        node->down();last=node;node=node->ch[0];
    }
    return last;
}
set<pii> dic;
inline void add_edge(int u,int v){
    if(u>v) swap(u,v);
    if(find_root(node[u])==find_root(node[v])) return;
    dic.insert(pii(u,v));
    link(node[u],node[v]);
}
inline void del_edge(int u,int v){
    if(u>v) swap(u,v);
    if(dic.find(pii(u,v))==dic.end()) return;
    dic.erase(pii(u,v));
    split(node[u],node[v]);
}
```

2.5 LiChao Segment Tree

```
struct Line{
    int m, k, id;
    Line() : id( -1 ) {}
    Line( int a, int b, int c )
```

```

: m( a ), k( b ), id( c ) {}
int at( int x ) { return m * x + k; }
};
class LiChao {
private:
int n; vector< Line > nodes;
inline int lc( int x ) { return 2 * x + 1; }
inline int rc( int x ) { return 2 * x + 2; }
void insert( int l, int r, int id, Line ln ) {
int m = ( l + r ) >> 1;
if ( nodes[ id ].id == -1 ) {
nodes[ id ] = ln;
return;
}
bool atLeft = nodes[ id ].at( l ) < ln.at( l );
if ( nodes[ id ].at( m ) < ln.at( m ) ) {
atLeft ^= 1; swap( nodes[ id ], ln );
}
if ( r - l == 1 ) return;
if ( atLeft ) insert( l, m, lc( id ), ln );
else insert( m, r, rc( id ), ln );
}
int query( int l, int r, int id, int x ) {
int ret = 0;
if ( nodes[ id ].id != -1 )
ret = nodes[ id ].at( x );
int m = ( l + r ) >> 1;
if ( r - l == 1 ) return ret;
else if ( x < m )
return max( ret, query( l, m, lc( id ), x ) );
else
return max( ret, query( m, r, rc( id ), x ) );
}
public:
void build( int n_ ) {
n = n_; nodes.clear();
nodes.resize( n << 2, Line() );
}
void insert( Line ln ) { insert( 0, n, 0, ln ); }
int query( int x ) { return query( 0, n, 0, x ); }
} lichao;

```

2.6 Treap

```

namespace Treap{
#define sz( x ) ( ( x ) ? ( ( x )->size ) : 0 )
struct node{
int size;
uint32_t pri;
node *lc, *rc;
node() : size(0), pri(rand()), lc( 0 ), rc( 0 ) {}
void pull() {
size = 1;
if ( lc ) size += lc->size;
if ( rc ) size += rc->size;
}
};
node* merge( node* L, node* R ) {
if ( not L or not R ) return L ? L : R;
if ( L->pri > R->pri ) {
L->rc = merge( L->rc, R ); L->pull();
return L;
} else {
R->lc = merge( L, R->lc ); R->pull();
return R;
}
}
void split_by_size( node*rt, int k, node*&L, node*&R ) {
if ( not rt ) L = R = nullptr;
else if( sz( rt->lc ) + 1 <= k ) {
L = rt;
split_by_size( rt->rc, k-sz(rt->lc)-1, L->rc, R );
L->pull();
} else {
R = rt;
split_by_size( rt->lc, k, L, R->lc );
R->pull();
}
}
#undef sz
}

```

2.7 Sparse Table

```

template < typename T, typename Cmp_ = less< T > >
class SparseTable {
private:
vector< vector< T > > tbl;
vector< int > lg;
T cv( T a, T b ) {
return Cmp_()( a, b ) ? a : b;
}
public:
void init( T arr[], int n ) {
// 0-base
lg.resize( n + 1 );
lg[ 0 ] = -1;
for( int i=1; i<=n; ++i ) lg[i] = lg[i>>1] + 1;
tbl.resize( lg[n] + 1 );
tbl[ 0 ].resize( n );
copy( arr, arr + n, tbl[ 0 ].begin() );
for( int i = 1; i <= lg[ n ]; ++i ) {
int len = 1 << ( i - 1 ), sz = 1 << i;
tbl[ i ].resize( n - sz + 1 );
for( int j = 0; j <= n - sz; ++j )
tbl[i][j] = cv(tbl[i-1][j], tbl[i-1][j+len]);
}
}
T query( int l, int r ) {
// 0-base [l, r)
int wh = lg[ r - l ], len = 1 << wh;
return cv( tbl[ wh ][ l ], tbl[ wh ][ r - len ] );
}
};

```

2.8 Linear Basis

```

struct LinearBasis {
private:
int n, sz;
vector< llu > B;
inline llu two( int x ){ return ( ( llu ) 1 ) << x; }
public:
void init( int n_ ) {
n = n_; B.clear(); B.resize( n ); sz = 0;
}
void insert( llu x ) {
// add x into B
for( int i = n-1; i >= 0; --i ) if( two(i) & x ){
if ( B[ i ] ) x ^= B[ i ];
else {
B[ i ] = x; sz++;
for( int j = i - 1; j >= 0; --j )
if( B[ j ] && ( two( j ) & B[ i ] ) )
B[ i ] ^= B[ j ];
for( int j = i + 1; j < n; ++j )
if ( two( i ) & B[ j ] )
B[ j ] ^= B[ i ];
break;
}
}
}
inline int size() { return sz; }
bool check( llu x ) {
// is x in span(B) ?
for( int i = n-1; i >= 0; --i ) if( two(i) & x )
if ( B[ i ] ) x ^= B[ i ];
else return false;
return true;
}
llu kth_small(llu k) {
/** 1-base would always > 0 **/
/** should check it **/
/* if we choose at least one element
but size(B)(vectors in B)==N(original elements)
then we can't get 0 */
llu ret = 0;
for( int i = 0; i < n; ++i ) if( B[ i ] ) {
if( k & 1 ) ret ^= B[ i ];
k >>= 1;
}
return ret;
}
} base;

```

3 Graph

3.1 Euler Circuit

```
bool vis[ N ]; size_t la[ K ];
void dfs( int u, vector< int >& vec ) {
    while ( la[ u ] < G[ u ].size() ) {
        if( vis[ G[ u ][ la[ u ] ].second ] ) {
            ++ la[ u ];
            continue;
        }
        int v = G[ u ][ la[ u ] ].first;
        vis[ G[ u ][ la[ u ] ].second ] = true;
        ++ la[ u ]; dfs( v, vec );
        vec.push_back( v );
    }
}
```

3.2 BCC Edge

```
class BCC{
private:
    vector< int > low, dfn;
    int cnt;
    vector< bool > bridge;
    vector< vector< PII > > G;
    void dfs( int w, int f ) {
        low[ w ] = dfn[ w ] = cnt++;
        for ( auto [ u, t ] : G[ w ] ) {
            if ( u == f ) continue;
            if ( dfn[ u ] != 0 ) {
                low[ w ] = min( low[ w ], dfn[ u ] );
            } else {
                dfs( u, w );
                low[ w ] = min( low[ w ], low[ u ] );
                if ( low[ u ] > dfn[ w ] ) bridge[ t ] = true;
            }
        }
    }
public:
    void init( int n, int m ) {
        G.resize( n ); cnt = 0;
        fill( G.begin(), G.end(), vector< PII >() );
        bridge.clear(); bridge.resize( m );
        low.clear(); low.resize( n );
        dfn.clear(); dfn.resize( n );
    }
    void add_edge( int u, int v ) {
        // should check for multiple edge
        G[ u ].emplace_back( v, cnt );
        G[ v ].emplace_back( u, cnt ++ );
    }
    void solve(){
        cnt = 1;
        for (int i = 0; i < n; ++i)
            if (not vis[ i ]) dfs(i, i);
    }
    // the id will be same as insert order, 0-base
    bool is_bridge( int x ) { return bridge[ x ]; }
} bcc;
```

3.3 BCC Vertex

```
class BCC {
private:
    int n, t, ecnt;
    vector<vector<pair<int, int>>> G;
    vector<int> low, tin, st, bcc;
    vector<bool> ap, ins;
    void dfs(int x, int p) {
        tin[x] = low[x] = ++t;
        int ch = 0;
        for (auto u: G[x]) {
            if (u.first == p) continue;
            if (not ins[u.second]) {
                st.push_back(u.second);
                ins[u.second] = true;
            }
            if (tin[u.first]) {
                low[x] = min(low[x], tin[u.first]);
                continue;
            }
            ++ch; dfs(u.first, x);
            low[x] = min(low[x], low[u.first]);
        }
    }
}
```

```
if (low[u.first] >= tin[x]) {
    ap[x] = true; ++ecnt;
    while (true) {
        int e = st.back(); st.pop_back();
        bcc[e] = ecnt;
        if (e == u.second) break;
    }
}
if (ch == 1 and p == x) ap[x] = false;
}
public:
    void init(int n_) {
        n = n_, ecnt = 0; st.clear();
        G.clear(); G.resize(n);
        low.clear(); tin.clear();
        ap.assign(n, false);
    }
    void add_edge(int u, int v) {
        G[u].emplace_back(v, ecnt);
        G[v].emplace_back(u, ecnt++);
    }
    void solve() {
        ecnt = 0; bcc.resize(t);
        ins.assign(t, false);
        for (int i = 0; i < n; ++i)
            if (low[i] == 0) dfs(i, i);
    }
    int get_id(int x) { return bcc[x]; }
    int count() { return ecnt; }
    bool is_ap(int x) { return ap[x]; }
};
```

3.4 2-SAT (SCC)

```
class TwoSat{
private:
    int n;
    vector<vector<int>>> rG,G,sccs;
    vector<int> ord,idx;
    vector<bool> vis,result;
    void dfs(int u){
        vis[u]=true;
        for(int v:G[u])
            if(!vis[v]) dfs(v);
        ord.push_back(u);
    }
    void rdfs(int u){
        vis[u]=false;idx[u]=sccs.size()-1;
        sccs.back().push_back(u);
        for(int v:rG[u])
            if(vis[v])rdfs(v);
    }
public:
    void init(int n_){
        n=n_;G.clear();G.resize(n);
        rG.clear();rG.resize(n);
        sccs.clear();ord.clear();
        idx.resize(n);result.resize(n);
    }
    void add_edge(int u,int v){
        G[u].push_back(v);rG[v].push_back(u);
    }
    void orr(int x,int y){
        if ((x^y)==1)return;
        add_edge(x^1,y); add_edge(y^1,x);
    }
    bool solve(){
        vis.clear();vis.resize(n);
        for(int i=0;i<n;++i)
            if(not vis[i])dfs(i);
        reverse(ord.begin(),ord.end());
        for (int u:ord){
            if(!vis[u])continue;
            sccs.push_back(vector<int>());
            rdfs(u);
        }
        for(int i=0;i<n;i+=2)
            if(idx[i]==idx[i+1])
                return false;
        vector<bool> c(sccs.size());
        for(size_t i=0;i<sccs.size();++i){
            for(size_t j=0;j<sccs[i].size();++j){

```



```

    result[sccs[i][j]]=c[i];
    c[idx[sccs[i][j]^1]]=!c[i];
}
}
return true;
}
bool get(int x){return result[x];}
inline int get_id(int x){return idx[x];}
inline int count(){return sccs.size();}
} sat2;

```

3.5 Lowbit Decomposition

```

class LowbitDecomp{
private:
    int time_, chain_, LOG_N;
    vector< vector< int > > G, fa;
    vector< int > tl, tr, chain, chain_st;
    // chain_ : number of chain
    // tl, tr[ u ] : subtree interval in the seq. of u
    // chain_st[ u ] : head of the chain contains u
    // chain[ u ] : chain id of the chain u is on
    inline int lowbit( int x ) {
        return x & ( -x );
    }
    void predfs( int u, int f ) {
        chain[ u ] = 0;
        for ( int v : G[ u ] ) {
            if ( v == f ) continue;
            predfs( v, u );
            if( lowbit( chain[ u ] ) < lowbit( chain[ v ] ) )
                chain[ u ] = chain[ v ];
        }
        if ( not chain[ u ] )
            chain[ u ] = chain_++;
    }
    void dfschain( int u, int f ) {
        fa[ u ][ 0 ] = f;
        for ( int i = 1 ; i < LOG_N ; ++ i )
            fa[ u ][ i ] = fa[ fa[ u ][ i - 1 ] ][ i - 1 ];
        tl[ u ] = time_++;
        if ( not chain_st[ chain[ u ] ] )
            chain_st[ chain[ u ] ] = u;
        for ( int v : G[ u ] )
            if ( v != f and chain[ v ] == chain[ u ] )
                dfschain( v, u );
        for ( int v : G[ u ] )
            if ( v != f and chain[ v ] != chain[ u ] )
                dfschain( v, u );
        tr[ u ] = time_;
    }
    inline bool anc( int u, int v ) {
        return tl[ u ] <= tl[ v ] \
            and tr[ v ] <= tr[ u ];
    }
public:
    inline int lca( int u, int v ) {
        if ( anc( u, v ) ) return u;
        for ( int i = LOG_N - 1 ; i >= 0 ; -- i )
            if ( not anc( fa[ u ][ i ], v ) )
                u = fa[ u ][ i ];
        return fa[ u ][ 0 ];
    }
    void init( int n ) {
        n++;
        for ( LOG_N = 0 ; ( 1 << LOG_N ) < n ; ++ LOG_N );
        fa.clear();
        fa.resize( n, vector< int >( LOG_N ) );
        G.clear(); G.resize( n );
        tl.clear(); tl.resize( n );
        tr.clear(); tr.resize( n );
        chain.clear(); chain.resize( n );
        chain_st.clear(); chain_st.resize( n );
    }
    void add_edge( int u, int v ) {
        // 1-base
        G[ u ].push_back( v );
        G[ v ].push_back( u );
    }
    void decompose(){
        chain_ = 1;
        predfs( 1, 1 );
        time_ = 0;
    }

```

```

    dfschain( 1, 1 );
}
PII get_inter( int u ) { return {tl[ u ], tr[ u ]}; }
vector< PII > get_path( int u, int v ){
    vector< PII > res;
    int g = lca( u, v );
    while ( chain[ u ] != chain[ g ] ) {
        int s = chain_st[ chain[ u ] ];
        res.emplace_back( tl[ s ], tl[ u ] + 1 );
        u = fa[ s ][ 0 ];
    }
    res.emplace_back( tl[ g ], tl[ u ] + 1 );
    while ( chain[ v ] != chain[ g ] ) {
        int s = chain_st[ chain[ v ] ];
        res.emplace_back( tl[ s ], tl[ v ] + 1 );
        v = fa[ s ][ 0 ];
    }
    res.emplace_back( tl[ g ] + 1, tl[ v ] + 1 );
    return res;
}
/* res : list of intervals from u to v
 * ( note only nodes work, not edge )
 * usage :
 * vector< PII >& path = tree.get_path( u, v )
 * for( auto [ l, r ] : path ) {
 *     0-base [ l, r )
 * }
 */
} tree;

```

3.6 MaxClique

```

// contain a self loop u to u, then u won't in clique
template < size_t MAXN >
class MaxClique{
private:
    using bits = bitset< MAXN >;
    bits popped, G[ MAXN ], ans;
    size_t deg[ MAXN ], deo[ MAXN ], n;
    void sort_by_degree() {
        popped.reset();
        for ( size_t i = 0 ; i < n ; ++ i )
            deg[ i ] = G[ i ].count();
        for ( size_t i = 0 ; i < n ; ++ i ) {
            size_t mi = MAXN, id = 0;
            for ( size_t j = 0 ; j < n ; ++ j )
                if ( not popped[ j ] and deg[ j ] < mi )
                    mi = deg[ id = j ];
            popped[ deo[ i ] = id ] = 1;
            for( size_t u = G[ i ]._Find_first();
                u < n ; u = G[ i ]._Find_next( u ) )
                -- deg[ u ];
        }
    }
    void BK( bits R, bits P, bits X ) {
        if ( R.count()+P.count() <= ans.count() ) return;
        if ( not P.count() and not X.count() ) {
            if ( R.count() > ans.count() ) ans = R;
            return;
        }
        /* greedily choose max degree as pivot
        bits cur = P | X; size_t pivot = 0, sz = 0;
        for ( size_t u = cur._Find_first();
            u < n ; u = cur._Find_next( u ) )
            if ( deg[ u ] > sz ) sz = deg[ pivot = u ];
        cur = P & ( ~G[ pivot ] );
        */ // or simply choose first
        bits cur = P & ( ~G[ ( P | X )._Find_first() ] );
        for ( size_t u = cur._Find_first();
            u < n ; u = cur._Find_next( u ) ) {
            if ( R[ u ] ) continue;
            R[ u ] = 1;
            BK( R, P & G[ u ], X & G[ u ] );
            R[ u ] = P[ u ] = 0, X[ u ] = 1;
        }
    }
public:
    void init( size_t n_ ) {
        n = n_;
        for ( size_t i = 0 ; i < n ; ++ i )
            G[ i ].reset();
        ans.reset();
    }
}

```

```

void add_edges( int u, bits S ) { G[ u ] = S; }
void add_edge( int u, int v ) {
    G[ u ][ v ] = G[ v ][ u ] = 1;
}
int solve() {
    sort_by_degree(); // or simply iota( deo... )
    for ( size_t i = 0 ; i < n ; ++ i )
        deg[ i ] = G[ i ].count();
    bits pob, nob = 0; pob.set();
    for (size_t i=n; i<MAXN; ++i) pob[i] = 0;
    for ( size_t i = 0 ; i < n ; ++ i ) {
        size_t v = deo[ i ];
        bits tmp; tmp[ v ] = 1;
        BK( tmp, pob & G[ v ], nob & G[ v ] );
        pob[ v ] = 0, nob[ v ] = 1;
    }
    return static_cast< int >( ans.count() );
}
};

```

3.7 MaxCliqueDyn

```

constexpr int kN = 150;
struct MaxClique { // Maximum Clique
    bitset<kN> a[kN], cs[kN];
    int ans, sol[kN], q, cur[kN], d[kN], n;
    void init(int _n) {
        n = _n; for (int i = 0; i < n; i++) a[i].reset();
    }
    void addEdge(int u, int v) { a[u][v] = a[v][u] = 1; }
    void csort(vector<int> &r, vector<int> &c) {
        int mx = 1, km = max(ans - q + 1, 1), t = 0,
            m = int(r.size());
        cs[1].reset(); cs[2].reset();
        for (int i = 0; i < m; i++) {
            int p = r[i], k = 1;
            while ((cs[k] & a[p]).count()) k++;
            if (k > mx) cs[++mx + 1].reset();
            cs[k][p] = 1;
            if (k < km) r[t++] = p;
        }
        c.resize(m);
        if (t) c[t - 1] = 0;
        for (int k = km; k <= mx; k++) {
            for (int p = int(cs[k]._Find_first());
                p < kN; p = int(cs[k]._Find_next(p))) {
                r[t] = p; c[t++] = k;
            }
        }
    }
    void dfs(vector<int> &r, vector<int> &c, int l,
        bitset<kN> mask) {
        while (!r.empty()) {
            int p = r.back(); r.pop_back();
            mask[p] = 0;
            if (q + c.back() <= ans) return;
            cur[q++] = p;
            vector<int> nr, nc;
            bitset<kN> nmask = mask & a[p];
            for (int i : r)
                if (a[p][i]) nr.push_back(i);
            if (!nr.empty()) {
                if (l < 4) {
                    for (int i : nr)
                        d[i] = int((a[i] & nmask).count());
                    sort(nr.begin(), nr.end(),
                        [&](int x, int y) {
                            return d[x] > d[y];
                        });
                }
                csort(nr, nc); dfs(nr, nc, l + 1, nmask);
            } else if (q > ans) {
                ans = q; copy(cur, cur + q, sol);
            }
            c.pop_back(); q--;
        }
    }
    int solve(bitset<kN> mask) { // vertex mask
        vector<int> r, c;
        for (int i = 0; i < n; i++)
            if (mask[i]) r.push_back(i);
        for (int i = 0; i < n; i++)
            d[i] = int((a[i] & mask).count());
    }
};

```

```

sort(r.begin(), r.end(),
    [&](int i, int j) { return d[i] > d[j]; });
csort(r, c);
dfs(r, c, 1, mask);
return ans; // sol[0 ~ ans-1]
}
} graph;

```

3.8 Virtual Tree

```

inline bool cmp(const int &i, const int &j) {
    return dfn[i] < dfn[j];
}
void build(int vectrices[], int k) {
    static int stk[MAX_N];
    sort(vectrices, vectrices + k, cmp);
    stk[sz++] = 0;
    for (int i = 0; i < k; ++i) {
        int u = vectrices[i], lca = LCA(u, stk[sz - 1]);
        if (lca == stk[sz - 1]) stk[sz++] = u;
        else {
            while (sz >= 2 && dep[stk[sz - 2]] >= dep[lca]) {
                addEdge(stk[sz - 2], stk[sz - 1]);
                sz--;
            }
            if (stk[sz - 1] != lca) {
                addEdge(lca, stk[sz - 1]);
                stk[sz++] = lca, vectrices[cnt++] = lca;
            }
            stk[sz++] = u;
        }
    }
    for (int i = 0; i < sz - 1; ++i)
        addEdge(stk[i], stk[i + 1]);
}

```

3.9 Tree Hashing

```

uint64_t hsah( int u, int f ) {
    uint64_t r = 127;
    for ( int v : G[ u ] ) {
        if ( v == f ) continue;
        uint64_t hh = hsah( v, u );
        r = r + ( hh * hh ) % mod;
    }
    return r;
}

```

3.10 Minimum Mean Cycle

```

/* minimum mean cycle 0(VE) */
struct MMC{
#define FZ(n) memset((n),0,sizeof(n))
#define E 101010
#define V 1021
#define inf 1e9
    struct Edge { int v,u; double c; };
    int n, m, prv[V][V], prve[V][V], vst[V];
    Edge e[E];
    vector<int> edgeID, cycle, rho;
    double d[V][V];
    void init( int _n ) { n = _n; m = 0; }
    // WARNING: TYPE matters
    void add_edge( int vi , int ui , double ci )
    { e[ m ++ ] = { vi , ui , ci }; }
    void bellman_ford() {
        for(int i=0; i<n; i++) d[0][i]=0;
        for(int i=0; i<n; i++) {
            fill(d[i+1], d[i+1]+n, inf);
            for(int j=0; j<m; j++) {
                int v = e[j].v, u = e[j].u;
                if(d[i][v]<inf && d[i+1][u]>d[i][v]+e[j].c) {
                    d[i+1][u] = d[i][v]+e[j].c;
                    prv[i+1][u] = v;
                    prve[i+1][u] = j;
                }
            }
        }
    }
    double solve(){
        // returns inf if no cycle, mmc otherwise
        double mmc=inf;
        int st = -1;
        bellman_ford();
    }
};

```

```

for(int i=0; i<n; i++) {
    double avg=-inf;
    for(int k=0; k<n; k++) {
        if(d[n][i]<inf-eps)
            avg=max(avg, (d[n][i]-d[k][i])/(n-k));
        else avg=max(avg, inf);
    }
    if (avg < mmc) tie(mmc, st) = tie(avg, i);
}
FZ(vst);edgeID.clear();cycle.clear();rho.clear();
for (int i=n; !vst[st]; st=prv[i--][st]) {
    vst[st]++;
    edgeID.PB(prve[i][st]);
    rho.PB(st);
}
while (vst[st] != 2) {
    int v = rho.back(); rho.pop_back();
    cycle.PB(v);
    vst[v]++;
}
reverse(ALL(edgeID));
edgeID.resize(SZ(cycle));
return mmc;
}
} mmc;

```

3.11 Mo's Algorithm on Tree

```

int q; vector< int > G[N];
struct Que{
    int u, v, id;
} que[ N ];
int dfn[N], dfn_, block_id[N], block_, stk[N], stk_;
void dfs( int u, int f ) {
    dfn[ u ] = dfn_++; int saved_rbp = stk_;
    for ( int v : G[ u ] ) {
        if ( v == f ) continue;
        dfs( v, u );
        if ( stk_ - saved_rbp < SQRT_N ) continue;
        for ( ++ block_ ; stk_ != saved_rbp ; )
            block_id[ stk_ -- stk_ ] = block_;
    }
    stk[ stk_ ++ ] = u;
}
bool inPath[ N ];
void Diff( int u ) {
    if ( inPath[ u ] ^ 1 ) { /*remove this edge*/ }
    else { /*add this edge*/ }
}
void traverse( int& origin_u, int u ) {
    for ( int g = lca( origin_u, u ) ;
        origin_u != g ; origin_u = parent_of[ origin_u ] )
        Diff( origin_u );
    for ( int v = u; v != origin_u; v = parent_of[v] )
        Diff( v );
    origin_u = u;
}
void solve() {
    dfs( 1, 1 );
    while ( stk_ ) block_id[ stk_ -- stk_ ] = block_;
    sort( que, que + q, [](const Que& x, const Que& y) {
        return tie( block_id[ x.u ], dfn[ x.v ] )
            < tie( block_id[ y.u ], dfn[ y.v ] );
    } );
    int U = 1, V = 1;
    for ( int i = 0 ; i < q ; ++ i ) {
        pass( U, que[ i ].u );
        pass( V, que[ i ].v );
        // we could get our answer of que[ i ].id
    }
}
/*
Method 2:
dfs u:
    push u
    iterate subtree
    push u
Let P = LCA(u, v), and St(u)<=St(v)
if (P == u) query[St(u), St(v)]
else query[Ed(u), St(v)], query[St(P), St(P)]
*/

```

3.12 Minimum Steiner Tree

```

// Minimum Steiner Tree
//  $O(V \cdot 3^T + V^2 \cdot 2^T)$ 
struct SteinerTree{
#define V 33
#define T 8
#define INF 1023456789
    int n, dst[V][V], dp[1 << T][V], tdst[V];
    void init( int _n ){
        n = _n;
        for( int i = 0 ; i < n ; i ++ ){
            for( int j = 0 ; j < n ; j ++ )
                dst[ i ][ j ] = INF;
            dst[ i ][ i ] = 0;
        }
    }
    void add_edge( int ui, int vi, int wi ){
        dst[ ui ][ vi ] = min( dst[ ui ][ vi ], wi );
        dst[ vi ][ ui ] = min( dst[ vi ][ ui ], wi );
    }
    void shortest_path(){
        for( int k = 0 ; k < n ; k ++ )
            for( int i = 0 ; i < n ; i ++ )
                for( int j = 0 ; j < n ; j ++ )
                    dst[ i ][ j ] = min( dst[ i ][ j ],
                        dst[ i ][ k ] + dst[ k ][ j ] );
    }
    int solve( const vector<int>& ter ){
        int t = (int)ter.size();
        for( int i = 0 ; i < ( 1 << t ) ; i ++ )
            for( int j = 0 ; j < n ; j ++ )
                dp[ i ][ j ] = INF;
        for( int i = 0 ; i < n ; i ++ )
            dp[ 0 ][ i ] = 0;
        for( int msk = 1 ; msk < ( 1 << t ) ; msk ++ ){
            if ( msk == ( msk & (-msk) ) ){
                int who = __lg( msk );
                for( int i = 0 ; i < n ; i ++ )
                    dp[ msk ][ i ] = dst[ ter[ who ] ][ i ];
                continue;
            }
            for( int i = 0 ; i < n ; i ++ )
                for( int submsk = ( msk - 1 ) & msk ; submsk ;
                    submsk = ( submsk - 1 ) & msk )
                    dp[ msk ][ i ] = min( dp[ msk ][ i ],
                        dp[ submsk ][ i ] +
                        dp[ msk ^ submsk ][ i ] );
            for( int i = 0 ; i < n ; i ++ ){
                tdst[ i ] = INF;
                for( int j = 0 ; j < n ; j ++ )
                    tdst[ i ] = min( tdst[ i ],
                        dp[ msk ][ j ] + dst[ j ][ i ] );
            }
            for( int i = 0 ; i < n ; i ++ )
                dp[ msk ][ i ] = tdst[ i ];
        }
        int ans = INF;
        for( int i = 0 ; i < n ; i ++ )
            ans = min( ans, dp[ ( 1 << t ) - 1 ][ i ] );
        return ans;
    }
} solver;

```

3.13 Directed Minimum Spanning Tree

```

template <typename T> struct DMST {
    T g[maxn][maxn], fw[maxn];
    int n, fr[maxn];
    bool vis[maxn], inc[maxn];
    void clear() {
        for(int i = 0; i < maxn; ++i) {
            for(int j = 0; j < maxn; ++j) g[i][j] = inf;
            vis[i] = inc[i] = false;
        }
    }
    void addEdge(int u, int v, T w){g[u][v]=min(g[u][v],w);}
    T operator()(int root, int _n) {
        n = _n; T ans = 0;
        if (dfs(root) != n) return -1;
        while (true) {
            for(int i = 1; i <= n; ++i) fw[i] = inf, fr[i] = i;
            for (int i = 1; i <= n; ++i) if (!inc[i]) {
                for (int j = 1; j <= n; ++j) {
                    if (!inc[j] && i != j && g[j][i] < fw[i]) {

```



```

        fw[i] = g[j][i]; fr[i] = j;
    }
}
int x = -1;
for(int i = 1; i <= n; ++i) if(i != root && !inc[i]){
    int j = i, c = 0;
    while(j != root && fr[j] != i && c <= n) ++c, j = fr[j];
    if (j == root || c > n) continue;
    else { x = i; break; }
}
if (!x) {
    for (int i = 1; i <= n; ++i)
        if (i != root && !inc[i]) ans += fw[i];
    return ans;
}
int y = x;
for (int i = 1; i <= n; ++i) vis[i] = false;
do {
    ans += fw[y]; y = fr[y]; vis[y] = inc[y] = true;
} while (y != x);
inc[x] = false;
for (int k = 1; k <= n; ++k) if (vis[k]) {
    for (int j = 1; j <= n; ++j) if (!vis[j]) {
        if (g[x][j] > g[k][j]) g[x][j] = g[k][j];
        if (g[j][k] < inf && g[j][k] - fw[k] < g[j][x])
            g[j][x] = g[j][k] - fw[k];
    }
}
return ans;
}
int dfs(int now) {
    int r = 1; vis[now] = true;
    for (int i = 1; i <= n; ++i)
        if (g[now][i] < inf && !vis[i]) r += dfs(i);
    return r;
}
};

```

3.14 Dominator Tree

```

namespace dominator {
vector<int> g[maxn], r[maxn], rdom[maxn];
int dfn[maxn], rev[maxn], fa[maxn], sdom[maxn];
int dom[maxn], val[maxn], rp[maxn], tk;
void init(int n) {
    // vertices are numbered from 0 to n - 1
    fill(dfn, dfn + n, -1); fill(rev, rev + n, -1);
    fill(fa, fa + n, -1); fill(val, val + n, -1);
    fill(sdom, sdom + n, -1); fill(rp, rp + n, -1);
    fill(dom, dom + n, -1); tk = 0;
    for (int i = 0; i < n; ++i) {
        g[i].clear(); r[i].clear(); rdom[i].clear();
    }
}
void add_edge(int x, int y) { g[x].push_back(y); }
void dfs(int x) {
    rev[dfn[x] = tk] = x;
    fa[tk] = sdom[tk] = val[tk] = tk; tk++;
    for (int u : g[x]) {
        if (dfn[u] == -1) dfs(u), rp[dfn[u]] = dfn[x];
        r[dfn[u]].push_back(dfn[x]);
    }
}
void merge(int x, int y) { fa[x] = y; }
int find(int x, int c = 0) {
    if (fa[x] == x) return c ? -1 : x;
    int p = find(fa[x], 1);
    if (p == -1) return c ? fa[x] : val[x];
    if (sdom[val[x]] > sdom[val[fa[x]]]) val[x] = val[fa[x]];
    fa[x] = p;
    return c ? p : val[x];
}
vector<int> build(int s, int n) {
    // return the father of each node in the dominator tree
    // p[i] = -2 if i is unreachable from s
    dfs(s);
    for (int i = tk - 1; i >= 0; --i) {
        for (int u : r[i]) sdom[i] = min(sdom[i], sdom[find(u)]);
        if (i) rdom[sdom[i]].push_back(i);
        for (int &u : rdom[i]) {
            int p = find(u);

```

```

            if (sdom[p] == i) dom[u] = i;
            else dom[u] = p;
        }
        if (i) merge(i, rp[i]);
    }
    vector<int> p(n, -2); p[s] = -1;
    for (int i = 1; i < tk; ++i)
        if (sdom[i] != dom[i]) dom[i] = dom[dom[i]];
    for (int i = 1; i < tk; ++i) p[rev[i]] = rev[dom[i]];
    return p;
}
}

```

4 Matching & Flow

4.1 Kuhn Munkres

```

class KM {
private:
    static constexpr lld INF = 1LL << 60;
    vector<lld> h1, hr, slk;
    vector<int> fl, fr, pre, qu;
    vector<vector<lld>> w;
    vector<bool> vl, vr;
    int n, ql, qr;
    bool check(int x) {
        if (vl[x] = true, fl[x] != -1)
            return vr[qu[qr++] = fl[x]] = true;
        while (x != -1) swap(x, fr[fl[x] = pre[x]]);
        return false;
    }
    void bfs(int s) {
        fill(slk.begin(), slk.end(), INF);
        fill(vl.begin(), vl.end(), false);
        fill(vr.begin(), vr.end(), false);
        ql = qr = 0;
        qu[qr++] = s;
        vr[s] = true;
        while (true) {
            lld d;
            while (ql < qr) {
                for (int x = 0, y = qu[ql++]; x < n; ++x) {
                    if (!vl[x] && slk[x] >= (d = h1[x] + hr[y] - w[x][y])) {
                        if (pre[x] = y, d) slk[x] = d;
                        else if (!check(x)) return;
                    }
                }
            }
            d = INF;
            for (int x = 0; x < n; ++x)
                if (!vl[x] && d > slk[x]) d = slk[x];
            for (int x = 0; x < n; ++x) {
                if (vl[x]) h1[x] += d;
                else slk[x] -= d;
                if (vr[x]) hr[x] -= d;
            }
            for (int x = 0; x < n; ++x)
                if (!vl[x] && !slk[x] && !check(x)) return;
        }
    }
public:
    void init(int n_) {
        n = n_; qu.resize(n);
        fl.clear(); fl.resize(n, -1);
        fr.clear(); fr.resize(n, -1);
        hr.clear(); hr.resize(n); h1.resize(n);
        w.clear(); w.resize(n, vector<lld>(n));
        slk.resize(n); pre.resize(n);
        vl.resize(n); vr.resize(n);
    }
    void set_edge(int u, int v, lld x) { w[u][v] = x; }
    lld solve() {
        for (int i = 0; i < n; ++i)
            h1[i] = *max_element(w[i].begin(), w[i].end());
        for (int i = 0; i < n; ++i) bfs(i);
        lld res = 0;
        for (int i = 0; i < n; ++i) res += w[i][fl[i]];
        return res;
    }
} km;

```

4.2 Bipartite Matching

```

class BipartiteMatching{

```

```
private:
vector<int> X[N], Y[N];
int fX[N], fY[N], n;
bitset<N> walked;
bool dfs(int x){
    for(auto i:X[x]){
        if(walked[i])continue;
        walked[i]=1;
        if(fY[i]==-1||dfs(fY[i])){
            fY[i]=x;fX[x]=i;
            return 1;
        }
    }
    return 0;
}
public:
void init(int _n){
    n=_n; walked.reset();
    for(int i=0;i<n;i++){
        X[i].clear();Y[i].clear();
        fX[i]=fY[i]=-1;
    }
}
void add_edge(int x, int y){
    X[x].push_back(y); Y[y].push_back(x);
}
int solve(){
    int cnt = 0;
    for(int i=0;i<n;i++){
        walked.reset();
        if(dfs(i)) cnt++;
    }
    // return how many pair matched
    return cnt;
}
};
```

4.3 General Graph Matching

```
const int N = 514, E = (2e5) * 2;
struct Graph{
    int to[E],bro[E],head[N],e;
    int lnk[N],vis[N],stp,n;
    void init( int _n ){
        stp = 0; e = 1; n = _n;
        for( int i = 0 ; i <= n ; i ++ )
            head[i] = lnk[i] = vis[i] = 0;
    }
    void add_edge(int u,int v){
        // 1-base
        to[e]=v,bro[e]=head[u],head[u]=e++;
        to[e]=u,bro[e]=head[v],head[v]=e++;
    }
    bool dfs(int x){
        vis[x]=stp;
        for(int i=head[x];i;i=bro[i]){
            int v=to[i];
            if(!lnk[v]){
                lnk[x]=v,lnk[v]=x;
                return true;
            }else if(vis[lnk[v]]<stp){
                int w=lnk[v];
                lnk[x]=v,lnk[v]=x,lnk[w]=0;
                if(dfs(w)) return true;
                lnk[w]=v,lnk[v]=w,lnk[x]=0;
            }
        }
        return false;
    }
    int solve(){
        int ans = 0;
        for(int i=1;i<=n;i++)
            if(not lnk[i]){
                stp++; ans += dfs(i);
            }
        return ans;
    }
} graph;
```

4.4 Minimum Weight Matching (Clique version)

```
struct Graph {
    // 0-base (Perfect Match)
    int n, edge[MXN][MXN];
```

```
int match[MXN],dis[MXN],onstk[MXN];
vector<int> stk;
void init(int _n) {
    n = _n;
    for (int i=0; i<n; i++)
        for (int j=0; j<n; j++)
            edge[i][j] = 0;
}
void set_edge(int u, int v, int w) {
    edge[u][v] = edge[v][u] = w;
}
bool SPFA(int u){
    if (onstk[u]) return true;
    stk.PB(u);
    onstk[u] = 1;
    for (int v=0; v<n; v++){
        if (u != v && match[u] != v && !onstk[v]){
            int m = match[v];
            if (dis[m] > dis[u] - edge[v][m] + edge[u][v]){
                dis[m] = dis[u] - edge[v][m] + edge[u][v];
                onstk[v] = 1;
                stk.PB(v);
                if (SPFA(m)) return true;
                stk.pop_back();
                onstk[v] = 0;
            }
        }
    }
    onstk[u] = 0;
    stk.pop_back();
    return false;
}

int solve() {
    // find a match
    for (int i=0; i<n; i+=2){
        match[i] = i+1;
        match[i+1] = i;
    }
    while (true){
        int found = 0;
        for (int i=0; i<n; i++)
            dis[i] = onstk[i] = 0;
        for (int i=0; i<n; i++){
            stk.clear();
            if (!onstk[i] && SPFA(i)){
                found = 1;
                while (SZ(stk)>=2){
                    int u = stk.back(); stk.pop_back();
                    int v = stk.back(); stk.pop_back();
                    match[u] = v;
                    match[v] = u;
                }
            }
        }
        if (!found) break;
    }
    int ret = 0;
    for (int i=0; i<n; i++)
        ret += edge[i][match[i]];
    return ret>1;
} graph;
```

4.5 Flow Models

- Maximum/Minimum flow with lower bound / Circulation problem
 - Construct super source S and sink T .
 - For each edge (x, y, l, u) , connect $x \rightarrow y$ with capacity $u - l$.
 - For each vertex v , denote by $in(v)$ the difference between the sum of incoming lower bounds and the sum of outgoing lower bounds.
 - If $in(v) > 0$, connect $S \rightarrow v$ with capacity $in(v)$, otherwise, connect $v \rightarrow T$ with capacity $-in(v)$.
 - To maximize, connect $t \rightarrow s$ with capacity ∞ (skip this in circulation problem), and let f be the maximum flow from S to T . If $f \neq \sum_{v \in V, in(v) > 0} in(v)$, there's no solution. Otherwise, the maximum flow from s to t is the answer.
 - To minimize, let f be the maximum flow from S to T . Connect $t \rightarrow s$ with capacity ∞ and let the flow from S to T be f' . If $f + f' \neq \sum_{v \in V, in(v) > 0} in(v)$, there's no solution. Otherwise, f' is the answer.
- The solution of each edge e is $l_e + f_e$, where f_e corresponds to the flow of edge e on the graph.
- Construct minimum vertex cover from maximum matching M on bipartite graph (X, Y)

1. Redirect every edge: $y \rightarrow x$ if $(x, y) \in M$, $x \rightarrow y$ otherwise.
 2. DFS from unmatched vertices in X .
 3. $x \in X$ is chosen iff x is unvisited.
 4. $y \in Y$ is chosen iff y is visited.
- Minimum cost cyclic flow
 1. Construct super source S and sink T
 2. For each edge (x, y, c) , connect $x \rightarrow y$ with $(cost, cap) = (c, 1)$ if $c > 0$, otherwise connect $y \rightarrow x$ with $(cost, cap) = (-c, 1)$
 3. For each edge with $c < 0$, sum these cost as K , then increase $d(y)$ by 1, decrease $d(x)$ by 1
 4. For each vertex v with $d(v) > 0$, connect $S \rightarrow v$ with $(cost, cap) = (0, d(v))$
 5. For each vertex v with $d(v) < 0$, connect $v \rightarrow T$ with $(cost, cap) = (0, -d(v))$
 6. Flow from S to T , the answer is the cost of the flow $C + K$
 - Maximum density induced subgraph
 1. Binary search on answer, suppose we're checking answer T
 2. Construct a max flow model, let K be the sum of all weights
 3. Connect source $s \rightarrow v, v \in G$ with capacity K
 4. For each edge (u, v, w) in G , connect $u \rightarrow v$ and $v \rightarrow u$ with capacity w
 5. For $v \in G$, connect it with sink $v \rightarrow t$ with capacity $K + 2T - (\sum_{e \in E(v)} w(e)) - 2w(v)$
 6. T is a valid answer if the maximum flow $f < K|V|$
 - Minimum weight edge cover
 1. For each $v \in V$ create a copy v' , and connect $u' \rightarrow v'$ with weight $w(u, v)$.
 2. Connect $v \rightarrow v'$ with weight $2\mu(v)$, where $\mu(v)$ is the cost of the cheapest edge incident to v .
 3. Find the minimum weight perfect matching on G' .
 - Project selection problem
 1. If $p_v > 0$, create edge (s, v) with capacity p_v ; otherwise, create edge (v, t) with capacity $-p_v$.
 2. Create edge (u, v) with capacity w with w being the cost of choosing u without choosing v .
 3. The mincut is equivalent to the maximum profit of a subset of projects.
 - 0/1 quadratic programming

$$\sum_x c_x x + \sum_y c_y \bar{y} + \sum_{xy} c_{xy} x \bar{y} + \sum_{xyx'y'} c_{xyx'y'} (x \bar{y} + x' \bar{y}')$$

can be minimized by the mincut of the following graph:

1. Create edge (x, t) with capacity c_x and create edge (s, y) with capacity c_y .
2. Create edge (x, y) with capacity c_{xy} .
3. Create edge (x, y) and edge (x', y') with capacity $c_{xyx'y'}$.

4.6 Dinic

```
class Dinic{
private:
    using CapT = int64_t;
    struct Edge{
        int to, rev;
        CapT cap;
    };
    int n, st, ed;
    vector<vector<Edge>> G;
    vector<int> lv, idx;
    bool BFS(){
        fill(lv.begin(), lv.end(), -1);
        queue<int> bfs;
        bfs.push(st);
        lv[st] = 0;
        while(!bfs.empty()){
            int u = bfs.front(); bfs.pop();
            for(auto e: G[u]){
                if(e.cap <= 0 || lv[e.to] != -1) continue;
                lv[e.to] = lv[u] + 1;
                bfs.push(e.to);
            }
        }
        return (lv[ed] != -1);
    }
    CapT DFS(int u, CapT f){
        if(u == ed) return f;
        CapT ret = 0;
        for(int& i = idx[u]; i < (int)G[u].size(); ++i){
            auto& e = G[u][i];
            if(e.cap <= 0 || lv[e.to] != lv[u] + 1) continue;
            CapT nf = DFS(e.to, min(f, e.cap));
            ret += nf; e.cap -= nf; f -= nf;
            G[e.to][e.rev].cap += nf;
            if(f == 0) return ret;
        }
    }
}
```

```
if(ret == 0) lv[u] = -1;
return ret;
}
public:
    void init(int n_, int st_, int ed_){
        n = n_, st = st_, ed = ed_;
        G.resize(n); lv.resize(n);
        fill(G.begin(), G.end(), vector<Edge>());
    }
    void add_edge(int u, int v, CapT c){
        G[u].push_back({v, (int)G[v].size(), c});
        G[v].push_back({u, ((int)G[u].size())-1, 0});
    }
    CapT max_flow(){
        CapT ret = 0;
        while(BFS()){
            idx.assign(n, 0);
            CapT f = DFS(st, numeric_limits<CapT>::max());
            ret += f;
            if(f == 0) break;
        }
        return ret;
    }
} flow;
```

4.7 Minimum Cost Maximum Flow

```
class MiniCostMaxiFlow{
    using CapT = int;
    using WeiT = int64_t;
    using PCW = pair<CapT, WeiT>;
    static constexpr CapT INF_CAP = 1 << 30;
    static constexpr WeiT INF_WEI = 1LL << 60;
private:
    struct Edge{
        int to, back;
        WeiT wei;
        CapT cap;
        Edge() {}
        Edge(int a, int b, WeiT c, CapT d):
            to(a), back(b), wei(c), cap(d)
        {}
    };
    int ori, edd;
    vector<vector<Edge>> G;
    vector<int> fa, wh;
    vector<bool> inq;
    vector<WeiT> dis;
    PCW SPFA(){
        fill(inq.begin(), inq.end(), false);
        fill(dis.begin(), dis.end(), INF_WEI);
        queue<int> qq; qq.push(ori);
        dis[ori] = 0;
        while(!qq.empty()){
            int u = qq.front(); qq.pop();
            inq[u] = 0;
            for(int i = 0; i < SZ[G[u]]; ++i){
                Edge e = G[u][i];
                int v = e.to;
                WeiT d = e.wei;
                if(e.cap <= 0 || dis[v] <= dis[u] + d) continue;
                dis[v] = dis[u] + d;
                fa[v] = u, wh[v] = i;
                if(inq[v]) continue;
                qq.push(v);
                inq[v] = 1;
            }
        }
        if(dis[edd] == INF_WEI)
            return {-1, -1};
        CapT mw = INF_CAP;
        for(int i = edd; i != ori; i = fa[i])
            mw = min(mw, G[fa[i]][wh[i]].cap);
        for(int i = edd; i != ori; i = fa[i]){
            auto &eg = G[fa[i]][wh[i]];
            eg.cap -= mw;
            G[eg.to][eg.back].cap += mw;
        }
        return {mw, dis[edd]};
    }
public:
    void init(int a, int b, int n){
```

```

ori=a,edd=b;
G.clear();G.resize(n);
fa.resize(n);wh.resize(n);
inq.resize(n); dis.resize(n);
}
void add_edge(int st,int ed,WeiT w,CapT c){
    G[st].emplace_back(ed,SZ(G[ed]),w,c);
    G[ed].emplace_back(st,SZ(G[st])-1,-w,0);
}
PCW solve(){
    /* might modify to
    cc += ret.first * ret.second
    or
    ww += ret.first * ret.second
    */
    CapT cc=0; WeiT ww=0;
    while(true){
        PCW ret=SPFA();
        if(ret.first==1) break;
        cc+=ret.first;
        ww+=ret.second;
    }
    return {cc,ww};
}
} mcmf;

```

4.8 Global Min-Cut

```

const int maxn = 500 + 5;
int w[maxn][maxn], g[maxn];
bool v[maxn], del[maxn];
void add_edge(int x, int y, int c) {
    w[x][y] += c; w[y][x] += c;
}
pair<int, int> phase(int n) {
    memset(v, false, sizeof(v));
    memset(g, 0, sizeof(g));
    int s = -1, t = -1;
    while (true) {
        int c = -1;
        for (int i = 0; i < n; ++i) {
            if (del[i] || v[i]) continue;
            if (c == -1 || g[i] > g[c]) c = i;
        }
        if (c == -1) break;
        v[s = t, t = c] = true;
        for (int i = 0; i < n; ++i) {
            if (del[i] || v[i]) continue;
            g[i] += w[c][i];
        }
    }
    return make_pair(s, t);
}
int mincut(int n) {
    int cut = 1e9;
    memset(del, false, sizeof(del));
    for (int i = 0; i < n - 1; ++i) {
        int s, t; tie(s, t) = phase(n);
        del[t] = true; cut = min(cut, g[t]);
        for (int j = 0; j < n; ++j) {
            w[s][j] += w[t][j]; w[j][s] += w[j][t];
        }
    }
    return cut;
}

```

5 Math

5.1 Prime Table

```

1002939109, 1020288887, 1028798297, 1038684299,
1041211027, 1051762951, 1058585963, 1063020809,
1147930723, 1172520109, 1183835981, 1187659051,
1241251303, 1247184097, 1255940849, 1272759031,
1287027493, 1288511629, 1294632499, 1312650799,
1868732623, 1884198443, 1884616807, 1885059541,
1909942399, 1914471137, 1923951707, 1925453197,
1979612177, 1980446837, 1989761941, 2007826547,
2008033571, 2011186739, 2039465081, 2039728567,
2093735719, 2116097521, 2123852629, 2140170259,
3148478261, 3153064147, 3176351071, 3187523093,
3196772239, 3201312913, 3203063977, 3204840059,
3210224309, 3213032591, 3217689851, 3218469083,
3219857533, 3231880427, 3235951699, 3273767923,
3276188869, 3277183181, 3282463507, 3285553889,
3319309027, 3327005333, 3327574903, 3341387953,
3373293941, 3380077549, 3380892997, 3381118801

```

5.2 $\lfloor \frac{n}{i} \rfloor$ Enumeration

$$T_0 = 1, T_{i+1} = \lfloor \frac{n}{T_i + 1} \rfloor$$

5.3 ax+by=gcd

```

// ax+ny = 1, ax+ny == ax == 1 (mod n)
void exgcd(lld x, lld y, lld &g, lld &a, lld &b) {
    if (y == 0) g=x, a=1, b=0;
    else exgcd(y, x%y, g, b, a), b-=(x/y)*a;
}

```

5.4 Pollard Rho

```

// does not work when n is prime
// return any non-trivial factor
llu pollard_rho(llu n){
    static auto f=[](llu x, llu k, llu m){
        return add(k, mul(x, x, m), m);
    };
    if (!(n&1)) return 2;
    mt19937 rnd(120821011);
    while(true){
        llu y=2, yy=y, x=rnd()%n, t=1;
        for(llu sz=2; t==1; sz<<=1) {
            for(llu i=0; i<sz; ++i){
                if(t!=1) break;
                yy=f(yy, x, n);
                t=gcd(yy>y?yy-y:y-yy, n);
            }
            y=yy;
        }
        if(t!=1&&t!=n) return t;
    }
}

```

5.5 Pi Count (Linear Sieve)

```

static constexpr int N = 1000000 + 5;
lld pi[N];
vector<int> primes;
bool sieved[N];
lld cube_root(lld x){
    lld s=cbrt(x-static_cast<long double>(0.1));
    while(s*s*s <= x) ++s;
    return s-1;
}
lld square_root(lld x){
    lld s=sqrt(x-static_cast<long double>(0.1));
    while(s*s <= x) ++s;
    return s-1;
}
void init(){
    primes.reserve(N);
    primes.push_back(1);
    for(int i=2; i<N; i++) {
        if(!sieved[i]) primes.push_back(i);
        pi[i] = !sieved[i] + pi[i-1];
        for(int p: primes) if(p > 1) {
            if(p * i >= N) break;
            sieved[p * i] = true;
            if(p % i == 0) break;
        }
    }
}
lld phi(lld m, lld n) {
    static constexpr int MM = 80000, NN = 500;
    static lld val[MM][NN];
    if(m<MM&&n<NN&&val[m][n]) return val[m][n]-1;
    if(n == 0) return m;
    if(primes[n] >= m) return 1;
    lld ret = phi(m, n-1)-phi(m/primes[n], n-1);
    if(m<MM&&n<NN) val[m][n] = ret+1;
    return ret;
}
lld pi_count(lld);
lld P2(lld m, lld n) {
    lld sm = square_root(m), ret = 0;
    for(lld i = n+1; primes[i]<=sm; i++)
        ret+=pi_count(m/primes[i])-pi_count(primes[i])+1;
    return ret;
}
lld pi_count(lld m) {
    if(m < N) return pi[m];
    lld n = pi_count(cube_root(m));
}

```

```
return phi(m, n) + n - 1 - P2(m, n);
}
```

5.6 Range Sieve

```
const int MAX_SQRT_B = 50000;
const int MAX_L = 200000 + 5;

bool is_prime_small[MAX_SQRT_B];
bool is_prime[MAX_L];

void sieve(lld l, lld r){
    // [l, r)
    for(lld i=2;i*i<r;i++) is_prime_small[i] = true;
    for(lld i=l;i<r;i++) is_prime[i-1] = true;
    if(l==1) is_prime[0] = false;
    for(lld i=2;i*i<r;i++){
        if(!is_prime_small[i]) continue;
        for(lld j=i*i;j<r;j+=i) is_prime_small[j]=false;
        for(lld j=std::max(2LL, (l+i-1)/i)*i;j<r;j+=i)
            is_prime[j-1]=false;
    }
}
```

5.7 Miller Rabin

```
bool isprime(llu x){
    static llu magic[]={2,325,9375,28178,\
        450775,9780504,1795265022};
    static auto witn=[](llu a,llu u,llu n,int t){
        a = mpow(a,u,n);
        if (!a)return 0;
        while(t--){
            ll u2=mul(a,a,n);
            if(a2==1 && a!=1 && a!=n-1)
                return 1;
            a = a2;
        }
        return a!=1;
    };
    if(x<2)return 0;
    if(!(x&1))return x==2;
    ll u=x-1;int t=0;
    while(!(x1&1))x1>=1,t++;
    for(llu m:magic)if(witn(m,x1,x,t))return 0;
    return 1;
}
```

5.8 Inverse Element

```
// x's inverse mod k
long long GetInv(long long x, long long k){
    // k is prime: euler_k=k-1
    return qPow(x, euler_phi(k)-1);
}
// if you need [1, x] (most use: [1, k-1])
void solve(int x, long long k){
    inv[1] = 1;
    for(int i=2;i<x;i++)
        inv[i] = ((long long)(k - k/i) * inv[k % i]) % k;
}
```

5.9 Euler Phi Function

```
/*
    extended euler:
    a^b mod p
    if gcd(a, p)==1: a^(b%phi(p))
    elif b < phi(p): a^b mod p
    else a^(b%phi(p) + phi(p))
*/
lld euler_phi(int x){
    lld r=1;
    for(int i=2;i*i<=x;i++){
        if(x%i==0){
            x/=i; r*=(i-1);
            while(x%i==0){
                x/=i; r*=i;
            }
        }
    }
    if(x>1) r*=x-1;
    return r;
}
vector<int> primes;
```

```
bool notprime[N];
lld phi[N];
void euler_sieve(int n){
    for(int i=2;i<n;i++){
        if(!notprime[i]){
            primes.push_back(i); phi[i] = i-1;
        }
        for(auto j: primes){
            if(i*j >= n) break;
            notprime[i*j] = true;
            phi[i*j] = phi[i] * phi[j];
            if(i % j == 0){
                phi[i*j] = phi[i] * j;
                break;
            }
        }
    }
}
```

5.10 Gauss Elimination

```
void gauss(vector<vector<double>> &d) {
    int n = d.size(), m = d[0].size();
    for (int i = 0; i < m; ++i) {
        int p = -1;
        for (int j = i; j < n; ++j) {
            if (fabs(d[j][i]) < eps) continue;
            if (p == -1 || fabs(d[j][i]) > fabs(d[p][i])) p=j;
        }
        if (p == -1) continue;
        for (int j = 0; j < m; ++j) swap(d[p][j], d[i][j]);
        for (int j = 0; j < n; ++j) {
            if (i == j) continue;
            double z = d[j][i] / d[i][i];
            for (int k = 0; k < m; ++k) d[j][k] -= z*d[i][k];
        }
    }
}
```

5.11 Fast Fourier Transform

```
/*
    polynomial multiply:
    DFT(a, len); DFT(b, len);
    for(int i=0;i<len;i++) c[i] = a[i]*b[i];
    iDFT(c, len);
    (len must be 2^k and >= 2*(max(a, b)))
    Hand written Cplx would be 2x faster
*/
Cplx omega[2][N];
void init_omega(int n) {
    static constexpr llf PI=acos(-1);
    const llf arg=(PI+PI)/n;
    for(int i=0;i<n;i++)
        omega[0][i]={cos(arg*i),sin(arg*i)};
    for(int i=0;i<n;i++)
        omega[1][i]=conj(omega[0][i]);
}
void tran(Cplx arr[],int n,Cplx omg[]) {
    for(int i=0,j=0;i<n;i++){
        if(i>j)swap(arr[i],arr[j]);
        for(int l=n>>1;(j^=1)<l;l>=1);
    }
    for (int l=2;l<=n;l<=1){
        int m=l>>1;
        for(auto p=arr;p!=arr+n;p+=l){
            for(int i=0;i<m;i++){
                Cplx t=omg[n/l*i]*p[m+i];
                p[m+i]=p[i]-t; p[i]+=t;
            }
        }
    }
}
void DFT(Cplx arr[],int n){tran(arr,n,omega[0]);}
void iDFT(Cplx arr[],int n){
    tran(arr,n,omega[1]);
    for(int i=0;i<n;i++) arr[i]/=n;
}
```

5.12 High Speed Linear Recurrence

```
#define mod 998244353
const int N=1000010;
int n,k,m,f[N],h[N],a[N],b[N],ib[N];
```



```

int pw(int x, int y){
    int re=1;
    if(y<0)y+=mod-1;
    while(y){
        if(y&1)re=(ll)re*x%mod;
        y>>=1;x=(ll)x*x%mod;
    }
    return re;
}
void inc(int&x, int y){x+=y;if(x>=mod)x-=mod;}
namespace poly{
    const int G=3;
    int rev[N],L;
    void ntt(int*A,int len,int f){
        for(L=0;(1<<L)<len;++L);
        for(int i=0;i<len;++i){
            rev[i]=(rev[i>>1]>>1)|((i&1)<<(L-1));
            if(i<rev[i])swap(A[i],A[rev[i]]);
        }
        for(int i=1;i<len;i<=1){
            int wn=pw(G,f*(mod-1)/(i<<1));
            for(int j=0;j<len;j+=i<<1){
                int w=1;
                for(int k=0;k<i;++k,w=(ll)w*wn%mod){
                    int x=A[j+k],y=(ll)w*A[j+k+i]%mod;
                    A[j+k]=(x+y)%mod,A[j+k+i]=(x-y+mod)%mod;
                }
            }
        }
        if(!~f){
            int iv=pw(len,mod-2);
            for(int i=0;i<len;++i)A[i]=(ll)A[i]*iv%mod;
        }
    }
    void cls(int*A,int l,int r){
        for(int i=l;i<r;++i)A[i]=0;
    }
    void cpy(int*A,int*B,int l){
        for(int i=0;i<l;++i)A[i]=B[i];
    }
    void inv(int*A,int*B,int l){
        if(l==1){B[0]=pw(A[0],mod-2);return;}
        static int t[N];
        int len=l<<1;
        inv(A,B,l>>1);
        cpy(t,A,l);cls(t,l,len);
        ntt(t,len,1);ntt(B,len,1);
        for(int i=0;i<len;++i)
            B[i]=(ll)B[i]*(2-(ll)t[i]*B[i]%mod+mod)%mod;
        ntt(B,len,-1);cls(B,l,len);
    }
    void pmod(int*A){
        static int t[N];
        int l=k+1,len=1;while(len<=(k<<1))len<=1;
        cpy(t,A,(k<<1)+1);
        reverse(t,t+(k<<1)+1);
        cls(t,l,len);
        ntt(t,len,1);
        for(int i=0;i<len;++i)t[i]=(ll)t[i]*ib[i]%mod;
        ntt(t,len,-1);
        cls(t,l,len);
        reverse(t,t+1);
        ntt(t,len,1);
        for(int i=0;i<len;++i)t[i]=(ll)t[i]*b[i]%mod;
        ntt(t,len,-1);
        cls(t,l,len);
        for(int i=0;i<k;++i)A[i]=(A[i]-t[i]+mod)%mod;
        cls(A,k,len);
    }
    void pow(int*A,int n){
        if(n==1){cls(A,0,k+1);A[1]=1;return;}
        pow(A,n>>1);
        int len=1;while(len<=(k<<1))len<=1;
        ntt(A,len,1);
        for(int i=0;i<len;++i)A[i]=(ll)A[i]*A[i]%mod;
        ntt(A,len,-1);
        pmod(A);
        if(n&1){
            for(int i=k;i--i)A[i]=A[i-1];A[0]=0;
            pmod(A);
        }
    }
}
int main(){

```

```

n=rd();k=rd();
for(int i=1;i<=k;++i)f[i]=(mod+rd())%mod;
for(int i=0;i<k;++i)h[i]=(mod+rd())%mod;
for(int i=a[k]=b[k]=1;i<=k;++i)
    a[k-i]=b[k-i]=(mod-f[i])%mod;
int len=1;while(len<=(k<<1))len<=1;
reverse(a,a+k+1);
poly::inv(a,ib,len);
poly::cls(ib,k+1,len);
poly::ntt(b,len,1);
poly::ntt(ib,len,1);
poly::pow(a,n);
int ans=0;
for(int i=0;i<k;++i)inc(ans,(ll)a[i]*h[i]%mod);
printf("%d\n",ans);
return 0;
}

```

5.13 Chinese Remainder

```

lld crt(lld ans[], lld pri[], int n){
    lld M = 1, ret = 0;
    for(int i=0;i<n;i++) M *= pri[i];
    for(int i=0;i<n;i++){
        lld iv = (gcd(M/pri[i],pri[i]).FF+pri[i])%pri[i];
        ret += (ans[i]*(M/pri[i])%M * iv)%M;
        ret %= M;
    }
    return ret;
}
/*
Another:
x = a1 % m1
x = a2 % m2
g = gcd(m1, m2)
assert((a1-a2)%g==0)
[p, q] = exgcd(m2/g, m1/g)
return a2+m2*(p*(a1-a2)/g)
0 <= x < lcm(m1, m2)
*/

```

5.14 Berlekamp Massey

```

// x: 1-base, p[]: 0-base
template<size_t N>
vector<llf> BM(llf x[N],size_t n){
    size_t f[N]={0},t=0;llf d[N];
    vector<llf> p[N];
    for(size_t i=1,b=0;i<=n;++i){
        for(size_t j=0;j<p[t].size();++j)
            d[i]+=x[i-j-1]*p[t][j];
        if(abs(d[i]-x[i])<=EPS)continue;
        f[t]=i;if(!t){p[++t].resize(i);continue;}
        vector<llf> cur(i-f[b]-1);
        llf k=-d[i]/d[f[b]];cur.PB(-k);
        for(size_t j=0;j<p[b].size();j++)
            cur.PB(p[b][j]*k);
        if(cur.size()<p[t].size())cur.resize(p[t].size());
        for(size_t j=0;j<p[t].size();j++)cur[j]+=p[t][j];
        if(i-f[b]+p[b].size()>p[t].size()) b=t;
        p[++t]=cur;
    }
    return p[t];
}

```

5.15 NTT

```

// Remember coefficient are mod P
/* p=a*2^n+1
n  2^n      p      a      root
16  65536   65537   1      3
20  1048576 7340033  7      3 */
// (must be 2^k)
template<LL P, LL root, int MAXN>
struct NTT{
    static LL bigmod(LL a, LL b){
        LL res = 1;
        for(LL bs = a; b; b>>=1, bs=(bs*bs)%P)
            if(b&1) res=(res*bs)%P;
        return res;
    }
    static LL inv(LL a, LL b){
        if(a==1)return 1;
        return (((LL)(a-inv(b*a,a))*b+1)/a)%b;
    }
};

```

```

}
LL omega[MAXN+1];
NTT() {
    omega[0] = 1;
    LL r = bigmod(root, (P-1)/MAXN);
    for (int i=1; i<=MAXN; i++)
        omega[i] = (omega[i-1]*r)%P;
}
// n must be 2^k
void tran(int n, LL a[], bool inv_ntt=false){
    int basic = MAXN / n, theta = basic;
    for (int m = n; m >= 2; m >= 1) {
        int mh = m >> 1;
        for (int i = 0; i < mh; i++) {
            LL w = omega[i*theta*MAXN];
            for (int j = i; j < n; j += m) {
                int k = j + mh;
                LL x = a[j] - a[k];
                if (x < 0) x += P;
                a[j] += a[k];
                if (a[j] > P) a[j] -= P;
                a[k] = (w * x) % P;
            }
        }
        theta = (theta * 2) % MAXN;
    }
    int i = 0;
    for (int j = 1; j < n - 1; j++) {
        for (int k = n >> 1; k > (i ^ k); k >= 1);
        if (j < i) swap(a[i], a[j]);
    }
    if (inv_ntt) {
        LL ni = inv(n,P);
        reverse(a+1, a+n);
        for (i = 0; i < n; i++)
            a[i] = (a[i] * ni) % P;
    }
};
const LL P=2013265921, root=31;
const int MAXN=4194304;
NTT<P, root, MAXN> ntt;

```

5.16 Polynomial Operations

```

using VI = vector<int>;
Poly Inverse(Poly f) {
    int n = f.size();
    Poly q(1, fpow(f[0], kMod - 2));
    for (int s = 2;; s <= 1) {
        if (f.size() < s) f.resize(s);
        Poly fv(f.begin(), f.begin() + s);
        Poly fq(q.begin(), q.end());
        fv.resize(s + s); fq.resize(s + s);
        ntt::Transform(fv, s + s);
        ntt::Transform(fq, s + s);
        for (int i = 0; i < s + s; ++i)
            fv[i] = 1LL * fv[i] * fq[i] % kMod * fq[i] % kMod;
        ntt::InverseTransform(fv, s + s);
        Poly res(s);
        for (int i = 0; i < s; ++i) {
            res[i] = kMod - fv[i];
            if (i < (s >> 1)) {
                int v = 2 * q[i] % kMod;
                (res[i] += v) >= kMod ? res[i] -= kMod : 0;
            }
        }
        q = res;
        if (s >= n) break;
    }
    q.resize(n);
    return q;
}
Poly Divide(const Poly &a, const Poly &b) {
    int n = a.size(), m = b.size(), k = 2;
    while (k < n - m + 1) k <= 1;
    Poly ra(k), rb(k);
    for (int i = 0; i < min(n, k); ++i) ra[i] = a[n-1-i];
    for (int i = 0; i < min(m, k); ++i) rb[i] = b[m-1-i];
    auto rbi = Inverse(rb);
    auto res = Multiply(rbi, ra);
    res.resize(n - m + 1);
    reverse(res.begin(), res.end());
}

```

```

return res;
}
Poly Modulo(const Poly &a, const Poly &b) {
    if (a.size() < b.size()) return a;
    auto dv = Multiply(Divide(a, b), b);
    assert(dv.size() == a.size());
    for (int i = 0; i < dv.size(); ++i)
        dv[i] = (a[i] + kMod - dv[i]) % kMod;
    while (!dv.empty() && dv.back() == 0) dv.pop_back();
    return dv;
}
Poly Integral(const Poly &f) {
    int n = f.size();
    VI res(n + 1);
    for (int i = 0; i < n; ++i)
        res[i+1] = 1LL * f[i] * fpow(i + 1, kMod - 2) % kMod;
    return res;
}
Poly Evaluate(const Poly &f, const VI &x) {
    if (x.empty()) return Poly();
    int n = x.size();
    vector<Poly> up(n * 2);
    for (int i = 0; i < n; ++i) up[i+n] = {kMod-x[i], 1};
    for (int i = n - 1; i > 0; --i)
        up[i] = Multiply(up[i * 2], up[i * 2 + 1]);
    vector<Poly> down(n * 2);
    down[1] = Modulo(f, up[1]);
    for (int i = 2; i < n * 2; ++i)
        down[i] = Modulo(down[i >> 1], up[i]);
    VI y(n);
    for (int i = 0; i < n; ++i) y[i] = down[i + n][0];
    return y;
}
Poly Interpolate(const VI &x, const VI &y) {
    int n = x.size();
    vector<Poly> up(n * 2);
    for (int i = 0; i < n; ++i) up[i+n] = {kMod-x[i], 1};
    for (int i = n - 1; i > 0; --i)
        up[i] = Multiply(up[i * 2], up[i * 2 + 1]);
    VI a = Evaluate(Derivative(up[1]), x);
    for (int i = 0; i < n; ++i)
        a[i] = 1LL * y[i] * fpow(a[i], kMod - 2) % kMod;
    vector<Poly> down(n * 2);
    for (int i = 0; i < n; ++i) down[i + n] = {a[i]};
    for (int i = n - 1; i > 0; --i) {
        auto lhs = Multiply(down[i * 2], up[i * 2 + 1]);
        auto rhs = Multiply(down[i * 2 + 1], up[i * 2]);
        assert(lhs.size() == rhs.size());
        down[i].resize(lhs.size());
        for (int j = 0; j < lhs.size(); ++j)
            down[i][j] = (lhs[j] + rhs[j]) % kMod;
    }
    return down[1];
}
Poly Log(Poly f) {
    int n = f.size();
    if (n == 1) return {0};
    auto d = Derivative(f);
    f.resize(n - 1);
    d = Multiply(d, Inverse(f));
    d.resize(n - 1);
    return Integral(d);
}
Poly Exp(Poly f) {
    int n = f.size();
    Poly q(1, 1); f[0] += 1;
    for (int s = 1; s < n; s <= 1) {
        if (f.size() < s + s) f.resize(s + s);
        Poly g(f.begin(), f.begin() + s + s);
        Poly h(q.begin(), q.end());
        h.resize(s + s); h = Log(h);
        for (int i = 0; i < s + s; ++i)
            g[i] = (g[i] + kMod - h[i]) % kMod;
        g = Multiply(g, q);
        g.resize(s + s); q = g;
    }
    assert(q.size() >= n);
    q.resize(n);
    return q;
}
Poly SquareRootImpl(Poly f) {
    if (f.empty()) return {0};
}

```

```

int z = QuadraticResidue(f[0], kMod), n = f.size();
constexpr int kInv2 = (kMod + 1) >> 1;
if (z == -1) return {-1};
VI q(1, z);
for (int s = 1; s < n; s <= 1) {
    if (f.size() < s + s) f.resize(s + s);
    VI fq(q.begin(), q.end());
    fq.resize(s + s);
    VI f2 = Multiply(fq, fq);
    f2.resize(s + s);
    for (int i = 0; i < s + s; ++i)
        f2[i] = (f2[i] + kMod - f[i]) % kMod;
    f2 = Multiply(f2, Inverse(fq));
    f2.resize(s + s);
    for (int i = 0; i < s + s; ++i)
        fq[i] = (fq[i] + kMod - 1LL * f2[i] * kInv2 % kMod) % kMod;
    q = fq;
}
q.resize(n);
return q;
}
Poly SquareRoot(Poly f) {
    int n = f.size(), m = 0;
    while (m < n && f[m] == 0) m++;
    if (m == n) return VI(n);
    if (m & 1) return {-1};
    auto s = SquareRootImpl(VI(f.begin() + m, f.end()));
    if (s[0] == -1) return {-1};
    VI res(n);
    for (int i = 0; i < s.size(); ++i) res[i + m/2] = s[i];
    return res;
}

```

5.17 FWT

```

/* xor convolution:
* x = (x0,x1) , y = (y0,y1)
* z = ( x0y0 + x1y1 , x0y1 + x1y0 )
* =>
* x' = ( x0+x1 , x0-x1 ) , y' = ( y0+y1 , y0-y1 )
* z' = ( ( x0+x1 )( y0+y1 ) , ( x0-x1 )( y0-y1 ) )
* z = (1/2) * z'
* or convolution:
* x = (x0, x0+x1), inv = (x0, x1-x0) w/o final div
* and convolution:
* x = (x0+x1, x1), inv = (x0-x1, x1) w/o final div */
const LL MOD = 1e9+7;
inline void fwt(LL x[ MAXN ], int N, bool inv=0) {
    for (int d = 1; d < N; d <= 1) {
        int d2 = d << 1;
        for (int s = 0; s < N; s += d2)
            for (int i = s, j = s+d; i < s+d; i++, j++) {
                LL ta = x[i], tb = x[j];
                x[i] = ta+tb;
                x[j] = ta-tb;
                if (x[i] >= MOD) x[i] -= MOD;
                if (x[j] < 0) x[j] += MOD;
            }
    }
    if (inv)
        for (int i = 0; i < N; i++) {
            x[i] *= inv(N, MOD);
            x[i] %= MOD;
        }
}

```

5.18 DiscreteLog

```

// Baby-step Giant-step Algorithm
lld BSGS(lld P, lld B, lld N) {
    // find B^L = N mod P
    unordered_map<lld, int> R;
    lld sq = (lld)sqrt(P);
    lld t = 1;
    for (int i = 0; i < sq; i++) {
        if (t == N) return i;
        if (!R.count(t)) R[t] = i;
        t = (t * B) % P;
    }
    lld f = inverse(t, P);
    for (int i=0; i<=sq+1; i++) {
        if (R.count(N))
            return i * sq + R[N];
        N = (N * f) % P;
    }
}

```

```

}
return -1;
}

```

5.19 Quadratic residue

```

struct Status{
    ll x,y;
};
ll w;
Status mult(const Status& a,const Status& b,ll mod){
    Status res;
    res.x=(a.x*b.x+a.y*b.y%mod*w)%mod;
    res.y=(a.x*b.y+a.y*b.x)%mod;
    return res;
}
inline Status qpow(Status _base,ll _pow,ll _mod){
    Status res = {1, 0};
    while(_pow>0){
        if(_pow&1) res=mult(res,_base,_mod);
        _base=mult(_base,_base,_mod);
        _pow>>=1;
    }
    return res;
}
inline ll check(ll x,ll p){
    return qpow_mod(x,(p-1)>>1,p);
}
inline ll get_root(ll n,ll p){
    if(p==2) return 1;
    if(check(n,p)==p-1) return -1;
    ll a;
    while(true){
        a=rand()%p;
        w=((a*a-n)%p+p)%p;
        if(check(w,p)==p-1) break;
    }
    Status res = {a, 1};
    res=qpow(res,(p+1)>>1,p);
    return res.x;
}

```

5.20 De-Bruijn

```

int res[maxn], aux[maxn], sz;
void db(int t, int p, int n, int k) {
    if (t > n) {
        if (n % p == 0)
            for (int i = 1; i <= p; ++i)
                res[sz++] = aux[i];
    } else {
        aux[t] = aux[t - p];
        db(t + 1, p, n, k);
        for (int i = aux[t - p] + 1; i < k; ++i) {
            aux[t] = i;
            db(t + 1, t, n, k);
        }
    }
}
int de_bruijn(int k, int n) {
    // return cyclic string of len k^n s.t. every string
    // of len n using k char appears as a substring.
    if (k == 1) {
        res[0] = 0;
        return 1;
    }
    for (int i = 0; i < k * n; i++) aux[i] = 0;
    sz = 0;
    db(1, 1, n, k);
    return sz;
}

```

5.21 Simplex Construction

Standard form: maximize $\sum_{1 \leq i \leq n} c_i x_i$ such that for all $1 \leq j \leq m$, $\sum_{1 \leq i \leq n} A_{ji} x_i \leq b_j$, and $x_i \geq 0$ for all $1 \leq i \leq n$.

1. In case of minimization, let $c'_i = -c_i$
2. $\sum_{1 \leq i \leq n} A_{ji} x_i \geq b_j \rightarrow \sum_{1 \leq i \leq n} -A_{ji} x_i \leq -b_j$
3. $\sum_{1 \leq i \leq n} A_{ji} x_i = b_j$
 - $\sum_{1 \leq i \leq n} A_{ji} x_i \leq b_j$
 - $\sum_{1 \leq i \leq n} A_{ji} x_i \geq b_j$
4. If x_i has no lower bound, replace x_i with $x_i - x'_i$

5.22 Simplex

```
namespace simplex {
// maximize c^T x under Ax <= B
// return VD(n, -inf) if the solution doesn't exist
// return VD(n, +inf) if the solution is unbounded
using VD = vector<double>;
using VVD = vector<vector<double>>;
const double eps = 1e-9;
const double inf = 1e+9;
int n, m;
VVD d;
vector<int> p, q;
void pivot(int r, int s) {
double inv = 1.0 / d[r][s];
for (int i = 0; i < m + 2; ++i)
for (int j = 0; j < n + 2; ++j)
if (i != r && j != s)
d[i][j] -= d[r][j] * d[i][s] * inv;
for(int i=0;i<m+2;++i) if (i != r) d[i][s] *= -inv;
for(int j=0;j<n+2;++j) if (j != s) d[r][j] *= +inv;
d[r][s] = inv; swap(p[r], q[s]);
}
bool phase(int z) {
int x = m + z;
while (true) {
int s = -1;
for (int i = 0; i <= n; ++i) {
if (!z && q[i] == -1) continue;
if (s == -1 || d[x][i] < d[x][s]) s = i;
}
if (d[x][s] > -eps) return true;
int r = -1;
for (int i = 0; i < m; ++i) {
if (d[i][s] < eps) continue;
if (r == -1 || \
d[i][n+1]/d[i][s] < d[r][n+1]/d[r][s]) r = i;
}
if (r == -1) return false;
pivot(r, s);
}
}
VD solve(const VVD &a, const VD &b, const VD &c) {
m = b.size(), n = c.size();
d = VVD(m + 2, VD(n + 2));
for (int i = 0; i < m; ++i)
for (int j = 0; j < n; ++j) d[i][j] = a[i][j];
p.resize(m), q.resize(n + 1);
for (int i = 0; i < m; ++i)
p[i] = n + i, d[i][n] = -1, d[i][n + 1] = b[i];
for (int i = 0; i < n; ++i) q[i] = i, d[m][i] = -c[i];
q[n] = -1, d[m + 1][n] = 1;
int r = 0;
for (int i = 1; i < m; ++i)
if (d[i][n + 1] < d[r][n + 1]) r = i;
if (d[r][n + 1] < -eps) {
pivot(r, n);
if (!phase(1) || d[m + 1][n + 1] < -eps)
return VD(n, -inf);
for (int i = 0; i < m; ++i) if (p[i] == -1) {
int s = min_element(d[i].begin(), d[i].end() - 1)
- d[i].begin();
pivot(i, s);
}
}
if (!phase(0)) return VD(n, inf);
VD x(n);
for (int i = 0; i < m; ++i)
if (p[i] < n) x[p[i]] = d[i][n + 1];
return x;
}
}
```

6 Geometry

6.1 Circle Class

```
template<typename T>
struct Circle{
static constexpr llf EPS = 1e-8;
Point<T> o; T r;
vector<Point<llf>> operator&(const Circle& aa)const{
llf d=o.dis(aa.o);
if(d>r+aa.r+EPS || d<fabs(r-aa.r)-EPS) return {};
```

```
llf dt = (r*r - aa.r*aa.r)/d, d1 = (d+dt)/2;
Point<llf> dir = (aa.o-o); dir /= d;
Point<llf> pcrs = dir*d1 + o;
dt=sqrt(max(0.0L, r*r - d1*d1)), dir=dir.rot90();
return {pcrs + dir*dt, pcrs - dir*dt};
};
```

6.2 Segment Class

```
const long double EPS = 1e-8;
template<typename T>
struct Segment{
// p1.x < p2.x
Line<T> base;
Point<T> p1, p2;
Segment(): base(Line<T>()), p1(Point<T>()), p2(Point<T>()){}
assert(on_line(p1, base) and on_line(p2, base));
Segment(Line<T> _, Point<T> __, Point<T> ___): base(_),
p1(__), p2(___){
assert(on_line(p1, base) and on_line(p2, base));
}
template<typename T2>
Segment(const Segment<T2>& _): base(_.base), p1(_.p1),
p2(_.p2) {}
typedef Point<long double> Pt;
friend bool on_segment(const Point<T>& p, const
Segment& l){
if(on_line(p, l.base))
return (l.p1.x-p.x)*(p.x-l.p2.x)>=0 and (l.p1.y-p.y)
*(p.y-l.p2.y)>=0;
return false;
}
friend bool have_inter(const Segment& a, const Segment
& b){
if(is_parallel(a.base, b.base)){
return on_segment(a.p1, b) or on_segment(a.p2, b) or
on_segment(b.p1, a) or on_segment(b.p2, a);
}
Pt inter = get_inter(a.base, b.base);
return on_segment(inter, a) and on_segment(inter, b);
}
friend inline Pt get_inter(const Segment& a, const
Segment& b){
if(!have_inter(a, b)){
return NOT_EXIST;
}else if(is_parallel(a.base, b.base)){
if(a.p1 == b.p1){
if(on_segment(a.p2, b) or on_segment(b.p2, a))
return INF_P;
else return a.p1;
}else if(a.p1 == b.p2){
if(on_segment(a.p2, b) or on_segment(b.p1, a))
return INF_P;
else return a.p1;
}else if(a.p2 == b.p1){
if(on_segment(a.p1, b) or on_segment(b.p2, a))
return INF_P;
else return a.p2;
}else if(a.p2 == b.p2){
if(on_segment(a.p1, b) or on_segment(b.p1, a))
return INF_P;
else return a.p2;
}
return INF_P;
}
return get_inter(a.base, b.base);
}
friend ostream& operator<<(ostream& ss, const Segment&
o){
ss<<o.base<<" , "<<o.p1<<" ~ "<<o.p2;
return ss;
}
};
```

```
template<typename T>
inline Segment<T> get_segment(const Point<T>& a, const
Point<T>& b){
return Segment<T>(get_line(a, b), a, b);
}
```

6.3 Line Class

```

const Point<long double> INF_P(-1e20, 1e20);
const Point<long double> NOT_EXIST(1e20, 1e-20);
template<typename T>
struct Line{
    static constexpr long double EPS = 1e-8;
    // ax+by+c = 0
    T a, b, c;
    Line(T _=0, T __=1, T ___=0): a(_), b(__), c(___){
        assert(fabs(a)>EPS or fabs(b)>EPS);}
    template<typename T2>
    Line(const Line<T2>& x): a(x.a), b(x.b), c(x.c){}
    typedef Point<long double> Pt;
    bool equal(const Line& o, true_type) const {
        return fabs(a-o.a)<EPS &&
            fabs(b-o.b)<EPS && fabs(c-o.c)<EPS;}
    bool equal(const Line& o, false_type) const {
        return a==o.a and b==o.b and c==o.c;}
    bool operator==(const Line& o) const {
        return equal(o, is_floating_point<T>());}
    bool operator!=(const Line& o) const {
        return !(*this == o);}
    friend inline bool on_line__(const Point<T>& p, const
        Line& l, true_type){
        return fabs(l.a*p.x + l.b*p.y + l.c) < EPS;}
    friend inline bool on_line__(const Point<T>& p, const
        Line& l, false_type){
        return l.a*p.x + l.b*p.y + l.c == 0;}
    friend inline bool on_line(const Point<T>&p, const
        Line& l){
        return on_line__(p, l, is_floating_point<T>());}
    friend inline bool is_parallel__(const Line& x, const
        Line& y, true_type){
        return fabs(x.a*y.b - x.b*y.a) < EPS;}
    friend inline bool is_parallel__(const Line& x, const
        Line& y, false_type){
        return x.a*y.b == x.b*y.a;}
    friend inline bool is_parallel(const Line& x, const
        Line& y){
        return is_parallel__(x, y, is_floating_point<T>());}
    friend inline Pt get_inter(const Line& x, const Line&
        y){
        typedef long double llf;
        if(x==y) return INF_P;
        if(is_parallel(x, y)) return NOT_EXIST;
        llf delta = x.a*y.b - x.b*y.a;
        llf delta_x = x.b*y.c - x.c*y.b;
        llf delta_y = x.c*y.a - x.a*y.c;
        return Pt(delta_x / delta, delta_y / delta);}
    friend ostream&operator<<(ostream&ss, const Line&o){
        ss<<o.a<<"x"<<o.b<<"y"<<o.c<<"=0";
        return ss;}
};

template<typename T>
inline Line<T> get_line(const Point<T>& a, const Point<
    T>& b){
    return Line<T>(a.y-b.y, b.x-a.x, (b.y-a.y)*a.x-(b.x-a.
        x)*a.y);}

```

6.4 Triangle Circumcentre

```

template<typename T>
Circle<llf> get_circum(const Point<T>& a, const Point<T>
    &b, const Point<T>& c){
    llf a1 = a.x-b.x, b1 = a.y-b.y;
    llf c1 = (a.x+b.x)/2 * a1 + (a.y+b.y)/2 * b1;
    llf a2 = a.x-c.x, b2 = a.y-c.y;
    llf c2 = (a.x+c.x)/2 * a2 + (a.y+c.y)/2 * b2;
    Circle<llf> cc;
    cc.o.x = (c1*b2-b1*c2)/(a1*b2-b1*a2);
    cc.o.y = (a1*c2-c1*a2)/(a1*b2-b1*a2);
    cc.r = hypot(cc.o.x-a.x, cc.o.y-a.y);
    return cc;}

```

6.5 2D Convex Hull

```

template<typename T>
class ConvexHull_2D{
private:
    typedef Point<T> PT;
    vector<PT> d;
    struct myhash{
        uint64_t operator()(const PT& a) const {
            uint64_t xx=0, yy=0;
            memcpy(&xx, &a.x, sizeof(a.x));
            memcpy(&yy, &a.y, sizeof(a.y));
            uint64_t ret = xx*17+yy*31;
            ret = (ret ^ (ret >> 16))*0x9E3779B1;
            ret = (ret ^ (ret >> 13))*0xC2B2AE35;
            ret = ret ^ xx;
            return (ret ^ (ret << 3)) * yy;
        }
    };
    unordered_set<PT, myhash> in_hull;
public:
    void init(){in_hull.clear();d.clear();}
    void insert(const PT& x){d.PB(x);}
    void solve(){
        sort(ALL(d), [](const PT& a, const PT& b){
            return tie(a.x, a.y) < tie(b.x, b.y)});
        vector<PT> s(SZ(d)<<1); int o = 0;
        for(auto p: d) {
            while(o>=2 && cross(p-s[o-2], s[o-1]-s[o-2])<=0)
                o--;
            s[o++] = p;
        }
        for(int i=SZ(d)-2, t = o+1; i>=0; i--){
            while(o>=t&&cross(d[i]-s[o-2], s[o-1]-s[o-2])<=0)
                o--;
            s[o++] = d[i];
        }
        s.resize(o-1); swap(s, d);
        for(auto i: s) in_hull.insert(i);
    }
    vector<PT> get(){return d;}
    bool in_it(const PT& x){
        return in_hull.find(x)!=in_hull.end();}
};

```

6.6 3D Convex Hull

```

// return the faces with pt indexes
int flag[MXN][MXN];
struct Point{
    ld x,y,z;
    Point operator * (const ld &b) const {
        return (Point){x*b,y*b,z*b};}
    Point operator * (const Point &b) const {
        return(Point){y*b.z-b.y*z,z*b.x-b.z*x,x*b.y-b.x*y};
    }
};
Point ver(Point a, Point b, Point c) {
    return (b - a) * (c - a);}
vector<Face> convex_hull_3D(const vector<Point> pt) {
    int n = SZ(pt), ftop = 0;
    REP(i,n) REP(j,n) flag[i][j] = 0;
    vector<Face> now;
    now.emplace_back(0,1,2);
    now.emplace_back(2,1,0);
    for (int i=3; i<n; i++){
        ftop++; vector<Face> next;
        REP(j, SZ(now)) {
            Face& f=now[j]; int ff = 0;
            ld d=(pt[i]-pt[f.a]).dot(
                ver(pt[f.a], pt[f.b], pt[f.c]));
            ver(pt[f.a], pt[f.b], pt[f.c]));
            if (d <= 0) next.push_back(f);
            if (d > 0) ff=ftop;
            else if (d < 0) ff=-ftop;
            flag[f.a][f.b]=flag[f.b][f.c]=flag[f.c][f.a]=ff;
        }
        REP(j, SZ(now)) {
            Face& f=now[j];
            if (flag[f.a][f.b] > 0 &&
                flag[f.a][f.b] != flag[f.b][f.a])
                next.emplace_back(f.a,f.b,i);
            if (flag[f.b][f.c] > 0 &&
                flag[f.b][f.c] != flag[f.c][f.b])

```



```

    next.emplace_back(f.b,f.c,i);
    if (flag[f.c][f.a] > 0 &&
        flag[f.c][f.a] != flag[f.a][f.c])
        next.emplace_back(f.c,f.a,i);
    }
    now=next;
}
return now;
}

```

6.7 2D Farthest Pair

```

// stk is from convex hull
n = (int)(stk.size());
int pos = 1, ans = 0; stk.push_back(stk[0]);
for(int i=0;i<n;i++) {
    while(abs(cross(stk[i+1]-stk[i],
        stk[(pos+1)%n]-stk[i])) >
        abs(cross(stk[i+1]-stk[i],
        stk[pos]-stk[i]))) pos = (pos+1)%n;
    ans = max({ans, dis(stk[i], stk[pos]),
        dis(stk[i+1], stk[pos])});
}

```

6.8 2D Closest Pair

```

struct cmp_y {
    bool operator()(const P& p, const P& q) const {
        return p.y < q.y;
    }
};
multiset<P, cmp_y> s;
void solve(P a[], int n) {
    sort(a, a + n, [](const P& p, const P& q) {
        return tie(p.x, p.y) < tie(q.x, q.y);
    });
    llf d = INF; int pt = 0;
    for (int i = 0; i < n; ++i) {
        while (pt < i and a[i].x - a[pt].x >= d)
            s.erase(s.find(a[pt++]));
        auto it = s.lower_bound(P(a[i].x, a[i].y - d));
        while (it != s.end() and it->y - a[i].y < d)
            d = min(d, dis(*it, a[i]));
        s.insert(a[i]);
    }
}

```

6.9 kD Closest Pair (3D ver.)

```

llf solve(vector<P> v) {
    shuffle(v.begin(), v.end(), mt19937());
    // maybe could replace vector<P> with only P
    unordered_map<lld, unordered_map<lld,
        unordered_map<lld, vector<P>>>> m;
    llf d = dis(v[0], v[1]);
    auto Idx = [&d] (lld x) -> lld {
        return round(x * 2 / d) + 0.1; };
    auto rebuild_m = [&m, &v, &Idx](int k) {
        m.clear();
        for (int i = 0; i < k; ++i)
            m[Idx(v[i].x)][Idx(v[i].y)]
                [Idx(v[i].z)].push_back(v[i]);
    };
    rebuild_m(2);
    for (size_t i = 2; i < v.size(); ++i) {
        const lld kx = Idx(v[i].x), ky = Idx(v[i].y),
            kz = Idx(v[i].z); bool found = false;
        for (int x = -2; x <= 2; ++x) {
            const lld nx = x + kx;
            if (m.find(nx) == m.end()) continue;
            auto& mm = m[nx];
            for (int y = -2; y <= 2; ++y) {
                const lld ny = y + ky;
                if (mm.find(ny) == mm.end()) continue;
                auto& mmm = mm[ny];
                for (int z = -2; z <= 2; ++z) {
                    const lld nz = z + kz;
                    if (mmm.find(nz) == mmm.end()) continue;
                    for (auto p: mmm[nz]) {
                        if (dis(p, v[i]) < d) {
                            d = dis(p, v[i]);
                            found = true;
                        }
                    }
                }
            }
        }
    }
}

```

```

    }
    }
    if (found) rebuild_m(i + 1);
    else m[kx][ky][kz].push_back(v[i]);
}
return d;
}

```

6.10 Simulated Annealing

```

llf anneal() {
    mt19937 rnd_engine( seed );
    uniform_real_distribution< llf > rnd( 0, 1 );
    const llf dT = 0.001;
    // Argument p
    llf S_cur = calc( p ), S_best = S_cur;
    for ( llf T = 2000 ; T > EPS ; T -= dT ) {
        // Modify p to p_prime
        const llf S_prime = calc( p_prime );
        const llf delta_c = S_prime - S_cur;
        llf prob = min( ( llf ) 1, exp( -delta_c / T ) );
        if ( rnd( rnd_engine ) <= prob )
            S_cur = S_prime, p = p_prime;
        if ( S_prime < S_best ) // find min
            S_best = S_prime, p_best = p_prime;
    }
    return S_best;
}

```

6.11 Half Plane Intersection

```

inline int dcmp ( double x ) {
    if( fabs( x ) < eps ) return 0;
    return x > 0 ? 1 : -1;
}
struct Line {
    Point st, ed;
    double ang;
    Line(Point _s=Point(), Point _e=Point()):
        st(_s),ed(_e),ang(atan2(_e.y-_s.y,_e.x-_s.x)){}
    inline bool operator< ( const Line& rhs ) const {
        if(dcmp(ang - rhs.ang) != 0) return ang < rhs.ang;
        return dcmp( cross( st, ed, rhs.st ) ) < 0;
    }
};
// cross(pt, line.ed-line.st)>=0 <=> pt in half plane
vector< Line > lns;
deque< Line > que;
deque< Point > pt;
double HPI() {
    sort( lns.begin(), lns.end() );
    que.clear(); pt.clear();
    que.push_back( lns[ 0 ] );
    for ( int i = 1 ; i < (int)lns.size() ; i ++ ) {
        if(!dcmp(lns[i].ang - lns[i-1].ang)) continue;
        while ( pt.size() > 0 &&
            dcmp(cross(lns[i].st,lns[i].ed,pt.back()))<0){
            pt.pop_back();que.pop_back();
        }
        while ( pt.size() > 0 &&
            dcmp(cross(lns[i].st,lns[i].ed,pt.front()))<0){
            pt.pop_front(); que.pop_front();
        }
        pt.push_back(get_point( que.back(), lns[ i ] ));
        que.push_back( lns[ i ] );
    }
    while ( pt.size() > 0 &&
        dcmp(cross(que[0].st, que[0].ed, pt.back()))<0){
        que.pop_back();
        pt.pop_back();
    }
    while ( pt.size() > 0 &&
        dcmp(cross(que.back().st,que.back().ed,pt[0]))<0){
        que.pop_front();
        pt.pop_front();
    }
    pt.push_back(get_point(que.front(), que.back()));
    vector< Point > conv;
    for ( int i = 0 ; i < (int)pt.size() ; i ++ )
        conv.push_back( pt[ i ] );
    double ret = 0;
    for ( int i = 1 ; i + 1 < (int)conv.size() ; i ++ )
        ret += abs(cross(conv[0], conv[i], conv[i + 1]));
}

```

```
return ret / 2.0;
}
```

6.12 Ternary Search on Integer

```
int TernarySearch(int l, int r) {
    // max value @ (l, r]
    while (r - l > 1) {
        int m = (l + r) >> 1;
        if (f(m) > f(m + 1)) r = m;
        else l = m;
    }
    return l + 1;
}
```

6.13 Minimum Covering Circle

```
template<typename T>
Circle<llf> MinCircleCover(const vector<PT>& pts) {
    random_shuffle(ALL(pts));
    Circle<llf> c = {pts[0], 0};
    for(int i=0; i<SZ(pts); i++) {
        if(pts[i].in(c)) continue;
        c = {pts[i], 0};
        for(int j=0; j<i; j++) {
            if(pts[j].in(c)) continue;
            c.o = (pts[i] + pts[j]) / 2;
            c.r = pts[i].dis(c.o);
            for(int k=0; k<j; k++) {
                if(pts[k].in(c)) continue;
                c = get_circum(pts[i], pts[j], pts[k]);
            }
        }
    }
    return c;
}
```

6.14 KDTree (Nearest Point)

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

```
int touch(Node* r, int x, int y, LL d2) {
    LL dis = sqrt(d2)+1;
    if (x<r->x1-dis || x>r->x2+dis ||
        y<r->y1-dis || y>r->y2+dis)
        return 0;
    return 1;
}
void nearest(Node* r, int x, int y, int &mID, LL &md2) {
    if (!r || !touch(r, x, y, md2)) return;
    LL d2 = dis2(r->x, r->y, x, y);
    if (d2 < md2 || (d2 == md2 && mID < r->id)) {
        mID = r->id;
        md2 = d2;
    }
    // search order depends on split dim
    if ((r->f == 0 && x < r->x) ||
        (r->f == 1 && y < r->y)) {
        nearest(r->L, x, y, mID, md2);
        nearest(r->R, x, y, mID, md2);
    } else {
        nearest(r->R, x, y, mID, md2);
        nearest(r->L, x, y, mID, md2);
    }
}
int query(int x, int y) {
    int id = 1029384756;
    LL d2 = 102938475612345678LL;
    nearest(root, x, y, id, d2);
    return id;
}
} tree;
```

7 Stringology

7.1 Hash

```
class Hash {
private:
    const int p = 127, q = 1051762951;
    int sz, prefix[N], power[N];
    int add(int x, int y) { return x+y>=q?x+y-q:x+y; }
    int sub(int x, int y) { return x-y<0?x-y+q:x-y; }
    int mul(int x, int y) { return 1LL*x*y%q; }
public:
    void init(const string &x) {
        sz = x.size(); prefix[0]=0; power[0]=1;
        for (int i=1; i<=sz; i++)
            prefix[i]=add(mul(prefix[i-1], p), x[i-1]);
        for (int i=1; i<=sz; i++) power[i]=mul(power[i-1], p);
    }
    int query(int l, int r) {
        // 1-base [l, r]
        return sub(prefix[r], mul(prefix[l], power[r-l]));
    }
};
```

7.2 Suffix Array

```
namespace sfxarray {
    bool t[maxn * 2];
    int hi[maxn], rev[maxn];
    int _s[maxn * 2], sa[maxn * 2], c[maxn * 2];
    int x[maxn], p[maxn], q[maxn * 2];
    // sa[i]: sa[i]-th suffix is the \
    // i-th lexicographically smallest suffix.
    // hi[i]: longest common prefix \
    // of suffix sa[i] and suffix sa[i - 1].
    void pre(int *sa, int *c, int n, int z) {
        memset(sa, 0, sizeof(int) * n);
        memcpy(x, c, sizeof(int) * z);
    }
    void induce(int *sa, int *c, int *s, bool *t, int n, int z) {
        memcpy(x + 1, c, sizeof(int) * (z - 1));
        for (int i = 0; i < n; ++i)
            if (sa[i] && !t[sa[i] - 1])
                sa[x[s[sa[i] - 1]]++] = sa[i] - 1;
        memcpy(x, c, sizeof(int) * z);
        for (int i = n - 1; i >= 0; --i)
            if (sa[i] && t[sa[i] - 1])
                sa[--x[sa[i] - 1]] = sa[i] - 1;
    }
    void sais(int *s, int *sa, int *p, int *q,
        bool *t, int *c, int n, int z) {
```

```

bool uniq = t[n - 1] = true;
int nn=0, nmzx=-1, *nsa = sa+n, *ns=s+n, last=-1;
memset(c, 0, sizeof(int) * z);
for (int i = 0; i < n; ++i) uniq &= ++c[s[i]] < 2;
for (int i = 0; i < z - 1; ++i) c[i + 1] += c[i];
if (uniq) {
    for (int i = 0; i < n; ++i) sa[--c[s[i]]] = i;
    return;
}
for (int i = n - 2; i >= 0; --i)
    t[i] = (s[i]==s[i + 1] ? t[i + 1] : s[i]<s[i + 1]);
pre(sa, c, n, z);
for (int i = 1; i <= n - 1; ++i)
    if (t[i] && !t[i - 1])
        sa[--x[s[i]]] = p[q[i] = nn++] = i;
induce(sa, c, s, t, n, z);
for (int i = 0; i < n; ++i) {
    if (sa[i] && t[sa[i]] && !t[sa[i] - 1]) {
        bool neq = last < 0 || \
            memcmp(s + sa[i], s + last,
                (p[q[sa[i]] + 1] - sa[i]) * sizeof(int));
        ns[q[last = sa[i]]] = nmzx += neq;
    }
}
sais(ns, nsa, p+nn, q+n, t+n, c+z, nn, nmzx+1);
pre(sa, c, n, z);
for (int i = nn - 1; i >= 0; --i)
    sa[--x[s[p[nsa[i]]]]] = p[nsa[i]];
induce(sa, c, s, t, n, z);
}

void build(const string &s) {
    for (int i = 0; i < (int)s.size(); ++i) _s[i] = s[i];
    _s[(int)s.size()] = 0; // s shouldn't contain 0
    sais(_s, sa, p, q, t, c, (int)s.size() + 1, 256);
    for (int i = 0; i < (int)s.size(); ++i) sa[i]=sa[i+1];
    for (int i = 0; i < (int)s.size(); ++i) rev[sa[i]]=i;
    int ind = 0; hi[0] = 0;
    for (int i = 0; i < (int)s.size(); ++i) {
        if (!rev[i]) {
            ind = 0;
            continue;
        }
        while (i + ind < (int)s.size() && \
            s[i + ind] == s[sa[rev[i] - 1] + ind]) ++ind;
        hi[rev[i]] = ind ? ind-- : 0;
    }
}

```

7.3 Aho-Corasick Algorithm

```

class AhoCorasick{
private:
    static constexpr int Z = 26;
    struct node{
        node *nxt[ Z ], *fail;
        vector< int > data;
        node(): fail( nullptr ) {
            memset( nxt, 0, sizeof( nxt ) );
            data.clear();
        }
    } *rt;
    inline int Idx( char c ) { return c - 'a'; }
public:
    void init() { rt = new node(); }
    void add( const string& s, int d ) {
        node* cur = rt;
        for ( auto c : s ) {
            if ( not cur->nxt[ Idx( c ) ] )
                cur->nxt[ Idx( c ) ] = new node();
            cur = cur->nxt[ Idx( c ) ];
        }
        cur->data.push_back( d );
    }
    void compile() {
        vector< node* > bfs;
        size_t ptr = 0;
        for ( int i = 0; i < Z; ++i ) {
            if ( not rt->nxt[ i ] ) {
                // uncomment 2 lines to make it DFA
                // rt->nxt[i] = rt;
                continue;
            }
            rt->nxt[ i ]->fail = rt;
            bfs.push_back( rt->nxt[ i ] );
        }
    }
}

```

```

}
while ( ptr < bfs.size() ) {
    node* u = bfs[ ptr++ ];
    for ( int i = 0; i < Z; ++i ) {
        if ( not u->nxt[ i ] ) {
            // u->nxt[i] = u->fail->nxt[i];
            continue;
        }
        node* u_f = u->fail;
        while ( u_f ) {
            if ( not u_f->nxt[ i ] ) {
                u_f = u_f->fail; continue;
            }
            u->nxt[ i ]->fail = u_f->nxt[ i ];
            break;
        }
        if ( not u_f ) u->nxt[ i ]->fail = rt;
        bfs.push_back( u->nxt[ i ] );
    }
}

void match( const string& s, vector< int >& ret ) {
    node* u = rt;
    for ( auto c : s ) {
        while ( u != rt and not u->nxt[ Idx( c ) ] )
            u = u->fail;
        u = u->nxt[ Idx( c ) ];
        if ( not u ) u = rt;
        node* tmp = u;
        while ( tmp != rt ) {
            for ( auto d : tmp->data )
                ret.push_back( d );
            tmp = tmp->fail;
        }
    }
}
} ac;

```

7.4 Suffix Automaton

```

struct Node{
    Node *green, *edge[26];
    int max_len;
    Node(const int _max_len)
        : green(NULL), max_len(_max_len){
        memset(edge, 0, sizeof(edge));
    }
} *ROOT, *LAST;

void Extend(const int c) {
    Node *cursor = LAST;
    LAST = new Node((LAST->max_len) + 1);
    for(; cursor && cursor->edge[c]; cursor=cursor->green)
        cursor->edge[c] = LAST;
    if (!cursor)
        LAST->green = ROOT;
    else {
        Node *potential_green = cursor->edge[c];
        if((potential_green->max_len)==(cursor->max_len+1))
            LAST->green = potential_green;
        else {
            //assert(potential_green->max_len>(cursor->max_len+1));
            Node *wish = new Node((cursor->max_len) + 1);
            for(; cursor && cursor->edge[c]==potential_green;
                cursor = cursor->green)
                cursor->edge[c] = wish;
            for (int i = 0; i < 26; i++)
                wish->edge[i] = potential_green->edge[i];
            wish->green = potential_green->green;
            potential_green->green = wish;
            LAST->green = wish;
        }
    }
}

char S[10000001], A[10000001];
int N;
int main(){
    scanf("%d%s", &N, S);
    ROOT = LAST = new Node(0);
    for (int i = 0; S[i]; i++)
        Extend(S[i] - 'a');
    while (N--){
        scanf("%s", A);
        Node *cursor = ROOT;
    }
}

```

```

bool ans = true;
for (int i = 0; A[i]; i++){
    cursor = cursor->edge[A[i] - 'a'];
    if (!cursor) {
        ans = false;
        break;
    }
}
puts(ans ? "Yes" : "No");
}
return 0;
}

```

7.5 KMP

```

vector<int> kmp(const string &s) {
    vector<int> f(s.size(), 0);
    /* f[i] = length of the longest prefix
       (excluding s[0:i]) such that it coincides
       with the suffix of s[0:i] of the same length */
    /* i + 1 - f[i] is the length of the
       smallest recurring period of s[0:i] */
    int k = 0;
    for (int i = 1; i < (int)s.size(); ++i) {
        while (k > 0 && s[i] != s[k]) k = f[k - 1];
        if (s[i] == s[k]) ++k;
        f[i] = k;
    }
    return f;
}

vector<int> search(const string &s, const string &t) {
    // return 0-indexed occurrence of t in s
    vector<int> f = kmp(t), r;
    for (int i = 0, k = 0; i < (int)s.size(); ++i) {
        while (k > 0 && (k==(int)t.size() || s[i]!=t[k]))
            k = f[k - 1];
        if (s[i] == t[k]) ++k;
        if (k == (int)t.size()) r.push_back(i-t.size()+1);
    }
    return res;
}

```

7.6 Z value

```

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

```

7.7 Manacher

```

int z[maxn];
int manacher(const string& s) {
    string t = ".";
    for (char c:s) t += c, t += '.';
    int l = 0, r = 0, ans = 0;
    for (int i = 1; i < t.length(); ++i) {
        z[i] = (r > i ? min(z[2 * l - i], r - i) : 1);
        while (i - z[i] >= 0 && i + z[i] < t.length()) {
            if (t[i - z[i]] == t[i + z[i]]) ++z[i];
            else break;
        }
        if (i + z[i] > r) r = i + z[i], l = i;
    }
    for (int i=1; i<t.length(); ++i) ans = max(ans, z[i]-1);
    return ans;
}

```

7.8 Lexico Smallest Rotation

```

string mcp(string s){
    int n = s.length();
    s += s;
    int i=0, j=1;
    while (i<n && j<n){

```

```

    int k = 0;
    while (k < n && s[i+k] == s[j+k]) k++;
    if (s[i+k] <= s[j+k]) j += k+1;
    else i += k+1;
    if (i == j) j++;
    }
    int ans = i < n ? i : j;
    return s.substr(ans, n);
}

```

7.9 BWT

```

struct BurrowsWheeler{
#define SIGMA 26
#define BASE 'a'
    vector<int> v[ SIGMA ];
    void BWT(char* ori, char* res){
        // make ori -> ori + ori
        // then build suffix array
    }
    void iBWT(char* ori, char* res){
        for (int i = 0 ; i < SIGMA ; i ++ )
            v[ i ].clear();
        int len = strlen( ori );
        for (int i = 0 ; i < len ; i ++ )
            v[ ori[i] - BASE ].push_back( i );
        vector<int> a;
        for (int i = 0 , ptr = 0 ; i < SIGMA ; i ++ )
            for (auto j : v[ i ] ){
                a.push_back( j );
                ori[ ptr ++ ] = BASE + i;
            }
        for (int i = 0 , ptr = 0 ; i < len ; i ++ ){
            res[ i ] = ori[ a[ ptr ] ];
            ptr = a[ ptr ];
        }
        res[ len ] = 0;
    }
} bwt;

```

7.10 Palindromic Tree

```

struct palindromic_tree{
    struct node{
        int next[26], f, len;
        int cnt, num, st, ed;
        node(int l=0):f(0),len(l),cnt(0),num(0) {
            memset(next, 0, sizeof(next));
        };
    };
    vector<node> st;
    vector<char> s;
    int last, n;
    void init(){
        st.clear(); s.clear(); last=1; n=0;
        st.push_back(0); st.push_back(-1);
        st[0].f=1; s.push_back(-1);
    }
    int getFail(int x){
        while(s[n-st[x].len-1]!=s[n])x=st[x].f;
        return x;
    }
    void add(int c){
        s.push_back(c-'a'); ++n;
        int cur=getFail(last);
        if(!st[cur].next[c]){
            int now=st.size();
            st.push_back(st[cur].len+2);
            st[now].f=st[getFail(st[cur].f)].next[c];
            st[cur].next[c]=now;
            st[now].num=st[st[now].f].num+1;
        }
        last=st[cur].next[c];
        ++st[last].cnt;
    }
    int size(){ return st.size()-2; }
} pt;

int main() {
    string s; cin >> s; pt.init();
    for (int i=0; i<S2(s); i++) {
        int prvsz = pt.size(); pt.add(s[i]);
        if (prvsz != pt.size()) {
            int r = i, l = r - pt.st[pt.last].len + 1;
            // pal @ [l,r]: s.substr(l, r-l+1)
        }
    }
    return 0;
}

```

8 Misc

8.1 Theorems

8.1.1 Kirchhoff's Theorem

Denote L be a $n \times n$ matrix as the Laplacian matrix of graph G , where $L_{ii} = d(i)$, $L_{ij} = -c$ where c is the number of edge (i, j) in G .

- The number of undirected spanning in G is $|\det(\tilde{L}_{11})|$.
- The number of directed spanning tree rooted at r in G is $|\det(\tilde{L}_{rr})|$.

8.1.2 Tutte's Matrix

Let D be a $n \times n$ matrix, where $d_{ij} = x_{ij}$ (x_{ij} is chosen uniform randomly) if $i < j$ and $(i, j) \in E$, otherwise $d_{ij} = -d_{ji} \cdot \frac{\text{rank}(D)}{2}$ is the maximum matching on G .

8.1.3 Cayley's Formula

- Given a degree sequence d_1, d_2, \dots, d_n for each labeled vertices, there're $\frac{(n-2)!}{(d_1-1)!(d_2-1)!\dots(d_n-1)!}$ spanning trees.
- Let $T_{n,k}$ be the number of labeled forests on n vertices with k components, such that vertex $1, 2, \dots, k$ belong to different components. Then $T_{n,k} = k n^{n-k-1}$.

8.1.4 Erdős–Gallai theorem

A sequence of non-negative integers $d_1 \geq d_2 \geq \dots \geq d_n$ can be represented as the degree sequence of a finite simple graph on n vertices if and only if $d_1 + d_2 + \dots + d_n$ is even and

$$\sum_{i=1}^k d_i \leq k(k-1) + \sum_{i=k+1}^n \min(d_i, k)$$

holds for all $1 \leq k \leq n$.

8.1.5 Havel–Hakimi algorithm

find the vertex who has greatest degree unused, connect it with other greatest vertex.

8.1.6 Hall's marriage theorem

Let G be a finite bipartite graph with bipartite sets X and Y . For a subset W of X , let $N_G(W)$ denote the set of all vertices in Y adjacent to some element of W . Then there is an X -saturating matching iff $\forall W \subseteq X, |W| \leq |N_G(W)|$

8.1.7 Euler's planar graph formula

$$V - E + F = C + 1, E \leq 3V - 6(?)$$

8.1.8 Pick's theorem

For simple polygon, when points are all integer, we have $A = \#\{\text{lattice points in the interior}\} + \frac{\#\{\text{lattice points on the boundary}\}}{2} - 1$

8.1.9 Lucas's theorem

$\binom{m}{n} \equiv \prod_{i=0}^k \binom{m_i}{n_i} \pmod{p}$, where $m = m_k p^k + m_{k-1} p^{k-1} + \dots + m_1 p + m_0$, and $n = n_k p^k + n_{k-1} p^{k-1} + \dots + n_1 p + n_0$.

8.2 MaximumEmptyRect

```
int max_empty_rect(int n, int m, bool blocked[N][N]) {
    static int mxu[2][N], me=0, he=1, ans=0;
    for (int i=0; i<m; i++) mxu[he][i]=0;
    for (int i=0; i<n; i++) {
        stack<PII, vector<PII>> stk;
        for (int j=0; j<m; ++j) {
            if (blocked[i][j]) mxu[me][j]=0;
            else mxu[me][j]=mxu[he][j]+1;
            int la = j;
            while (!stk.empty() && stk.top().FF > mxu[me][j]) {
                int x1 = i - stk.top().FF, x2 = i;
                int y1 = stk.top().SS, y2 = j;
                la = stk.top().SS; stk.pop();
                ans = max(ans, (x2-x1)*(y2-y1));
            }
            if (stk.empty() || stk.top().FF < mxu[me][j])
                stk.push({mxu[me][j], la});
        }
        while (!stk.empty()) {
            int x1 = i - stk.top().FF, x2 = i;
            int y1 = stk.top().SS-1, y2 = m-1;
            stk.pop(); ans = max(ans, (x2-x1)*(y2-y1));
        }
        swap(me, he);
    }
    return ans;
}
```

8.3 DP-opt Condition

8.3.1 totally monotone (concave/convex)

$$\forall i < i', j < j', B[i][j] \leq B[i'][j'] \implies B[i][j'] \leq B[i'][j']$$

$$\forall i < i', j < j', B[i][j] \geq B[i'][j'] \implies B[i][j'] \geq B[i'][j']$$

8.3.2 monge condition (concave/convex)

$$\forall i < i', j < j', B[i][j] + B[i'][j'] \geq B[i][j'] + B[i'][j]$$

$$\forall i < i', j < j', B[i][j] + B[i'][j'] \leq B[i][j'] + B[i'][j]$$

8.4 Convex 1D/1D DP

```
struct segment {
    int i, l, r;
    segment() {}
    segment(int a, int b, int c): i(a), l(b), r(c) {}
};
inline lld f(int l, int r) { return dp[l] + w(l+1, r); }
void solve() {
    dp[0] = 0;
    deque<segment> dq; dq.push_back(segment(0, 1, n));
    for (int i = 1; i <= n; ++i) {
        dp[i] = f(dq.front().i, i);
        while (dq.size() && dq.front().r < i+1) dq.pop_front();
        dq.front().l = i + 1;
        segment seg = segment(i, i + 1, n);
        while (dq.size() &&
            f(i, dq.back().l) < f(dq.back().i, dq.back().l))
            dq.pop_back();
        if (dq.size()) {
            int d = 1 << 20, c = dq.back().l;
            while (d >= 1) if (c + d <= dq.back().r)
                if (f(i, c+d) > f(dq.back().i, c+d)) c += d;
            dq.back().r = c; seg.l = c + 1;
        }
        if (seg.l <= n) dq.push_back(seg);
    }
}
```

8.5 ConvexHull Optimization

```
inline lld DivCeil(lld n, lld d) { // ceil(n/d)
    return n / d + ((n < 0) != (d > 0)) && (n % d);
}
struct Line {
    static bool flag;
    lld a, b, l, r; // y=ax+b in [l, r)
    lld operator()(lld x) const { return a * x + b; }
    bool operator<(const Line& i) const {
        return flag ? tie(a, b) < tie(i.a, i.b) : l < i.l;
    }
    lld operator&(const Line& i) const {
        return DivCeil(b - i.b, i.a - a);
    }
};
bool Line::flag = true;
class ConvexHullMax {
    set<Line> L;
public:
    ConvexHullMax() { Line::flag = true; }
    void InsertLine(lld a, lld b) { // add y = ax + b
        Line now = {a, b, -INF, INF};
        if (L.empty()) {
            L.insert(now);
            return;
        }
        Line::flag = true;
        auto it = L.lower_bound(now);
        auto prv = it == L.begin() ? it : prev(it);
        if (it != L.end() && ((it != L.begin() &&
            (*it)(it->l) >= now(it->l) &&
            (*prv)(prv->r - 1) >= now(prv->r - 1)) ||
            (it == L.begin() && it->a == now.a))) return;
        if (it != L.begin()) {
            while (prv != L.begin() &&
                (*prv)(prv->l) <= now(prv->l))
                prv = --L.erase(prv);
            if (prv == L.begin() && now.a == prv->a)
                L.erase(prv);
        }
        if (it != L.end())
            while (it != --L.end() &&
                (*it)(it->r) <= now(it->r))
                it = L.erase(it);
    }
}
```



```

if (it != L.begin()) {
    prv = prev(it);
    const_cast<Line*>(&*prv)->r=now.l=((*prv)&now);
}
if (it != L.end())
    const_cast<Line*>(&*it)->l=now.r=((*it)&now);
L.insert(it, now);
}
lld Query(lld a) const { // query max at x=a
    if (L.empty()) return -INF;
    Line::flag = false;
    auto it = --L.upper_bound({0, 0, a, 0});
    return (*it)(a);
}
};

```

8.6 Josephus Problem

```

// n people kill m for each turn
int f(int n, int m) {
    int s = 0;
    for (int i = 2; i <= n; i++)
        s = (s + m) % i;
    return s;
}
// died at kth
int kth(int n, int m, int k){
    if (m == 1) return n-1;
    for (k = k*m+m-1; k >= n; k = k-n+(k-n)/(m-1));
    return k;
}

```

8.7 Cactus Matching

```

vector<int> init_g[maxn], g[maxn*2];
int n, dfn[maxn], low[maxn], par[maxn], dfs_idx, bcc_id;
void tarjan(int u){
    dfn[u]=low[u]=++dfs_idx;
    for(int i=0; i<(int)init_g[u].size(); i++){
        int v=init_g[u][i];
        if(v==par[u]) continue;
        if(!dfn[v]){
            par[v]=u;
            tarjan(v);
            low[u]=min(low[u], low[v]);
            if(dfn[u]<low[v]){
                g[u].push_back(v);
                g[v].push_back(u);
            }
        }else{
            low[u]=min(low[u], dfn[v]);
            if(dfn[v]<dfn[u]){
                int temp_v=u;
                bcc_id++;
                while(temp_v!=v){
                    g[bcc_id+n].push_back(temp_v);
                    g[temp_v].push_back(bcc_id+n);
                    temp_v=par[temp_v];
                }
                g[bcc_id+n].push_back(v);
                g[v].push_back(bcc_id+n);
                reverse(g[bcc_id+n].begin(), g[bcc_id+n].end());
            }
        }
    }
}
int dp[maxn][2], min_dp[2][2], tmp[2][2], tp[2];
void dfs(int u, int fa){
    if(u<=n){
        for(int i=0; i<(int)g[u].size(); i++){
            int v=g[u][i];
            if(v==fa) continue;
            dfs(v, u);
            memset(tp, 0x8f, sizeof tp);
            if(v<=n){
                tp[0]=dp[u][0]+max(dp[v][0], dp[v][1]);
                tp[1]=max(
                    dp[u][0]+dp[v][0]+1,
                    dp[u][1]+max(dp[v][0], dp[v][1])
                );
            }else{
                tp[0]=dp[u][0]+dp[v][0];
                tp[1]=max(dp[u][0]+dp[v][1], dp[u][1]+dp[v][0]);
            }
        }
    }
}

```

```

    dp[u][0]=tp[0], dp[u][1]=tp[1];
}
} else{
    for(int i=0; i<(int)g[u].size(); i++){
        int v=g[u][i];
        if(v==fa) continue;
        dfs(v, u);
    }
    min_dp[0][0]=0;
    min_dp[1][1]=1;
    min_dp[0][1]=min_dp[1][0]=-0x3f3f3f3f;
    for(int i=0; i<(int)g[u].size(); i++){
        int v=g[u][i];
        if(v==fa) continue;
        memset(tmp, 0x8f, sizeof tmp);
        tmp[0][0]=max(
            min_dp[0][0]+max(dp[v][0], dp[v][1]),
            min_dp[0][1]+dp[v][0]
        );
        tmp[0][1]=min_dp[0][0]+dp[v][0]+1;
        tmp[1][0]=max(
            min_dp[1][0]+max(dp[v][0], dp[v][1]),
            min_dp[1][1]+dp[v][0]
        );
        tmp[1][1]=min_dp[1][0]+dp[v][0]+1;
        memcpy(min_dp, tmp, sizeof tmp);
    }
    dp[u][1]=max(min_dp[0][1], min_dp[1][0]);
    dp[u][0]=min_dp[0][0];
}
}
int main(){
    int m, a, b;
    scanf("%d%d", &n, &m);
    for(int i=0; i<m; i++){
        scanf("%d%d", &a, &b);
        init_g[a].push_back(b);
        init_g[b].push_back(a);
    }
    par[1]=-1;
    tarjan(1);
    dfs(1, -1);
    printf("%d\n", max(dp[1][0], dp[1][1]));
    return 0;
}

```

8.8 DLX

```

struct DLX {
    const static int maxn=210;
    const static int maxm=210;
    const static int maxnode=210*210;
    int n, m, size, row[maxnode], col[maxnode];
    int U[maxnode], D[maxnode], L[maxnode], R[maxnode];
    int H[maxn], S[maxm], ansd, ans[maxn];
    void init(int _n, int _m) {
        n = _n, m = _m;
        for(int i = 0; i <= m; ++i) {
            S[i] = 0;
            U[i] = D[i] = i;
            L[i] = i-1, R[i] = i+1;
        }
        R[L[0] = size = m] = 0;
        for(int i = 1; i <= n; ++i) H[i] = -1;
    }
    void Link(int r, int c) {
        ++S[col[++size] = c];
        row[size] = r; D[size] = D[c];
        U[D[c]] = size; U[size] = c; D[c] = size;
        if(H[r] < 0) H[r] = L[size] = R[size] = size;
        else {
            R[size] = R[H[r]];
            L[R[H[r]]] = size;
            L[size] = H[r];
            R[H[r]] = size;
        }
    }
    void remove(int c) {
        L[R[c]] = L[c]; R[L[c]] = R[c];
        for(int i = D[c]; i != c; i = D[i])
            for(int j = R[i]; j != i; j = R[j]) {
                U[D[j]] = U[j];
                D[U[j]] = D[j];
            }
    }
}

```

```

        --S[col[j]];
    }
}
void resume(int c) {
    L[R[c]] = c; R[L[c]] = c;
    for(int i = U[c]; i != c; i = U[i])
        for(int j = L[i]; j != i; j = L[j]) {
            U[D[j]] = j;
            D[U[j]] = j;
            ++S[col[j]];
        }
}
void dance(int d) {
    if(d>=ansd) return;
    if(R[0] == 0) {
        ansd = d;
        return;
    }
    int c = R[0];
    for(int i = R[0]; i; i = R[i])
        if(S[i] < S[c]) c = i;
    remove(c);
    for(int i = D[c]; i != c; i = D[i]) {
        ans[d] = row[i];
        for(int j = R[i]; j != i; j = R[j])
            remove(col[j]);
        dance(d+1);
        for(int j = L[i]; j != i; j = L[j])
            resume(col[j]);
    }
    resume(c);
}
}
} sol;

```

8.9 Tree Knapsack

```

int dp[N][K]; PII obj[N];
vector<int> G[N];
void dfs(int u, int mx){
    for(int s: G[u]) {
        if(mx < obj[s].first) continue;
        for(int i=0; i<=mx-obj[s].FF; i++)
            dp[s][i] = dp[u][i];
        dfs(s, mx - obj[s].first);
        for(int i=obj[s].FF; i<=mx; i++)
            dp[u][i] = max(dp[u][i],
                dp[s][i - obj[s].FF] + obj[s].SS);
    }
}
int main(){
    int n, k; cin >> n >> k;
    for(int i=1; i<=n; i++){
        int p; cin >> p;
        G[p].push_back(i);
        cin >> obj[i].FF >> obj[i].SS;
    }
    dfs(0, k); int ans = 0;
    for(int i=0; i<=k; i++) ans = max(ans, dp[0][i]);
    cout << ans << '\n';
    return 0;
}

```

8.10 N Queens Problem

```

vector< int > solve( int n ) {
    // no solution when n=2, 3
    vector< int > ret;
    if ( n % 6 == 2 ) {
        for ( int i = 2 ; i <= n ; i += 2 )
            ret.push_back( i );
        ret.push_back( 3 ); ret.push_back( 1 );
        for ( int i = 7 ; i <= n ; i += 2 )
            ret.push_back( i );
        ret.push_back( 5 );
    } else if ( n % 6 == 3 ) {
        for ( int i = 4 ; i <= n ; i += 2 )
            ret.push_back( i );
        ret.push_back( 2 );
        for ( int i = 5 ; i <= n ; i += 2 )
            ret.push_back( i );
        ret.push_back( 1 ); ret.push_back( 3 );
    } else {
        for ( int i = 2 ; i <= n ; i += 2 )
            ret.push_back( i );
    }
}

```

```

for ( int i = 1 ; i <= n ; i += 2 )
    ret.push_back( i );
}
return ret;
}

```

8.11 Aliens Optimization

```

long long Alien() {
    long long c = kInf;
    for (int d = 60; d >= 0; --d) {
        // cost can be negative, depending on the problem.
        if (c - (1LL << d) < 0) continue;
        long long ck = c - (1LL << d);
        pair<long long, int> r = check(ck);
        if (r.second == k) return r.first - ck * k;
        if (r.second < k) c = ck;
    }
    pair<long long, int> r = check(c);
    return r.first - c * k;
}

```