

Index

1 Enviroment Settings

1.1 .vimrc

2 Computational Geometry

2.1 Geometry on Plane

2.2 KDTree

3 Data Structure

3.1 PB DS

3.2 BigInteger

3.3 Fenwick Tree Range Modify [1, size]

3.4 Fenwick Tree 2D - [1, size][1, size]

3.5 Skew Heap

3.6 Splay Tree

3.7 Treap

3.8 劃分樹

4 Graph

4.1 Bron-Kerbosch

4.2 Dinic

4.3 Hungarian

4.4 maximum matching in general graph

5 Math

5.1 China remainder theorem

5.2 Euler's phi function $O(n)$

5.3 Extended Euclid's Algorithm

5.4 FFT

5.5 Gaussian Elimination

5.6 Miller Rabin

5.7 Möbius function

6 String

6.1 AhoCorasick

6.2 KMP

6.3 Longest Palindromic Substring

6.4 Suffix Array

6.5 Z Algorithm

7 Others

7.1 8 puzzle - IDA*

7.2 recursive to stack

1 Enviroment Settings

1.1 .vimrc

```
1 " set encoding
1 set encoding=utf-8
2 set fileencodings=utf-8,big5
2 set showmode
2 syntax on
2 set hlsearch
2 set background=dark
3 set laststatus=2
3 set wildmenu
3 set scrolloff=5 " keep at least 5 lines above/below
4 set ruler
5 set cursorline
5 set ic " ignore case when searching
5 set bs=2 " enable backspace
5 set number
6 set tabstop=4
7 set shiftwidth=4
7 set autoindent
8 set smarttab
8 set smartindent
8 """""""" abbr
8 syntax on
8 set enc=utf-8 fencs=utf-8,big5
10 set bs=2
10 set smd nu bg=dark hls ls=2 wmnu so=5 ru cul
11 set ts=4 sw=4 ai sta si
11 set list lcs=tab:>\ " # a space after '\ '
11 imap<F9> <ESC>:w<Enter><F9>
11 map<F9> :!g++ "%:t" -o "%:r.out" -Wall -Wshadow -O2 -Im && "./%:r.out"
12 map<F10> :!g++ "%:t" -o "%:r.out" -Wall -Wshadow -O2 -Im
12 autocmd! BufNewFile * silent! 0r ~/.vim/skel/Template.%.e
13
```

14

14

14

14

15

15

16

16

16

2 Computational Geometry

2.1 Geometry on Plane

```

struct node {
    double x,y;
    node() {}
    node(double _x, double _y) : x(_x),y(_y) {}
    node operator+(const node& rhs)const
    { return node(x+rhs.x,y+rhs.y); }
    node operator-(const node& rhs)const
    { return node(x-rhs.x,y-rhs.y); }
    node operator*(const double& rhs)const
    { return node(x*rhs,y*rhs); }
    node operator/(const double& rhs)const
    { return node(x/rhs,y/rhs); }
    double operator*(const node& rhs)const
    { return x*rhs.x+y*rhs.y; }
    double len2()const{ return x*x+y*y; }
    double len()const{ return sqrt(x*x+y*y); }
    node unit()const{ return *this/len(); }
    double operator^(const node& rhs)const{ return
        x*rhs.y-y*rhs.x; }
    node T()const{ return node(-y,x); }
    node rot(double rad)const{ //逆時針旋轉 弧度
        return node(cos(rad)*x-sin(rad)*y, sin(rad)*x
            +cos(rad)*y);
    }
};
node __mirror(node normal, double constant, node
point){ //2D3D
    double scale=(normal*point+constant)/(normal*
        normal);
    return point-normal*(2*scale);
}
node mirror(node p1, node p2, node p3){ //2D3D
    return __mirror((p2-p1).T(),(p2-p1).T()*p1*(-1)
        ,p3);
}
double ori(const node& p1,const node& p2, const
    node& p3){ //平行四邊形面積(帶正負)
    return (p2-p1)^(p3-p1);
}
bool intersect(const node& p1, const node& p2,
    const node& p3, const node& p4){
    return (ori(p1,p2,p3)*ori(p1,p2,p4)<0 && ori(p3
        ,p4,p1)*ori(p3,p4,p2)<0);
}
pair<node,node> two_circle_intersect(node p1,
    double r1, node p2, double r2){
    double degree=acos(((p2-p1).len2()+r1*r1-r2*r2)
        /(2*r1*(p2-p1).len()));
    return make_pair(p1+(p2-p1).unit().rot(degree)*
        r1, p1+(p2-p1).unit().rot(-degree)*r1);
}
node intersectionPoint(node p1, node p2, node p3,
    node p4){
    double a123 = (p2-p1)^(p3-p1);
    double a124 = (p2-p1)^(p4-p1);
    return (p4*a123-p3*a124)/(a123-a124);
}
}

bool cmpy( const NODE& a , const NODE& b ){
    return a.y < b.y;
}
}
NODE* KDTree( int L , int R , int depth ){
    if ( L > R ) return 0;
    int M = ( L + R ) >> 1;
    node[M].f = depth % 2;
    nth_element( node+L , node+M , node+R+1 , node[
        M].f ? cmpy : cmpx );
    node[M].L = KDTree( L , M-1 , depth+1 );
    node[M].R = KDTree( M+1 , R , depth+1 );
    node[M].x1 = node[M].x2 = node[M].x;
    node[M].y1 = node[M].y2 = node[M].y;
    if ( node[M].L ){
        node[M].x1 = min( node[M].x1 , node[M].L->x1
            );
        node[M].y1 = min( node[M].y1 , node[M].L->y1
            );
    }
    if ( node[M].R ){
        node[M].x2 = max( node[M].x2 , node[M].L->x2
            );
        node[M].y2 = max( node[M].y2 , node[M].L->y2
            );
    }
    return node+M;
}
}
inline int mayTouchRectangle( NODE* r , int x ,
    int y , long long d2 ){
    long long d = ( long long )( sqrt(d2) + 1 );
    return x >= r->x1 - d && x <= r->x2 + d && y >=
        r->y1 - d && y <= r->y2 + d;
}
}
// find the nearest point near p
// r is tree node
void nearest( NODE* r , NODE* p , long long &dmin
    ){
    if ( !r || !mayTouchRectangle( r , p->x , p->y
        , dmin ) ) return;
    if ( p->i != r->i ) dmin = min( dmin , dis( *r
        , *p ) ); // dis returns the dis^2
    int whichFirst = r->f ? p->y < r->y : p->x < r->
        x;
    if ( whichFirst ){
        nearest( r->L , p , dmin );
        nearest( r->R , p , dmin );
    }
    else{
        nearest( r->R , p , dmin );
        nearest( r->L , p , dmin );
    }
}
}

```

2.2 KDTree

```

struct NODE{
    int x , y;
    int x1 , x2 , y1 , y2;
    NODE *L , *R;
};
bool cmpx( const NODE& a , const NODE& b ){
    return a.x < b.x;
}

```

3 Data Structure

3.1 PB DS

```
#include <ext/pb_ds/assoc_container.hpp>
using namespace std;
using namespace __gnu_pbds;

#include <ext/pb_ds/priority_queue.hpp>
typedef __gnu_pbds::priority_queue<T, greater<T>,
    pairing_heap_tag> Heap;
/*
 * method: push, pop, modify(iter, val), erase,
 *         join
 * tags: pairing_heap_tag, binary_heap_tag,
 *        binomial_heap_tag, rc_binomial_heap_tag,
 *        thin_heap_tag
 */

#include <ext/pb_ds/tree_policy.hpp>
typedef tree<int, null_type, less<int>,
    rb_tree_tag,
    tree_order_statistics_node_update> RBTree;
typedef tree<int, null_type, less<int>,
    splay_tree_tag,
    tree_order_statistics_node_update> Splay;
/*
 * point_iterator find_by_order(size_type order)
 * size_type order_of_key(const_key_reference
 *     r_key) - number of elements < r_key
 * void split(const_key_reference r_key, tree &
 *     other) - move elements > r_key
 */

#include <ext/pb_ds/hash_policy.hpp>
typedef cc_hash_table<string, int> Hash;
typedef gp_hash_table<string, int> Hash;
```

3.2 BigInteger

```
#include <cstdio>
#include <cstring>
#include <iostream>
#include <iomanip>
using namespace std;
template<class T>
T abs(const T& n) {return n>=T(0)?n:-n;}
class BigInteger {
public:
    BigInteger(const int& num=0) : len(0), sign(1)
    {
        int num2=num;
        memset(arr, 0, sizeof(arr));
        if( num2<0 ) sign=-1, num2*=-1;
        while( num2 ) arr[len++]=num2%step, num2/=
            step;
    }
    BigInteger(const char* num0) : len(0), sign(1)
    {
        *this = num0;
    }
    BigInteger(const BigInteger& b) : len(b.len),
        sign(b.sign) {
        memset(arr, 0, sizeof(arr));
        for(int i=0; i<len; ++i) arr[i]=b.arr[i];
    }
    ~BigInteger() {}
    BigInteger & operator = (const BigInteger& b) {
        len=b.len;
        sign=b.sign;
        memset(arr, 0, sizeof(arr));
```

```
        for(int i=0; i<len; ++i) arr[i]=b.arr[i];
        return *this;
    }
    BigInteger & operator = (const int& num) {
        int num2=num;
        memset(arr, 0, sizeof(arr));
        len=0, sign=1;
        if( num2<0 ) sign=-1, num2*=-1;
        while( num2 ) arr[len++]=num2%step, num2/=
            step;
        return *this;
    }
    BigInteger & operator = (const char* num0) {
        char num[strlen(num0)];
        int offset = 0;
        len = 0;
        sign = 1;
        if( num0[0] == '-' ) sign = -1, ++offset;
        else if( num0[0] == '+' ) ++offset;
        while( num0[offset]!='0' ) ++offset;
        strcpy(num, num0+offset);
        int tmp = strlen(num);
        for(int i=tmp-digit; i>=0; i-=digit) {
            arr[len] = 0;
            for(int j=0; j<digit; ++j) arr[len] = arr[
                len]*10 + num[i+j]-'0';
            ++len;
        }
        arr[len] = 0;
        for(int j=0; j<tmp%digit; ++j) arr[len] = arr[
            len]*10 + num[j]-'0';
        if( tmp%digit ) ++len;
        return *this;
    }
    BigInteger operator + (const BigInteger& b)
        const {
        if( *this>0 && b<0 ) return *this-(-b);
        if( *this<0 && b>0 ) return -(-*this-b);
        BigInteger res=*this;
        int len2=max(res.len, b.len);
        for(int i=0; i<len2; ++i) {
            res.arr[i]+=b.arr[i];
            if( res.arr[i]>=step ) res.arr[i]-=step,
                res.arr[i+1]++;
        }
        res.len=len2;
        if(res.arr[len2]) ++res.len;
        return res;
    }
    BigInteger operator - (const BigInteger& b)
        const {
        if( *this<b ) return -(b-*this);
        if( *this<0 && b<0 ) return -(-*this+b);
        if( *this>0 && b<0 ) return *this+(-b);
        BigInteger res=*this;
        int len2=max(res.len, b.len);
        for(int i=0; i<len2; ++i) {
            res.arr[i]-=b.arr[i];
            if( res.arr[i]<0 ) res.arr[i]+=step, res.
                arr[i+1]--;
        }
        while( len2>0 && res.arr[len2-1]==0 ) --len2;
        res.len=len2;
        return res;
    }
    BigInteger operator * (const BigInteger& b)
        const {
        if( *this==0 || b==0 ) return BigInteger(0);
        BigInteger res;
        for(int i=0; i<len; ++i) {
```

```

    for(int j=0; j<b.len; ++j) {
        res.arr[i+j]+=arr[i]*b.arr[j];
        res.arr[i+j+1]+=res.arr[i+j]/step;
        res.arr[i+j]%=step;
    }
}
res.len=len+b.len-1;
while( res.arr[res.len] ) ++res.len;
res.sign=sign*b.sign;
return res;
}
BigInteger operator / (const int& b) const {
    if( b==0 ) return 0;
    BigInteger res;
    long long reduce=0;
    int signb=b>0?1:-1, b2=b*signb;
    for(int i=len-1; i>=0; --i) {
        res.arr[i] = (arr[i]+reduce*step)/b2;
        reduce = (arr[i]+reduce*step)%b2;
    }
    res.len = len;
    while( res.len>0 && res.arr[res.len-1]==0 )
        --res.len;
    if( res.len==0 ) res.sign=1;
    else res.sign=sign*signb;
    return res;
}
BigInteger operator / (const BigInteger& b)
    const {
    BigInteger abs_this=abs(*this);
    if( b==0 ) return 0;
    BigInteger st=0, ed, md;
    if( b.arr[0]>0 ) ed=abs_this/b.arr[0];
    else if( b.arr[1]*b.step+b.arr[0]>0 ) ed=
        abs_this/b.arr[1]*b.step+b.arr[0];
    else ed=abs_this;
    while( st<ed ) {
        md = (st+ed)/2+1;
        if( md*b<=abs_this ) st=md;
        else ed=md-1;
    }
    if( st.len==0 ) st.sign=1;
    else st.sign=sign*b.sign;

    return st;
}
BigInteger operator % (const int& b) const {
    if( b<=0 ) return 0;
    BigInteger res;
    long long reduce=0;
    for(int i=len-1; i>=0; --i)
        reduce = (arr[i]+reduce*step)%b;
    return reduce*sign;
}
BigInteger operator % (const BigInteger& b)
    const {
    if( b.isInt() ) return *this%int(b.toInt());
    if( b<=0 ) return 0;
    return *this-*this/b*b;
}
bool operator < (const BigInteger& b) const {
    if( sign!=b.sign ) return sign<b.sign;
    if( len!=b.len ) return len*sign<b.len*b.sign;
    ;
    for(int i=len-1; i>=0; --i)
        if( arr[i]!=b.arr[i] ) return arr[i]*sign<b
            .arr[i]*b.sign;
    return false;
}
bool operator == (const BigInteger& b) const {
    if( sign!=b.sign ) return false;
    if( len!=b.len ) return false;
    for(int i=len-1; i>=0; --i)
        if( arr[i]!=b.arr[i] ) return false;
    return true;
}
bool operator <= (const BigInteger& b) const {
    return *this<b || *this==b;
}
bool operator > (const BigInteger& b) const {
    return b<*this;
}
bool operator >= (const BigInteger& b) const {
    return b<=*this;
}
bool operator != (const BigInteger& b) const {
    return !(*this==b);
}
BigInteger operator-() const {
    BigInteger res = *this;
    if( res.len>0 ) res.sign*=-1;
    return res;
}
template<class T> BigInteger operator + (const
    T& b) const {return *this+BigInteger(b);}
template<class T> BigInteger operator - (const
    T& b) const {return *this-BigInteger(b);}
template<class T> bool operator == (const T&
    b) const {return *this==BigInteger(b);}
void print(const char *str="") const {
    if( len==0 ) printf("0");
    else {
        printf("%d", arr[len-1]*sign);
        for(int i=len-2; i>=0; --i) printf("%04d",
            arr[i]);
    }
    printf("%s", str);
}
bool isInt() const {
    if( len>2 ) return false;
    if( len<2 ) return true;
    long long res=toInt();
    return res<(1ll<<31) && res>=-(1ll<<31);
}
friend ostream& operator << ( ostream& out,
    const BigInteger &rhs ) {
    if( rhs.len==0 ) out << '0';
    else {
        out << rhs.arr[rhs.len-1]*rhs.sign;
        for(int i=rhs.len-2; i>=0; --i) out <<
            setfill('0') << setw(BigInteger::digit)
            << rhs.arr[i];
    }
    return out;
}
long long toInt() const {return sign*(1ll*arr
    [1]*step+arr[0]);}
private:
    static const int length = 100;
    static const int digit = 4, step = 10000;
    int arr[length];
    int len, sign;
};
istream& operator >> ( istream& in, BigInteger &
    rhs ) {
    char s[1000];
    in >> s;
    rhs = s;
    return in;
}

```

3.3 Fenwick Tree Range Modify [1, size]

```

inline int lowbit(int x) { return x&-x; }
template<class T>

```

```

class fenwick {
public:
    fenwick(int __size=SIZE) {
        size = __size+10;
        a = new T[size], b=new T[size];
        memset(a, 0, sizeof(T)*size);
        memset(b, 0, sizeof(T)*size);
    }
    ~fenwick() { delete[] a, delete[] b; }
    inline void add(int l, int r, long long n) {
        __add(a, r, r*n), __add(a, l-1, (l-1)*-n);
        __add(b, r, n), __add(b, l-1, -n);
    }
    inline long long sum(int l, int r) { return
        __sum(r)-__sum(l-1); }
private:
    int size;
    T *a, *b;
    inline void __add(T *arr, int x, T n) { for(; x
        &&n&&x<size; x+=lowbit(x)) arr[x]+=n; }
    inline T __sum(T x) { return __sum(a, x)+(__sum
        (b, size)-__sum(b, x))*x; }
    inline T __sum(T *arr, int x) {
        T res=0;
        for(; x; x-=lowbit(x)) res+=arr[x];
        return res;
    }
};

```

3.4 Fenwick Tree 2D - [1, size][1, size]

```

int tree[size+1][size+1]={0};
inline int lowbit(const int &x) {return x&(-x);}
inline void add(int x, int y, int z) {
    for(int i; x<=n; x+=lowbit(x))
        for(i=y; i<=n; i+=lowbit(i)) tree[x][i]+=z;
}
inline int query(short x, short y) {
    int res=0;
    for(int i; x; x-=lowbit(x))
        for(i=y; i; i-=lowbit(i))
            res+=tree[x][i];
    return res;
}

```

3.5 Skew Heap

```

/*
 * merge : root = merge(x, y)
 * pop   : root = merge(root.lc, root.rc)
 */
const int MAXSIZE = 10000;

class Node {
public:
    int num, lc, rc;
    Node(int _v=0) : num(_v), lc(-1), rc(-1) {}
} tree[MAXSIZE];

int merge(int x, int y){
    if( x==-1 ) return y;
    if( y==-1 ) return x;
    if( tree[x].num<tree[y].num ) // key
        swap(x, y);
    tree[x].rc = merge(tree[x].rc, y);
    swap(tree[x].lc, tree[x].rc);
    return x;
}

```

3.6 Splay Tree

```

template<class T>

```

```

struct TNode {
    TNode<T> *c[2], *fa;
    T val, inc, sum;
    int sz;
    void down() {
        val += inc;
        if( lc->fa ) lc->inc += inc;
        if( rc->fa ) rc->inc += inc;
        inc = 0;
    }
    void up() {
        sz = lc->sz + rc->sz + 1;
        sum = val;
        if( lc->fa ) sum += lc->sum + lc->inc*lc->sz;
        if( rc->fa ) sum += rc->sum + rc->inc*rc->sz;
    }
};

template<class T>
class SplayTree {
public:
    void init(const int& n) {
        null = &node[0];
        null->fa = NULL;
        null->val = null->inc = null->sum = null->sz
            = 0;
        ncnt = 0;
        root = newnode(-1, null);
        root->rc = newnode(-1, root);
        root->rc->lc = build(1, n, root->rc);
        root->rc->up(), root->up();
    }
    void update(int l, int r, T val) {
        RotateTo(l-1, null);
        RotateTo(r+1, root);
        root->rc->lc->inc += val;
        root->rc->lc->up();
    }
    ll query(int l, int r) {
        if( l>r ) swap(l, r);
        RotateTo(l-1, null);
        RotateTo(r+1, root);
        TNode<T> *now = root->rc->lc;
        now->up();
        return now->sum + now->inc*now->sz;
    }
private:
    TNode<T> *root, *null;
    TNode<T> node[MAXN];
    int ncnt;
    TNode<T>* newnode(T val, TNode<T> *fa) {
        TNode<T> *x = &node[++ncnt];
        x->lc = x->rc = null;
        x->fa = fa;
        x->val = x->sum = val, x->inc = 0, x->sz = 1;
        return x;
    }
    TNode<T>* build(int l, int r, TNode<T> *fa) {
        if( l>r ) return null;
        int md = (l+r)>>1;
        TNode<T> *now = newnode(all[md], fa);
        now->lc = build(l, md-1, now);
        now->rc = build(md+1, r, now);
        now->up();
        return now;
    }
    void RotateTo(int x, TNode<T> *aim) {
        // find k-th element
        TNode<T> *now = root;
        while( now->lc->sz != x ) {
            if( now->lc->sz > x ) now = now->lc;

```

```

    else x -= now->lc->sz+1, now = now->rc;
}
splay(now, aim);
}
void splay(TNode<T> *now, TNode<T> *aim) {
    // make now become aim's child
    TNode<T> *fa, *fafa;
    while( now->fa != aim ) {
        if( now->fa->fa == aim ) Rotate(now, now->
            fa->lc==now);
        else {
            fa = now->fa, fafa = fa->fa;
            int pos = ( fafa->c[1] == fa );
            if( fa->c[pos] == now ) Rotate(fa, !pos);
            else Rotate(now, pos);
            Rotate(now, !pos);
        }
    }
    now->up();
    if( aim == null ) root = now;
}
void Rotate(TNode<T> *now, int fl) {
    // fl : 0 - L-Rotate
    //       1 - R-Rotate
    TNode<T> *fa = now->fa;
    now->down();
    fa->c[!fl] = now->c[fl];
    if( now->c[fl] != null ) now->c[fl]->fa = fa;
    now->fa = fa->fa;
    if( fa->fa != null ) fa->fa->c[ fa->fa->c
        [1]==fa ] = now;
    now->c[fl] = fa, fa->fa = now;
    now->inc = fa->inc, fa->inc = 0;
    fa->up();
}
};
SplayTree<ll> tree;

```

3.7 Treap

```

struct Node {
    Node *l,*r;
    int v,delta,rev,size,minx,w;
    void up() {
        minx = v;
        size = 1;
        if(l) size += l->size, minx = min(minx, l->
            minx);
        if(r) size += r->size, minx = min(minx, r->
            minx);
    }
    void down() {
        if(delta) {
            if(l) l->delta += delta, l->v += delta, l->
                minx += delta;
            if(r) r->delta += delta, r->v += delta, r->
                minx += delta;
            delta = 0;
        }
        if(rev) {
            swap(l,r);
            if(l) l->rev ^= 1;
            if(r) r->rev ^= 1;
            rev = 0;
        }
    }
}
}*root = NULL, *list = NULL;
inline int sz(Node *o) { return o ? o->size : 0;
}
int ran() {
    static int ranx = 123456789;

```

```

    ranx += (ranx<<2) + 1;
    return ranx;
}
void New_node(Node *&o, int val) {
    if(list == NULL) {
        Node *tt = new Node[100];
        for(int i = 0; i < 100; i++) {
            tt[i].w = ran();
            tt[i].r = list;
            list = tt + i;
        }
    }
    o = list;
    list = o->r;
    o->l = o->r = NULL;
    o->v = o->minx = val;
    o->size = 1;
    o->delta = o->rev = 0;
}
void Reuse(Node *o) { if(o) { o->r = list; list =
    o; } }
void cut(Node *o, Node *&p, Node *&q, int num) {
    if(num == 0) {
        p = NULL; q = o;
    } else if(num == sz(o)) {
        p = o; q = NULL;
    } else {
        o->down();
        if(num <= sz(o->l)) {
            q = o;
            cut(o->l,p,q->l,num);
            q->up();
        } else {
            p = o;
            cut(o->r,p->r,q,num-sz(o->l)-1);
            p->up();
        }
    }
}
void merge(Node *&o, Node *p, Node *q) {
    if(!p || !q) {
        o = p ? p : q;
    } else {
        if(p->w > q->w) {
            p->down();
            o = p;
            merge(o->r,p->r,q);
        } else {
            q->down();
            o = q;
            merge(o->l,p,q->l);
        }
        o->up();
    }
}
void insert(Node *&o, int pos, int val) {
    if(o == NULL) {
        New_node(o,val);
    } else {
        Node *l , *r , *n;
        New_node( n , val );
        cut ( o , l , r , pos );
        merge( l , l , n );
        merge( root , l , r );
    }
}
void add(int l, int r, int val) {
    Node *a, *b, *c;
    cut(root,a,b,l-1);
    cut(b,b,c,r-l+1);

```

```

    b->v += val;
    b->minx += val;
    b->delta += val;
    merge(a,a,b);
    merge(root,a,c);
}
void remove(int pos) {
    Node *a, *b, *c;
    cut(root,a,b,pos-1);
    cut(b,b,c,1);
    merge(root,a,c);
    Reuse(b);
}
int query(int l, int r) {
    Node *a, *b, *c;
    cut(root,a,b,l-1);
    cut(b,b,c,r-l+1);
    int ret = b->minx;
    merge(a,a,b);
    merge(root,a,c);
    return ret;
}
void reverse(int l, int r) {
    Node *a, *b, *c;
    cut(root,a,b,l-1);
    cut(b,b,c,r-l+1);
    b->rev ^= 1;
    merge(a,a,b);
    merge(root,a,c);
}
void revolve(int l, int m, int r) {
    Node *a, *b, *c, *d;
    cut(root,a,b,l-1);
    cut(b,b,c,m-l+1);
    cut(c,c,d,r-m);
    merge(a,a,c);
    merge(a,a,b);
    merge(root,a,d);
}

```

3.8 劃分樹

```

#include <iostream>
#include <cstdio>
#include <algorithm>
using namespace std;
#define N 100005
int a[N], as[N]; // 原數組, 排序後數組
int n, m;
int sum[20][N]; // 紀錄第i層的1~j劃分到左子樹的元素個數(包括j)
int tree[20][N]; // 紀錄第i層元素序列
void build(int c, int l, int r) {
    int i, mid=(l+r)>>1, lm=mid-l+1, lp=1, rp=mid+1;
    for (i=l; i<=mid; i++)
        if (as[i] < as[mid]) lm--;
        // 先假設左邊的(mid-l+1)個數都等於as[mid], 然後把實際上小於as[mid]的減去
    for (i = 1; i <= r; i++){
        if (i == 1) sum[c][i] = 0;
        // sum[i]表示[l, i]內有多少個數分到左邊, 用DP來維護
        else sum[c][i] = sum[c][i-1];
        if (tree[c][i] == as[mid]){
            if (lm){
                lm--;
                sum[c][i]++;
                tree[c+1][lp++] = tree[c][i];
            }else
                tree[c+1][rp++] = tree[c][i];
        } else if (tree[c][i] < as[mid]){
            sum[c][i]++;
            tree[c+1][lp++] = tree[c][i];
        } else
            tree[c+1][rp++] = tree[c][i];
    }
    if (l == r) return;
    build(c+1, l, mid);
    build(c+1, mid+1, r);
}
int query(int c, int l, int r, int ql, int qr, int k){
    int s; // [l, ql)內將被劃分到左子樹的元素數目
    int ss; // [ql, qr]內將被劃分到左子樹的元素數目
    int mid=(l+r)>>1;
    if (l == r) return tree[c][l];
    if (l == ql){ // 這裡要特殊處理!
        s = 0;
        ss = sum[c][qr];
    }else{
        s = sum[c][ql-1];
        ss = sum[c][qr]-s;
    } // 假設要在區間[l, r]中查找第k大元素, t為當前節點, lch, rch為左右孩子, left, mid為節點t左邊界和中間點。
    if (k <= ss){ // sum[r]-sum[l-1]>=k, 查找lch[t], 區間對應為[left+sum[l-1], left+sum[r]-1]
        return query(c+1, l, mid, l+s, l+s+ss-1, k);
    }else{
        // sum[r]-sum[l-1]<k, 查找rch[t], 區間對應為[mid+1+l-left-sum[l-1], mid+1+r-left-sum[r]]
        return query(c+1, mid+1, r, mid-l+1+ql-s, mid-l+1+qr-s-ss, k-ss);
    }
}
int main(){
    int i, j, k;
    while(~scanf("%d%d", &n, &m)){
        for(i=1; i<=n; i++){
            scanf("%d", &a[i]);
            tree[0][i] = as[i] = a[i];
        }
        sort(as+1, as+1+n);
        build(0, 1, n);
        while(m--){
            scanf("%d%d%d", &i, &j, &k);
            // i, j分別為區間起始點, k為該區間第k大的數。
            printf("%d\n", query(0, 1, n, i, j, k));
        }
    }
    return 0;
}

```

4 Graph

4.1 Bron-Kerbosch

```
typedef long long ll;
int n;
vector<ll> v, ne;
// ne[u] is the neighbours of u
// v is the result, P = (1<n) - 1
void BronKerbosch(ll R, ll P, ll X){
    if ((P == 0LL) && (X == 0LL)) {v.push_back(R);
        return ;}
    int u = 0;
    for (; u < n; u++) if ( (P|X) & (1LL << u) )
        break;
    for (int i = 0; i < n; i++)
        if ( (P&~ne[u]) & (1LL << i) ){
            BronKerbosch(R | (1LL << i), P & ne[i], X &
                ne[i]);
            P -= (1LL << i); X |= (1LL << i);
        }
}
```

4.2 Dinic

```
class Flow {
public:
    Flow(int _ncnt) :ncnt(_ncnt), ecnt(1), path(new
        int[_ncnt + 2]), d(new int[_ncnt + 2]),
        visited(new bool[_ncnt + 2]){
        memset(path, 0, sizeof(int)*(_ncnt + 1));
    }
    ~Flow(){
        delete[](path);
        delete[](d);
        delete[](visited);
    }
    void Reset(){
        memset(path, 0, sizeof(int)*(_ncnt + 1));
        ecnt = 1;
    }
    void AddEdge(int s, int t, int cap){
        edge[++ecnt].tar = t, edge[ecnt].cap = cap,
        edge[ecnt].next = path[s], path[s] = ecnt
        ;
        edge[++ecnt].tar = s, edge[ecnt].cap = 0,
        edge[ecnt].next = path[t], path[t] = ecnt
        ;
    }
    int MaxFlow(int s, int t){ // Dinic
        int f = 0, df;
        while (BFS(s, t) < ncnt){
            while (true){
                memset(visited, 0, sizeof(bool)*(ncnt +
                    1));
                df = DFS(s, INF, t);
                if (!df) break;
                f += df;
            }
        }
        return f;
    }
private:
    static const int eMaxSize = 40002, INF = (int)
        1e9;
    int ecnt, ncnt;
    int *path, *d; // d for Dicic distance
    bool *visited;

    struct Edge{
```

```
        int tar, cap, next;
    }edge[eMaxSize];

    int DFS(int a, int df, int t){
        if (a == t) return df;
        if (visited[a]) return 0;
        visited[a] = true;
        for (int i = path[a]; i; i = edge[i].next){
            int b = edge[i].tar;
            if (edge[i].cap > 0 && d[b] == d[a] + 1){
                int f = DFS(b, std::min(df, edge[i].cap),
                    t);
                if (f){
                    edge[i].cap -= f, edge[i ^ 1].cap += f;
                    return f;
                }
            }
        }
        return 0;
    }
}
```

```
int BFS(int s, int t){
    memset(d, 0x7f, sizeof(int)*(ncnt + 1));
    memset(visited, 0, sizeof(bool)*(ncnt + 1));
    d[s] = 0; visited[s] = true;
    std::queue<int> Q;
    Q.push(s);
    while (!Q.empty()){
        int a = Q.front(); Q.pop();
        for (int i = path[a]; i; i = edge[i].next){
            int b = edge[i].tar;
            if (visited[b] || edge[i].cap == 0)
                continue;
            visited[b] = true;
            d[b] = d[a] + 1;
            if (b == t) return d[b];
            Q.push(b);
        }
    }
    return d[t];
}
```

```
Flow flow( 1001 );
```

4.3 Hungarian

```
#include <stdio.h>
#include <string.h>
#include <algorithm>
using namespace std;
#define N 550 //max number of
    vertices in one part
#define INF 100000000 //just infinity

int cost[N][N]; //cost matrix
int n, max_match; //n workers and n jobs
int lx[N], ly[N]; //labels of X and Y
    parts
int xy[N]; //xy[x] - vertex that is
    matched with x,
int yx[N]; //yx[y] - vertex that is
    matched with y
bool S[N], T[N]; //sets S and T in
    algorithm
int slack[N]; //as in the algorithm
    description
int slackx[N]; //slackx[y] such a
    vertex, that l(slackx[y]) + l(y) - w(slackx[y]
    ],y) = slack[y]
int pre[N]; //array for memorizing
    alternating paths
```



```

void init_labels() {
    memset(lx, 0, sizeof(lx));
    memset(ly, 0, sizeof(ly));
    for (int x = 0; x < n; x++)
        for (int y = 0; y < n; y++)
            lx[x] = max(lx[x], cost[x][y]);
}

void update_labels() {
    int x, y, delta = INF;           //init delta
    as infinity
    for (y = 0; y < n; y++)          //calculate
        delta using slack
        if (!T[y])
            delta = min(delta, slack[y]);
    for (x = 0; x < n; x++)          //update X
        labels
        if (S[x]) lx[x] -= delta;
    for (y = 0; y < n; y++)          //update Y
        labels
        if (T[y]) ly[y] += delta;
    for (y = 0; y < n; y++)          //update
        slack array
        if (!T[y])
            slack[y] -= delta;
}

void add_to_tree(int x, int prex) {
    S[x] = true;
    pre[x] = prex;
    for (int y = 0; y < n; y++)
        if (lx[x] + ly[y] - cost[x][y] < slack[y]){
            slack[y] = lx[x] + ly[y] - cost[x][y];
            slackx[y] = x;
        }
}

void augment() {
    if (max_match == n) return;
    int x, y, root;
    int q[N], wr = 0, rd = 0;

    memset(S, false, sizeof(S));
    memset(T, false, sizeof(T));
    memset(pre, -1, sizeof(pre));
    for (x = 0; x < n; x++)
        if (xy[x] == -1){
            q[wr++] = root = x;
            pre[x] = -2;
            S[x] = true;
            break;
        }

    for (y = 0; y < n; y++){
        slack[y] = lx[root] + ly[y] - cost[root][y];
        slackx[y] = root;
    }

    while (true){
        while (rd < wr){
            x = q[rd++];
            for (y = 0; y < n; y++)
                if (cost[x][y] == lx[x] + ly[y] && !T[y]){
                    if (yx[y] == -1) break;
                    T[y] = true;
                    q[wr++] = yx[y];
                }
            //add vertex yx[y], which is
        }
    }
}

```

```

        matched with y, to the queue
        add_to_tree(yx[y], x);
    }
    //add
    edges (x,y) and (y,yx[y]) to the
    tree
    if (y < n) break;

    //augmenting path found!
}
if (y < n) break;

    //augmenting path found!
update_labels();

    //augmenting path not found, so improve
    labeling
    wr = rd = 0;
    for (y = 0; y < n; y++)
        if (!T[y] && slack[y] == 0){
            if (yx[y] == -1){
                //exposed vertex in Y found -
                augmenting path exists!
                x = slackx[y];
                break;
            }
            else{
                T[y] = true;

                //else just add y to T,
                if (!S[yx[y]]){
                    q[wr++] = yx[y];
                }
                //
                add vertex yx[y], which is
                matched with y, to the queue
                add_to_tree(yx[y], slackx[y]);
                //and add edges
                (x,y) and (y, yx[y]) to the tree
            }
        }
    }
    if (y < n) break;

    //augmenting path found!
}
if (y < n){
    //we found augmenting path!
    max_match++;

    //increment matching
    //in this cycle we inverse edges along
    augmenting path
    for (int cx = x, cy = y, ty; cx != -2; cx =
        pre[cx], cy = ty){
        ty = xy[cx];
        yx[cy] = cx;
        xy[cx] = cy;
    }
    augment();

    //recall function, go to step 1 of the
    algorithm
}
}
int hungarian(){
    int ret = 0;
    //weight of
    the optimal matching
}

```

```

max_match = 0; //number of
    vertices in current matching
memset(xy, -1, sizeof(xy));
memset(yx, -1, sizeof(yx));
init_labels(); //step 0
augment(); //steps 1-3
for (int x = 0; x < n; x++) //forming
    answer there
    ret += cost[x][xy[x]];
return ret;
}
int main(){
    while ( scanf("%d",&n) == 1 ){
        for ( int i = 0 ; i < n ; i++ )
            for ( int j = 0 ; j < n ; j++ )
                scanf("%d",&cost[i][j]);
        int ret = hungarian();
        for ( int i = 0 ; i < n ; i++ )
            printf("%d%c",lx[i],i==n-1?'\\n':' ');
        for ( int i = 0 ; i < n ; i++ )
            printf("%d%c",ly[i],i==n-1?'\\n':' ');
        printf("%d\\n",ret);
    }
    return 0;
}

```

4.4 maximum matching in general graph

//Problem:<http://acm.timus.ru/problem.aspx?space=1&num=1099>

```

#include <cstdio>
#include <cstdlib>
#include <cstring>
#include <iostream>
#include <algorithm>
using namespace std;
const int N=250;
int n;
int head;
int tail;
int Start;
int Finish;
int link[N]; //表示哪個點匹配了哪個點
int Father[N]; //這個就是增廣路的Father……但是用起來太精髓了
int Base[N]; //該點屬於哪朵花
int Q[N];
bool mark[N];
bool map[N][N];
bool InBlossom[N];
bool in_Queue[N];

void CreateGraph(){
    int x,y;
    scanf("%d",&n);
    while (scanf("%d%d",&x,&y)!=EOF)
        map[x][y]=map[y][x]=1;
}

void BlossomContract(int x,int y){
    fill(mark,mark+n+1,false);
    fill(InBlossom,InBlossom+n+1,false);
    #define pre Father[link[i]]
    int lca,i;
    for (i=x;i;pre){i=Base[i]; mark[i]=true; }
    for (i=y;i;pre){i=Base[i]; if (mark[i]) {lca=i; break;} } //尋找lca之旅……一定要注意i=Base[i]
    for (i=x;Base[i]!=lca;i=pre){
        if (Base[pre]!=lca) Father[pre]=link[i]; //對於BFS樹中的父邊是匹配邊的點，Father向後跳
        InBlossom[Base[i]]=true;
    }
}

```

```

    InBlossom[Base[link[i]]]=true;
}
for (i=y;Base[i]!=lca;i=pre){
    if (Base[pre]!=lca) Father[pre]=link[i]; //同理
    InBlossom[Base[i]]=true;
    InBlossom[Base[link[i]]]=true;
}
#undef pre
if (Base[x]!=lca) Father[x]=y; //注意不能從lca這個奇環的關鍵點跳回來
if (Base[y]!=lca) Father[y]=x;
for (i=1;i<=n;i++){
    if (InBlossom[Base[i]]){
        Base[i]=lca;
        if (!in_Queue[i]){
            Q[++tail]=i;
            in_Queue[i]=true; //要注意如果本來連向BFS樹中父結點的邊是非匹配邊的點，可能是沒有入隊的
        }
    }
}

void Change(){
    int x,y,z;
    z=Finish;
    while (z){
        y=Father[z];
        x=link[y];
        link[y]=z;
        link[z]=y;
        z=x;
    }
}

void FindAugmentPath(){
    fill(Father,Father+n+1,0);
    fill(in_Queue,in_Queue+n+1,false);
    for (int i=1;i<=n;i++) Base[i]=i;
    head=0; tail=1;
    Q[1]=Start;
    in_Queue[Start]=1;
    while (head!=tail){
        int x=Q[++head];
        for (int y=1;y<=n;y++){
            if (map[x][y] && Base[x]!=Base[y] && link[x]!=y) //無意義的邊
                if ( Start==y || link[y] && Father[link[y]] ) //精髓地用Father表示該點是否
                    BlossomContract(x,y);
            else if (!Father[y]){
                Father[y]=x;
                if (link[y]){
                    Q[++tail]=link[y];
                    in_Queue[link[y]]=true;
                }
            }
            else{
                Finish=y;
                Change();
                return;
            }
        }
    }
}

void Edmonds(){
    memset(link,0,sizeof(link));
    for (Start=1;Start<=n;Start++){
        if (link[Start]==0)
            FindAugmentPath();
    }
}

void output(){

```

```

fill(mark,mark+n+1,false);
int cnt=0;
for (int i=1;i<=n;i++)
    if (link[i]) cnt++;
printf("%d\n",cnt);
for (int i=1;i<=n;i++){
    if (!mark[i] && link[i]){
        mark[i]=true;
        mark[link[i]]=true;
        printf("%d %d\n",i,link[i]);
    }
}
int main(){
    CreateGraph();
    Edmonds();
    output();
    return 0;
}

```

5 Math

5.1 China remainder theorem

$$ans \equiv a_i \pmod{m_i}$$

```

int china_remainder_theorem(int n, int ai[], int
    mi[]) {
    int gcdn, x, y, reduce, tmp;
    for(int i=1; i<n; ++i) {
        gcdn=ext_gcd(mi[i-1], mi[i], x, y);
        reduce=ai[i]-ai[i-1];
        if( reduce%gcdn!=0 )
            return -1;
        tmp=mi[i]/gcdn;
        x=(reduce/gcdn*x%tmp+tmp)%tmp;
        ai[i] = ai[i-1] + mi[i-1]*x;
        mi[i] = mi[i-1]*tmp;
    }
    return ai[n-1]%mod;
}

```

5.2 Euler's phi function $O(n)$

1. $\gcd(x, y) = d \Rightarrow \phi(xy) = \frac{\phi(x)\phi(y)}{\phi(d)}$
2. p is prime $\Rightarrow \phi(p^k) = p^{k-1}\phi(p)$
3. p is prime $\Rightarrow \phi(p^k) = \phi(p^{k-1}) \times p$
4. $n = p_1^{k_1} p_2^{k_2} \dots p_m^{k_m}$
 $\Rightarrow \phi(n) = p_1^{k_1-1} \phi(p_1) p_2^{k_2-1} \phi(p_2) \dots p_m^{k_m-1} \phi(p_m)$

```

const int MAXN = 100000;
int phi[MAXN], prime[MAXN], pn=0;
memset(phi, 0, sizeof(phi));
for(int i=2; i<MAXN; ++i) {
    if( phi[i]==0 ) prime[pn++]=i, phi[i]=i-1;
    for(int j=0; j<pn; ++j) {
        if( i*prime[j]>MAXN ) break;
        if( i%prime[j]==0 ) {
            phi[i*prime[j]] = phi[i] * prime[j];
            break;
        }
        phi[i*prime[j]] = phi[i] * phi[prime[j]];
    }
}

```

5.3 Extended Euclid's Algorithm

$$ax + by = \gcd(a, b)$$

```

int ext_gcd(int a, int b, int &x, int &y){
    int x2;
    if( b==0 ) {
        x=1, y=0;
        return a;
    }
    int gcdn=ext_gcd(b, a%b, x, y), x2=x;
    x=y, y=x2-a/b*y;
    return gcdn;
}
int ext_gcd(int a, int b, int &x, int &y){
    int t, px=1, py=0, tx,ty;
    x=0, y=1;
    while(a%b!=0) {
        tx=x, ty=y;
        x=x*(-a/b)+px, y=y*(-a/b)+py;
        px=tx, py=ty;
        t=a, a=b, b=t%b;
    }
    return b;
}

```

5.4 FFT

```
#include<cstdio>
#include<cstdlib>
#include<vector>
using namespace std;

typedef long long ll;

int ODD[1<<20], EVEN[1<<20], ODD_B[1<<20], EVEN_B
[1<<20];

int mul_order(int n) {
    n--;
    int high_bit = n&(-n);
    for(n-=high_bit; n; n-=high_bit)
        high_bit = n&(-n);
    return high_bit<<2;
}

// return a^x mod p
int mod_pow(int a, int x, int p) {
    if(x==0) return 1;
    ll ret = mod_pow(a,x>>1,p);
    ret*=ret;
    ret%=p;
    return (x&1)?(ret*a)%p:ret;
}

// only works for prime p
int mod_inverse(int x, int p) { return mod_pow(x,
    p-2,p); }

// n is a power of 2 and answer is at most
    upper_bound
// 2013265921=1+2^27*3*5 is a prime
inline int suitable_prime(int n, int upper_bound)
    { return 2013265921; }

// not general version
int primitive_root(int p) {
    int ret;
    srand(714091); // THOR
    // srand(time(NULL));
    for(ret=rand()%p;;ret=rand()%p) {
        if(mod_pow(ret,(p-1)/2,p)!=1 &&
            mod_pow(ret,(p-1)/3,p)!=1 &&
            mod_pow(ret,(p-1)/5,p)!=1)
            return ret;
    }
}

// nth principle root of unity (mod p)
int principal_root(int n, int p) {
    int g=primitive_root(p);
    return mod_pow(g,(p-1)/n,p);
}

void cooley_tukey(int *a, int *b, int n, ll r, ll
    p) {
    if(n>1) {
        int half_n=n>>1;
        int *odd=ODD+half_n, *even=EVEN+half_n;
        int *odd_b=ODD_B+half_n, *even_b=EVEN_B+
            half_n;
        for(int i=0; i<n; i+=2) {
            even[i>>1]=a[i];
            odd[i>>1]=a[1+i];
        }
        cooley_tukey(even,even_b,n>>1,r*r%p,p);
        cooley_tukey(odd,odd_b,n>>1,r*r%p,p);
```

```
        ll iter=1, p2=p*p;
        for(int i=0; i<half_n; i++) {
            ll odd_part=iter*odd_b[i];
            b[i]=(even_b[i]+odd_part)%p;
            b[half_n+i]=(even_b[i]+p2-odd_part)%p;
            iter*=r;
            iter%=p;
        }
    }
    else b[0]=a[0];
}

void print(int *a, int n) {
    for(int i=0; i<n; i++)
        printf("%d%c",a[i],i==n-1?'\\n':' ');
}

// c=a*b where c is initially empty
void multiply(int *a, int *b, int *c,
    int n, ll inv_n, ll r, ll inv_r, ll p) {
    int *f, *g, *h;
    f=new int[n];
    g=new int[n];
    h=new int[n];
    cooley_tukey(a,f,n,r,p);
    cooley_tukey(b,g,n,r,p);
    for(int i=0; i<n; i++) h[i]=(ll)f[i]*g[i]%p;
    cooley_tukey(h,c,n,inv_r,p);
    for(int i=0; i<n; i++) c[i]=c[i]*inv_n%p;
    delete[] f;
    delete[] g;
    delete[] h;
}

int main() {
    int n, N;
    scanf("%d",&n);
    N=mul_order(n);
    printf("N=%d\\n",N);
    int *a, *b, *c;
    a=new int[N];
    b=new int[N];
    c=new int[N];
    for(int i = 0; i < n; i++) scanf("%d",&a[i]);
    for(int i = 0; i < n; i++) scanf("%d",&b[i]);
    for(int i = n; i < N; i++) a[i]=b[i]=0;
    int p=suitable_prime(N,10007);
    ll r=principal_root(N,p);
    ll inv_r=mod_inverse(r,p);
    ll inv_n=mod_inverse(N,p);
    multiply(a,b,c,N,inv_n,r,inv_r,p);
    int last=N-1;
    while(last>=0 && c[last]==0) last--;
    for(int i = 0; i<=last; i++)
        printf("%d%c",c[i],last==i?'\\n':' ');
    return 0;
}
```

5.5 Gaussian Elimination

```
// default for module version, comments for
    double version
//double mmap[row][column];
const ll modn = 1000000007;
ll mmap[row][column];
ll inv(ll b)
{
    return (b==1)?1:inv(modn%b)*(modn-modn/b)%modn;
}
void gauss(ll mat[row][column],int n,int m)
{
```

```

int k=0;
for(int i=0; i<m; i++)
    for(int j=k; j<n; j++)
        if(mat[j][i]!=0){
            for(int l=i; l<m; l++)
                swap(mat[k][l],mat[j][l]);
            for(j++; j<n; j++){
                if(mat[j][i]==0)
                    continue;
                //double scale=mat[j][i]/mat[k][i];
                long long scale=mat[j][i]*inv(mat[k][i]
                )%modn; //mod version
                for(int p=i+1; p<m; p++)
                    //mat[j][p]-=mat[k][p]*scale;
                    mat[j][p]=(mat[j][p]-mat[k][p]*scale%
                    modn+modn)%modn;
                mat[j][i]=0;
            }
            k++;
            break;
        }
}

memset(fcnt, 0, sizeof(fcnt));
for(int i=2; i<=n; ++i) {
    if( isp[i] ) {
        fcnt[i] = 1;
        for(int j=i+i; j<=n; j+=i) {
            isp[j] = false;
            if( fcnt[j]!=-1 ) fcnt[j]++;
        }
        if( i<=10000 )
            for(int ii=i*i, j=ii; j<=n; j+=ii) {
                fcnt[j] = -1;
            }
    }
}
mobius[0] = 0;
mobius[1] = 1;
for(int i=2; i<=n; ++i) {
    if( fcnt[i]==-1 ) mobius[i] = 0;
    else if( fcnt[i]&1 ) mobius[i] = -1;
    else mobius[i] = 1;
}
}

```

5.6 Miller Rabin

```

ll mul(ll a, ll b, ll n) { // a*b%n
    ll r = 0;
    a %= n, b %= n;
    while(b){
        if( b&1 ) r = a+r>=n ? a+r-n : a+r;
        a = a+a>=n ? a+a-n : a+a;
        b >>= 1;
    }
    return r;
}
ll powmod(ll a, ll d, ll n) { // a^d%n
    if(d==0) return 1ll;
    if(d==1) return a%n;
    return mul(powmod(mul(a, a, n), d>>1, n), d%2?a
    :1, n);
}
bool miller_rabin(ll n, ll a) {
    if(__gcd(a,n)==n) return true;
    if(__gcd(a,n)!=1) return false;
    ll d = n-1, r = 0, res;
    while(d%2==0) { ++r; d>>=1; }
    res = powmod(a, d, n);
    if(res==1||res==n-1) return true;
    while(r--){
        res = mul(res, res, n);
        if(res==n-1) return true;
    }
    return false;
}
bool isPrime(ll n) {
    ll as[7]={2, 325, 9375, 28178, 450775, 9780504,
    1795265022}; // 2, 7, 61
    for(int i=0; i<7; i++)
        if( !miller_rabin(n, as[i]) )
            return false;
    return true;
}

```

5.7 Möbius function

```

int* isp;
char fcnt[N+5];
int mobius[N+5];
void make_mobius(int n) {
    isp = mobius;
    memset(mobius, true, sizeof(mobius));
}

```

6 String

6.1 AhoCorasick

```
#include <queue>
using namespace std;

template<int NodeSZ>
class AhoCorasick {
public:
    AhoCorasick() { clear(); }
    void clear() {
        all[0] = Node();
        ncnt = 1;
    }
    void insert(char *s) {
        Node *curr = &all[0], *next;
        for(int i=0; s[i]; ++i) {
            next = curr->next[idx(s[i])];
            if( next == NULL )
                next = &all[ncnt], all[ncnt++] = Node();
            curr = curr->next[idx(s[i])] = next;
        }
        curr->val++;
    }
    void build() {
        queue<Node*> qq;
        qq.push(&all[0]);
        while( !qq.empty() ) {
            Node *curr = qq.front(), *fail;
            qq.pop();
            for(int i=0; i<NodeSZ; ++i) {
                if( !curr->next[i] ) continue;
                qq.push(curr->next[i]);
                fail = curr->fail;
                while( fail && !fail->next[i] )
                    fail = fail->fail;
                curr->next[i]->fail = fail ? fail->next[i] : &all[0];
            }
        }
    }
    int count(char *s) {
        build();
        int cnt = 0;
        Node *curr = &all[0], *tmp;
        for(int i=0, ch; s[i]; ++i) {
            ch = idx(s[i]);
            while( curr && !curr->next[ch] )
                curr = curr->fail;
            curr = curr ? curr->next[ch] : all[0].next[ch];
            tmp = curr;
            while( tmp && tmp->val ) {
                cnt += tmp->val;
                tmp->val = 0;
                tmp = tmp->fail;
            }
        }
        return cnt;
    }
private:
    struct Node {
        Node() : val(0), fail(NULL) {
            for(int i=0; i<NodeSZ; ++i) next[i] = NULL;
        }
        int val;
        Node *fail, *next[NodeSZ];
    };
    Node all[250005];
```

```
int ncnt;
inline int idx(char c) { return c-'a'; }
};
AhoCorasick<26> AC;
```

6.2 KMP

```
int KMP(char pat[5005], char str[5005]) {
    if( strlen(pat)>strlen(str) ) return -1;
    int failure[5005];
    int len=strlen(pat);
    for(int i=1, j=failure[0]=-1; i<len; ++i) {
        while( j>=0 && pat[j+1]^pat[i] ) j=failure[j];
        if( pat[j+1]==pat[i] ) ++j;
        failure[i]=j;
    }
    for(int i=0, j=-1; str[i]; ++i) {
        while( j>=0 && str[i]^pat[j+1] ) j=failure[j];
        if( str[i]==pat[j+1] ) ++j;
        if( j==len-1 ) {
            return i-len+1; // rec this!!
            j=failure[j];
        }
    }
    return -1;
}
```

6.3 Longest Palindromic Substring

```
char t[1001]; // 要處理的字串
char s[1001 * 2]; // 中間插入特殊字元的t。
int Z[1001 * 2], L, R; // Gusfield's Algorithm
// 由a往左、由b往右，對稱地作字元比對。
int match(int a, int b) {
    int i = 0;
    while (a-i>=0 && b+i<N && s[a-i] == s[b+i]) i++;
    return i;
}
void longest_palindromic_substring()
{
    int N = strlen(t);
    // 在t中插入特殊字元，存放到s。
    memset(s, '.', N*2+1);
    for (int i=0; i<N; ++i) s[i*2+1] = t[i];
    N = N*2+1;
    // modified Gusfield's Algorithm
    Z[0] = 1;
    L = R = 0;
    for (int i=1; i<N; ++i) {
        int ii = L - (i - L); // i的映射位置
        int n = R + 1 - i;
        if (i > R) {
            Z[i] = match(i, i);
            L = i;
            R = i + Z[i] - 1;
        }
        else if (Z[ii] == n) {
            Z[i] = n + match(i-n, i+n);
            L = i;
            R = i + Z[i] - 1;
        }
        else Z[i] = min(Z[ii], n);
    }
    // 尋找最長迴文子字串的長度。
    int n = 0, p = 0;
    for (int i=0; i<N; ++i)
        if (Z[i] > n) n = Z[p = i];
    // 記得去掉特殊字元。
```

```

cout << "最長迴文子字串的長度是" << (n-1) / 2;
// 印出最長迴文子字串，記得別印特殊字元。
for (int i=p-Z[p]+1; i<=p+Z[p]-1; ++i)
    if (i & 1) cout << s[i];
}

```

6.4 Suffix Array

```

int myrank[LEN], sa[LEN];
int height[LEN];
int y[LEN], cnt[LEN], rr[2][LEN];
inline bool same(int *_myrank, int a, int b, int
    1) { return *_myrank[a]==*_myrank[b]&&*_myrank[a
    +1]==*_myrank[b+1]; }
void make_height(char str[]) {
    int len=strlen(str);
    MSET(height, 0);
    for(int i=0, j=0; i<len; ++i, j=height[myrank[i
        -1]]-1) {
        if( myrank[i]==1 ) continue;
        if( j<0 ) j=0;
        while( i+j<len && sa[myrank[i]-1]+j<len &&
            str[i+j]==str[sa[myrank[i]-1]+j] ) ++j;
        height[myrank[i]]=j;
    }
}
void sa2(char str[], int n, int MAX = 256) {
    printf("%s!! %d %d\n", str, n, MAX);
    int *rank1=rr[0], *rank2=rr[1];
    int *myrank1=rr[0], *myrank2=rr[1]; // rolling
        array
    int *y = myrank; // share memory
    MSET(rr[1], 0);
    MSET(cnt, 0);
    int i, p=0;
    for(i=0; i<n; ++i) myrank2[i]=str[i], cnt[
        myrank2[i]]++;
    for(i=1; i<MAX; ++i) cnt[i]+=cnt[i-1];
    for(i=n-1; i>=0; --i) sa[--cnt[myrank2[i]]]=i;
    for(int j=1; p<n; j<=1, MAX=p) {
        // 表示用第二個key(myrank2)排序後 從 y[i] 開
            始的後綴排第i名
        for(p=0, i=n-j; i<n; ++i) y[p++]=i;
        for(i=0; i<n; ++i) if( sa[i]>=j ) y[p++]=sa[i
            ]-j;
        for(i=0; i<MAX; ++i) cnt[i]=0;
        for(i=0; i<n; ++i) cnt[ myrank2[y[i]] ] ++;
        for(i=1; i<MAX; ++i) cnt[i]+=cnt[i-1];
        for(i=n-1; i>=0; --i) sa[ --cnt[ myrank2[y[i
            ]] ] ] =y[i];
        for(p=i=1, myrank1[sa[0]]=0; i<n; ++i)
            myrank1[sa[i]]=same(myrank2, sa[i], sa[i
                -1], j)?p-1:p++;
        std::swap(myrank1, myrank2);
    }
    for(int i=0; i<n; ++i) myrank[i]=myrank2[i];
    make_height(str);
}
int main() {
    char str[LEN];
    scanf("%s", str);
    int len = strlen(str);
    sa2(str, len+1);
    for(int i=1; i<=len; ++i) printf("%d %d %s\n",
        i, height[i], str+sa[i]);
}

```

6.5 Z Algorithm

```

void Z(char G[], int z[]){
    int len = strlen(G);

```

```

z[0] = len;
int L = 0, R = 1;
for ( int i = 1 ; i < len ; i++ ) {
    if ( i >= R || z[i-L] >= R-i ) {
        int x = (i>=R) ? i : R;
        while ( x < len && G[x] == G[x-i] )
            x++;
        z[i] = x - i;
        if ( x > i ) L = i , R = x;
    }
    else z[i] = z[i-L];
}

```

7 Others

7.1 8 puzzle - IDA*

// 一個盤面。其數值1~8代表方塊號碼，0代表空格。
 int board[3][3] = {2, 3, 4, 1, 5, 0, 7, 6, 8};
 // 檢查 *permutation inversion*。檢查不通過，表示盤面不合理。

```
bool check_permutation_inversion(int board[3][3])
{
    int inversion = 0;
    for (int a=0; a<9; ++a)
        for (int b=0; b<a; ++b) {
            int i = a / 3, j = a % 3;
            int ii = b / 3, jj = b % 3;
            if (board[i][j] && board[ii][jj]
                && board[i][j] < board[ii][jj])
                inversion++;
        }
    int row_number_of_0 = 0;
    for (int i=0; i<3 && !row_number_of_0; ++i)
        for (int j=0; j<3 && !row_number_of_0; ++j)
            if (board[i][j] == 0)
                row_number_of_0 = i+1;
    return (inversion + row_number_of_0) % 2 == 0;
}
```

////////////////////////////////////
 // heuristic function, 採用不在正確位置上的方塊個數。

```
int h(int board[3][3])
{
    int cost = 0;
    for (int i=0; i<3; ++i)
        for (int j=0; j<3; ++j)
            if (board[i][j])
                if (board[i][j] != i*3 + j + 1)
                    cost++;
    return cost;
}
////////////////////////////////////
int taxicab_distance(int x1, int y1, int x2, int y2)
{
    return abs(x1 - x2) + abs(y1 - y2);
}
```

// heuristic function, 採用 *taxicab distance*。

```
int h(int board[3][3]) {
    // 每塊方塊的正確位置。{0,0}是為了方便編寫程式而多加的。
    static const int right_pos[9][2] = {
        {0,0},
        {0,0}, {0,1}, {0,2},
        {1,0}, {1,1}, {1,2},
        {2,0}, {2,1}
    };
    // 計算每個方塊與其正確位置的 taxicab distance 的總和。
    int cost = 0;
    for (int i=0; i<3; ++i)
        for (int j=0; j<3; ++j)
            if (board[i][j])
                cost += taxicab_distance(
                    i, j,
                    right_pos[board[i][j]][0],
                    right_pos[board[i][j]][1]
                );
    return cost;
}
```

// 上下左右

```
const string operator[4] = {"up", "down", "right", "left"};
```

```
const int dx[4] = {-1, 1, 0, 0}, dy[4] = {0, 0, 1, -1};
char solution[30];
// 正確的推動方式，其數值是方向0~3。
const int reverse_dir[4] = {1, 0, 3, 2};
// 用表格紀錄每一個方向的反方向。可用於避免來回推動的判斷。
```

```
int board[3][3] = {2, 3, 4, 1, 5, 0, 7, 6, 8};
// 起始狀態。其數值1~8代表方塊號碼，0代表空格。
```

```
int sx = 1, sy = 2;
// 空格的位置。可馬上知道推動方塊的目的地。
```

```
bool onboard(int x, int y)
{
    return x>=0 && x<3 && y>=0 && y<3;
}
```

```
int IDAstar(int x, int y, int gv, int prev_dir,
            int& bound, bool& ans) {
    int hv = h(board);
    if (gv + hv > bound) return gv + hv;
    // 超過，回傳下次的 bound
    if (hv == 0) {ans = true; return gv;}
    // 找到最佳解
```

```
int next_bound = 1e9;
for (int i=0; i<4; ++i) {
    // 四種推動方向
    int nx = x + dx[i], ny = y + dy[i];
    // 空格的新位置
    if (reverse_dir[i] == prev_dir) continue;
    // 避免來回推動
    if (!onboard(nx, ny)) continue;
    // 避免出界
    solution[gv] = oper[i];
    // 紀錄推動方向
    swap(board[x][y], board[nx][ny]);
    // 推動
    int v = IDAstar(nx, ny, gv+1, i, bound, ans);
    if (ans) return v;
    next_bound = min(next_bound, v);
    swap(board[nx][ny], board[x][y]);
    // 回復原狀態
}
return next_bound;
}
```

```
void eight_puzzle() {
    if (!check_permutation_inversion(board)) {
        cout << "盤面不合理，無法解得答案。" << endl;
        return;
    }
    // IDA*
    bool ans = false;
    int bound = 0;
    while (!ans && bound <= 50)
        bound = IDAstar(sx, sy, 0, -1, bound, ans);
    if (!ans) {
        cout << "50步內無法解得答案。" << endl;
        return;
    }
    // 印出移動方法
    for (int i=0; i<bound; ++i)
        cout << operation[solution[i]] << ' ';
    cout << endl;
}
```

7.2 recursive to stack

replace all variable in data into layer[layer].variable

```
struct data {
```



```
    parameter;
    local variabla;
    direction;    //new
} layer[10000];
int lay=0; //new
type reval; //new
void go() {
// at the beginning
start:
// call recursive function
    direction = 1;
    lay++, parameter = value;
    goto start;
point1:
    variable = reval;
// return
    reval = value;
    lay--;
    goto trans;
// at the end
trans:
    switch (direction) {
        case 1:
            goto point1;
    }
}
```

The End