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1 Enviroment Settings

```

1 1.1 .vimrc
1 syntax on
  set enc=utf-8 fencs=utf-8,big5
2 set bs=2
2 set smd nu bg=dark hls ls=2 wmnu so=5 ru cul
2 set ts=4 sw=4 ai sta si
2 set list lcs=tab:>\ "# a space after '\ '
2 map<F9> :!g++ "%" -o "%:r.out" -Wall -Wshadow -O2
  -Im -std=c++11 && echo "==== done =====" &&
  "%:r.out"
3
3
3
3
5
5
6
6
6
6
8

```

2 Computational Geometry

2.1 Geometry on Plane

```
struct node {
    double x,y;
    node(double _x=0, double _y=0) : 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 operator^(const node& rhs) const
    { return x*rhs.y-y*rhs.x; }
    double len2() const { return x*x+y*y; }
    double len() const { return sqrt(x*x+y*y); }
    node unit() const { return *this/len(); }
    node T() const { return node(-y,x); }
    node rot(double rad) const { // rotate counter-
        clockwise in rad
        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);
}
```

2.2 Minimum Covering Circle

```
node center(node p0, node p1, node p2) {
    node a = p1-p0;
    node b = p2-p0;
    double c1 = a.len2()/2;
    double c2 = b.len2()/2;
    double d = a^b;
    double x = p0.x + (c1 * b.y - c2 * a.y) / d;
```

```
double y = p0.y + (a.x * c2 - b.x * c1) / d;
return node(x, y);
}
```

```
pair<node,double> mcc(node p[], int n) {
    random_shuffle(p, p+n);
    node oo;
    double r2 = 0;
    for(int i=0; i<n; i++) {
        if ((oo-p[i]).len2() <= r2) continue;
        oo = p[i];
        r2 = 0;
        for(int j=0; j<i; j++) {
            if ((oo-p[j]).len2() <= r2) continue;
            oo = (p[i]+p[j]) / 2;
            r2 = (oo-p[j]).len2();
            for(int k=0; k<j; k++) {
                if ((oo-p[k]).len2() <= r2) continue;
                oo = center(p[i], p[j], p[k]);
                r2 = (oo-p[k]).len2();
            }
        }
    }
    return make_pair(oo, r2);
}
```

2.3 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;
}

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].R->x2
            );
        node[M].y2 = max( node[M].y2 , node[M].R->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 );
    }
}

```

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
 * point_iterator push(const_reference r_val)
 * pop
 * void modify(point_iterator it, const_reference
 *             r_new_val)
 * size_type erase_if(Pred prd) - return erased
 *         number
 * void join(priority_queue &other)
 * void split(Pred prd, priority_queue &other) -
 *         move v into other if prd(v)
 *
 * 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)
 *         [0, size)
 * 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/trie_policy.hpp>
#include<ext/pb_ds/tag_and_trait.hpp>
typedef trie<string, null_type,
    trie_string_access_traits<>, pat_trie_tag,
    trie_prefix_search_node_update> Trie;
typedef trie<string, null_type,
    string_trie_e_access_traits, pat_trie_tag,
    trie_prefix_search_node_update> Trie;
/*
 * pair<Trie::iterator, bool> insert(string s) -
 *         iterator and is new string
 * pair<Trie::iterator, Trie::iterator>
 *         prefix_range(string pre)
 */

#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, 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]={{} };
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

```

class Treap{
private:
    class Node{
public:
        Node( ){ }
    }
}

```

```

Node( int val ){ initVal( val ); }
void initVal( int val ){
    pri = rand();
    this -> val = val;
    this -> maxSum = val;
    this -> maxSumLeft = val;
    this -> maxSumRight = val;
    this -> size = 1;
    this -> l = r = NULL;
    this -> reverse = false;
    this -> setValTag = false;
    this -> sum = val;
}
int pri, val, size, maxSum, sum;
int maxSumLeft, maxSumRight;
bool reverse, setValTag;
Node *l, *r;
};

Node* root;
Node* pool;
Node** stk;
int top;
int getSize( Node *x ){
    return x ? x->size : 0;
}
int getMaxSumLeft( Node *x ){
    return x ? x->maxSumLeft : -INF;
}
int getMaxSumRight( Node *x ){
    return x ? x->maxSumRight : -INF;
}
int getMaxSum( Node *x ){
    return x ? x->maxSum : -INF;
}
int getSum( Node *x ){
    return x ? x->sum : 0;
}

void setVal( Node *x, int val ){
    x->val = val;
    x->maxSumLeft = x->maxSumRight = x->maxSum =
        val > 0 ? getSize( x ) * val : val;
    x->sum = val * getSize( x );
    x->setValTag = true;
}
void setReverse( Node *x ){
    swap( x->l, x->r );
    swap( x->maxSumLeft, x->maxSumRight );
    x->reverse = !x->reverse;
}
void pull( Node *x ){
    x->size = getSize( x->l ) + getSize( x->r ) +
        1;
    int maxSum = max( 0, getMaxSumRight( x->l )
        ) + x->val + max( 0, getMaxSumLeft( x->r
        ) );
    maxSum = max( maxSum, max( getMaxSum( x->l )
        , getMaxSum( x->r ) ) );
    x->maxSum = maxSum;

    int maxSumLeft = max( getMaxSumLeft( x->l )
        , getSum( x->l ) + x->val + max( 0,
        getMaxSumLeft( x->r ) ) );
    x->maxSumLeft = maxSumLeft;

    int maxSumRight = max( getMaxSumRight( x->r )
        , getSum( x->r ) + x->val + max( 0,
        getMaxSumRight( x->l ) ) );
    x->maxSumRight = maxSumRight;

    x->sum = getSum( x->l ) + x->val + getSum( x
        ->r );
}
void push( Node *x ){
    if ( x->reverse ){
        if ( x->r ) setReverse( x->r );
        if ( x->l ) setReverse( x->l );
        x->reverse = false;
    }
    if ( x->setValTag ){
        if ( x->r ) setVal( x->r, x->val );
        if ( x->l ) setVal( x->l, x->val );
        x->setValTag = false;
    }
}
void split( Node *root, Node* &x, Node* &y,
    int k ){
    if ( !root ){
        x = y = NULL;
        return;
    }
    if ( getSize( root->l ) >= k ){
        y = root;
        push( y );
        split( root->l, x, y->l, k );
        pull( y );
    }
    else{
        x = root;
        push( x );
        split( root->r, x->r, y, k-getSize( root
            ->l )-1 );
        pull( x );
    }
}
Node* Merge( Node *x, Node *y ){
    if ( !x || !y )
        return x ? x : y;

    if ( x->pri > y->pri ){
        push( x );
        x->r = Merge( x->r, y );
        pull( x );
        return x;
    }
    else{
        push( y );
        y->l = Merge( x, y->l );
        pull( y );
        return y;
    }
}
public:
Treap(){
    root = NULL;
    pool = new Node[MAX_SIZE];
    stk = new Node*[MAX_SIZE];
    for ( top = 0; top < MAX_SIZE; top++ )
        stk[top] = &pool[top];
}
~Treap(){
    delete[] pool;
    delete[] stk;
}
Node* newNode( int val ){
    Node *ret = stk[--top];
    ret -> initVal(val);
    return ret;
}

```

```

void release( Node *x ){
    if ( x->l )
        release( x->l );
    if ( x->r )
        release( x->r );
    stk[top++] = x;
}

void insert( int val ){
    root = Merge( root , newNode( val ) );
}

void insert( int k , queue<int>& q ){
    Node *l, *r, *newTree = NULL;
    split( root , l , r , k );
    while ( !q.empty() ){
        int a = q.front(); q.pop();
        newTree = Merge( newTree , newNode( a ) );
    }
    root = Merge( l , Merge( newTree , r ) );
}

void remove( int k , int sz ){
    Node *l, *m , *r;
    split( root , l , m , k-1 );
    split( m , m , r , sz );
    release( m );
    root = Merge( l , r );
}

void setVal( int k , int sz , int val ){
    Node *l, *m , *r;
    split( root , l , m , k-1 );
    split( m , m , r , sz );
    setVal( m , val );
    root = Merge( l , Merge( m , r ) );
}

void reverse( int k , int sz ){
    Node *l, *m , *r;
    split( root , l , m , k-1 );
    split( m , m , r , sz );
    setReverse( m );
    root = Merge( l , Merge( m , r ) );
}

int getSum( int k , int sz ){
    int ret = 0;
    Node *l, *m , *r;
    split( root , l , m , k-1 );
    split( m , m , r , sz );
    ret = getSum( m );
    root = Merge( l , Merge( m , r ) );
    return ret;
}

int getMaxSum( ){
    return getMaxSum( root );
}
};

```

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=1; 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+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:
    int ncnt;
    void reset() {
        for(int i=0; i<3605; ++i)
            edge[i].clear();
    }
    void AddEdge(int s, int t){
        edge[s].emplace_back(t, 1, edge[t].size());
        edge[t].emplace_back(s, 0, edge[s].size()-1);
        //
    }
    int MaxFlow(int s, int t){ // Dinic
        int f = 0, df;
        while (BFS(s, t)!=-1){
            while (true){
                memset(vst, 0, sizeof(vst));
                df = DFS(s, 1<<30, t);
                if (!df) break;
                f += df;
            }
        }
        return f;
    }
}
```

private:

```
int d[3605]; // Dicic distance
bool vst[3605];
```

```
struct Edge {
    Edge(const int& t, const int& c, const int& r
        ) : tar(t), cap(c), rev(r) {}
    int tar;
    int cap;
    int rev;
    operator tuple<int&,int&,int&>() { return
        tuple<int&,int&,int&>{tar, cap, rev}; }
};
vector<Edge> edge[3605];
```

```
int DFS(int now, int df, int t){
    if (now==t) return df;
    if (vst[now]) return 0;
    vst[now] = true;
    int nxt, re;
    int cap;
```

```
for(auto& edg: edge[now]) {
    tie(nxt, cap, re) = edg;
    if (cap>0 && d[nxt]==d[now]+1){
        int f = DFS(nxt, min(df, cap), t);
        if (f){
            edg.cap -= f;
            edge[nxt][re].cap += f;
            return f;
        }
    }
}
return 0;
}
```

```
int BFS(int s, int t){
    memset(d, -1, sizeof(d));
    memset(vst, false, sizeof(vst));
    d[s] = 0;
    vst[s] = true;
    queue<int> qq;
    qq.push(s);
    int now, nxt, re;
    int cap;
    while (!qq.empty()) {
        now = qq.front();
        qq.pop();
        for(auto& edg: edge[now]) {
            tie(nxt, cap, re) = edg;
            if (!vst[nxt] && cap) {
                vst[nxt] = true;
                d[nxt] = d[now] + 1;
                if (nxt==t) return d[nxt];
                qq.push(nxt);
            }
        }
    }
    return d[t];
}
```

Flow flow;

4.3 General Graph Matching (bcw)

```
#include <iostream>
#include <queue>
#include <cstring>
```

using namespace std;

```
struct GenMatch { // 1-base
    static const int MAXN = 514;
    int V;
    bool edg[MAXN][MAXN];
    int pr[MAXN];
    bool inq[MAXN], inb[MAXN], inp[MAXN];
    queue<int> qq;
    int st, ed;
    int bk[MAXN], djs[MAXN];
    void init(int _V) {
        V = _V;
        memset(edg, 0, sizeof(edg));
        for(int i=0; i<=V; i++) {
            pr[i] = bk[i] = djs[i] = 0;
            inq[i] = inb[i] = 0;
        }
    }
    void add_edge(int u, int v) {
        edg[u][v] = edg[v][u] = 1;
    }
    int lca(int u,int v) {
```

```

for (int i=0; i<=V; i++) inp[i] = 0;
while(1) {
    u = djs[u];
    inp[u] = true;
    if (u==st) break;
    u = bk[pr[u]];
}
while(1) {
    v = djs[v];
    if (inp[v]) return v;
    v = bk[pr[v]];
}
}
void upd(int u, int idx) {
    int v;
    while (djs[u]!=idx) {
        v = pr[u];
        inb[djs[u]] = inb[djs[v]] = true;
        u = bk[v];
        if (djs[u]!=idx) bk[u] = v;
    }
}
void blo(int u, int v) {
    int nb = lca(u, v);
    for (int i=0; i<=V; i++) inb[i] = false;
    upd(u, nb);
    upd(v, nb);
    if (djs[u]!=nb) bk[u] = v;
    if (djs[v]!=nb) bk[v] = u;
    for (int tu=1; tu<=V; tu++)
        if (inb[djs[tu]]) {
            djs[tu] = nb;
            if (!inq[tu]){
                qq.push(tu);
                inq[tu] = 1;
            }
        }
}
void flow() {
    for (int i=1; i<=V; i++) {
        inq[i] = false;
        bk[i] = 0;
        djs[i] = i;
    }

    while(qq.size()) qq.pop();
    qq.push(st);
    inq[st] = 1;
    ed = 0;
    while(qq.size()) {
        int u = qq.front(); qq.pop();
        for(int v = 1; v <= V; v++)
            if (edg[u][v] && djs[u]!=djs[v] && pr[u]
                !=v) {
                if (v==st || (pr[v]>0 && bk[pr[v]]>0))
                    blo(u,v);
                else if (!bk[v]) {
                    bk[v] = u;
                    if (pr[v]>0) {
                        if (!inq[pr[v]]) qq.push(pr[v]);
                    } else {
                        ed=v;
                        return;
                    }
                }
            }
    }
}
void aug() {
    int u = ed, v, w;

```

```

while(u > 0) {
    v = bk[u];
    w = pr[v];
    pr[v] = u;
    pr[u] = v;
    u = w;
}
}
int solve() {
    int ans = 0;
    for (int i=0; i<=V; i++) pr[i] = 0;
    for (int u=1; u<=V; u++)
        if (!pr[u]) {
            st = u;
            flow();
            if (ed>0) {
                aug();
                ans++;
            }
        }
    return ans;
}
} G;

int main() {
    G.init(100);
    for(int i=0; i<10; i++) {
        int u, v;
        cin >> u >> v;
        G.add_edge(u, v);
    }
    cout << G.solve() << endl;
}

```

4.4 Heavy-Light Decomposition

```

#include <cstdio>
#include <cstring>
#include <list>
#include <algorithm>
#define clear(x,y) memset(x, y, sizeof(x))
using namespace std;
const int N=100005;
class zkw_seg_tree {
public:
    struct node {
        node() {add=sum=0, len=1;}
        int len, add, sum;
    };
    zkw_seg_tree(int size) { // [1,size]
        dep=lg2(size-1)+1;
        delta=(1<<dep)-1;
        arr=new node[1<<(dep+1)];
        for(int i=delta; i>0; --i) arr[i].len=arr[i+1]
            .len<<1;
    }
    ~zkw_seg_tree() {
        delete[] arr;
    }
    inline void update(int l, int r, int num=1) {
        l+=delta-1, r+=delta+1;
        int l0=l, r0=r;
        while( r-l>1 ) {
            if( (l&1)^1 ) ++l, arr[l].add+=num, arr[l].
                sum+=arr[l].len*num;
            if( (r&1)^0 ) --r, arr[r].add+=num, arr[r].
                sum+=arr[r].len*num;
            l>>=1, r>>=1;
        }
        __update(l0), __update(r0);
    }
}

```

```

inline int query(int l, int r) {
    __down(l+delta), __down(r+delta);
    l+=delta-1, r+=delta+1;
    int res=0;
    while( r-l>1 ) {
        if( (l&1)^1 ) res+=arr[l+1].sum;
        if( (r&1)^0 ) res+=arr[r-1].sum;
        l>>=1, r>>=1;
    }
    return res;
}
private:
node *arr;
int dep;
int delta;
inline int lg2(int x) {int r;for(r=-1; x; x
    >>=1, ++r);return r;}
inline void __update(int x) {
    while( x>1 ) x>>=1, arr[x].sum=arr[x+x].sum+
        arr[x+x+1].sum+arr[x].len+arr[x].add;
}
inline void __down(int x) {
    for(int i=dep, tmp; i>0; --i) {
        tmp=x>>i;
        arr[tmp<<1].add+=arr[tmp].add, arr[(tmp<<1)
            +1].add+=arr[tmp].add;
        arr[tmp<<1].sum+=arr[tmp].add*arr[tmp<<1].
            len, arr[(tmp<<1)+1].sum+=arr[tmp].add*
            arr[tmp<<1].len;
        arr[tmp].add=0;
    }
}
} segtree(N);
list<int> all[N];
int dep[N];
int chn[N], son[N], fat[N], anc[N];
int flag;
int seg_pos[N];
void dfs1(int now) {
    chn[now]=0;
    son[now]=-1;
    for(list<int>::iterator ee=all[now].begin(); ee
        !=all[now].end(); ++ee) {
        if( !~dep[*ee] ) {
            dep[*ee]=dep[now]+1, fat[*ee]=now;
            dfs1(*ee);
            chn[now]+=chn[*ee];
            if( !~son[now] || chn[*ee]>chn[son[now]] )
                son[now]=*ee;
        }
        chn[now]++;
    }
}
void dfs2(int now, int now_anc) {
    anc[now]=now_anc;
    seg_pos[now]=flag++;
    if( ~son[now] ) dfs2(son[now], now_anc);
    for(list<int>::iterator ee=all[now].begin(); ee
        !=all[now].end(); ++ee)
        if( fat[*ee]==now && son[now]!=*ee )
            dfs2(*ee, *ee);
}
inline int cmd(int ch, int v1, int v2) {
    int res=0;
    while( anc[v1]!=anc[v2] ) {
        if( dep[anc[v1]]>dep[anc[v2]] ) swap(v1, v2);
        // anc[v2] is deeper
        if( ch==1 ) {
            if( anc[v2]^v2 ) segtree.update(seg_pos[son
                [anc[v2]]], seg_pos[v2]);
            segtree.update(seg_pos[anc[v2]], seg_pos[
                anc[v2]]);
        }
        else {
            if( anc[v2]^v2 ) res+=segtree.query(seg_pos
                [son[anc[v2]]], seg_pos[v2]);
            res+=segtree.query(seg_pos[anc[v2]],
                seg_pos[anc[v2]]);
        }
        v2=fat[anc[v2]];
    }
    if( v1!=v2 ) {
        if( dep[v1]>dep[v2] ) swap(v1, v2); // v2 is
            deeper
        if( ch==1 ) segtree.update(seg_pos[son[v1]],
            seg_pos[v2]);
        else res+=segtree.query(seg_pos[son[v1]],
            seg_pos[v2]);
    }
    return res;
}
int main() {
    int n, q;
    scanf("%d%d", &n, &q);
    for(int i=0, v1, v2; i<n-1; ++i){
        scanf("%d%d", &v1, &v2);
        all[v1].push_back(v2), all[v2].push_back(v1);
    }
    clear(dep, -1);
    dep[1]=0, fat[1]=0, flag=0;
    dfs1(1);
    dfs2(1, 1);
    char ch[5];
    int v1, v2;
    for(int i=0; i<q; ++i) {
        scanf("%s %d %d", ch, &v1, &v2);
        if( ch[0]=='P' ) cmd(1, v1, v2);
        else printf("%d\n", cmd(2, v1, v2));
    }
}

```

4.5 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 vertex yx[y], which is
            //matched with y, to the queue
            add_to_tree(yx[y], x);
        }

        //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));
    }
}

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];
            }

            //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();
}

//weight of
the optimal matching
//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;
}

```

4.6 Kuhn Munkres (bcw)

```

struct KM{
// Maximum Bipartite Weighted Matching (Perfect Match)
static const int MXN = 650;
static const int INF = 2147483647; // Long Long
int n,match[MXN],vx[MXN],vy[MXN];
int edge[MXN][MXN],lx[MXN],ly[MXN],slack[MXN];
// ^^^ Long Long
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 add_edge(int x, int y, int w){ // Long Long
    edge[x][y] = w;
}
bool DFS(int x){
    vx[x] = 1;
    for (int y=0; y<n; y++){
        if (vy[y]) continue;
        if (lx[x]+ly[y] > edge[x][y]){
            slack[y] = min(slack[y], lx[x]+ly[y]-edge[x][y]);
        } else {
            vy[y] = 1;
            if (match[y] == -1 || DFS(match[y])){
                match[y] = x;
                return true;
            }
        }
    }
    return false;
}
int solve(){
    fill(match,match+n,-1);
    fill(lx,lx+n,-INF);
    fill(ly,ly+n,0);
    for (int i=0; i<n; i++)
        for (int j=0; j<n; j++)
            lx[i] = max(lx[i], edge[i][j]);
    for (int i=0; i<n; i++){
        fill(slack,slack+n,INF);
        while (true){
            fill(vx,vx+n,0);
            fill(vy,vy+n,0);

```

```

            if ( DFS(i) ) break;
            int d = INF; // Long Long
            for (int j=0; j<n; j++)
                if (!vy[j]) d = min(d, slack[j]);
            for (int j=0; j<n; j++){
                if (vx[j]) lx[j] -= d;
                if (vy[j]) ly[j] += d;
                else slack[j] -= d;
            }
        }
    }
    int res=0;
    for (int i=0; i<n; i++)
        res += edge[match[i]][i];
    return res;
}
}graph;

```

4.7 Manhattan MST (bcw)

```

#include<bits/stdc++.h>
#define REP(i,n) for(int i=0;i<n;i++)
using namespace std;
typedef long long LL;
const int N=200100;
int n,m;
struct PT {int x,y,z,w,id;}p[N];
inline int dis(const PT &a,const PT &b){return
    abs(a.x-b.x)+abs(a.y-b.y);}
inline bool cpx(const PT &a,const PT &b){return a
    .x!=b.x? a.x>b.x:a.y>b.y;}
inline bool cpz(const PT &a,const PT &b){return a
    .z<b.z;}
struct E{int a,b,c;}e[8*N];
bool operator<(const E&a,const E&b){return a.c<b.c;}
struct Node{
    int L,R,key;
}node[4*N];
int s[N];
int F(int x){return s[x]==x?x:s[x]=F(s[x]);}
void U(int a,int b){s[F(b)]=F(a);}
void init(int id,int L,int R) {
    node[id]=(Node){L,R,-1};
    if(L==R)return;
    init(id*2,L,(L+R)/2);
    init(id*2+1,(L+R)/2+1,R);
}
void ins(int id,int x) {
    if(node[id].key==-1 || p[node[id].key].w>p[x].w)
        node[id].key=x;
    if(node[id].L==node[id].R)return;
    if(p[x].z<=(node[id].L+node[id].R)/2)ins(id*2,x);
    else ins(id*2+1,x);
}
int Q(int id,int L,int R){
    if(R<node[id].L || L>node[id].R)return -1;
    if(L<=node[id].L && node[id].R<=R)return node[id].key;
    int a=Q(id*2,L,R),b=Q(id*2+1,L,R);
    if(b==-1 || (a!=-1 && p[a].w<p[b].w)) return a;
    else return b;
}
void calc() {
    REP(i,n) {
        p[i].z=p[i].y-p[i].x;
        p[i].w=p[i].x+p[i].y;
    }
    sort(p,p+n,cpz);
    int cnt=0,j,k;

```

```

for(int i=0;i<n;i=j){
    for(j=i+1;p[j].z==p[i].z && j<n;j++);
    for(k=i,cnt++;k<j;k++)p[k].z=cnt;
}
init(1,1,cnt);
sort(p,p+n,cpx);
REP(i,n) {
    j=Q(1,p[i].z,cnt);
    if(j!=-1)e[m++]=(E){p[i].id,p[j].id,dis(p[i],
        p[j])};
    ins(1,i);
}
}
LL MST() {
    LL r=0;
    sort(e,e+m);
    REP(i,m) {
        if(F(e[i].a)==F(e[i].b))continue;
        U(e[i].a,e[i].b);
        r+=e[i].c;
    }
    return r;
}
int main(){
    int ts;
    scanf("%d",&ts);
    while (ts--) {
        m = 0;
        scanf("%d",&n);
        REP(i,n) {
            scanf("%d%d",&p[i].x,&p[i].y);
            p[i].id=s[i]=i;
        }
        calc();
        REP(i,n)p[i].y= -p[i].y;
        calc();
        REP(i,n)swap(p[i].x,p[i].y);
        calc();
        REP(i,n)p[i].x=-p[i].x;
        calc();
        printf("%lld\n",MST()*2);
    }
    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<stdio>
#include<stdlib>
#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

```

const int LEN = 1000;
int rk[LEN], sa[LEN];
int height[LEN];
int cnt[LEN], rr[2][LEN];
inline bool same(int *_rk, int a, int b, int l) {
    return _rk[a]==_rk[b]&&_rk[a+1]==_rk[b+1]; }
void make_height(char str[]) {
    int len=strlen(str);
    memset(height, 0, sizeof(height));
    for(int i=0, j=0; i<len; ++i, j=height[rk[i]-1]-1) {
        if (rk[i]==1) continue;
        if (j<0) j=0;
        while (i+j<len && sa[rk[i]-1]+j<len &&
            str[i+j]==str[sa[rk[i]-1]+j]) ++j;
        height[rk[i]]=j;
    }
}
void suffix_array(char str[], int n, int MAXRK = 256) {
    int *rk1=rr[0], *rk2=rr[1]; // rolling array
    int *y = rk; // share memory
    memset(rr[1], 0, sizeof(rr[1]));
    memset(cnt, 0, sizeof(cnt));
    int i, p;
    for(i=0; i<n; ++i) rk2[i]=str[i], cnt[rk2[i]]++;
    for(i=1; i<MAXRK; ++i) cnt[i]+=cnt[i-1];
    for(i=n-1; i>=0; --i) sa[--cnt[rk2[i]]]=i;
    for(int j=1; p<n; j<=1, MAXRK=p) {
        // 表示用第二個key(rk2)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;
        memset(cnt, 0, sizeof(cnt));
        for(i=0; i<n; ++i) cnt[ rk2[y[i]] ] ++;
        for(i=1; i<MAXRK; ++i) cnt[i]+=cnt[i-1];
        for(i=n-1; i>=0; --i) sa[ --cnt[ rk2[y[i]] ] ]=y[i];
        for(p=i=1, rk1[sa[0]]=0; i<n; ++i)
            rk1[sa[i]] = same(rk2, sa[i], sa[i-1], j) ?
                p-1 : p++;
        swap(rk1, rk2);
    }
    copy(rk, rk+n, rk2);
    make_height(str);
}
int main() {
    char str[LEN];
    scanf("%s", str);
    int len = strlen(str);
    suffix_array(str, len+1);
    for(int i=1; i<=len; ++i) printf("%d %d %s\n",
        i, height[i], str+sa[i]);
}

```

6.5 Suffix Tree

```

// SWERC 2015 - Text Processor
// Approach: Suffix Tree + Sliding Window. O(|S|
// + Q)
// Author: Miguel Oliveira

```

```

#include <algorithm>
#include <cstdio>
#include <cstring>
#include <queue>
#include <string>
#include <vector>
using namespace std;

struct SuffixTree {
    struct Node {
        int l, r, par, link = -1, num_children = 0,
            next[26];

        Node(int l=0, int r=0, int par=-1) : l(l), r(r),
            par(par) {
            memset(next, -1, sizeof next);
        }

        int Length() { return r - l; }
        int& get(char c) { return next[c-'a']; }

        void SetEdge(char c, int node_index) {
            if (next[c-'a'] != -1 && node_index == -1)
                --num_children;
            else if (next[c-'a'] == -1 && node_index != -1)
                ++num_children;
            next[c-'a'] = node_index;
        }
    };

    string text;
    queue<int> qleaves;
    vector<Node> tree;
    State ptr = State(0, 0);
    long long num_substrings = 0;

    SuffixTree(char* str) {
        text = string(str);
        tree.reserve(2 * text.size() + 1);
        tree.push_back(Node(0));
    }

    State Go(State st, int l, int r) {
        while (l < r) {
            if (st.pos == tree[st.v].Length()) {
                st = State(tree[st.v].get(text[l]), 0);
                if (st.v == -1)
                    return st;
            } else {
                if (text[ tree[st.v].l + st.pos ] != text[l])
                    return State(-1, -1);
                if (r-1 < tree[st.v].Length() - st.pos)
                    return State(st.v, st.pos + r-1);
                l += tree[st.v].Length() - st.pos;
                st.pos = tree[st.v].Length();
            }
        }
        return st;
    }

    int Split(const State& st) {
        if (st.pos == tree[st.v].Length())
            return st.v;
        if (st.pos == 0)
            return tree[st.v].par;
    }
}

```

```

    const Node& v = tree[st.v];
    int id = tree.size();
    tree.push_back(Node(v.l, v.l + st.pos, v.par)
    );
    tree[v.par].SetEdge(text[v.l], id);
    tree[id].SetEdge(text[v.l + st.pos], st.v);
    tree[st.v].par = id;
    tree[st.v].l += st.pos;
    return id;
}

int GetLink(int v) {
    if (tree[v].link != -1) return tree[v].link;
    if (tree[v].par == -1) return 0;
    int to = GetLink(tree[v].par);
    return tree[v].link = Split(Go(State(to, tree[
        to].Length()), tree[v].l + (tree[v].par
        ==0), tree[v].r));
}

void TreeExtend(int pos) {
    int mid;
    num_substrings += qleaves.size();
    do {
        State nptr = Go(ptr, pos, pos+1);
        if (nptr.v != -1) {
            ptr = nptr;
            return;
        }
        mid = Split(ptr);
        int leaf = tree.size();
        num_substrings++; // new leaf.
        qleaves.push(leaf);
        tree.push_back(Node(pos, text.size(), mid))
        ;
        tree[mid].SetEdge(text[pos], leaf);
        ptr.v = GetLink(mid);
        ptr.pos = tree[ptr.v].Length();
    } while (mid != 0);
}

void TreeDelete(int pos) {
    int leaf = qleaves.front();
    qleaves.pop();
    int par = tree[leaf].par;
    while (tree[leaf].num_children == 0) {
        if (ptr.v != leaf) {
            tree[par].SetEdge(text[tree[leaf].l], -1)
            ;
            num_substrings -= min(tree[leaf].r, pos)
            - tree[leaf].l;
            leaf = par;
            par = tree[leaf].par;
        } else {
            if (ptr.pos == min(tree[leaf].r, pos) -
                tree[leaf].l)
                break;
            int mid = Split(ptr);
            ptr.v = mid;
            num_substrings -= min(tree[leaf].r, pos)
            - tree[leaf].l;
            tree[mid].SetEdge(text[tree[leaf].l], -1)
            ;
            tree[leaf] = tree[mid];
            tree[tree[mid].par].SetEdge(text[tree[mid]
                ].l], leaf);
            tree.pop_back();
            break;
        }
    }
}

    if (leaf != 0 && tree[leaf].num_children ==
        0) {
        qleaves.push(leaf);
        int to = (tree[leaf].par == 0) ? 0 : tree[
            tree[leaf].par].link;
        ptr = Go(State(to, tree[to].Length()), tree
            [leaf].l + (tree[leaf].par==0), tree[
                leaf].r);
        tree[leaf].l = pos - tree[leaf].Length();
        tree[leaf].r = text.size();
    }
}

int main() {
    const int MAXN = 100100;
    long long ans_window[MAXN];
    char text[MAXN];
    int w, n, q;
    scanf("%s %d %d", text, &n, &w);
    SuffixTree suffix_tree(text);
    for (int i = 1; i <= (int)suffix_tree.text.size
        (); ++i) {
        suffix_tree.TreeExtend(i-1);
        if (i >= w) {
            ans_window[i-w] = suffix_tree.
                num_substrings;
            suffix_tree.TreeDelete(i);
        }
    }
    for (int i = 0; i < n; ++i) {
        scanf("%d", &q);
        printf("%lld\n", ans_window[q-1]);
    }
    return 0;
}

6.6 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