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1 Basic

1.1 Default Code

```

1 #include <bits/stdc++.h>
2 using namespace std;
2 using lld = int64_t;
2 using llu = uint64_t;
2 using llf = long double;
2 using PII = pair<int,int>;
2 using PIL = pair<int,lld>;
3 using PLI = pair<lld,int>;
3 using PLL = pair<lld,lld>;
4 template<typename T>
4 using maxHeap = priority_queue<T,vector<T>,less<T>>;
4 template<typename T>
5 using minHeap = priority_queue<T,vector<T>,greater<T>>;
5 #define FF first
5 #define SS second
5 #define SZ(x) ((int)((x).size()))
5 #define ALL(x) begin(x), end(x)
6 #define PB push_back
6 #define WC(x) while((x)-->0)
6 template<typename Iter>
7 ostream& _out(ostream& s, Iter b, Iter e) {
8     s<<"[";
8     for ( auto it=b; it!=e; it++ ) s<<("{it==b?\"\": \" \"}<*it
9         ;
9     s<<"]";
9     return s;
9 }
9 template<typename A, typename B>
9 ostream& operator <<( ostream& s, const pair<A,B> &p )
9 { return s<<"("<<p.FF<<" "<<p.SS<<" )"; }
10 template<typename T>
10 ostream& operator <<( ostream& s, const vector<T> &c )
10 { return _out(s,ALL(c)); }
10 bool debug = 0;
10 #define DUMP(x) if(debug) cerr<<__PRETTY_FUNCTION__<<" "
10 <<__LINE__<<" - "<<(#x)<<"="<<(x)<<"'\n'
11 template<typename T>
11 void DEBUG(const T& x){if(debug) cerr<<x;}
11 template<typename T, typename... Args>
11 void DEBUG(const T& head,const Args& ...tail){
12     if(debug){cerr<<head; DEBUG(tail...);}
12 }
12 int main(int argc, char* argv[]){
13     if(argc>1 and string(argv[1])=="-D") debug=1;
13     if(!debug){ios_base::sync_with_stdio(0);cin.tie(0);}
13     return 0;
14 }

```

1.2 IncreaseStackSize

```

//stack resize
asm( "mov %0,%esp\n" :: "g"(mem+10000000) );
//change esp to rsp if 64-bit system

//stack resize (linux)
#include <sys/resource.h>
void increase_stack_size() {
    const rlim_t ks = 64*1024*1024;
    struct rlimit rl;
    int res=getrlimit(RLIMIT_STACK, &rl);
    if(res==0){
        if(rl.rlim_cur<ks){
            rl.rlim_cur=ks;
            res=setrlimit(RLIMIT_STACK, &rl);
        }
    }
}

// craziest way
static void run_with_stack_size(void (*func)(), size_t
    stsize) {
    char *stack, *send;
    stack=(char *)malloc(stsize);
    send=stack+stsize-16;
    send=(char *)((uintptr_t)send/16*16);
    asm volatile(
        "mov %%rsp, (%0)\n"
        "mov %0, %%rsp\n"

```

```

:
: "r" (send));
func();
asm volatile(
    "mov (%0), %rsp\n"
:
: "r" (send));
free(stack);
}

```

1.3 Pragma optimization

```

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

```

1.4 Debugger

```

#!/usr/bin/env python3
import subprocess, platform

os_name = platform.system()
cmd = []
prefix = ""

if os_name == 'Windows':
    cmd=["cmd", "/C"]
else:
    cmd = ["bash", "-c"]
    prefix = "./"

def GetTestData(exe):
    myout=subprocess.check_output(cmd+["%s%s"%(prefix,
        exe)])
    return myout.decode("utf8")
def Judge(a,b,testdata):
    f = open("test.in", "w+")
    f.write(testdata)
    f.close()
    c=subprocess.check_output(cmd+["%s%s < test.in"%(
        prefix, a)])
    d=subprocess.check_output(cmd+["%s%s < test.in"%(
        prefix, b)])
    if not c == d:
        print("answer: %s"%c.decode("utf8"),end="")
        print("output: %s"%d.decode("utf8"),end="")
        print("WA!")
        return False
    return True
if __name__ == '__main__':
    cnt = 0
    isOK = True
    while isOK:
        cnt += 1
        print(cnt)
        isOK = Judge("1234.exe", "test.exe", GetTestData("
            gen.exe"))

```

1.5 Quick Random

```

template<class T,T x1,T x2,T x3,int y1,int y2,int y3>
struct PRNG {
    using S = typename std::make_signed<T>::type;
    T s;
    PRNG(T _s = 0) : s(_s) {}
    T next() {
        T z = (s += x1);
        z = (z ^ (z >> y1)) * x2;
        z = (z ^ (z >> y2)) * x3;
        return z ^ (z >> y3);
    }
    T next(T n) { return next() % n; }
    T next(S l, S r) { return l + next(r - l + 1); }
    T operator()() { return next(); }
    T operator()(T n) { return next(n); }
    S operator()(S l, S r) { return next(l, r); }
    static T gen(T s) { return PRNG(s)(); }
    template<class U>

```

```

void shuffle(U first, U last) {
    size_t n = last - first;
    for (size_t i = 0; i < n; i++) swap(first[i],
        first[next(i + 1)]);
}
};
using R32 = PRNG<uint32_t, 0x9E3779B1, 0x85EBCA6B, 0
    xC2B2AE35, 16, 13, 16>;
R32 r32;
using R64 = PRNG<uint64_t, 0x9E3779B97F4A7C15, 0
    xBF58476D1CE4E5B9, 0x94D049BB133111EB, 30, 27, 31>;
R64 r64;

```

1.6 IO Optimization

```

static inline int gc() {
    static char buf[1 << 20], *p = buf, *end = buf;
    if (p == end) {
        if ((end = buf + fread(buf, 1, 1 << 20, stdin)) ==
            buf) return EOF;
        p = buf;
    }
    return *p++;
}
template<typename T>
static inline bool gn(T &_){
    register int c = gc(); register T __ = 1; _ = 0;
    while(!isdigit(c) and c!=EOF and c!='-') c = gc();
    if(c == '-') { __ = -1; c = gc(); }
    if(c == EOF) return false;
    while(isdigit(c)) _ = _ * 10 + c - '0', c = gc();
    _ *= __;
    return true;
}
template <typename T, typename ...Args>
static inline bool gn(T &x, Args& ...args){return gn(x)
    and gn(args...);}

```

2 Data Structure

2.1 BigInt

```

class BigInt{
private:
    using lld = int_fast64_t;
    #define PRINTF_ARG PRIuFAST64
    #define LOG_BASE_STR "9"
    static constexpr lld BASE = 1000000000;
    static constexpr int LOG_BASE = 9;
    vector<lld> dig;
    bool neg;
    inline int len()const{return (int)dig.size();}
    inline int cmp_minus(const BigInt& a) const {
        if(len() == 0 and a.len() == 0) return 0;
        if(neg ^ a.neg) return (int)a.neg*2 - 1;
        if(len() != a.len()) return neg?a.len()-len():len()
            -a.len();
        for(int i=len()-1;i>=0;i-- if(dig[i] != a.dig[i]
            )) {
            return neg?a.dig[i]-dig[i]:dig[i]-a.dig[i];
        }
        return 0;
    }
    inline void trim(){
        while(!dig.empty() and dig.back()==0) dig.
            pop_back();
        if(dig.empty()) neg = false;
    }
public:
    BigInt(): dig(vector<lld>()), neg(false){}
    BigInt(lld a): dig(vector<lld>()){
        neg = a<0; dig.push_back(abs(a));
        trim();
    }
    BigInt(const string& a): dig(vector<lld>()){
        assert(!a.empty()); neg = (a[0]=='-');
        for(int i=((int)(a.size()))-1;i>=neg;i-=LOG_BASE)
            {
                lld cur = 0;

```

```

    for(int j=min(LOG_BASE-1, i-neg);j>=0;j--) cur
        = cur*10+a[i-j]-'0';
    dig.push_back(cur);
} trim();
}
inline bool operator<(const BigInt& a) const{return
    cmp_minus(a)<0;}
inline bool operator<=(const BigInt& a) const{return
    cmp_minus(a)<=0;}
inline bool operator==(const BigInt& a) const{return
    cmp_minus(a)==0;}
inline bool operator!=(const BigInt& a) const{return
    cmp_minus(a)!=0;}
inline bool operator>(const BigInt& a) const{return
    cmp_minus(a)>0;}
inline bool operator>=(const BigInt& a) const{return
    cmp_minus(a)>=0;}
BigInt operator-() const {
    BigInt ret = *this;
    ret.neg ^= 1;
    return ret;
}
BigInt operator+(const BigInt& a) const {
    if(neg) return -(-(*this)+(-a));
    if(a.neg) return (*this)-(-a);
    int n = max(a.len(), len());
    BigInt ret; ret.dig.resize(n);
    lld pro = 0;
    for(int i=0;i<n;i++) {
        ret.dig[i] = pro;
        if(i < a.len()) ret.dig[i] += a.dig[i];
        if(i < len()) ret.dig[i] += dig[i];
        pro = 0;
        if(ret.dig[i] >= BASE) pro = ret.dig[i]/BASE;
        ret.dig[i] -= BASE*pro;
    }
    if(pro != 0) ret.dig.push_back(pro);
    return ret;
}
BigInt operator-(const BigInt& a) const {
    if(neg) return -(-(*this) - (-a));
    if(a.neg) return (*this) + (-a);
    int diff = cmp_minus(a);
    if(diff < 0) return -(a - (*this));
    if(diff == 0) return 0;
    BigInt ret; ret.dig.resize(len(), 0);
    for(int i=0;i<len();i++) {
        ret.dig[i] += dig[i];
        if(i < a.len()) ret.dig[i] -= a.dig[i];
        if(ret.dig[i] < 0){
            ret.dig[i] += BASE;
            ret.dig[i+1]--;
        }
    }
    ret.trim();
    return ret;
}
BigInt operator*(const BigInt& a) const {
    if(len()==0 or a.len()==0) return 0;
    BigInt ret; ret.dig.resize(len()+a.len()+1);
    ret.neg = neg ^ a.neg;
    for(int i=0;i<len();i++) for(int j=0;j<a.len();j
        ++){
        ret.dig[i+j] += dig[i] * a.dig[j];
        if(ret.dig[i+j] >= BASE) {
            lld x = ret.dig[i+j] / BASE;
            ret.dig[i+j+1] += x;
            ret.dig[i+j] -= x * BASE;
        }
    }
    ret.trim();
    return ret;
}
BigInt operator/(const BigInt& a) const {
    assert(a.len());
    if(len() < a.len()) return 0;
    BigInt ret; ret.dig.resize(len()-a.len()+1);
    ret.neg = a.neg;
    for(int i=len()-a.len();i>=0;i--){
        lld l = 0, r = BASE;
        while(r-l > 1){
            lld mid = (l+r)>>1;
            ret.dig[i] = mid;
            if(ret*a <= (neg?-(*this):(*this))) l = mid;
            else r = mid;
        }
    }
}

```

```

    ret.dig[i] = 1;
}
ret.neg ^= neg; ret.trim();
return ret;
}
BigInt operator%(const BigInt& a) const {
    return (*this) - (*this) / a * a;
}
friend BigInt abs(BigInt a){
    a.neg = 1; return a;
}
friend void swap(BigInt& a, BigInt& b){
    swap(a.dig, b.dig); swap(a.neg, b.neg);
}
friend istream& operator>>(istream& ss, BigInt& a){
    string s; ss >> s;
    a = s;
    return ss;
}
friend ostream& operator<<(ostream& ss, const
    BigInt& a){
    if(a.len() == 0) return ss << '0';
    if(a.neg) ss << '-';
    ss << a.dig.back();
    for(int i=a.len()-2;i>=0;i--) ss << setw(LOG_BASE
        ) << setfill('0') << a.dig[i];
    return ss;
}
inline void print() const {
    if(len() == 0){putchar('0');return;}
    if(neg) putchar('-');
    printf("%" PRINTF_ARG, dig.back());
    for(int i=len()-2;i>=0;i--) printf("%0"
        LOG_BASE_STR PRINTF_ARG, dig[i]);
}
#undef PRINTF_ARG
#undef LOG_BASE_STR
};

```

2.2 unordered_map

```

#include <ext/pb_ds/assoc_container.hpp>
using __gnu_pbds::cc_hash_table;
using __gnu_pbds::gp_hash_table;
template<typename A, typename B> using hTable1 =
    cc_hash_table<A,B>;
template<typename A, typename B> using hTable2 =
    gp_hash_table<A,B>;

```

2.3 extc_balance_tree

```

#include <ext/pb_ds/assoc_container.hpp>
using __gnu_pbds::tree;
using __gnu_pbds::rb_tree_tag;
using __gnu_pbds::ov_tree_tag;
using __gnu_pbds::splay_tree_tag;
using __gnu_pbds::null_type;
using __gnu_pbds::tree_order_statistics_node_update;
template<typename T>
using ordered_set = tree<T, null_type, less<T>,
    rb_tree_tag, tree_order_statistics_node_update>;
template<typename A, B>
using ordered_map = tree<A, B, less<A>, rb_tree_tag,
    tree_order_statistics_node_update>;
int main(){
    ordered_set<int> ss;
    ordered_map<int,int> mm;
    ss.insert(1);
    ss.insert(5);
    assert(*ss.find_by_order(0)==1);
    assert(ss.order_of_key(-1)==0);
    assert(ss.order_of_key(87)==2);
    return 0;
}

```

2.4 extc_heap

```

#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/priority_queue.hpp>

```

```

using __gnu_pbds::priority_queue;
using __gnu_pbds::pairing_heap_tag;
using __gnu_pbds::binary_heap_tag;
using __gnu_pbds::binomial_heap_tag;
using __gnu_pbds::rc_binomial_heap_tag;
using __gnu_pbds::thin_heap_tag;

int main() {
    priority_queue<int, less<int>, pairing_heap_tag> pq1,
        pq2;
    pq1.push(1);
    pq2.push(2);
    pq1.join(pq2);
    assert(pq2.size() == 0);
    auto it = pq1.push(87);
    pq1.modify(it, 19);
    while(!pq1.empty()) {
        pq1.top();
        pq1.pop();
    }
    return 0;
}

```

2.5 SkewHeap

```

template<typename T, typename cmp=less<T> >
class SkewHeap{
private:
    struct SkewNode{
        T x;
        SkewNode *lc, *rc;
        SkewNode(T a=0):x(a), lc(nullptr), rc(nullptr){}
    } *root;
    cmp CMP_;
    size_t count;
    SkewNode* Merge(SkewNode* a, SkewNode* b){
        if(!a or !b) return a?a:b;
        if(CMP_(a->x, b->x)) swap(a, b);
        a->rc = Merge(a->rc, b);
        swap(a->lc, a->rc);
        return a;
    }
    void clear(SkewNode*& a){
        if(!a) return;
        clear(a->lc); clear(a->rc);
        delete a; a = nullptr;
    }
public:
    SkewHeap(): root(nullptr), count(0){}
    bool empty(){return count==0;}
    size_t size(){return count;}
    T top(){return root->x;}
    void clear(){clear(root);count = 0;}
    void push(const T& x){
        SkewNode* a = new SkewNode(x);
        count += 1;
        root = Merge(root, a);
    }
    void join(SkewHeap& a){
        count += a.count; a.count = 0;
        root = Merge(root, a.root);
    }
    void pop(){
        count -= 1;
        SkewNode* rt = Merge(root->lc, root->rc);
        delete root; root = rt;
    }
    friend void swap(SkewHeap& a, SkewHeap& b){
        swap(a.root, b.root);
    }
};

```

2.6 Disjoint Set

```

class DJS{
private:
    vector<int> fa, sz, sv;
    vector<pair<int*, int>> opt;
    inline void assign(int *k, int v){
        opt.emplace_back(k, *k);
        *k = v;
    }
}

```

```

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

```

2.7 Treap

```

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

```

```

        split_by_sum( rt->rc, k - sm( rt->lc ) - rt->cnt,
            L->rc, R );
        L->pull();
    } else {
        R = rt;
        split_by_sum( rt->lc, k, L, R->lc );
        R->pull();
    }
}
#undef sz
#undef sm
}

```

2.8 SparseTable

```

template<typename T, typename Cmp_ = less<T>>
class SparseTable{
private:
    vector<vector<T>> table;
    vector<int> lg;
    T cmp_(T a, T b){
        return Cmp_()(a, b)?a:b;
    }
public:
    void init(T arr[], int n){
        // 0-base
        lg.resize(n+1);
        lg[0] = -1, lg[1] = 0;
        for(int i=2; i<=n; i++) lg[i] = lg[i>>1]+1;
        table.resize(lg[n]+1);
        table[0].resize(n);
        for(int i=0; i<n; i++) table[0][i] = arr[i];
        for(int i=1; i<=lg[n]; i++){
            int len = 1<<(i-1), sz = 1<<i;
            table[i].resize(n-sz+1);
            for(int j=0; j<=n-sz; j++){
                table[i][j] = cmp_(table[i-1][j], table[i-1][j+
                    len]);
            }
        }
    }
    T query(int l, int r){
        // 0-base [l, r)
        int wh = lg[r-l], len=1<<wh;
        return cmp_(table[wh][l], table[wh][r-len]);
    }
};

```

2.9 Linear Basis

```

struct LinearBasis{
private:
    int n, sz;
    vector<llu> B;
    inline llu two(int x){return ((llu)1)<<x;}
public:
    void init(int n){
        n = n_; B.clear();
        B.resize(n); sz = 0;
    }
    void insert(llu x){
        // add x into B
        for(int i=n-1; i>=0; i--) if(two(i) & x){
            if(B[i] x ^= B[i];
            else{
                B[i] = x; sz++;
                for(int j=i-1; j>=0; j--)
                    if(B[j] and two(j) & B[i])
                        B[i] ^= B[j];
                for(int j=i+1; j<n; j++)
                    if(two(i) & B[j])
                        B[j] ^= B[i];
                break;
            }
        }
    }
    inline int size(){return sz;}
    bool check(llu x){
        // is x in span(B) ?
        for(int i=n-1; i>=0; i--) if(two(i) & x) {
            if(B[i] x ^= B[i];
            else return false;
        }
    }
};

```

```

    }
    return true;
}
llu kth_small(llu k) {
    /** 1-base would always > 0 */
    /** should check it */
    /** if we choose at least one element
        but size(B)(vectors in B)==N(original elements)
        then we can't get 0 */
    llu ret = 0;
    for(int i=0; i<n; i++) if(B[i]) {
        if(k & 1) ret ^= B[i];
        k >>= 1;
    }
    return ret;
}
} base;

```

3 Graph

3.1 BCC Edge

```

class BCC{
private:
    vector<int> low, dfn;
    int cnt;
    vector<bool> bcc;
    vector<vector<PII>> G;
    void dfs(int w, int f){
        dfn[w] = cnt++;
        low[w] = dfn[w];
        for(auto i: G[w]){
            int u = i.FF, t = i.SS;
            if(u == f) continue;
            if(dfn[u] != 0){
                low[w] = min(low[w], dfn[u]);
            } else {
                dfs(u, w);
                low[w] = min(low[w], low[u]);
                if(low[u] > dfn[w]) bcc[t] = true;
            }
        }
    }
public:
    void init(int n, int m){
        G.resize(n);
        fill(G.begin(), G.end(), vector<PII>());
        bcc.clear(); bcc.resize(m);
        low.clear(); low.resize(n);
        dfn.clear(); dfn.resize(n);
        cnt = 0;
    }
    void add_edge(int u, int v){
        // should check for multiple edge
        G[u].PB({v, cnt});
        G[v].PB({u, cnt});
        cnt++;
    }
    void solve(){cnt = 1; dfs(0, 0);}
    // the id will be same as insert order, 0-base
    bool is_bcc(int x){return bcc[x];}
} bcc;

```

3.2 BCC Vertex

```

class BCC{
private:
    vector<vector<pair<int,int>>> G;
    vector<int> dfn, low, id, sz;
    vector<bool> vis, ap;
    int n, ecnt, bcnt;
    void tarjan(int u, int f, int d){
        vis[u] = true;
        dfn[u] = low[u] = d;
        int child = 0;
        for(auto e: G[u]) if(e.first != f){
            int v = e.first;
            if(vis[v]){
                low[u] = min(low[u], dfn[v]);
            } else {

```

```

        tarjan(v, u, d+1);
        if(low[v] >= dfn[u]) ap[u] = true;
        low[u] = min(low[u], low[v]);
        child += 1;
    }
}
if(dfn[u]==0 and child <= 1) ap[u] = false;
}
void bfs_bcc(int x){
    // not sure
    queue<int> bfs;
    bfs.push(x); vis[x] = true;
    while(!bfs.empty()){
        int u = bfs.front(); bfs.pop();
        for(auto e: G[u]){
            id[e.second] = bcnt;
            if(ap[e.first] or vis[e.first]) continue;
            bfs.push(e.first); vis[e.first] = true;
            sz[bcnt] += 1;
        }
    }
}
public:
void init(int n){
    n = n; G.clear(); G.resize(n);
    dfn.resize(n); low.resize(n);
    vis.clear(); vis.resize(n);
    ap.clear(); ap.resize(n);
    ecnt = 0, bcnt = 0;
}
void add_edge(int u, int v){
    assert(0 <= u and u < n);
    assert(0 <= v and v < n);
    G[u].emplace_back(v, ecnt);
    G[v].emplace_back(u, ecnt);
    ecnt += 1;
}
void solve(){
    for(int i=0;i<n;i++) if(!vis[i]) {
        tarjan(i, i, 0);
    }
    id.resize(ecnt);
    vis.clear(); vis.resize(n);
    sz.clear(); sz.resize(n);
    for(int i=0;i<n;i++) if(ap[i]){
        bfs_bcc(i); bcnt += 1;
    }
}
bool isAP(int x){return ap[x];}
int count(){return bcnt;}
// bcc_id of edges by insert order (0-base)
int get_id(int x){return id[x];}
// bcc size by bcc_id
int get_size(int x){return sz[x];}
} bcc;

```

3.3 Strongly Connected Components

```

class SCC{
private:
    int n, num_;
    vector<vector<int>> G, rG;
    vector<int> ord, num;
    bool vis[N];
    void dfs(int u){
        if(vis[u]) return;
        vis[u]=1;
        for(auto v: G[u]) dfs(v);
        ord.PB(u);
    }
    void rdfs(int u){
        if(vis[u]) return;
        num[u] = num_;
        vis[u] = 1;
        for(auto v: rG[u]) rdfs(v);
    }
public:
    inline void init(int n_){
        n=n_, num_=0;
        G.resize(n); rG.resize(n);
        num.resize(n);
        for(int i=0;i<n;i++) G[i].clear();
        for(int i=0;i<n;i++) rG[i].clear();
    }
}

```

```

inline void add_edge(int st, int ed){
    G[st].PB(ed);
    rG[ed].PB(st);
}
void solve(){
    memset(vis, 0, sizeof(vis));
    for(int i=0;i<n;i++){
        if(!vis[i]) dfs(i);
    }
    reverse(ALL(ord));
    memset(vis, 0, sizeof(vis));
    for(auto i: ord){
        if(!vis[i]){
            rdfs(i);
            num_++;
        }
    }
}
inline int get_id(int x){return num[x];}
inline int count(){return num_;}
} scc;

```

3.4 Bipartite Matching

```

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

```

3.5 MinimumCostMaximumFlow

```

class MiniCostMaxiFlow{
    using CapT = int;
    using WeiT = int64_t;
    using PCW = pair<CapT,WeiT>;
    static constexpr CapT INF_CAP = 1 << 30;
    static constexpr WeiT INF_WEI = static_cast<WetT>(1)
        <<60;
private:
    struct Edge{
        int to, back;
        WeiT wei;
        CapT cap;
        Edge() {}
        Edge(int a,int b,WeiT c,CapT d):
            to(a),back(b),wei(c),cap(d)
    }
}

```

```

    {}
};
int ori, edd;
vector<vector<Edge>> G;
vector<int> fa, wh;
vector<bool> inq;
vector<WeiT> dis;
PCW SPFA() {
    fill(inq.begin(), inq.end(), false);
    fill(dis.begin(), dis.end(), INF_WEI);
    queue<int> qq; qq.push(ori);
    dis[ori]=0;
    while(!qq.empty()) {
        int u=qq.front(); qq.pop();
        inq[u] = 0;
        for(int i=0; i<SZ(G[u]); ++i) {
            Edge e=G[u][i];
            int v=e.to;
            WeiT d=e.wei;
            if(e.cap<=0 || dis[v]<=dis[u]+d)
                continue;
            dis[v]=dis[u]+d;
            fa[v]=u, wh[v]=i;
            if(inq[v]) continue;
            qq.push(v);
            inq[v]=1;
        }
    }
    if(dis[edd]==INF_WEI)
        return {-1, -1};
    CapT mw=INF_CAP;
    for(int i=edd; i!=ori; i=fa[i])
        mw=min(mw, G[fa[i]][wh[i]].cap);
    for(int i=edd; i!=ori; i=fa[i]) {
        auto &eg=G[fa[i]][wh[i]];
        eg.cap-=mw;
        G[eg.to][eg.back].cap+=mw;
    }
    return {mw, dis[edd]};
}
public:
void init(int a, int b, int n) {
    ori=a, edd=b;
    G.clear(); G.resize(n);
    fa.resize(n); wh.resize(n);
    inq.resize(n); dis.resize(n);
}
void add_edge(int st, int ed, WeiT w, CapT c) {
    G[st].emplace_back(ed, SZ(G[ed]), w, c);
    G[ed].emplace_back(st, SZ(G[st])-1, -w, 0);
}
PCW solve() {
    CapT cc=0; WeiT ww=0;
    while(true) {
        PCW ret=SPFA();
        if(ret.first===-1) break;
        cc+=ret.first;
        ww+=ret.second;
    }
    return {cc, ww};
}
} mcmf;

```

3.6 MaximumFlow

```

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

```

```

                lv[e.to] = lv[u] + 1;
                bfs.push(e.to);
            }
        }
        return (lv[ed] != -1);
    }
    CapT DFS(int u, CapT f) {
        if(u == ed) return f;
        CapT ret = 0;
        for(auto& e: G[u]) {
            if(e.cap <= 0 || lv[e.to] != lv[u]+1) continue;
            CapT nf = DFS(e.to, min(f, e.cap));
            ret += nf; e.cap -= nf; f -= nf;
            G[e.to][e.rev].cap += nf;
            if(f == 0) return ret;
        }
        if(ret == 0) lv[u] = -1;
        return ret;
    }
public:
    void init(int n_, int st_, int ed_) {
        n = n_, st = st_, ed = ed_;
        G.resize(n); lv.resize(n);
        fill(G.begin(), G.end(), vector<Edge>());
    }
    void add_edge(int u, int v, CapT c) {
        G[u].push_back({v, (int) G[v].size(), c});
        G[v].push_back({u, (int) G[u].size()-1, 0});
    }
    CapT max_flow() {
        CapT ret = 0;
        while(BFS()) {
            CapT f = DFS(st, numeric_limits<CapT>::max());
            ret += f;
            if(f == 0) break;
        }
        return ret;
    }
} flow;

```

3.7 Kuhn Munkres

```

struct KM {
    static constexpr lld INF = 1LL<<60;
    lld w[N][N], lx[N], ly[N], slack[N];
    int match[N], n, vx[N], vy[N], step_;
    void init(int n_) {
        n=n_, step_=0;
        memset(w, 0, sizeof(w));
        memset(lx, 0, sizeof(lx));
        memset(ly, 0, sizeof(ly));
        memset(slack, 0, sizeof(slack));
        memset(match, 0, sizeof(match));
        memset(vx, 0, sizeof(vx));
        memset(vy, 0, sizeof(vy));
    }
    void add_edge(int u, int v, lld w) { w[u][v]=w; }
    bool dfs(int x) {
        vx[x] = step_;
        for(int i = 0; i < n; ++i) {
            if(vy[i]==step_) continue;
            if(lx[x] + ly[i] > w[x][i]) {
                slack[i] = min(slack[i], lx[x] + ly[i] - w[x][i]);
            }
            continue;
        }
        vy[i] = step_;
        if(match[i] == -1 || dfs(match[i])) {
            match[i] = x;
            return true;
        }
    }
    return false;
}
lld solve() {
    fill_n(match, n, -1);
    fill_n(lx, n, -INF);
    fill_n(ly, n, 0);
    for(int i = 0; i < n; ++i)
        for(int j = 0; j < n; ++j)
            lx[i] = max(lx[i], w[i][j]);
    for(int i = 0; i < n; ++i) {
        fill_n(slack, n, INF);
        while(true) {

```



```

    step++;
    if (dfs(i)) break;
    lld dlt = INF;
    for (int j = 0; j < n; ++j) if (vy[j] != step_)
        dlt = min(dlt, slack[j]);
    for (int j = 0; j < n; ++j) {
        if (vx[j]==step_) lx[j] -= dlt;
        if (vy[j]==step_) ly[j] += dlt;
        else slack[j] -= dlt;
    }
}
lld res = 0;
for (int i = 0; i < n; ++i) res += w[match[i]][i];
return res;
} km;

```

3.8 2-SAT

```

// 2-SAT solver based on Kosaraju's algorithm.
// Variables are 0-based. Positive variables are stored
// in vertices 2n, corresponding negative variables
// in 2n+1
// TODO: This is quite slow (3x-4x slower than Gabow's
// algorithm)
struct TwoSat {
    int n;
    vector<vector<int>> > adj, radj, scc;
    vector<int> sid, vis, val;
    stack<int> stk;
    int scnt;
    // n: number of variables, including negations
    TwoSat(int n): n(n), adj(n), radj(n), sid(n), vis(n),
        val(n, -1) {}
    // adds an implication
    void impl(int x, int y) { adj[x].push_back(y); radj[y]
        .push_back(x); }
    // adds a disjunction
    void vee(int x, int y) { impl(x^1, y); impl(y^1, x); }
    // forces variables to be equal
    void eq(int x, int y) { impl(x, y); impl(y, x); impl(
        x^1, y^1); impl(y^1, x^1); }
    // forces variable to be true
    void tru(int x) { impl(x^1, x); }
    void dfs1(int x) {
        if (vis[x]++) return;
        for (int i = 0; i < adj[x].size(); i++) {
            dfs1(adj[x][i]);
        }
        stk.push(x);
    }
    void dfs2(int x) {
        if (!vis[x]) return; vis[x] = 0;
        sid[x] = scnt; scc.back().push_back(x);
        for (int i = 0; i < radj[x].size(); i++) {
            dfs2(radj[x][i]);
        }
    }
    // returns true if satisfiable, false otherwise
    // on completion, val[x] is the assigned value of
    // variable x
    // note, val[x] = 0 implies val[x^1] = 1
    bool two_sat() {
        scnt = 0;
        for (int i = 0; i < n; i++) {
            dfs1(i);
        }
        while (!stk.empty()) {
            int v = stk.top(); stk.pop();
            if (vis[v]) {
                scc.push_back(vector<int>());
                dfs2(v);
                scnt++;
            }
        }
        for (int i = 0; i < n; i += 2) {
            if (sid[i] == sid[i+1]) return false;
        }
        vector<int> must(scnt);
        for (int i = 0; i < scnt; i++) {
            for (int j = 0; j < scc[i].size(); j++) {
                val[scc[i][j]] = must[i];
            }
        }
    }
};

```

```

        must[sid[scc[i][j]^1]] = !must[i];
    }
}
return true;
}
};

```

3.9 HeavyLightDecomp

```

#define REP(i, s, e) for(int i = (s); i <= (e); i++)
#define REPD(i, s, e) for(int i = (s); i >= (e); i--)
const int MAXN = 100010;
const int LOG = 19;
struct HLD{
    int n;
    vector<int> g[MAXN];
    int sz[MAXN], dep[MAXN];
    int ts, tid[MAXN], tdi[MAXN], tl[MAXN], tr[MAXN];
    // ts : timestamp , useless after yutruli
    // tid[ u ] : pos. of node u in the seq.
    // tdi[ i ] : node at pos i of the seq.
    // tl , tr[ u ] : subtree interval in the seq. of
    // node u
    int prt[MAXN][LOG], head[MAXN];
    // head[ u ] : head of the chain contains u
    void dfssz(int u, int p){
        dep[u] = dep[p] + 1;
        prt[u][0] = p; sz[u] = 1; head[u] = u;
        for(int& v:g[u]) if(v != p){
            dep[v] = dep[u] + 1;
            dfssz(v, u);
            sz[u] += sz[v];
        }
    }
    void dfshl(int u){
        ts++;
        tid[u] = tl[u] = tr[u] = ts;
        tdi[tid[u]] = u;
        sort(ALL(g[u]),
            [&](int a, int b){return sz[a] > sz[b];});
        bool flag = 1;
        for(int& v:g[u]) if(v != prt[u][0]){
            if(flag) head[v] = head[u], flag = 0;
            dfshl(v);
            tr[u] = tr[v];
        }
    }
    inline int lca(int a, int b){
        if(dep[a] > dep[b]) swap(a, b);
        int diff = dep[b] - dep[a];
        REPD(k, LOG-1, 0) if(diff & (1<<k)){
            b = prt[b][k];
        }
        if(a == b) return a;
        REPD(k, LOG-1, 0) if(prt[a][k] != prt[b][k]){
            a = prt[a][k]; b = prt[b][k];
        }
        return prt[a][0];
    }
    void init( int _n ){
        n = _n; REP( i , 1 , n ) g[ i ].clear();
    }
    void addEdge( int u , int v ){
        g[ u ].push_back( v );
        g[ v ].push_back( u );
    }
    void yutruli(){
        dfssz(1, 0);
        ts = 0;
        dfshl(1);
        REP(k, 1, LOG-1) REP(i, 1, n)
            prt[i][k] = prt[prt[i][k-1]][k-1];
    }
    vector<PII> getPath( int u , int v ){
        vector<PII> res;
        while( tid[ u ] < tid[ head[ v ] ] ){
            res.push_back( PII(tid[ head[ v ] ] , tid[ v ] ) );
            v = prt[ head[ v ] ][ 0 ];
        }
        res.push_back( PII( tid[ u ] , tid[ v ] ) );
        reverse( ALL( res ) );
        return res;
    }
    /* res : list of intervals from u to v

```



```

* u must be ancestor of v
* usage :
* vector< PII >& path = tree.getPath( u , v )
* for( PII tp : path ) {
*     int l , r;tie( l , r ) = tp;
*     upd( l , r );
*     uu = tree.tdi[ l ] , vv = tree.tdi[ r ];
*     uu ~> vv is a heavy path on tree
* }
*/
}
} tree;

```

3.10 MaxClique

```

struct MaxClique {
    int n, deg[maxn], ans;
    bitset<maxn> adj[maxn];
    vector<pair<int, int>> edge;
    void init(int _n) {
        n = _n;
        for (int i = 0; i < n; ++i) adj[i].reset();
        for (int i = 0; i < n; ++i) deg[i] = 0;
        edge.clear();
    }
    void add_edge(int a, int b) {
        edge.emplace_back(a, b);
        ++deg[a]; ++deg[b];
    }
    int solve() {
        vector<int> ord;
        for (int i = 0; i < n; ++i) ord.push_back(i);
        sort(ord.begin(), ord.end(), [&](const int &a,
            const int &b) { return deg[a] < deg[b]; });
        vector<int> id(n);
        for (int i = 0; i < n; ++i) id[ord[i]] = i;
        for (auto e : edge) {
            int u = id[e.first], v = id[e.second];
            adj[u][v] = adj[v][u] = true;
        }
        bitset<maxn> r, p;
        for (int i = 0; i < n; ++i) p[i] = true;
        ans = 0;
        dfs(r, p);
        return ans;
    }
    void dfs(bitset<maxn> r, bitset<maxn> p) {
        if (p.count() == 0) return ans = max(ans, (int)
            r.count());
        if ((r | p).count() <= ans) return;
        int now = p._Find_first();
        bitset<maxn> cur = p & ~adj[now];
        for (now = cur._Find_first(); now < n; now =
            cur._Find_next(now)) {
            r[now] = true;
            dfs(r, p & adj[now]);
            r[now] = false;
            p[now] = false;
        }
    }
};

```

4 Math

4.1 Prime Table

```

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

```

4.2 $\lfloor \frac{n}{i} \rfloor$ Enumeration

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

4.3 ax+by=gcd

```

// By Adrien1018 (not knowing how to use.
// ax+ny = 1, ax+ny == ax == 1 (mod n)
tuple<int, int, int> extended_gcd(int a, int b) {
    if (!b) return make_tuple(a, 1, 0);
    int d, x, y;
    tie(d, x, y) = extended_gcd(b, a % b);
    return make_tuple(d, y, x - (a / b) * y);
}

```

4.4 Pollard Rho

```

// does not work when n is prime
lld modit(lld x, lld mod) {
    if (x >= mod) x -= mod;
    //if (x < 0) x += mod;
    return x;
}
lld mult(lld x, lld y, lld mod) {
    lld s = 0, m = x % mod;
    while (y) {
        if (y & 1) s = modit(s + m, mod);
        y >>= 1;
        m = modit(m + m, mod);
    }
    return s;
}
lld f(lld x, lld mod) {
    return modit(mult(x, x, mod) + 1, mod);
}
lld pollard_rho(lld n) {
    if (!(n & 1)) return 2;
    while (true) {
        lld y = 2, x = rand() % (n - 1) + 1, res = 1;
        for (int sz = 2; res == 1; sz *= 2) {
            for (int i = 0; i < sz && res <= 1; i++) {
                x = f(x, n);
                res = __gcd(abs(x - y), n);
            }
            y = x;
        }
        if (res != 0 && res != n) return res;
    }
}

```

4.5 Pi Count (Linear Sieve)

```

static constexpr int N = 1000000 + 5;
lld pi[N];
vector<int> primes;
bool sieved[N];
lld cube_root(lld x) {
    lld s = static_cast<lld>(cbrt(x - static_cast<long
        double>(0.1)));
    while (s * s * s <= x) ++s;
    return s - 1;
}
lld square_root(lld x) {
    lld s = static_cast<lld>(sqrt(x - static_cast<long
        double>(0.1)));
    while (s * s <= x) ++s;
    return s - 1;
}
void init() {
    primes.reserve(N);
    primes.push_back(1);
    for (int i = 2; i < N; i++) {
        if (!sieved[i]) primes.push_back(i);
        pi[i] = !sieved[i] + pi[i - 1];
        for (int p : primes) if (p > 1) {
            if (p * i >= N) break;
            sieved[p * i] = true;
            if (p % i == 0) break;
        }
    }
}

```

```

    }
}
lld phi(lld m, lld n) {
    static constexpr int MM = 80000, NN = 500;
    static lld val[MM][NN];
    if(m < MM and n < NN and val[m][n]) return val[m][n]
        - 1;
    if(n == 0) return m;
    if(primes[n] >= m) return 1;
    lld ret = phi(m, n - 1) - phi(m / primes[n], n - 1);
    if(m < MM and n < NN) val[m][n] = ret + 1;
    return ret;
}
lld pi_count(lld);
lld P2(lld m, lld n) {
    lld sm = square_root(m), ret = 0;
    for(lld i = n+1; primes[i] <= sm; i++)
        ret += pi_count(m / primes[i]) - pi_count(primes[i]
            ) + 1;
    return ret;
}
lld pi_count(lld m) {
    if(m < N) return pi[m];
    lld n = pi_count(cube_root(m));
    return phi(m, n) + n - 1 - P2(m, n);
}

```

4.6 NloglogN Sieve

```

void Sieve(int n){
    for(int i=2;i<=n;i++){
        if(notprime[i]) continue;
        primes.push_back(i);
        for(int j=i*i;j<=n;j+=i) notprime[j]=true;
    }
}

```

4.7 Range Sieve

```

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

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

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

```

4.8 Miller Rabin

```

lld modu(lld a, lld m){
    while(a >= m) a -= m;
    return a;
}
lld mul(lld a, lld b, lld m){
    if(a < b) swap(a, b);
    lld ret = 0;
    while(b){
        if(b & 1) ret = modu(ret+a, m);
        a = modu(a+a, m);
        b >>= 1;
    }
    return ret;
}
lld qPow(lld a, lld k, lld m){
    lld ret = 1;
    a %= m;
    while(k){
        if(k & 1) ret = mul(ret, a, m);

```

```

        a = mul(a, a, m);
        k >>= 1;
    }
    return modu(ret, m);
}
bool witness(lld a, lld s, int t, lld n){
    lld b = qPow(a, s, n);
    if(b == 0) return false;
    while(t--){
        lld bb = mul(b, b, n);
        if(bb == 1 and b != 1 and b != n-1) return true;
        b = bb;
    }
    return b != 1;
}
bool miller_rabin(lld n){
    if(n < 2) return false;
    if(!(n & 1)) return (n==2);
    lld x = n-1; int t = 0;
    while(!(x&1)) x >>= 1, t++;
    lld sprp[] =
        {2,325,9375,28178,450775,9780504,1795265022};
    for(int i=0;i<7;i++){
        if(witness(sprp[i]%n, x, t, n)) return false;
    }
    return true;
}

```

4.9 Inverse Element

```

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

```

4.10 Euler Phi Function

```

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

```

```

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

```

```

        break;
    }
}
}
}

```

4.11 Gauss Elimination

```

typedef long double llf;
const int N = 300;
const llf EPS = 1e-8;

// make m[i][i] = x, m[i][j] = 0
// v is for solving equation:
// for(int i=0;i<n;i++) ans[pos[i]] = val[i]/mtx[i][pos
[i]];
// for(int i=0;i<n;i++) cout << ans[i] << '\n';
bool Gauss(llf m[N][N], llf v[N], int n, int pos[N]){
    for(int i=0;i<n;i++){
        int x=-1, y=-1; llf e = 0;
        for(int j=i;j<n;j++) for(int k=i;k<n;k++){
            if(fabs(m[j][pos[k]])>e){
                e = fabs(m[j][pos[k]]);
                x = j, y = k;
            }
        }
        if(x==-1 or y==-1) return false;
        swap(m[x], m[i]);
        swap(v[x], v[i]);
        swap(pos[y], pos[i]);
        for(int j=i+1;j<n;j++){
            llf xi = m[j][pos[i]]/m[i][pos[i]];
            for(int k=0;k<n;k++) m[j][pos[k]] -= xi*m[i][pos
[k]];
            v[j] -= xi*v[i];
        }
    }
    for(int i=n-1;i>=0;i--){
        for(int j=i-1;j>=0;j--){
            llf xi = m[j][pos[i]]/m[i][pos[i]];
            for(int k=0;k<n;k++) m[j][pos[k]] -= xi*m[i][pos
[k]];
            v[j] -= xi*v[i];
        }
    }
    return true;
}

```

4.12 Fast Fourier Transform

```

/*
    polynomial multiply:
    FFT(a, N, true);
    FFT(b, N, true);
    for(int i=0;i<MAXN;i++) c[i] = a[i]*b[i];
    FFT(c, N, false);
    yeah~ go result in c
    (N must be 2^k and >= len(a)+len(b))
*/
typedef long double llf;
typedef complex<llf> cplx;
const int MAXN = 262144;
const llf PI = acos((llf)-1);

cplx A[MAXN], B[MAXN], C[MAXN], omega[MAXN+1];

void init_omega(){
    const cplx I = {0, 1};
    for(int i=0;i<MAXN;i++) omega[i] = exp(i*2*PI/MAXN*I
);
}

void FFT(cplx arr[], int n, bool ori){
    // n must be 2^k
    int theta = MAXN / n;
    for(int len=n;len>=2;len>>=1){
        int tot = len>>1;
        for(int i=0;i<tot;i++){
            cplx omg = omega[ori?i*theta%MAXN:MAXN-(i*theta%
MAXN)];
            for(int j=i;j<n;j+=len){
                int k = j+tot;

```

```

                cplx x = arr[j] - arr[k];
                arr[j] += arr[k];
                arr[k] = omg * x;
            }
        }
        theta = (theta * 2) % MAXN;
    }
    int i = 0;
    for(int j=1;j<n-1;j++){
        for(int k=n>>1;k>(i^=k);k>>=1);
        if(j < i) swap(arr[j], arr[i]);
    }
    if(ori) return;
    for(int i=0;i<n;i++) arr[i] /= n;
}

```

4.13 Chinese Remainder

```

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

```

4.14 NTT

```

// Remember coefficient are mod P
/* p=a*2^n+1
n      2^n      p      a      root
16     65536     65537     1     3
20     1048576    7340033    7     3 */
// (must be 2^k)
template<LL P, LL root, int MAXN>
struct NTT{
    static LL bigmod(LL a, LL b) {
        LL res = 1;
        for (LL bs = a; b >= 1, bs = (bs * bs) % P)
            if(b&1) res=(res*bs)%P;
        return res;
    }
    static LL inv(LL a, LL b) {
        if(a==1) return 1;
        return (((LL) (a-inv(b%a,a))*b+1)/a)%b;
    }
    LL omega[MAXN+1];
    NTT() {
        omega[0] = 1;
        LL r = bigmod(root, (P-1)/MAXN);
        for (int i=1; i<=MAXN; i++)
            omega[i] = (omega[i-1]*r)%P;
    }
    // n must be 2^k
    void tran(int n, LL a[], bool inv_ntt=false){
        int basic = MAXN / n, theta = basic;
        for (int m = n; m >= 2; m >= 1) {
            int mh = m >> 1;
            for (int i = 0; i < mh; i++) {
                LL w = omega[i*theta%MAXN];
                for (int j = i; j < n; j += m) {
                    int k = j + mh;
                    LL x = a[j] - a[k];
                    if (x < 0) x += P;
                    a[j] += a[k];
                    if (a[j] > P) a[j] -= P;
                    a[k] = (w * x) % P;

```

```

    }
}
theta = (theta * 2) % MAXN;
}
int i = 0;
for (int j = 1; j < n - 1; j++) {
    for (int k = n >> 1; k > (i ^ k); k >= 1);
    if (j < i) swap(a[i], a[j]);
}
if (inv_ntt) {
    LL ni = inv(n,P);
    reverse(a+1, a+n);
    for (i = 0; i < n; i++)
        a[i] = (a[i] * ni) % P;
}
}
};
const LL P=2013265921,root=31;
const int MAXN=4194304;
NTT<P, root, MAXN> ntt;

```

4.15 DiscreteLog

```

// Baby-step Giant-step Algorithm
// a x + by = g
void exgcd(long long x, long long y, long long &g,
           long long &a, long long &b) {
    if (y == 0)
        g = x, a = 1, b = 0;
    else
        exgcd(y, x%y, g, b, a), b -= (x/y) * a;
}
long long inverse(long long x, long long p) {
    long long g, b, r;
    exgcd(x, p, g, r, b);
    if (g < 0) r = -r;
    return (r%p + p)%p;
}
long long BSGS(long long P, long long B, long long N) {
    // find B^L = N mod P
    unordered_map<long long, int> R;
    long long sq = (long long) sqrt(P);
    long long t = 1, f;
    for (int i = 0; i < sq; i++) {
        if (t == N)
            return i;
        if (!R.count(t))
            R[t] = i;
        t = (t * B) % P;
    }
    f = inverse(t, P);
    for (int i = 0; i <= sq+1; i++) {
        if (R.count(N))
            return i * sq + R[N];
        N = (N * f) % P;
    }
    return -1;
}

```

5 Geometry

5.1 Point Class

```

template<typename T>
struct Point{
    typedef long double llf;
    static constexpr llf EPS = 1e-8;
    T x, y;
    Point(T __=0, T __=0): x(__), y(__){}
    template<typename T2>
    Point(const Point<T2>& a): x(a.x), y(a.y){}
    inline llf theta() const {
        return atan2((llf)y, (llf)x);
    }
    inline llf dis() const {
        return hypot((llf)x, (llf)y);
    }
    inline llf dis(const Point& o) const {
        return hypot((llf)(x-o.x), (llf)(y-o.y));
    }
}

```

```

}
Point operator-(const Point& o) const {
    return Point(x-o.x, y-o.y);
}
Point operator+=(const Point& o){
    x+=o.x, y+=o.y;
    return *this;
}
Point operator+(const Point& o) const {
    return Point(x+o.x, y+o.y);
}
Point operator+=(const Point& o){
    x+=o.x, y+=o.y;
    return *this;
}
Point operator*(const T& k) const {
    return Point(x*k, y*k);
}
Point operator*=(const T& k){
    x*=k, y*=k;
    return *this;
}
Point operator/(const T& k) const {
    return Point(x/k, y/k);
}
Point operator/=(const T& k){
    x/=k, y/=k;
    return *this;
}
Point operator-() const {
    return Point(-x, -y);
}
Point rot90() const {
    return Point(-y, x);
}
template<typename T2>
bool in(const Circle<T2>& a) const {
    /* Add struct Circle at top */
    return a.o.dis(*this)+EPS <= a.r;
}
bool equal(const Point& o, true_type) const {
    return fabs(x-o.x) < EPS and fabs(y-o.y) < EPS;
}
bool equal(const Point& o, false_type) const {
    return tie(x, y) == tie(o.x, o.y);
}
bool operator==(const Point& o) const {
    return equal(o, is_floating_point<T>());
}
bool operator!=(const Point& o) const {
    return !(*this == o);
}
bool operator<(const Point& o) const {
    return theta() < o.theta();
    // sort like what pairs did
    // if(is_floating_point<T>()) return fabs(x-o.x)<
    // EPS?y<o.y:x<o.x;
    // else return tie(x, y) < tie(o.x, o.y);
}
friend inline T cross(const Point& a, const Point& b)
{
    return a.x*b.y - b.x*a.y;
}
friend inline T dot(const Point& a, const Point& b){
    return a.x*b.x + a.y*b.y;
}
friend ostream& operator<<(ostream& ss, const Point&
o){
    ss<<"("<<o.x<<"", "<<o.y<<"");
    return ss;
}
}
};

```

5.2 Circle Class

```

template<typename T>
struct Circle{
    static constexpr llf EPS = 1e-8;
    Point<T> o;
    T r;
    vector<Point<llf>> operator&(const Circle& aa)const{
        // https://www.cnblogs.com/wangzming/p/8338142.html
        llf d=o.dis(aa.o);
    }
}

```

```

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

```

5.3 Line Class

```

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

```

5.4 Triangle Circumcentre

```

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

    Circle<llf> cc;
    cc.o.x = (c1*b2-b1*c2)/(a1*b2-b1*a2);
    cc.o.y = (a1*c2-c1*a2)/(a1*b2-b1*a2);
    cc.r = hypot(cc.o.x-a.x, cc.o.y-a.y);
    return cc;
}

```

5.5 2D Convex Hull

```

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

```

5.6 2D Farthest Pair

```

// stk is from convex hull
n = (int)(stk.size());
int pos = 1, ans = 0; stk.push_back(arr[0]);
for(int i=0;i<n;i++){

```

```

while(abs(cross(stk[i+1]-stk[i], stk[(pos+1)%n]-stk[i
]))\
> abs(cross(stk[i+1]-stk[i], stk[pos]-stk[i]))) pos
= (pos+1)%n;
ans = max({ans, dis(stk[i], stk[pos]), dis(stk[i+1],
stk[pos])});
}

```

5.7 2D Coset Pair

```

struct Point{
    llf x, y;
    llf dis;
} arr[N];

inline llf get_dis(Point a, Point b){
    return hypot(a.x-b.x, a.y-b.y);
}

llf solve(){
    int cur = rand()%n;
    for(int i=0;i<n;i++) arr[i].dis = get_dis(arr[cur],
arr[i]);
    sort(arr, arr+n, [](Point a, Point b){return a.dis <
b.dis;});
    llf ans = 1e50;
    for(int i=0;i<n;i++){
        for(int j=i+1;j<n;j++){
            if(arr[j].dis - arr[i].dis > ans) break;
            ans = min(ans, get_dis(arr[i], arr[j]));
        }
    }
    return ans;
}

```

5.8 SimulateAnnealing

```

double getY(double);
int main(){
    int rr, ll;
    default_random_engine rEng(time(NULL));
    uniform_real_distribution<double> Range(-1,1);
    uniform_real_distribution<double> expR(0,1);
    auto Random=bind(Range,rEng), expRand=bind(expR,rEng)
;
    int step=0;
    double pace=rr-ll, mini=0.95; // need to search for
it
    double x=max(min(Random()*pace+ll, rr), ll), y=getY(x
);
    while(pace>=1e-7){
        double newX = max(min(x + Random()*pace, rr), ll);
        double newY = getY(newX);
        if(newY < y || expRand() < exp(-step))
            x=newX, y=newY;
        step++;
        pace*=mini;
    }
}

```

5.9 Ternary Search on Integer

```

int TernarySearch(int l, int r) {
    // (l, r]
    while (r - l > 1){
        int mid = (l + r)>>1;
        if (f(mid) > f(mid + 1)) r = mid;
        else l = mid;
    }
    return l+1;
}

```

5.10 Minimum Covering Circle

```

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

```

5.11 KDTree (Nearest Point)

```

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

        tree[M].L = build_tree(L, M-1, dep+1);
        if (tree[M].L) {
            tree[M].x1 = min(tree[M].x1, tree[M].L->x1);
            tree[M].x2 = max(tree[M].x2, tree[M].L->x2);
            tree[M].y1 = min(tree[M].y1, tree[M].L->y1);
            tree[M].y2 = max(tree[M].y2, tree[M].L->y2);
        }
        tree[M].R = build_tree(M+1, R, dep+1);
        if (tree[M].R) {
            tree[M].x1 = min(tree[M].x1, tree[M].R->x1);
            tree[M].x2 = max(tree[M].x2, tree[M].R->x2);
            tree[M].y1 = min(tree[M].y1, tree[M].R->y1);
            tree[M].y2 = max(tree[M].y2, tree[M].R->y2);
        }
        return tree+M;
    }
    int touch(Node* r, int x, int y, LL d2){
        LL dis = sqrt(d2)+1;
        if (x<r->x1-dis || x>r->x2+dis ||
            y<r->y1-dis || y>r->y2+dis)
            return 0;
        return 1;
    }
    void nearest(Node* r, int x, int y,
        int &mID, LL &md2){
        if (!r || !touch(r, x, y, md2)) return;

```

```

LL d2 = dis2(r->x, r->y, x, y);
if (d2 < md2 || (d2 == md2 && mID < r->id)) {
    mID = r->id;
    md2 = d2;
}
// search order depends on split dim
if ((r->f == 0 && x < r->x) ||
    (r->f == 1 && y < r->y)) {
    nearest(r->L, x, y, mID, md2);
    nearest(r->R, x, y, mID, md2);
} else {
    nearest(r->R, x, y, mID, md2);
    nearest(r->L, x, y, mID, md2);
}
}
int query(int x, int y) {
    int id = 1029384756;
    LL d2 = 102938475612345678LL;
    nearest(root, x, y, id, d2);
    return id;
}
}tree;

```

6 Stringology

6.1 Hash

```

class Hash{
private:
    static const int N = 1000000;
    const int p = 127, q = 1208220623;
    int sz, prefix[N], power[N];
    inline int add(int x, int y){return x+y>=q?x+y-q:x+y;}
    inline int sub(int x, int y){return x-y<0?x-y+q:x-y;}
    inline int mul(int x, int y){return 1LL*x*y%q;}
public:
    void init(const std::string &x){
        sz = x.size();
        prefix[0]=0;
        for(int i=1;i<=sz;i++) prefix[i]=add(mul(prefix[i-1], p), x[i-1]);
        power[0]=1;
        for(int i=1;i<=sz;i++) power[i]=mul(power[i-1], p);
    }
    int query(int l, int r){
        // 1-base (l, r)
        return sub(prefix[r], mul(prefix[l], power[r-l]));
    }
};

```

6.2 Suffix Array

```

//help by http://www.geeksforgeeks.org/suffix-array-set
//2-a-nlognlogn-algorithm/
struct sfx{
    int index;
    int r,nr;
};
char str[N + 10];
int len;
vector<sfx> srs[N + 10];
int mapping[N + 10];
sfx sa[N + 10];
bool cmp(sfx a,sfx b){
    if(a.r==b.r){
        return a.nr<b.nr;
    }else{
        return a.r<b.r;
    }
}
void SA(){
    len = strlen(str);
    for(int i=0;i<len;i++){
        sa[i].index = i;
        sa[i].r=str[i];
        sa[i].nr=(i+1>=len)?0:str[i+1];
    }
    //sort(sa,sa+len,cmp);
    radixSort();
}

```

```

for(int j=2;j<=len;j*=2){
    int cnt=1;
    int rr = sa[0].r;
    sa[0].r=cnt;
    mapping[sa[0].index]=0;
    for(int i=1;i<len;i++){
        if(sa[i].r == rr && sa[i].nr == sa[i-1].nr){
            rr=sa[i].r;
            sa[i].r=cnt;
        }else{
            rr=sa[i].r;
            sa[i].r=++cnt;
        }
        mapping[sa[i].index]=i;
    }
    for(int i=0;i<len;i++){
        int nn = sa[i].index+j;
        sa[i].nr = (nn>=len)?0:sa[mapping[nn]].r;
    }
    //sort(sa, sa+len, cmp);
    radixSort();
}
}
void radixSort(){
    int m = 0;
    for(int i=0;i<len;i++){
        srs[sa[i].nr].PB(sa[i]);
        m=max(m,sa[i].nr);
    }
    int cnt=0;
    for(int i=0;i<=m;i++){
        if(srs[i].empty())continue;
        for(auto j:srs[i]){
            sa[cnt++] = j;
        }
        srs[i].clear();
    }
    m = 0;
    for(int i=0;i<len;i++){
        srs[sa[i].r].PB(sa[i]);
        m=max(m,sa[i].r);
    }
    cnt=0;
    for(int i=0;i<=m;i++){
        if(srs[i].empty())continue;
        for(auto j:srs[i]){
            sa[cnt++] = j;
        }
        srs[i].clear();
    }
}
}

```

6.3 KMP

```

int F[N<<1];
void KMP(char s1[], char s2[], int n, int m){
    // make F[] for s1+'\0'+s2;
    char ss[N<<1];
    int len = n+m+1;
    for(int i=0;i<n;i++) ss[i] = s1[i];
    ss[n] = '\0';
    for(int i=0;i<m;i++) ss[i+1+n] = s2[i];
    F[0] = F[1] = 0;
    for(int i=1;i<len;i++){
        int j = F[i];
        while(j > 0 and ss[i]!=ss[j]) j = F[j];
        F[i+1] = (ss[i]==ss[j]?j+1:0);
    }
    // just find (F[len2+i] == len2), i from 1 to len+1
    for matching
}
/*
[0, i]是個循環字串，且循環節為i-f[i]:
if(f[i]>0 and i%(i-f[i])==0) cout << i << " " << i/(i-f[i]) << '\n';
*/

```

6.4 Z value

```

char s[MAXN];
int len,z[MAXN];

```



```

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

```

6.5 Lexicographically Smallest Rotation

```

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

```

```

struct segment {
    int i, l, r;
    segment() {}
    segment(int a, int b, int c): i(a), l(b), r(c) {}
};

inline long long f(int l, int r) {
    return dp[l] + w(l + 1, r);
}

void solve() {
    dp[0] = 0ll;
    deque<segment> deq; deq.push_back(segment(0, 1, n));
    for (int i = 1; i <= n; ++i) {
        dp[i] = f(deq.front().i, i);
        while (deq.size() && deq.front().r < i + 1) deq.
            pop_front();
        deq.front().l = i + 1;
        segment seg = segment(i, i + 1, n);
        while (deq.size() && f(i, deq.back().l) < f(deq.
            back().i, deq.back().l)) deq.pop_back();
        if (deq.size()) {
            int d = 1048576, c = deq.back().l;
            while (d >= 1) if (c + d <= deq.back().r) {
                if (f(i, c + d) > f(deq.back().i, c + d)) c +=
                    d;
            }
            deq.back().r = c; seg.l = c + 1;
        }
        if (seg.l <= n) deq.push_back(seg);
    }
}

```

7 Misc

7.1 MaximumEmptyRect

```

int largest_empty_rectangle() {
    int max_area = 0;
    for (int i=1; i<=n; ++i) {
        for (int j=1; j<=n; ++j)
            if (array[i][j]) wl[j] = wl[j-1] + 1;
        else wl[j] = 0;
        for (int j=n; j>=1; --j)
            if (array[i][j]) wr[j] = wr[j+1] + 1;
        else wr[j] = 0;
        for (int j=1; j<=n; ++j)
            if (array[i][j]) h[j] = h[j] + 1;
        else h[j] = 0;
        for (int j=1; j<=n; ++j)
            if (l[j] == 0) l[j] = wl[j];
            else l[j] = min(wl[j], l[j]);
        for (int j=1; j<=n; ++j)
            if (r[j] == 0) r[j] = wr[j];
            else r[j] = min(wr[j], r[j]);
        for (int j=1; j<=n; ++j)
            max_area = max(max_area, (l[j] + r[j] - 1) * h[j]);
    }
    return max_area;
}

```

7.2 DP-opt Condition

7.2.1 totally monotone (concave/convex)

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

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

7.2.2 monge condition (concave/convex)

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

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

7.3 Convex 1D/1D DP