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1 Basic

1.1 Default Code

```

1 #include <bits/stdc++.h>
1 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>
4 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)
7 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);
8     s<<"]";
8     return s;
8 }
8
9 template<typename A, typename B>
9 ostream& operator<<(ostream& s, const pair<A,B>&p)
9 { return s<<"("<<p.FF<<" "<<p.SS<<" "<<")"; }
9 template<typename T>
9 ostream& operator<<(ostream& s, const vector<T>&c)
9 { return _out(s,ALL(c)); }
9
10 bool debug = 0;
10 #define DUMP(x) if(debug) cerr<<__PRETTY_FUNCTION__<<": "
10 <<__LINE__<<" - "<<(#x)<<"="<<(x)<<"<<"\n"
10
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) {
11     if(debug) { cerr<<head; DEBUG(tail...); }
11 }
11
12 int main(int argc, char* argv[]) {
12     if(argc>1&&string(argv[1])=="-D") debug=1;
12     if(!debug) { ios_base::sync_with_stdio(0); cin.tie(0); }
12     return 0;
12 }

```

1.2 IncreaseStackSize

```

//stack resize(change esp to rsp if 64-bit system)
asm( "mov %0,%esp\n" :: "g"(mem+10000000) );
// 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; }
    S 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,
    0xBF58476D1CE4E5B9,0x94D049BB133111EB,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 PRIdFAST64
    #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] = l;
    }
    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:
    int n, ecnt;
    vector< vector< pair< int, int > > > G;
    vector< int > low, id;
    vector< bool > vis, ap;
    void dfs( int u, int f, int dfn ) {
        low[ u ] = dfn; vis[ u ] = true;
        for ( auto e : G[ u ] ) if ( e.first != f ) {
            if ( vis[ e.first ] ) {
                low[ u ] = min( low[ u ], low[ e.first ] );
            } else {
                dfs( e.first, u, dfn + 1 );
                if ( low[ e.first ] >= dfn ) ap[ u ] = true;
            }
        }
    }
    void mark( int u, int idd ) {
        // really????????
        if ( ap[ u ] ) return;
        for ( auto e : G[ u ] )
            if ( id[ e.second ] != -1 ) {
                id[ e.second ] = idd;
                mark( e.first, idd );
            }
    }
public:
    void init( int n_ ) {
        ecnt = 0, n = n_;
        G.clear();
        G.resize( n );
        low.clear();
        low.resize( n );
        ap.clear();
        ap.resize( n );
        vis.clear();
        vis.resize( n );
    }
    void add_edge( int u, int v ) {
        G[ u ].emplace_back( v, ecnt );
        G[ v ].emplace_back( u, ecnt ++ );
    }
    void solve() {
        for ( int i = 0 ; i < n ; ++ i )
            if ( not vis[ i ] ) dfs( i, i, 0 );
    }

```

```

    id.resize( ecnt );
    fill( id.begin(), id.end(), -1 );
    ecnt = 0;
    for ( int i = 0 ; i < n ; ++ i )
        if ( ap[ i ] ) for ( auto e : G[ i ] )
            if( id[ e.second ] != -1 ) {
                id[ e.second ] = ecnt;
                mark( e.first, ecnt ++ );
            }
    int get_id( int x ) { return id[ x ]; }
    int count() { return ecnt; }
    bool is_ap( int u ) { return ap[ u ]; }
} bcc;

```

3.3 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;
    }
};

```

3.4 Minimum Cost Maximum Flow

```

class MiniCostMaxiFlow{
using CapT = int;
using WeiT = int64_t;
using PCW = pair<CapT,WeiT>;
static constexpr CapT INF_CAP = 1 << 30;
static constexpr WeiT INF_WEI = 1LL<<60;
private:
    struct Edge{
        int to, back;
        WeiT wei;
        CapT cap;
        Edge() {}
        Edge(int a,int b,WeiT c,CapT d):
            to(a),back(b),wei(c),cap(d)
        {}
    };
    int ori, edd;
    vector<vector<Edge>> G;
    vector<int> fa, wh;
    vector<bool> inq;
    vector<WeiT> dis;
    PCW SPFA(){

```

```

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

```

3.5 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 or 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 or 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;

```

3.6 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;

```

3.7 2-SAT

```

class TwoSat{
private:
    int n;
    vector<vector<int>> rG, G, sccs;
    vector<int> ord, idx;
    vector<bool> vis, result;
    void dfs(int u){
        vis[u]=true;
        for(int v:G[u])
            if(!vis[v])
                dfs(v);
        ord.push_back(u);
    }
    void rdfs(int u){
        vis[u]=false;
        idx[u]=sccs.size()-1;
        sccs.back().push_back(u);
        for(int v:rG[u])
            if(vis[v])
                rdfs(v);
    }
public:
    void init(int n_){
        n=n_;
        G.clear();
        G.resize(n);
        rG.clear();
        rG.resize(n);
        sccs.clear();
        ord.clear();
        idx.resize(n);
        result.resize(n);
    }
    void add_edge(int u, int v){
        G[u].push_back(v);
        rG[v].push_back(u);
    }
    void orr(int x, int y){
        if ((x^y)==1) return;
        add_edge(x^1, y);
        add_edge(y^1, x);
    }
    bool solve(){
        vis.clear();
        vis.resize(n);
        for(int i=0; i<n; ++i)
            if(not vis[i])
                dfs(i);
        reverse(ord.begin(), ord.end());
        for (int u:ord){
            if(!vis[u])
                continue;
            sccs.push_back(vector<int>());
            rdfs(u);
        }
        for(int i=0; i<n; i+=2)
            if(idx[i]==idx[i+1])
                return false;
        vector<bool> c(sccs.size());
        for(size_t i=0; i<sccs.size(); ++i){
            for(size_t j=0; j<sccs[i].size(); ++j){
                result[sccs[i][j]]=c[i];
                c[idx[sccs[i][j]^1]]!=c[i];
            }
        }
        return true;
    }
    bool get(int x){return result[x];}
    inline int get_id(int x){return idx[x];}
    inline int count(){return sccs.size();}
} sat2;

```


3.8 Heavy Light Decomposition

```
#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;
```

3.9 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

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

4.4 Pollard Rho

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

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

```

```
lld n = pi_count(cube_root(m));
return phi(m, n) + n - 1 - P2(m, n);
}
```

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) {
    // [l, r)
    for(lld i=2; i*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*i<r; i++) {
        if(!is_prime_small[i]) continue;
        for(lld j=i*i; j*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

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

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

```

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)
lp, qj = exgcd(m2/g, m1/g)
return a2+m2*(p*(a1-a2)/g)
0 <= x < lcm(m1, m2)
*/

```

4.14 Berlekamp Massey

```

// x: 1-base, p[]: 0-base
template<size_t N>
vector<llf> BM(llf x[N], size_t n){
    size_t f[N]={0}, t=0; llf d[N];
}

```

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

4.15 NTT

```
// Remember coefficient are mod P
/* p=a*2^n+1
n    2^n    p    a    root
16   65536   65537   1    3
20   1048576 7340033   7    3 */
// (must be 2^k)
template<LL P, LL root, int MAXN>
struct NTT{
    static LL bigmod(LL a, LL b) {
        LL res = 1;
        for (LL bs = a; b; b >= 1, bs = (bs * bs) % P)
            if(b&1) res=(res*bs)%P;
        return res;
    }
    static LL inv(LL a, LL b) {
        if(a==1)return 1;
        return (((LL) (a-inv(b%a,a))*b+1)/a)%b;
    }
    LL omega[MAXN+1];
    NTT() {
        omega[0] = 1;
        LL r = bigmod(root, (P-1)/MAXN);
        for (int i=1; i<=MAXN; i++)
            omega[i] = (omega[i-1]*r)%P;
    }
    // n must be 2^k
    void tran(int n, LL a[], bool inv_ntt=false){
        int basic = MAXN / n, theta = basic;
        for (int m = n; m >= 2; m >= 1) {
            int mh = m >> 1;
            for (int i = 0; i < mh; i++) {
                LL w = omega[i*theta%MAXN];
                for (int j = i; j < n; j += m) {
                    int k = j + mh;
                    LL x = a[j] - a[k];
                    if (x < 0) x += P;
                    a[j] += a[k];
                    if (a[j] > P) a[j] -= P;
                    a[k] = (w * x) % P;
                }
            }
            theta = (theta * 2) % MAXN;
        }
        int i = 0;
        for (int j = 1; j < n - 1; j++) {
            for (int k = n >> 1; k > (i ^ k); k >= 1);
            if (j < i) swap(a[i], a[j]);
        }
        if (inv_ntt) {
            LL ni = inv(n,P);
            reverse(a+1, a+n);
            for (i = 0; i < n; i++)
                a[i] = (a[i] * ni) % P;
        }
    }
};
const LL P=2013265921,root=31;
const int MAXN=4194304;
NTT<P, root, MAXN> ntt;
```

4.16 DiscreteLog

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

5 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 ?
        cmpx : cmpy);
    tree[M].x1 = tree[M].x2 = tree[M].x;
    tree[M].y1 = tree[M].y2 = tree[M].y;

    tree[M].L = build_tree(L, M-1, 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) ? str[i+1] : 0;
    }
    //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) ? sa[mapping[nn]].r : 0;
        }
        //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);
}

```

6.6 BWT

```

struct BurrowsWheeler{
#define SIGMA 26
#define BASE 'a'
    vector<int> v[ SIGMA ];
    void BWT(char* ori, char* res){
        // make ori-> ori + ori

```

```

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

```

7 Misc

7.1 MaximumEmptyRect

```

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

```

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

```

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

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

```



```
void solve() {
    dp[0] = 011;
    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);
    }
}
```