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1 Reminder

1.1 Bug List

- 沒開 long long
- 陣列戳出界／陣列開不夠大
- 寫好的函式忘記呼叫
- 變數打錯
- 0-base / 1-base
- 忘記初始化
- == 打成 =
- <= 打成 <+
- dp[i] 從 dp[i-1] 轉移時忘記特判 i > 0
- std::sort 比較運算子寫成 < 或是讓 = 的情況為 true
- 漏 case
- 線段樹改值懶標初始值不能設為 0
- DFS 的時候不小心覆寫到全域變數
- 浮點數誤差
- unsigned int128
- 多筆測資不能沒讀完直接 return
- 記得刪 cerr

1.2 OwO

- 可以構造複雜點的測資幫助思考
- 真的卡太久請跳題
- Enjoy The Contest!

2 Basic

2.1 Default

```
#include <bits/stdc++.h>

using namespace std;
using ll = long long;
using pii = pair<int, int>;
using pll = pair<ll, ll>;

#define endl '\n'

#define F first
#define S second
#define ep emplace
#define pb push_back
#define eb emplace_back
#define ALL(x) x.begin(), x.end()
#define SZ(x) (int)x.size()

namespace{
const int INF = 0x3f3f3f3f;
const ll LINF = 0x3f3f3f3f3f3f3f3f;

template<typename T> using V=vector<T>;
template<typename T1,typename T2=T1> using P = pair<T1, T2>;

void _debug() {}
template<typename A,typename... B> void _debug(A a,B... b){
    cerr<<a<<' ',_debug(b...);
}

#define debug(...) cerr<<#__VA_ARGS__<<" ":_debug(
__VA_ARGS__),cerr<<endl;

template<typename T>
ostream& operator<<(ostream& os,const vector<T>& v){
    for(const auto& i:v)
        os<<i<<' ';
    return os;
}

}

/*-----*/

const ll MOD = 1e9 + 7;
const int maxn = 2e5 + 5;
```

```

42
43 void init() {
44     ;
45 }
46
47 void solve() {
48     ;
49 }
50
51 /*
52
53 */
54
55 signed main() {
56     cin.tie(0), ios::sync_with_stdio(0);
57
58     int T = 1;
59     // cin >> T;
60     while (T--) {
61         init();
62         solve();
63     }
64
65     return 0;
66 }
67

```

2.2 Vimrc

```

1 set number relativenumber ai t_Co=256 tabstop=4
2 set mouse=a shiftwidth=4 encoding=utf8
3 set bs=2 ruler laststatus=2 cmdheight=2
4 set clipboard=unnamedplus showcmd autoread
5 set belloff=all
6 filetype indent on
7 "set guifont Hack:h16
8 ":set guifont?
9
10 inoremap ( (<Esc>i
11 inoremap " ""<Esc>i
12 inoremap [ [<Esc>i
13 inoremap ' '<Esc>i
14 inoremap { {<CR><Esc>ko
15
16 vmap <C-c> "+y
17 inoremap <C-v> <Esc>p
18 nnoremap <C-v> p
19
20 nnoremap <tab> gt
21 nnoremap <S-tab> gT
22 inoremap <C-n> <Esc>:tabnew<CR>
23 nnoremap <C-n> :tabnew<CR>
24
25 inoremap <F9> <Esc>:w<CR>:!~/runcpp.sh %:p:t %:p:h<CR>
26 nnoremap <F9> :w<CR>:!~/runcpp.sh %:p:t %:p:h<CR>
27
28 syntax on
29 colorscheme desert
30 set filetype=cpp
31 set background=dark
32 hi Normal ctermfg=white ctermbg=black

```

2.3 Runcpp.sh

```

1 #! /bin/bash
2 clear
3 echo "Start compiling $1..."
4 echo
5 g++ -O2 -std=c++20 -Wall -Wextra -Wshadow $2/$1 -o $2/
6 out
7 if [ "$?" -ne 0 ]
8 then
9     exit 1
10 fi
11 echo
12 echo "Done compiling"
13 echo "=====
14 echo "Input file:"
15 echo

```

```

16 cat $2/in.txt
17 echo
18 echo "=====
19 echo
20 declare startTime=`date +%s%N`
21 $2/out < $2/in.txt > $2/out.txt
22 declare endTime=`date +%s%N`
23 delta=`expr $endTime - $startTime`
24 delta=`expr $delta / 1000000`
25 cat $2/out.txt
26 echo
27 echo "time: $delta ms"

```

2.4 Stress

```

1 g++ gen.cpp -o gen.out
2 g++ ac.cpp -o ac.out
3 g++ wa.cpp -o wa.out
4 for ((i=0;;i++))
5 do
6     echo "$i"
7     ./gen.out > in.txt
8     ./ac.out < in.txt > ac.txt
9     ./wa.out < in.txt > wa.txt
10    diff ac.txt wa.txt || break
11 done

```

2.5 PBDS

```

1 #include <bits/extc++.h>
2 using namespace __gnu_pbds;
3
4 // map
5 tree<int, int, less<>, rb_tree_tag,
6     tree_order_statistics_node_update> tr;
7 tr.order_of_key(element);
8 tr.find_by_order(rank);
9
10 // set
11 tree<int, null_type, less<>, rb_tree_tag,
12     tree_order_statistics_node_update> tr;
13 tr.order_of_key(element);
14 tr.find_by_order(rank);
15
16 // priority queue
17 __gnu_pbds::priority_queue<int, less<int> > big_q; //
18     Big First
19 __gnu_pbds::priority_queue<int, greater<int> > small_q;
20 // Small First
21 q1.join(q2); // join

```

2.6 Random

```

1 mt19937 gen(chrono::steady_clock::now().
2     time_since_epoch().count());
3 uniform_int_distribution<int> dis(1, 100);
4 cout << dis(gen) << endl;
5 shuffle(v.begin(), v.end(), gen);

```

3 Python

3.1 I/O

```

1 import sys
2 input = sys.stdin.readline
3
4 # Input
5 def readInt():
6     return int(input())
7 def readList():
8     return list(map(int, input().split()))
9 def readStr():
10    s = input()
11    return list(s[:len(s) - 1])
12 def readVars():
13    return map(int, input().split())
14

```

```

15 # Output
16 sys.stdout.write(string)
17
18 # faster
19 def main():
20     pass
21 main()

```

3.2 Decimal

```

1 from decimal import *
2 getcontext().prec = 2500000
3 getcontext().Emax = 2500000
4 a,b = Decimal(input()),Decimal(input())
5 a*=b
6 print(a)

```

4 Data Structure

4.1 Heavy Light Decomposition

```

1 const int N=2e5+5;
2 int n,dfn[N],son[N],top[N],num[N],dep[N],p[N];
3 vector<int>path[N];
4 struct node
5 {
6     int mx,sum;
7 }seg[N<<2];
8 void update(int x,int l,int r,int qx,int val)
9 {
10     if(l==r)
11     {
12         seg[x].mx=seg[x].sum=val;
13         return;
14     }
15     int mid=(l+r)>>1;
16     if(qx<=mid)update(x<<1,l,mid,qx,val);
17     else update(x<<1|1,mid+1,r,qx,val);
18     seg[x].mx=max(seg[x<<1].mx,seg[x<<1|1].mx);
19     seg[x].sum=seg[x<<1].sum+seg[x<<1|1].sum;
20 }
21 int big(int x,int l,int r,int ql,int qr)
22 {
23     if(ql<=l&&r<=qr)return seg[x].mx;
24     int mid=(l+r)>>1;
25     int res=-INF;
26     if(ql<=mid)res=max(res,big(x<<1,l,mid,ql,qr));
27     if(mid<qr)res=max(res,big(x<<1|1,mid+1,r,ql,qr));
28     return res;
29 }
30 int ask(int x,int l,int r,int ql,int qr)
31 {
32     if(ql<=l&&r<=qr)return seg[x].sum;
33     int mid=(l+r)>>1;
34     int res=0;
35     if(ql<=mid)res+=ask(x<<1,l,mid,ql,qr);
36     if(mid<qr)res+=ask(x<<1|1,mid+1,r,ql,qr);
37     return res;
38 }
39 void dfs1(int now)
40 {
41     son[now]=-1;
42     num[now]=1;
43     for(auto i:path[now])
44     {
45         if(!dep[i])
46         {
47             dep[i]=dep[now]+1;
48             p[i]=now;
49             dfs1(i);
50             num[now]+=num[i];
51             if(son[now]==-1||num[i]>num[son[now]])son[
                    now]=i;
52         }
53     }
54 }
55 int cnt;
56 void dfs2(int now,int t)
57 {

```

```

58     top[now]=t;
59     cnt++;
60     dfn[now]=cnt;
61     if(son[now]==-1)return;
62     dfs2(son[now],t);
63     for(auto i:path[now])
64         if(i!=p[now]&&i!=son[now])
65             dfs2(i,i);
66 }
67 int path_big(int x,int y)
68 {
69     int res=-INF;
70     while(top[x]!=top[y])
71     {
72         if(dep[top[x]]<dep[top[y]])swap(x,y);
73         res=max(res,big(1,1,n,dfn[top[x]],dfn[x]));
74         x=p[top[x]];
75     }
76     if(dfn[x]>dfn[y])swap(x,y);
77     res=max(res,big(1,1,n,dfn[x],dfn[y]));
78     return res;
79 }
80 int path_sum(int x,int y)
81 {
82     int res=0;
83     while(top[x]!=top[y])
84     {
85         if(dep[top[x]]<dep[top[y]])swap(x,y);
86         res+=ask(1,1,n,dfn[top[x]],dfn[x]);
87         x=p[top[x]];
88     }
89     if(dfn[x]>dfn[y])swap(x,y);
90     res+=ask(1,1,n,dfn[x],dfn[y]);
91     return res;
92 }
93 void buildTree()
94 {
95     FOR(i,0,n-1)
96     {
97         int a,b;cin>>a>>b;
98         path[a].pb(b);
99         path[b].pb(a);
100     }
101 }
102 void buildHLD(int root)
103 {
104     dep[root]=1;
105     dfs1(root);
106     dfs2(root,root);
107     FOR(i,1,n+1)
108     {
109         int now;cin>>now;
110         update(1,1,n,dfn[i],now);
111     }
112 }

```

4.2 Skew Heap

```

1 struct node{
2     node *l,*r;
3     int v;
4     node(int x):v(x){
5         l=r=nullptr;
6     }
7 };
8 node* merge(node* a,node* b){
9     if(!a||!b) return a?:b;
10    // min heap
11    if(a->v>b->v) swap(a,b);
12    a->r=merge(a->r,b);
13    swap(a->l,a->r);
14    return a;
15 }

```

4.3 Leftist Heap

```

1 struct node{
2     node *l,*r;
3     int d, v;
4     node(int x):d(1),v(x){

```

```

5         l=r=nullptr;
6     }
7 };
8 static inline int d(node* x){return x?x->d:0;}
9 node* merge(node* a,node* b){
10     if(!a||!b) return a?:b;
11     // min heap
12     if(a->v>b->v) swap(a,b);
13     a->r=merge(a->r,b);
14     if(d(a->l)<d(a->r))
15         swap(a->l,a->r);
16     a->d=d(a->r)+1;
17     return a;
18 }

```

4.4 Persistent Treap

```

1 struct node {
2     node *l, *r;
3     char c; int v, sz;
4     node(char x = '$'): c(x), v(mt()), sz(1) {
5         l = r = nullptr;
6     }
7     node(node* p) {*this = *p;}
8     void pull() {
9         sz = 1;
10        for (auto i : {l, r})
11            if (i) sz += i->sz;
12    }
13 } arr[maxn], *ptr = arr;
14 inline int size(node* p) {return p ? p->sz : 0;}
15 node* merge(node* a, node* b) {
16     if (!a || !b) return a ? : b;
17     if (a->v < b->v) {
18         node* ret = new(ptr++) node(a);
19         ret->r = merge(ret->r, b); ret->pull();
20         return ret;
21     }
22     else {
23         node* ret = new(ptr++) node(b);
24         ret->l = merge(a, ret->l); ret->pull();
25         return ret;
26     }
27 }
28 P<node*> split(node* p, int k) {
29     if (!p) return {nullptr, nullptr};
30     if (k >= size(p->l) + 1) {
31         auto [a, b] = split(p->r, k - size(p->l) - 1);
32         node* ret = new(ptr++) node(p);
33         ret->r = a; ret->pull();
34         return {ret, b};
35     }
36     else {
37         auto [a, b] = split(p->l, k);
38         node* ret = new(ptr++) node(p);
39         ret->l = b; ret->pull();
40         return {a, ret};
41     }
42 }

```

4.5 Li Chao Tree

```

1 constexpr int maxn = 5e4 + 5;
2 struct line {
3     ld a, b;
4     ld operator()(ld x) {return a * x + b;}
5 } arr[(maxn + 1) << 2];
6 bool operator<(line a, line b) {return a.a < b.a;}
7 #define m ((l+r)>>1)
8 void insert(line x, int i = 1, int l = 0, int r = maxn) {
9     if (r - l == 1) {
10        if (x(l) > arr[i](l))
11            arr[i] = x;
12        return;
13    }
14    line a = max(arr[i], x), b = min(arr[i], x);
15    if (a(m) > b(m))
16        arr[i] = a, insert(b, i << 1, l, m);
17    else

```

```

18        arr[i] = b, insert(a, i << 1 | 1, m, r);
19    }
20 ld query(int x, int i = 1, int l = 0, int r = maxn) {
21     if (x < l || r <= x) return -numeric_limits<ld>::
22         max();
23     if (r - l == 1) return arr[i](x);
24     return max({arr[i](x), query(x, i << 1, l, m),
25         query(x, i << 1 | 1, m, r)});
26 }
27 #undef m

```

4.6 Time Segment Tree

```

1 constexpr int maxn = 1e5 + 5;
2 V<P<int>> arr[(maxn + 1) << 2];
3 V<int> dsu, sz;
4 V<tuple<int, int, int>> his;
5 int cnt, q;
6 int find(int x) {
7     return x == dsu[x] ? x : find(dsu[x]);
8 }
9 inline bool merge(int x, int y) {
10     int a = find(x), b = find(y);
11     if (a == b) return false;
12     if (sz[a] > sz[b]) swap(a, b);
13     his.emplace_back(a, b, sz[b]), dsu[a] = b, sz[b] +=
14         sz[a];
15     return true;
16 }
17 inline void undo() {
18     auto [a, b, s] = his.back(); his.pop_back();
19     dsu[a] = a, sz[b] = s;
20 }
21 #define m ((l + r) >> 1)
22 void insert(int ql, int qr, P<int> x, int i = 1, int l
23     = 0, int r = q) {
24     // debug(ql, qr, x); return;
25     if (qr <= l || r <= ql) return;
26     if (ql <= l && r <= qr) {arr[i].push_back(x);
27         return;}
28     if (qr <= m)
29         insert(ql, qr, x, i << 1, l, m);
30     else if (m <= ql)
31         insert(ql, qr, x, i << 1 | 1, m, r);
32     else {
33         insert(ql, qr, x, i << 1, l, m);
34         insert(ql, qr, x, i << 1 | 1, m, r);
35     }
36 }
37 void traversal(V<int>& ans, int i = 1, int l = 0, int r
38     = q) {
39     int opcnt = 0;
40     // debug(i, l, r);
41     for (auto [a, b] : arr[i])
42         if (merge(a, b))
43             opcnt++, cnt--;
44     if (r - l == 1) ans[l] = cnt;
45     else {
46         traversal(ans, i << 1, l, m);
47         traversal(ans, i << 1 | 1, m, r);
48     }
49     while (opcnt--)
50         undo(), cnt++;
51     arr[i].clear();
52 }
53 #undef m
54 inline void solve() {
55     int n, m; cin>>n>>m>>q,q++;
56     dsu.resize(cnt = n), sz.assign(n, 1);
57     iota(dsu.begin(), dsu.end(), 0);
58     // a, b, time, operation
59     unordered_map<ll, V<int>> s;
60     for (int i = 0; i < m; i++) {
61         int a, b; cin>>a>>b;
62         if (a > b) swap(a, b);
63         s[((ll)a << 32) | b].emplace_back(0);
64     }
65     for (int i = 1; i < q; i++) {
66         int op,a, b;
67         cin>>op>>a>>b;
68         if (a > b) swap(a, b);

```

```

65     switch (op) {
66     case 1:
67         s[((1ll)a << 32) | b].push_back(i);
68         break;
69     case 2:
70         auto tmp = s[((1ll)a << 32) | b].back();
71         s[((1ll)a << 32) | b].pop_back();
72         insert(tmp, i, P<int> {a, b});
73     }
74 }
75 for (auto [p, v] : s) {
76     int a = p >> 32, b = p & -1;
77     while (v.size()) {
78         insert(v.back(), q, P<int> {a, b});
79         v.pop_back();
80     }
81 }
82 V<int> ans(q);
83 traversal(ans);
84 for (auto i : ans)
85     cout<<i<<' ';
86 cout<<endl;
87 }

```

5 DP

5.1 Aliens

```

1  int n; ll k;
2  vector<ll> a;
3  vector<pll> dp[2];
4  void init() {
5      cin >> n >> k;
6      Each(i, dp) i.clear(), i.resize(n);
7      a.clear(); a.resize(n);
8      Each(i, a) cin >> i;
9  }
10 pll calc(ll p) {
11     dp[0][0] = mp(0, 0);
12     dp[1][0] = mp(-a[0], 0);
13     FOR(i, 1, n, 1) {
14         if (dp[0][i-1].F > dp[1][i-1].F + a[i] - p) {
15             dp[0][i] = dp[0][i-1];
16         } else if (dp[0][i-1].F < dp[1][i-1].F + a[i] -
17             p) {
18             dp[0][i] = mp(dp[1][i-1].F + a[i] - p, dp
19                 [1][i-1].S+1);
20         } else {
21             dp[0][i] = mp(dp[0][i-1].F, min(dp[0][i-1].
22                 S, dp[1][i-1].S+1));
23         }
24         if (dp[0][i-1].F - a[i] > dp[1][i-1].F) {
25             dp[1][i] = mp(dp[0][i-1].F - a[i], dp[0][i
26                 -1].S);
27         } else if (dp[0][i-1].F - a[i] < dp[1][i-1].F)
28             {
29             dp[1][i] = dp[1][i-1];
30         } else {
31             dp[1][i] = mp(dp[1][i-1].F, min(dp[0][i-1].
32                 S, dp[1][i-1].S));
33         }
34     }
35     return dp[0][n-1];
36 }
37 void solve() {
38     ll l = 0, r = 1e7;
39     pll res = calc(0);
40     if (res.S <= k) return cout << res.F << endl, void
41         ();
42     while (l < r) {
43         ll mid = (l+r)>>1;
44         res = calc(mid);
45         if (res.S <= k) r = mid;
46         else l = mid+1;
47     }
48     res = calc(l);
49     cout << res.F + k*1 << endl;
50 }

```

6 Graph

6.1 Bellman-Ford + SPFA

```

1  int n, m;
2
3  // Graph
4  vector<vector<pair<int, ll> > > g;
5  vector<ll> dis;
6  vector<bool> negCycle;
7
8  // SPFA
9  vector<int> rlx;
10 queue<int> q;
11 vector<bool> inq;
12 vector<int> pa;
13 void SPFA(vector<int>& src) {
14     dis.assign(n+1, LINF);
15     negCycle.assign(n+1, false);
16     rlx.assign(n+1, 0);
17     while (!q.empty()) q.pop();
18     inq.assign(n+1, false);
19     pa.assign(n+1, -1);
20
21     for (auto& s : src) {
22         dis[s] = 0;
23         q.push(s); inq[s] = true;
24     }
25
26     while (!q.empty()) {
27         int u = q.front();
28         q.pop(); inq[u] = false;
29         if (rlx[u] >= n) {
30             negCycle[u] = true;
31         }
32         else for (auto& e : g[u]) {
33             int v = e.first;
34             ll w = e.second;
35             if (dis[v] > dis[u] + w) {
36                 dis[v] = dis[u] + w;
37                 rlx[v] = rlx[u] + 1;
38                 pa[v] = u;
39                 if (!inq[v]) {
40                     q.push(v);
41                     inq[v] = true;
42                 }
43             }
44         }
45     }
46
47     // Bellman-Ford
48     queue<int> q;
49     vector<int> pa;
50     void BellmanFord(vector<int>& src) {
51         dis.assign(n+1, LINF);
52         negCycle.assign(n+1, false);
53         pa.assign(n+1, -1);
54
55         for (auto& s : src) dis[s] = 0;
56
57         for (int rlx = 1; rlx <= n; rlx++) {
58             for (int u = 1; u <= n; u++) {
59                 if (dis[u] == LINF) continue; // Important
60                 !!
61                 for (auto& e : g[u]) {
62                     int v = e.first; ll w = e.second;
63                     if (dis[v] > dis[u] + w) {
64                         dis[v] = dis[u] + w;
65                         pa[v] = u;
66                         if (rlx == n) negCycle[v] = true;
67                     }
68                 }
69             }
70         }
71
72         // Negative Cycle Detection
73         void NegCycleDetect() {
74             /* No Neg Cycle: NO
75             Exist Any Neg Cycle:
76             YES
77             v0 v1 v2 ... vk v0 */
78
79             vector<int> src;
80             for (int i = 1; i <= n; i++)
81                 src.emplace_back(i);
82         }
83     }
84 }

```

```

77 SPFA(src);
78 // BellmanFord(src);
79
80 int ptr = -1;
81 for (int i = 1; i <= n; i++) if (negCycle[i])
82     { ptr = i; break; }
83
84 if (ptr == -1) { return cout << "NO" << endl, void
85     (); }
86
87 cout << "YES\n";
88 vector<int> ans;
89 vector<bool> vis(n+1, false);
90
91 while (true) {
92     ans.emplace_back(ptr);
93     if (vis[ptr]) break;
94     vis[ptr] = true;
95     ptr = pa[ptr];
96 }
97 reverse(ans.begin(), ans.end());
98
99 vis.assign(n+1, false);
100 for (auto& x : ans) {
101     cout << x << ' ';
102     if (vis[x]) break;
103     vis[x] = true;
104 }
105 cout << endl;
106 }
107
108 // Distance Calculation
109 void calcDis(int s) {
110     vector<int> src;
111     src.emplace_back(s);
112     SPFA(src);
113     // BellmanFord(src);
114
115     while (!q.empty()) q.pop();
116     for (int i = 1; i <= n; i++)
117         if (negCycle[i]) q.push(i);
118
119     while (!q.empty()) {
120         int u = q.front(); q.pop();
121         for (auto& e : g[u]) {
122             int v = e.first;
123             if (!negCycle[v]) {
124                 q.push(v);
125                 negCycle[v] = true;
126             }
127         }
128     }
129 }

```

6.2 BCC - AP

```

1 int n, m;
2 int low[maxn], dfn[maxn], instp;
3 vector<int> E, g[maxn];
4 bitset<maxn> isap;
5 bitset<maxn> vis;
6 stack<int> stk;
7 int bccnt;
8 vector<int> bcc[maxn];
9 inline void popout(int u) {
10     bccnt++;
11     bcc[bccnt].emplace_back(u);
12     while (!stk.empty()) {
13         int v = stk.top();
14         if (u == v) break;
15         stk.pop();
16         bcc[bccnt].emplace_back(v);
17     }
18 }
19 void dfs(int u, bool rt = 0) {
20     stk.push(u);
21     low[u] = dfn[u] = ++instp;
22     int kid = 0;
23     Each(e, g[u]) {
24         if (vis[e]) continue;
25         vis[e] = true;
26         int v = E[e]^u;
27         if (!dfn[v]) {

```

```

28         // tree edge
29         kid++; dfs(v);
30         low[u] = min(low[u], low[v]);
31         if (!rt && low[v] >= dfn[u]) {
32             // bcc found: u is ap
33             isap[u] = true;
34             popout(u);
35         }
36     } else {
37         // back edge
38         low[u] = min(low[u], dfn[v]);
39     }
40 }
41 // special case: root
42 if (rt) {
43     if (kid > 1) isap[u] = true;
44     popout(u);
45 }
46 }
47 void init() {
48     cin >> n >> m;
49     fill(low, low+maxn, INF);
50     REP(i, m) {
51         int u, v;
52         cin >> u >> v;
53         g[u].emplace_back(i);
54         g[v].emplace_back(i);
55         E.emplace_back(u^v);
56     }
57 }
58 void solve() {
59     FOR(i, 1, n+1, 1) {
60         if (!dfn[i]) dfs(i, true);
61     }
62     vector<int> ans;
63     int cnt = 0;
64     FOR(i, 1, n+1, 1) {
65         if (isap[i]) cnt++, ans.emplace_back(i);
66     }
67     cout << cnt << endl;
68     Each(i, ans) cout << i << ' ';
69     cout << endl;
70 }

```

6.3 BCC - Bridge

```

1 int n, m;
2 vector<int> g[maxn], E;
3 int low[maxn], dfn[maxn], instp;
4 int bccnt, bccid[maxn];
5 stack<int> stk;
6 bitset<maxn> vis, isbrg;
7 void init() {
8     cin >> n >> m;
9     REP(i, m) {
10         int u, v;
11         cin >> u >> v;
12         E.emplace_back(u^v);
13         g[u].emplace_back(i);
14         g[v].emplace_back(i);
15     }
16     fill(low, low+maxn, INF);
17 }
18 void popout(int u) {
19     bccnt++;
20     while (!stk.empty()) {
21         int v = stk.top();
22         if (v == u) break;
23         stk.pop();
24         bccid[v] = bccnt;
25     }
26 }
27 void dfs(int u) {
28     stk.push(u);
29     low[u] = dfn[u] = ++instp;
30
31     Each(e, g[u]) {
32         if (vis[e]) continue;
33         vis[e] = true;
34
35         int v = E[e]^u;

```

```

36     if (dfn[v]) {
37         // back edge
38         low[u] = min(low[u], dfn[v]);
39     } else {
40         // tree edge
41         dfs(v);
42         low[u] = min(low[u], low[v]);
43         if (low[v] == dfn[v]) {
44             isbrg[e] = true;
45             popout(u);
46         }
47     }
48 }
49 }
50 void solve() {
51     FOR(i, 1, n+1, 1) {
52         if (!dfn[i]) dfs(i);
53     }
54     vector<pii> ans;
55     vis.reset();
56     FOR(u, 1, n+1, 1) {
57         Each(e, g[u]) {
58             if (!isbrg[e] || vis[e]) continue;
59             vis[e] = true;
60             int v = E[e]^u;
61             ans.emplace_back(mp(u, v));
62         }
63     }
64     cout << (int)ans.size() << endl;
65     Each(e, ans) cout << e.F << ' ' << e.S << endl;
66 }

```

6.4 SCC - Tarjan

```

1 // 2-SAT
2 vector<int> E, g[maxn]; // 1~n, n+1~2n
3 int low[maxn], in[maxn], instp;
4 int sccnt, sccid[maxn];
5
6 stack<int> stk;
7 bitset<maxn> ins, vis;
8
9 int n, m;
10
11 void init() {
12     cin >> m >> n;
13     E.clear();
14     fill(g, g+maxn, vector<int>());
15     fill(low, low+maxn, INF);
16     memset(in, 0, sizeof(in));
17     instp = 1;
18     sccnt = 0;
19     memset(sccid, 0, sizeof(sccid));
20     ins.reset();
21     vis.reset();
22 }
23
24 inline int no(int u) {
25     return (u > n ? u-n : u+n);
26 }
27
28 int ecnt = 0;
29 inline void clause(int u, int v) {
30     E.eb(no(u)^v);
31     g[no(u)].eb(ecnt++);
32     E.eb(no(v)^u);
33     g[no(v)].eb(ecnt++);
34 }
35
36 void dfs(int u) {
37     in[u] = instp++;
38     low[u] = in[u];
39     stk.push(u);
40     ins[u] = true;
41
42     Each(e, g[u]) {
43         if (vis[e]) continue;
44         vis[e] = true;
45
46         int v = E[e]^u;
47         if (ins[v]) low[u] = min(low[u], in[v]);

```

```

48     else if (!in[v]) {
49         dfs(v);
50         low[u] = min(low[u], low[v]);
51     }
52 }
53
54 if (low[u] == in[u]) {
55     sccnt++;
56     while (!stk.empty()) {
57         int v = stk.top();
58         stk.pop();
59         ins[v] = false;
60         sccid[v] = sccnt;
61         if (u == v) break;
62     }
63 }
64 }
65
66 int main() {
67     WiWiHorz
68     init();
69
70     REP(i, m) {
71         char su, sv;
72         int u, v;
73         cin >> su >> u >> sv >> v;
74         if (su == '-') u = no(u);
75         if (sv == '-') v = no(v);
76         clause(u, v);
77     }
78
79     FOR(i, 1, 2*n+1, 1) {
80         if (!in[i]) dfs(i);
81     }
82
83     FOR(u, 1, n+1, 1) {
84         int du = no(u);
85         if (sccid[u] == sccid[du]) {
86             return cout << "IMPOSSIBLE\n", 0;
87         }
88     }
89
90     FOR(u, 1, n+1, 1) {
91         int du = no(u);
92         cout << (sccid[u] < sccid[du] ? '+' : '-') << '
93             ' << ' ';
94     }
95     cout << endl;
96
97     return 0;
98 }

```

6.5 Eulerian Path - Undir

```

1 // from 1 to n
2 #define gg return cout << "IMPOSSIBLE\n", void();
3
4 int n, m;
5 vector<int> g[maxn];
6 bitset<maxn> inodd;
7
8 void init() {
9     cin >> n >> m;
10    inodd.reset();
11    for (int i = 0; i < m; i++) {
12        int u, v; cin >> u >> v;
13        inodd[u] = inodd[u] ^ true;
14        inodd[v] = inodd[v] ^ true;
15        g[u].emplace_back(v);
16        g[v].emplace_back(u);
17    }
18    stack<int> stk;
19    void dfs(int u) {
20        while (!g[u].empty()) {
21            int v = g[u].back();
22            g[u].pop_back();
23            dfs(v);
24        }
25        stk.push(u);}

```


6.6 Eulerian Path - Dir

```

1 // from node 1 to node n
2 #define gg return cout << "IMPOSSIBLE\n", 0
3
4 int n, m;
5 vector<int> g[maxn];
6 stack<int> stk;
7 int in[maxn], out[maxn];
8
9 void init() {
10 cin >> n >> m;
11 for (int i = 0; i < m; i++) {
12     int u, v; cin >> u >> v;
13     g[u].emplace_back(v);
14     out[u]++, in[v]++;
15 }
16 for (int i = 1; i <= n; i++) {
17     if (i == 1 && out[i]-in[i] != 1) gg;
18     if (i == n && in[i]-out[i] != 1) gg;
19     if (i != 1 && i != n && in[i] != out[i]) gg;
20 }
21 void dfs(int u) {
22     while (!g[u].empty()) {
23         int v = g[u].back();
24         g[u].pop_back();
25         dfs(v);
26     }
27     stk.push(u);
28 }
29 void solve() {
30     dfs(1);
31     for (int i = 1; i <= n; i++)
32         if ((int)g[i].size()) gg;
33     while (!stk.empty()) {
34         int u = stk.top();
35         stk.pop();
36         cout << u << ' ';
37     }
38 }

```

6.7 Hamilton Path

```

1 // top down DP
2 // Be Aware Of Multiple Edges
3 int n, m;
4 ll dp[maxn][1<<maxn];
5 int adj[maxn][maxn];
6
7 void init() {
8     cin >> n >> m;
9     fill(dp[0], dp[maxn-1]+(1<<maxn), -1);
10 }
11
12 void DP(int i, int msk) {
13     if (dp[i][msk] != -1) return;
14     dp[i][msk] = 0;
15     REP(j, n) if (j != i && (msk & (1<<j)) && adj[j][i]) {
16         int sub = msk ^ (1<<i);
17         if (dp[j][sub] == -1) DP(j, sub);
18         dp[i][msk] += dp[j][sub] * adj[j][i];
19         if (dp[i][msk] >= MOD) dp[i][msk] %= MOD;
20     }
21 }
22
23
24 int main() {
25     WiwiHorz
26     init();
27
28     REP(i, m) {
29         int u, v;
30         cin >> u >> v;
31         if (u == v) continue;
32         adj[--u][--v]++;
33     }
34
35     dp[0][1] = 1;
36     FOR(i, 1, n, 1) {
37         dp[i][1] = 0;
38         dp[i][1|(1<<i)] = adj[0][i];
39     }

```

```

39     }
40     FOR(msk, 1, (1<<n), 1) {
41         if (msk == 1) continue;
42         dp[0][msk] = 0;
43     }
44
45     DP(n-1, (1<<n)-1);
46     cout << dp[n-1][(1<<n)-1] << endl;
47
48     return 0;
49 }
50 }

```

6.8 Kth Shortest Path

```

1 // time: O(|E| \lg |E|+|V| \lg |V|+K)
2 // memory: O(|E| \lg |E|+|V|)
3 struct KSP{ // 1-base
4     struct nd{
5         int u,v; ll d;
6         nd(int ui=0,int vi=0,ll di=INF){ u=ui; v=vi; d=di; }
7     };
8     struct heap{ nd* edge; int dep; heap* chd[4]; };
9     static int cmp(heap* a,heap* b)
10     { return a->edge->d > b->edge->d; }
11     struct node{
12         int v; ll d; heap* H; nd* E;
13         node(){ }
14         node(ll _d,int _v,nd* _E){ d=_d; v=_v; E=_E; }
15         node(heap* _H,ll _d){ H=_H; d=_d; }
16         friend bool operator<(node a,node b)
17         { return a.d>b.d; }
18     };
19     int n,k,s,t,dst[N]; nd *nxt[N];
20     vector<nd*> g[N],rg[N]; heap *nullNd,*head[N];
21     void init(int _n,int _k,int _s,int _t){
22         n=_n; k=_k; s=_s; t=_t;
23         for(int i=1;i<=n;i++){
24             g[i].clear(); rg[i].clear();
25             nxt[i]=NULL; head[i]=NULL; dst[i]=-1;
26         }
27     }
28     void addEdge(int ui,int vi,ll di){
29         nd* e=new nd(ui,vi,di);
30         g[ui].push_back(e); rg[vi].push_back(e);
31     }
32     queue<int> dfsQ;
33     void dijkstra(){
34         while(dfsQ.size()) dfsQ.pop();
35         priority_queue<node> Q; Q.push(node(0,t,NULL));
36         while (!Q.empty()){
37             node p=Q.top(); Q.pop(); if(dst[p.v]!=-1)continue;
38             dst[p.v]=p.d; nxt[p.v]=p.E; dfsQ.push(p.v);
39             for(auto e:rg[p.v]) Q.push(node(p.d+e->d,e->u,e));
40         }
41     }
42     heap* merge(heap* curNd,heap* newNd){
43         if(curNd==nullNd) return newNd;
44         heap* root=new heap;memcpy(root,curNd,sizeof(heap));
45         if(newNd->edge->d<curNd->edge->d){
46             root->edge=newNd->edge;
47             root->chd[2]=newNd->chd[2];
48             root->chd[3]=newNd->chd[3];
49             newNd->edge=curNd->edge;
50             newNd->chd[2]=curNd->chd[2];
51             newNd->chd[3]=curNd->chd[3];
52         }
53         if(root->chd[0]->dep<root->chd[1]->dep)
54             root->chd[0]=merge(root->chd[0],newNd);
55         else root->chd[1]=merge(root->chd[1],newNd);
56         root->dep=max(root->chd[0]->dep,
57                     root->chd[1]->dep)+1;
58         return root;
59     }
60     vector<heap*> V;
61     void build(){

```



```

62 nullNd=new heap; nullNd->dep=0; nullNd->edge=new nd
;
63 fill(nullNd->chd,nullNd->chd+4,nullNd);
64 while(not dfsQ.empty()){
65     int u=dfsQ.front(); dfsQ.pop();
66     if(!nxt[u]) head[u]=nullNd;
67     else head[u]=head[nxt[u]->v];
68     V.clear();
69     for(auto&& e:g[u]){
70         int v=e->v;
71         if(dst[v]==-1) continue;
72         e->d+=dst[v]-dst[u];
73         if(nxt[u]!=e){
74             heap* p=new heap; fill(p->chd,p->chd+4,nullNd)
;
75             p->dep=1; p->edge=e; V.push_back(p);
76         }
77     }
78     if(V.empty()) continue;
79     make_heap(V.begin(),V.end(),cmp);
80 #define L(X) ((X<<1)+1)
81 #define R(X) ((X<<1)+2)
82     for(size_t i=0;i<V.size();i++){
83         if(L(i)<V.size()) V[i]->chd[2]=V[L(i)];
84         else V[i]->chd[2]=nullNd;
85         if(R(i)<V.size()) V[i]->chd[3]=V[R(i)];
86         else V[i]->chd[3]=nullNd;
87     }
88     head[u]=merge(head[u],V.front());
89 }
90 }
91 vector<ll> ans;
92 void first_K(){
93     ans.clear(); priority_queue<node> Q;
94     if(dst[s]==-1) return;
95     ans.push_back(dst[s]);
96     if(head[s]!=nullNd)
97         Q.push(node(head[s],dst[s]+head[s]->edge->d));
98     for(int _=1;_<k and not Q.empty();_++){
99         node p=Q.top();Q.pop(); ans.push_back(p.d);
100         if(head[p.H->edge->v]!=nullNd){
101             q.H=head[p.H->edge->v]; q.d=p.d+q.H->edge->d;
102             Q.push(q);
103         }
104         for(int i=0;i<4;i++){
105             if(p.H->chd[i]!=nullNd){
106                 q.H=p.H->chd[i];
107                 q.d=p.d-p.H->edge->d+p.H->chd[i]->edge->d;
108                 Q.push(q);
109             }
110         }
111     }
112     void solve(){ // ans[i] stores the i-th shortest path
113         dijkstra(); build();
114         first_K(); // ans.size() might less than k
115     }
116 } solver;

```

6.9 System of Difference Constraints

```

1 vector<vector<pair<int, ll>>> G;
2 void add(int u, int v, ll w) {
3     G[u].emplace_back(make_pair(v, w));
4 }

```

- $x_u - x_v \leq c \Rightarrow \text{add}(v, u, c)$
- $x_u - x_v \geq c \Rightarrow \text{add}(u, v, -c)$
- $x_u - x_v = c \Rightarrow \text{add}(v, u, c), \text{add}(u, v, -c)$
- $x_u \geq c \Rightarrow \text{add super vertex } x_0 = 0, \text{ then } x_u - x_0 \geq c \Rightarrow \text{add}(u, 0, -c)$
- Don't forget non-negative constraints for every variable if specified implicitly.
- Interval sum \Rightarrow Use prefix sum to transform into differential constraints. Don't forget $S_{i+1} - S_i \geq 0$ if x_{i+1} needs to be non-negative.
- $\frac{x_u}{x_v} \leq c \Rightarrow \log x_u - \log x_v \leq \log c$

7 String

7.1 Rolling Hash

```

1 const ll C = 27;
2 inline int id(char c) {return c-'a'+1;}
3 struct RollingHash {
4     string s; int n; ll mod;
5     vector<ll> Cexp, hs;
6     RollingHash(string& _s, ll _mod):
7         s(_s), n((int)_s.size()), mod(_mod)
8     {
9         Cexp.assign(n, 0);
10        hs.assign(n, 0);
11        Cexp[0] = 1;
12        for (int i = 1; i < n; i++) {
13            Cexp[i] = Cexp[i-1] * C;
14            if (Cexp[i] >= mod) Cexp[i] %= mod;
15        }
16        hs[0] = id(s[0]);
17        for (int i = 1; i < n; i++) {
18            hs[i] = hs[i-1] * C + id(s[i]);
19            if (hs[i] >= mod) hs[i] %= mod;
20        }
21        inline ll query(int l, int r) {
22            ll res = hs[r] - (l ? hs[l-1] * Cexp[r-l+1] : 0);
23            res = (res % mod + mod) % mod;
24            return res; }
25 };

```

7.2 Trie

```

1 struct node {
2     int c[26]; ll cnt;
3     node(): cnt(0) {memset(c, 0, sizeof(c));}
4     node(ll x): cnt(x) {memset(c, 0, sizeof(c));}
5 };
6 struct Trie {
7     vector<node> t;
8     void init() {
9         t.clear();
10        t.emplace_back(node());
11    }
12    void insert(string s) { int ptr = 0;
13        for (auto& i : s) {
14            if (!t[ptr].c[i-'a']) {
15                t.emplace_back(node());
16                t[ptr].c[i-'a'] = (int)t.size()-1;
17                ptr = t[ptr].c[i-'a'];
18                t[ptr].cnt++; }
19        }
20    }
21 };

```

7.3 KMP

```

1 int n, m;
2 string s, p;
3 vector<int> f;
4 void build() {
5     f.clear(); f.resize(m, 0);
6     int ptr = 0; for (int i = 1; i < m; i++) {
7         while (ptr && p[i] != p[ptr]) ptr = f[ptr-1];
8         if (p[i] == p[ptr]) ptr++;
9         f[i] = ptr;
10    }
11    void init() {
12        cin >> s >> p;
13        n = (int)s.size();
14        m = (int)p.size();
15        build(); }
16    void solve() {
17        int ans = 0, pi = 0;
18        for (int si = 0; si < n; si++) {
19            while (pi && s[si] != p[pi]) pi = f[pi-1];
20            if (s[si] == p[pi]) pi++;
21            if (pi == m) ans++, pi = f[pi-1];
22        }
23        cout << ans << endl; }

```

7.4 Z Value

```

1 string is, it, s;
2 int n; vector<int> z;
3 void init() {
4     cin >> is >> it;
5     s = it+'0'+is;
6     n = (int)s.size();
7     z.resize(n, 0); }
8 void solve() {
9     int ans = 0; z[0] = n;
10    for (int i = 1, l = 0, r = 0; i < n; i++) {
11        if (i <= r) z[i] = min(z[i-1], r-i+1);
12        while (i+z[i] < n && s[z[i]] == s[i+z[i]]) z[i]++;
13        if (i+z[i]-1 > r) l = i, r = i+z[i]-1;
14        if (z[i] == (int)it.size()) ans++;
15    }
16    cout << ans << endl; }

```

7.5 Manacher

```

1 int n; string S, s;
2 vector<int> m;
3 void manacher() {
4     s.clear(); s.resize(2*n+1, '.');
5     for (int i = 0, j = 1; i < n; i++, j += 2) s[j] = S[i];
6     m.clear(); m.resize(2*n+1, 0);
7     // m[i] := max k such that s[i-k, i+k] is palindrome
8     int mx = 0, mxk = 0;
9     for (int i = 1; i < 2*n+1; i++) {
10        if (mx-(i-mx) >= 0) m[i] = min(m[mx-(i-mx)], mx+mxk-
11            i);
12        while (0 <= i-m[i]-1 && i+m[i]+1 < 2*n+1 &&
13            s[i-m[i]-1] == s[i+m[i]+1]) m[i]++;
14        if (i+m[i] > mx+mxk) mx = i, mxk = m[i];
15    } }
16 void init() { cin >> S; n = (int)S.size(); }
17 void solve() {
18     manacher();
19     int mx = 0, ptr = 0;
20     for (int i = 0; i < 2*n+1; i++) if (mx < m[i])
21         { mx = m[i]; ptr = i; }
22     for (int i = ptr-mx; i <= ptr+mx; i++)
23         if (s[i] != '.') cout << s[i];
24     cout << endl; }

```

7.6 Suffix Array

```

1 #define F first
2 #define S second
3 struct SuffixArray { // don't forget s += "$";
4     int n; string s;
5     vector<int> suf, lcp, rk;
6     vector<int> cnt, pos;
7     vector<pair<pii, int>> buc[2];
8     void init(string _s) {
9         s = _s; n = (int)s.size();
10        // resize(n): suf, rk, cnt, pos, lcp, buc[0~1]
11    }
12    void radix_sort() {
13        for (int t : {0, 1}) {
14            fill(cnt.begin(), cnt.end(), 0);
15            for (auto& i : buc[t]) cnt[(t ? i.F.F : i.S) ]++;
16            for (int i = 0; i < n; i++)
17                pos[i] = (i ? 0 : pos[i-1] + cnt[i-1]);
18            for (auto& i : buc[t])
19                buc[t^1][pos[(t ? i.F.F : i.S) ]++] = i;
20        } }
21    bool fill_suf() {
22        bool end = true;
23        for (int i = 0; i < n; i++) suf[i] = buc[0][i].S;
24        rk[suf[0]] = 0;
25        for (int i = 1; i < n; i++) {
26            int dif = (buc[0][i].F != buc[0][i-1].F);
27            end &= dif;

```

```

28        rk[suf[i]] = rk[suf[i-1]] + dif;
29    } return end;
30    }
31    void sa() {
32        for (int i = 0; i < n; i++)
33            buc[0][i] = make_pair(make_pair(s[i], s[i]), i);
34        sort(buc[0].begin(), buc[0].end());
35        if (fill_suf()) return;
36        for (int k = 0; (1<<k) < n; k++) {
37            for (int i = 0; i < n; i++)
38                buc[0][i] = make_pair(make_pair(rk[i],
39                    rk[(i + (1<<k)) % n]), i);
40            radix_sort();
41            if (fill_suf()) return;
42        } }
43    void LCP() { int k = 0;
44        for (int i = 0; i < n-1; i++) {
45            if (rk[i] == 0) continue;
46            int pi = rk[i];
47            int j = suf[pi-1];
48            while (i+k < n && j+k < n && s[i+k] == s[j+k]) k++;
49            lcp[pi] = k;
50            k = max(k-1, 0);
51        } }
52    SuffixArray suffixarray;

```

7.7 SA-IS

```

1 const int N=300010;
2 struct SA{
3     #define REP(i,n) for(int i=0;i<int(n);i++)
4     #define REP1(i,a,b) for(int i=(a);i<=int(b);i++)
5     bool _t[N*2]; int _s[N*2], _sa[N*2];
6     int _c[N*2], x[N], _p[N], _q[N*2], hei[N], r[N];
7     int operator [](int i){ return _sa[i]; }
8     void build(int *s, int n, int m){
9         memcpy(_s, s, sizeof(int)*n);
10        sais(_s, _sa, _p, _q, _t, _c, n, m); mkhei(n);
11    }
12    void mkhei(int n){
13        REP(i,n) r[_sa[i]]=i;
14        hei[0]=0;
15        REP(i,n) if(r[i]) {
16            int ans=i>0?max(hei[r[i-1]]-1,0):0;
17            while(_s[i+ans]==_s[_sa[r[i]-1]+ans]) ans++;
18            hei[r[i]]=ans;
19        }
20    }
21    void sais(int *s, int *sa, int *p, int *q, bool *t, int *c,
22        int n, int z){
23        bool uniq=t[n-1]=true, neq;
24        int nn=0, nmzx=-1, *nsa=sa+n, *ns=s+n, lst=-1;
25        #define MS0(x,n) memset((x),0,n*sizeof(*(x)))
26        #define MAGIC(XD) MS0(sa,n);\
27        memcpy(x,c,sizeof(int)*z);\
28        memcpy(x+1,c,sizeof(int)*(z-1));\
29        REP(i,n) if(sa[i]&&!t[sa[i]-1]) sa[x[sa[i]-1]]+=sa[i]-1;\
30        memcpy(x,c,sizeof(int)*z);\
31        for(int i=n-1;i>=0;i--) if(sa[i]&&t[sa[i]-1]) sa[--x[sa[i]-1]]+=sa[i]-1;
32        MS0(c,z); REP(i,n) uniq&=++c[s[i]]<2;
33        REP(i,z-1) c[i+1]+=c[i];
34        if(uniq) { REP(i,n) sa[--c[s[i]]]=i; return; }
35        for(int i=n-2;i>=0;i--)
36            t[i]=(s[i]==s[i+1]?t[i+1]:s[i]<s[i+1]);
37        MAGIC(REP1(i,1,n-1) if(t[i]&&!t[i-1]) sa[--x[s[i]]]=p[q[i]=nn++]=i);
38        REP(i,n) if(sa[i]&&t[sa[i]]&&t[sa[i]-1]){
39            neq=lst<0||memcmp(s+sa[i],s+lst,(p[q[sa[i]]+1]-sa[i])*sizeof(int));
40            ns[q[lst=sa[i]]]=nmzx+=neq;
41        }
42        sais(ns, nsa, p+nn, q+n, t+n, c+z, nn, nmzx+1);
43        MAGIC(for(int i=nn-1;i>=0;i--) sa[--x[s[p[nsa[i]]]]]=p[nsa[i]]);
44    } }sa;

```

```

45 int H[N],SA[N],RA[N];
46 void suffix_array(int* ip,int len){
47     // should padding a zero in the back
48     // ip is int array, len is array length
49     // ip[0..n-1] != 0, and ip[len]=0
50     ip[len++]=0; sa.build(ip,len,128);
51     memcpy(H,sa.hei+1,len<<2); memcpy(SA,sa._sa+1,len<<2);
52     ;
53     for(int i=0;i<len;i++) RA[i]=sa.r[i]-1;
54     // resulting height, sa array \in [0,len)
55 }

```

7.8 Minimum Rotation

```

1 //rotate(begin(s), begin(s)+minRotation(s), end(s))
2 int minRotation(string s) {
3     int a = 0, n = s.size(); s += s;
4     for(int b = 0; b < n; b++) for(int k = 0; k < n; k++) {
5         if(a + k == b || s[a + k] < s[b + k]) {
6             b += max(0, k - 1);
7             break; }
8         if(s[a + k] > s[b + k]) {
9             a = b;
10            break;
11        } }
12     return a; }

```

7.9 Aho Corasick

```

1 struct Acautomata{
2     struct Node{
3         int cnt;
4         Node *go[26], *fail, *dic;
5         Node(){
6             cnt = 0; fail = 0; dic=0;
7             memset(go,0,sizeof(go));
8         }
9     }pool[1048576],*root;
10    int nMem;
11    Node* new_Node(){
12        pool[nMem] = Node();
13        return &pool[nMem++];
14    }
15    void init() { nMem = 0; root = new_Node(); }
16    void add(const string &str) { insert(root,str,0); }
17    void insert(Node *cur, const string &str, int pos){
18        for(int i=pos;i<str.size();i++){
19            if(!cur->go[str[i]-'a'])
20                cur->go[str[i]-'a'] = new_Node();
21            cur=cur->go[str[i]-'a'];
22        }
23        cur->cnt++;
24    }
25    void make_fail(){
26        queue<Node*> que;
27        que.push(root);
28        while (!que.empty()){
29            Node* fr=que.front(); que.pop();
30            for (int i=0; i<26; i++){
31                if (fr->go[i]){
32                    Node *ptr = fr->fail;
33                    while (ptr && !ptr->go[i]) ptr = ptr->fail;
34                    fr->go[i]->fail=ptr=(ptr?ptr->go[i]:root);
35                    fr->go[i]->dic=(ptr->cnt?ptr:ptr->dic);
36                    que.push(fr->go[i]);
37                } } }
38 }AC;

```

8 Geometry

8.1 Basic Operations

```

1 typedef long long T;
2 // typedef long double T;
3 const long double eps = 1e-8;
4
5 short sgn(T x) {
6     if (abs(x) < eps) return 0;

```

```

7     return x < 0 ? -1 : 1;
8 }
9
10 struct Pt {
11     T x, y;
12     Pt(T _x=0, T _y=0):x(_x), y(_y) {}
13     Pt operator+(Pt a) { return Pt(x+a.x, y+a.y); }
14     Pt operator-(Pt a) { return Pt(x-a.x, y-a.y); }
15     Pt operator*(T a) { return Pt(x*a, y*a); }
16     Pt operator/(T a) { return Pt(x/a, y/a); }
17     T operator*(Pt a) { return x*a.x + y*a.y; }
18     T operator^(Pt a) { return x*a.y - y*a.x; }
19     bool operator<(Pt a)
20         { return x < a.x || (x == a.x && y < a.y); }
21     //return sgn(x-a.x) < 0 || (sgn(x-a.x) == 0 && sgn(y-a.
22         y) < 0); }
23     bool operator==(Pt a)
24         { return sgn(x-a.x) == 0 && sgn(y-a.y) == 0; }
25
26     Pt mv(Pt a, Pt b) { return b-a; }
27     T len2(Pt a) { return a*a; }
28     T dis2(Pt a, Pt b) { return len2(b-a); }
29
30     short ori(Pt a, Pt b) { return ((a^b)>0) - ((a^b)<0); }
31     bool onseg(Pt p, Pt l1, Pt l2) {
32         Pt a = mv(p, l1), b = mv(p, l2);
33         return ((a^b) == 0) && ((a^b) <= 0);
34     }

```

8.2 InPoly

```

1 short inPoly(Pt p) {
2     // 0=Bound 1=In -1=Out
3     REP(i, n) if (onseg(p, E[i], E[(i+1)%n])) return 0;
4     int cnt = 0;
5     REP(i, n) if (banana(p, Pt(p.x+1, p.y+2e9),
6         E[i], E[(i+1)%n])) cnt ^= 1;
7     return (cnt ? 1 : -1);
8 }

```

8.3 Sort by Angle

```

1 int ud(Pt a) { // up or down half plane
2     if (a.y > 0) return 0;
3     if (a.y < 0) return 1;
4     return (a.x >= 0 ? 0 : 1);
5 }
6 sort(ALL(E), [&](const Pt& a, const Pt& b){
7     if (ud(a) != ud(b)) return ud(a) < ud(b);
8     return (a^b) > 0;
9 });

```

8.4 Line Intersect Check

```

1 inline bool banana(Pt p1, Pt p2, Pt q1, Pt q2) {
2     if (onseg(p1, q1, q2) || onseg(p2, q1, q2) ||
3         onseg(q1, p1, p2) || onseg(q2, p1, p2)) {
4         return true;
5     }
6     Pt p = mv(p1, p2), q = mv(q1, q2);
7     return (ori(p, mv(p1, q1)) * ori(p, mv(p1, q2)) < 0 &&
8         ori(q, mv(q1, p1)) * ori(q, mv(q1, p2)) < 0);
9 }

```

8.5 Line Intersection

```

1 // T: long double
2 Pt bananaPoint(Pt p1, Pt p2, Pt q1, Pt q2) {
3     if (onseg(q1, p1, p2)) return q1;
4     if (onseg(q2, p1, p2)) return q2;
5     if (onseg(p1, q1, q2)) return p1;
6     if (onseg(p2, q1, q2)) return p2;
7     double s = abs(mv(p1, p2) ^ mv(p1, q1));
8     double t = abs(mv(p1, p2) ^ mv(p1, q2));
9     return q2 * (s/(s+t)) + q1 * (t/(s+t));
10 }

```

8.6 Convex Hull

```

1 vector<Pt> hull;
2 void convexHull() {
3     hull.clear(); sort(ALL(E));
4     REP(t, 2) {
5         int b = SZ(hull);
6         Each(ei, E) {
7             while (SZ(hull) - b >= 2 &&
8                 ori(mv(hull[SZ(hull)-2], hull.back()),
9                     mv(hull[SZ(hull)-2], ei)) == -1) {
10                 hull.pop_back();
11             }
12             hull.eb(ei);
13         }
14         hull.pop_back();
15         reverse(ALL(E));
16     } }

```

8.7 Lower Concave Hull

```

1 struct Line {
2     mutable ll m, b, p;
3     bool operator<(const Line& o) const { return m < o.m; }
4     bool operator<(ll x) const { return p < x; }
5 };
6
7 struct LineContainer : multiset<Line, less<>> {
8     // (for doubles, use inf = 1/.0, div(a,b) = a/b)
9     const ll inf = LLONG_MAX;
10    ll div(ll a, ll b) { // floored division
11        return a / b - ((a ^ b) < 0 && a % b); }
12    bool isect(iterator x, iterator y) {
13        if (y == end()) { x->p = inf; return false; }
14        if (x->m == y->m) x->p = x->b > y->b ? inf : -inf;
15        else x->p = div(y->b - x->b, x->m - y->m);
16        return x->p >= y->p;
17    }
18    void add(ll m, ll b) {
19        auto z = insert({m, b, 0}); y = z++, x = y;
20        while (isect(y, z)) z = erase(z);
21        if (x != begin() && isect(--x, y)) isect(x, y = erase(y));
22        while ((y = x) != begin() && (--x)->p >= y->p)
23            isect(x, erase(y));
24    }
25    ll query(ll x) {
26        assert(!empty());
27        auto l = *lower_bound(x);
28        return l.m * x + l.b;
29    }
30 };

```

8.8 Polygon Area

```

1 T dbarea(vector<Pt>& e) {
2     ll res = 0;
3     REP(i, SZ(e)) res += e[i]^e[(i+1)%SZ(e)];
4     return abs(res);
5 }

```

8.9 Pick's Theorem

Consider a polygon which vertices are all lattice points.
Let i = number of points inside the polygon.

Let b = number of points on the boundary of the polygon.

Then we have the following formula:

$$Area = i + \frac{b}{2} - 1$$

8.10 Minimum Enclosing Circle

```

1 Pt circumcenter(Pt A, Pt B, Pt C) {
2     // a1(x-A.x) + b1(y-A.y) = c1
3     // a2(x-A.x) + b2(y-A.y) = c2

```

```

4     // solve using Cramer's rule
5     T a1 = B.x-A.x, b1 = B.y-A.y, c1 = dis2(A, B)/2.0;
6     T a2 = C.x-A.x, b2 = C.y-A.y, c2 = dis2(A, C)/2.0;
7     T D = Pt(a1, b1) ^ Pt(a2, b2);
8     T Dx = Pt(c1, b1) ^ Pt(c2, b2);
9     T Dy = Pt(a1, c1) ^ Pt(a2, c2);
10    if (D == 0) return Pt(-INF, -INF);
11    return A + Pt(Dx/D, Dy/D);
12 }
13 Pt center; T r2;
14 void minEncloseCircle() {
15     mt19937 gen(chrono::steady_clock::now().
16         time_since_epoch().count());
17     shuffle(ALL(E), gen);
18     center = E[0], r2 = 0;
19     for (int i = 0; i < n; i++) {
20         if (dis2(center, E[i]) <= r2) continue;
21         center = E[i], r2 = 0;
22         for (int j = 0; j < i; j++) {
23             if (dis2(center, E[j]) <= r2) continue;
24             center = (E[i] + E[j]) / 2.0;
25             r2 = dis2(center, E[i]);
26             for (int k = 0; k < j; k++) {
27                 if (dis2(center, E[k]) <= r2) continue;
28                 center = circumcenter(E[i], E[j], E[k]);
29                 r2 = dis2(center, E[i]);
30             }
31         }
32     } }

```

8.11 PolyUnion

```

1 struct PY{
2     int n; Pt pt[5]; double area;
3     Pt& operator[](const int x){ return pt[x]; }
4     void init(){ //n,pt[0~n-1] must be filled
5         area=pt[n-1]^pt[0];
6         for(int i=0;i<n-1;i++) area+=pt[i]^pt[i+1];
7         if((area/=2)<0)reverse(pt,pt+n),area=-area;
8     }
9 };
10 PY py[500]; pair<double,int> c[5000];
11 inline double segP(Pt &p,Pt &p1,Pt &p2){
12     if(dcmp(p1.x-p2.x)==0) return (p.y-p1.y)/(p2.y-p1.y);
13     return (p.x-p1.x)/(p2.x-p1.x);
14 }
15 double polyUnion(int n){ //py[0~n-1] must be filled
16     int i,j,ii,jj,ta,tb,r,d; double z,w,s,sum=0,tc,td;
17     for(i=0;i<n;i++) py[i][py[i].n]=py[i][0];
18     for(i=0;i<n;i++){
19         for(ii=0;ii<py[i].n;ii++){
20             r=0;
21             c[r++]=make_pair(0.0,0); c[r++]=make_pair(1.0,0);
22             for(j=0;j<n;j++){
23                 if(i==j) continue;
24                 for(jj=0;jj<py[j].n;jj++){
25                     ta=dcmp(tri(py[i][ii],py[i][ii+1],py[j][jj]))
26                     ;
27                     tb=dcmp(tri(py[i][ii],py[i][ii+1],py[j][jj+1]))
28                     +1));
29                     if(ta==0 && tb==0){
30                         if((py[j][jj+1]-py[j][jj])*(py[i][ii+1]-py[i][ii])>0&&j<i){
31                             c[r++]=make_pair(segP(py[j][jj],py[i][ii],py[i][ii+1]),1);
32                             c[r++]=make_pair(segP(py[j][jj+1],py[i][ii+1],py[i][ii+1]),-1);
33                         }
34                     }else if(ta>=0 && tb<0){
35                         tc=tri(py[j][jj],py[j][jj+1],py[i][ii]);
36                         td=tri(py[j][jj],py[j][jj+1],py[i][ii+1]);
37                         c[r++]=make_pair(tc/(tc-td),1);
38                     }else if(ta<0 && tb>=0){
39                         tc=tri(py[j][jj],py[j][jj+1],py[i][ii]);
40                         td=tri(py[j][jj],py[j][jj+1],py[i][ii+1]);
41                         c[r++]=make_pair(tc/(tc-td),-1);
42                     }
43                 }
44             }
45             sort(c,c+r);
46             z=min(max(c[0].first,0.0),1.0); d=c[0].second; s
47             =0;

```

```

43     for(j=1;j<r;j++){
44         w=min(max(c[j].first,0.0),1.0);
45         if(!d) s+=w-z;
46         d+=c[j].second; z=w;
47     }
48     sum+=(py[i][ii]^py[i][ii+1])*s;
49 }
50 }
51 return sum/2;
52 }

```

8.12 Minkowski Sum

```

1  /* convex hull Minkowski Sum*/
2  #define INF 10000000000000LL
3  int pos( const Pt& tp ){
4      if( tp.Y == 0 ) return tp.X > 0 ? 0 : 1;
5      return tp.Y > 0 ? 0 : 1;
6  }
7  #define N 300030
8  Pt pt[ N ], qt[ N ], rt[ N ];
9  LL Lx,Rx;
10 int dn,un;
11 inline bool cmp( Pt a, Pt b ){
12     int pa=pos( a ),pb=pos( b );
13     if(pa==pb) return (a^b)>0;
14     return pa<pb;
15 }
16 int minkowskiSum(int n,int m){
17     int i,j,r,p,q,fi,fj;
18     for(i=1,p=0;i<n;i++){
19         if( pt[i].Y<pt[p].Y ||
20            (pt[i].Y==pt[p].Y && pt[i].X<pt[p].X) ) p=i; }
21     for(i=1,q=0;i<m;i++){
22         if( qt[i].Y<qt[q].Y ||
23            (qt[i].Y==qt[q].Y && qt[i].X<qt[q].X) ) q=i; }
24     rt[0]=pt[p]+qt[q];
25     r=1; i=p; j=q; fi=fj=0;
26     while(1){
27         if((fj&&j==q) ||
28            ( (!fi||i==p) &&
29              cmp(pt[(p+1)%n]-pt[p],qt[(q+1)%m]-qt[q]) ) ){
30             rt[r]=rt[r-1]+pt[(p+1)%n]-pt[p];
31             p=(p+1)%n;
32             fi=1;
33         }else{
34             rt[r]=rt[r-1]+qt[(q+1)%m]-qt[q];
35             q=(q+1)%m;
36             fj=1;
37         }
38         if(r<=1 || ((rt[r]-rt[r-1])^(rt[r-1]-rt[r-2]))
39                    !=0) r++;
40         else rt[r-1]=rt[r];
41         if(i==p && j==q) break;
42     }
43     return r-1;
44 }
45 void initInConvex(int n){
46     int i,p,q;
47     LL Ly,Ry;
48     Lx=INF; Rx=-INF;
49     for(i=0;i<n;i++){
50         if(pt[i].X<Lx) Lx=pt[i].X;
51         if(pt[i].X>Rx) Rx=pt[i].X;
52     }
53     Ly=Ry=INF;
54     for(i=0;i<n;i++){
55         if(pt[i].X==Lx && pt[i].Y<Ly){ Ly=pt[i].Y; p=i; }
56         if(pt[i].X==Rx && pt[i].Y<Ry){ Ry=pt[i].Y; q=i; }
57     }
58     for(dn=0,i=p;i!=q;i=(i+1)%n){ qt[dn++]=pt[i]; }
59     qt[dn]=pt[q]; Ly=Ry=-INF;
60     for(i=0;i<n;i++){
61         if(pt[i].X==Lx && pt[i].Y>Ly){ Ly=pt[i].Y; p=i; }
62         if(pt[i].X==Rx && pt[i].Y>Ry){ Ry=pt[i].Y; q=i; }
63     }
64     for(un=0,i=p;i!=q;i=(i+n-1)%n){ rt[un++]=pt[i]; }

```

```

64     rt[un]=pt[q];
65 }
66 inline int inConvex(Pt p){
67     int L,R,M;
68     if(p.X<Lx || p.X>Rx) return 0;
69     L=0;R=dn;
70     while(L<R-1){ M=(L+R)/2;
71         if(p.X<qt[M].X) R=M; else L=M; }
72     if(tri(qt[L],qt[R],p)<0) return 0;
73     L=0;R=un;
74     while(L<R-1){ M=(L+R)/2;
75         if(p.X<rt[M].X) R=M; else L=M; }
76     if(tri(rt[L],rt[R],p)>0) return 0;
77     return 1;
78 }
79 int main(){
80     int n,m,i;
81     Pt p;
82     scanf("%d",&n);
83     for(i=0;i<n;i++) scanf("%lld%lld",&pt[i].X,&pt[i].Y);
84     scanf("%d",&m);
85     for(i=0;i<m;i++) scanf("%lld%lld",&qt[i].X,&qt[i].Y);
86     n=minkowskiSum(n,m);
87     for(i=0;i<n;i++) pt[i]=rt[i];
88     scanf("%d",&m);
89     for(i=0;i<m;i++) scanf("%lld%lld",&qt[i].X,&qt[i].Y);
90     n=minkowskiSum(n,m);
91     for(i=0;i<n;i++) pt[i]=rt[i];
92     initInConvex(n);
93     scanf("%d",&m);
94     for(i=0;i<m;i++){
95         scanf("%lld %lld",&p.X,&p.Y);
96         p.X*=3; p.Y*=3;
97         puts(inConvex(p)?"YES":"NO");
98     }
99 }

```

9 Number Theory

9.1 Pollard's rho

```

1  from itertools import count
2  from math import gcd
3  from sys import stdin
4
5  for s in stdin:
6      number, x = int(s), 2
7      break2 = False
8      for cycle in count(1):
9          y = x
10         if break2:
11             break
12         for i in range(1 << cycle):
13             x = (x * x + 1) % number
14             factor = gcd(x - y, number)
15             if factor > 1:
16                 print(factor)
17                 break2 = True
18                 break

```

9.2 Miller Rabin

```

1  // n < 4,759,123,141      3 : 2, 7, 61
2  // n < 1,122,004,669,633  4 : 2, 13, 23, 1662803
3  // n < 3,474,749,660,383      6 : pimes <= 13
4  // n < 2^64              7 :
5  // 2, 325, 9375, 28178, 450775, 9780504, 1795265022
6  bool witness(ll a,ll n,ll u,int t){
7      if(!(a%n)) return 0;
8      ll x=myspow(a,u,n);
9      for(int i=0;i<t;i++){
10         ll nx=mul(x,x,n);
11         if(nx==1&&x!=1&x!=n-1) return 1;
12         x=nx;
13     }
14     return x!=1;

```

```

15 }
16 bool miller_rabin(ll n, int s=100) {
17     // iterate s times of witness on n
18     // return 1 if prime, 0 otherwise
19     if(n<2) return 0;
20     if(!(n&1)) return n == 2;
21     ll u=n-1; int t=0;
22     while(!(u&1)) u>>=1, t++;
23     while(s--){
24         ll a=randll()%(n-1)+1;
25         if(witness(a,n,u,t)) return 0;
26     }
27     return 1;
28 }

```

9.3 Fast Power

Note: $a^n \equiv a^{(n \bmod (p-1))} \pmod{p}$

9.4 Extend GCD

```

1 ll GCD;
2 pll extgcd(ll a, ll b) {
3     if (b == 0) {
4         GCD = a;
5         return pll{1, 0};
6     }
7     pll ans = extgcd(b, a % b);
8     return pll{ans.S, ans.F - a/b * ans.S};
9 }
10 pll bezout(ll a, ll b, ll c) {
11     bool negx = (a < 0), negy = (b < 0);
12     pll ans = extgcd(abs(a), abs(b));
13     if (c % GCD != 0) return pll{-LLINF, -LLINF};
14     return pll{ans.F * c/GCD * (negx ? -1 : 1),
15               ans.S * c/GCD * (negy ? -1 : 1)};
16 }
17 ll inv(ll a, ll p) {
18     if (p == 1) return -1;
19     pll ans = bezout(a % p, -p, 1);
20     if (ans == pll{-LLINF, -LLINF}) return -1;
21     return (ans.F % p + p) % p;
22 }

```

9.5 Mu + Phi

```

1 const int maxn = 1e6 + 5;
2 ll f[maxn];
3 vector<int> lpf, prime;
4 void build() {
5     lpf.clear(); lpf.resize(maxn, 1);
6     prime.clear();
7     f[1] = ...; /* mu[1] = 1, phi[1] = 1 */
8     for (int i = 2; i < maxn; i++) {
9         if (lpf[i] == 1) {
10             lpf[i] = i; prime.emplace_back(i);
11             f[i] = ...; /* mu[i] = 1, phi[i] = i-1 */
12         }
13         for (auto& j : prime) {
14             if (i*j >= maxn) break;
15             lpf[i*j] = j;
16             if (i % j == 0) f[i*j] = ...; /* 0, phi[i]*j */
17             else f[i*j] = ...; /* -mu[i], phi[i]*phi[j] */
18             if (j >= lpf[i]) break;
19         }
20     }
21 }

```

9.6 Other Formulas

- Inversion:
 $aa^{-1} \equiv 1 \pmod{m}$. a^{-1} exists iff $\gcd(a, m) = 1$.
- Linear inversion:
 $a^{-1} \equiv (m - \lfloor \frac{m}{a} \rfloor) \times (m \bmod a)^{-1} \pmod{m}$
- Fermat's little theorem:
 $a^p \equiv a \pmod{p}$ if p is prime.

- Euler function:

$$\phi(n) = n \prod_{p|n} \frac{p-1}{p}$$

- Euler theorem:

$$a^{\phi(n)} \equiv 1 \pmod{n} \text{ if } \gcd(a, n) = 1.$$

- Extended Euclidean algorithm:

$$ax + by = \gcd(a, b) = \gcd(b, a \bmod b) = \gcd(b, a - \lfloor \frac{a}{b} \rfloor b) = bx_1 + (a - \lfloor \frac{a}{b} \rfloor b)y_1 = ay_1 + b(x_1 - \lfloor \frac{a}{b} \rfloor y_1)$$

- Divisor function:

$$\sigma_x(n) = \sum_{d|n} d^x. \quad n = \prod_{i=1}^r p_i^{a_i}.$$

$$\sigma_x(n) = \prod_{i=1}^r \frac{p_i^{(a_i+1)x} - 1}{p_i^x - 1} \text{ if } x \neq 0. \quad \sigma_0(n) = \prod_{i=1}^r (a_i + 1).$$

- Chinese remainder theorem (Coprime Moduli):

$$x \equiv a_i \pmod{m_i}.$$

$$M = \prod m_i. \quad M_i = M/m_i. \quad t_i = M_i^{-1}.$$

$$x = kM + \sum a_i t_i M_i, \quad k \in \mathbb{Z}.$$

- Chinese remainder theorem:

$$x \equiv a_1 \pmod{m_1}, x \equiv a_2 \pmod{m_2} \Rightarrow x = m_1 p + a_1 = m_2 q + a_2 \Rightarrow m_1 p - m_2 q = a_2 - a_1$$

Solve for (p, q) using ExtGCD.

$$x \equiv m_1 p + a_1 \equiv m_2 q + a_2 \pmod{\text{lcm}(m_1, m_2)}$$

- Avoiding Overflow: $ca \bmod cb = c(a \bmod b)$

- Dirichlet Convolution: $(f * g)(n) = \sum_{d|n} f(d)g(n/d)$

- Important Multiplicative Functions + Properties:

- $\epsilon(n) = [n = 1]$
- $1(n) = 1$
- $id(n) = n$
- $\mu(n) = 0$ if n has squared prime factor
- $\mu(n) = (-1)^k$ if $n = p_1 p_2 \cdots p_k$
- $\epsilon = \mu * 1$
- $\phi = \mu * id$
- $[n = 1] = \sum_{d|n} \mu(d)$
- $[gcd = 1] = \sum_{d|gcd} \mu(d)$

- Möbius inversion: $f = g * 1 \Leftrightarrow g = f * \mu$

9.7 Polynomial

```

1 const int maxk = 20;
2 const int maxn = 1<<maxk;
3 const ll LINF = 1e18;
4
5 /* P = r*2^k + 1
6 P          r    k    g
7 998244353  119  23    3
8 1004535809  479  21    3
9
10 P          r    k    g
11 3          1    1    2
12 5          1    2    2
13 17         1    4    3
14 97         3    5    5
15 193        3    6    5
16 257        1    8    3
17 7681       15    9   17
18 12289      3   12   11
19 40961      5   13    3
20 65537      1   16    3
21 786433     3   18   10
22 5767169   11   19    3
23 7340033    7   20    3
24 23068673   11   21    3
25 104857601  25   22    3
26 167772161  5   25    3
27 469762049  7   26    3
28 1004535809 479  21    3
29 2013265921 15  27   31

```



```

30 2281701377      17 27 3
31 3221225473      3 30 5
32 75161927681     35 31 3
33 77309411329      9 33 7
34 206158430209     3 36 22
35 2061584302081    15 37 7
36 2748779069441     5 39 3
37 6597069766657     3 41 5
38 39582418599937     9 42 5
39 79164837199873     9 43 5
40 263882790666241    15 44 7
41 1231453023109121   35 45 3
42 1337006139375617   19 46 3
43 3799912185593857   27 47 5
44 4222124650659841    15 48 19
45 7881299347898369     7 50 6
46 31525197391593473    7 52 3
47 180143985094819841    5 55 6
48 1945555039024054273 27 56 5
49 4179340454199820289 29 57 3
50 9097271247288401921 505 54 6 */
51
52 const int g = 3;
53 const ll MOD = 998244353;
54
55 ll pw(ll a, ll n) { /* fast pow */ }
56
57 #define siz(x) (int)x.size()
58
59 template<typename T>
60 vector<T>& operator+=(vector<T>& a, const vector<T>& b) {
61     if (siz(a) < siz(b)) a.resize(siz(b));
62     for (int i = 0; i < min(siz(a), siz(b)); i++) {
63         a[i] += b[i];
64         a[i] -= a[i] >= MOD ? MOD : 0;
65     }
66     return a;
67 }
68
69 template<typename T>
70 vector<T>& operator--(vector<T>& a, const vector<T>& b) {
71     if (siz(a) < siz(b)) a.resize(siz(b));
72     for (int i = 0; i < min(siz(a), siz(b)); i++) {
73         a[i] -= b[i];
74         a[i] += a[i] < 0 ? MOD : 0;
75     }
76     return a;
77 }
78
79 template<typename T>
80 vector<T> operator-(const vector<T>& a) {
81     vector<T> ret(siz(a));
82     for (int i = 0; i < siz(a); i++) {
83         ret[i] = -a[i] < 0 ? -a[i] + MOD : -a[i];
84     }
85     return ret;
86 }
87
88 vector<ll> X, iX;
89 vector<int> rev;
90
91 void init_ntt() {
92     X.clear(); X.resize(maxn, 1); // x1 = g^((p-1)/n)
93     iX.clear(); iX.resize(maxn, 1);
94
95     ll u = pw(g, (MOD-1)/maxn);
96     ll iu = pw(u, MOD-2);
97
98     for (int i = 1; i < maxn; i++) {
99         X[i] = X[i-1] * u;
100         iX[i] = iX[i-1] * iu;
101         if (X[i] >= MOD) X[i] %= MOD;
102         if (iX[i] >= MOD) iX[i] %= MOD;
103     }
104
105     rev.clear(); rev.resize(maxn, 0);
106     for (int i = 1, hb = -1; i < maxn; i++) {
107         if (!(i & (i-1))) hb++;
108         rev[i] = rev[i ^ (1<<hb)] | (1<<(maxk-hb-1));
109     } }
110
111 template<typename T>
112 void NTT(vector<T>& a, bool inv=false) {
113
114     int _n = (int)a.size();
115     int k = __lg(_n) + ((1<<__lg(_n)) != _n);
116     int n = 1<<k;
117     a.resize(n, 0);
118
119     short shift = maxk-k;
120     for (int i = 0; i < n; i++)
121         if (i > (rev[i]>>shift))
122             swap(a[i], a[rev[i]>>shift]);
123
124     for (int len = 2, half = 1, div = maxn>>1; len <= n
125         ; len<=1, half<=1, div>>=1) {
126         for (int i = 0; i < n; i += len) {
127             for (int j = 0; j < half; j++) {
128                 T u = a[i+j];
129                 T v = a[i+j+half] * (inv ? iX[j*div] :
130                     X[j*div]) % MOD;
131                 a[i+j] = (u+v >= MOD ? u+v-MOD : u+v);
132                 a[i+j+half] = (u-v < 0 ? u-v+MOD : u-v);
133             }
134         }
135     }
136
137     if (inv) {
138         T dn = pw(n, MOD-2);
139         for (auto& x : a) {
140             x *= dn;
141             if (x >= MOD) x %= MOD;
142         }
143     }
144 }
145
146 template<typename T>
147 inline void resize(vector<T>& a) {
148     int cnt = (int)a.size();
149     for (; cnt > 0; cnt--) if (a[cnt-1]) break;
150     a.resize(max(cnt, 1));
151 }
152
153 template<typename T>
154 vector<T>& operator*=(vector<T>& a, vector<T> b) {
155     int na = (int)a.size();
156     int nb = (int)b.size();
157     a.resize(na + nb - 1, 0);
158     b.resize(na + nb - 1, 0);
159
160     NTT(a); NTT(b);
161     for (int i = 0; i < (int)a.size(); i++) {
162         a[i] *= b[i];
163         if (a[i] >= MOD) a[i] %= MOD;
164     }
165     NTT(a, true);
166     resize(a);
167     return a;
168 }
169
170 template<typename T>
171 void inv(vector<T>& ia, int N) {
172     vector<T> _a(move(ia));
173     ia.resize(1, pw(_a[0], MOD-2));
174     vector<T> a(1, -_a[0] + (-_a[0] < 0 ? MOD : 0));
175
176     for (int n = 1; n < N; n<=1) {
177         // n -> 2*n
178         // ia' = ia(2-a*ia);
179
180         for (int i = n; i < min(siz(_a), (n<<1)); i++)
181             a.emplace_back(-_a[i] + (-_a[i] < 0 ? MOD : 0));
182
183         vector<T> tmp = ia;
184         ia *= a;
185         ia.resize(n<<1);
186         ia[0] = ia[0] + 2 >= MOD ? ia[0] + 2 - MOD : ia[0] + 2;
187         ia *= tmp;
188         ia.resize(n<<1);
189     }
190     ia.resize(N);
191 }

```



```

187
188 template<typename T>
189 void mod(vector<T>& a, vector<T>& b) {
190     int n = (int)a.size()-1, m = (int)b.size()-1;
191     if (n < m) return;
192
193     vector<T> ra = a, rb = b;
194     reverse(ra.begin(), ra.end()); ra.resize(min(n+1, n
195         -m+1));
196     reverse(rb.begin(), rb.end()); rb.resize(min(m+1, n
197         -m+1));
198
199     inv(rb, n-m+1);
200
201     vector<T> q = move(ra);
202     q *= rb;
203     q.resize(n-m+1);
204     reverse(q.begin(), q.end());
205
206     q *= b;
207     a -= q;
208     resize(a);
209 }
210
211 /* Kitamasa Method (Fast Linear Recurrence):
212 Find a[K] (Given a[j] = c[0]a[j-N] + ... + c[N-1]a[j
213 -1])
214 Let B(x) = x^N - c[N-1]x^(N-1) - ... - c[1]x^1 - c[0]
215 Let R(x) = x^K mod B(x) (get x^K using fast pow and
216 use poly mod to get R(x))
217 Let r[i] = the coefficient of x^i in R(x)
218 => a[K] = a[0]r[0] + a[1]r[1] + ... + a[N-1]r[N-1] */

```

10 Linear Algebra

10.1 Gaussian-Jordan Elimination

```

1 int n; vector<vector<ll>> > v;
2 void gauss(vector<vector<ll>>& v) {
3     int r = 0;
4     for (int i = 0; i < n; i++) {
5         bool ok = false;
6         for (int j = r; j < n; j++) {
7             if (v[j][i] == 0) continue;
8             swap(v[j], v[r]);
9             ok = true; break;
10        }
11        if (!ok) continue;
12        ll div = inv(v[r][i]);
13        for (int j = 0; j < n+1; j++) {
14            v[r][j] *= div;
15            if (v[r][j] >= MOD) v[r][j] %= MOD;
16        }
17        for (int j = 0; j < n; j++) {
18            if (j == r) continue;
19            ll t = v[j][i];
20            for (int k = 0; k < n+1; k++) {
21                v[j][k] -= v[r][k] * t % MOD;
22                if (v[j][k] < 0) v[j][k] += MOD;
23            }
24        }
25    }
26 }

```

10.2 Determinant

1. Use GJ Elimination, if there's any row consists of only 0, then $\det = 0$, otherwise $\det = \text{product of diagonal elements}$.

2. Properties of \det :

- Transpose: Unchanged
- Row Operation 1 - Swap 2 rows: $-\det$
- Row Operation 2 - $k\vec{r}_i$: $k \times \det$
- Row Operation 3 - $k\vec{r}_i$ add to \vec{r}_j : Unchanged

11 Flow / Matching

11.1 Dinic

```

1 struct Dinic
2 {
3     int n,s,t,level[N],iter[N];
4     struct edge{int to, cap, rev;};
5     vector<edge> path[N];
6     void init(int _n,int _s,int _t)
7     {
8         n=_n,s=_s,t=_t;
9         FOR(i,0,n+1)path[i].clear();
10    }
11    void add(int a,int b,int c)
12    {
13        edge now;
14        now.to=b,now.cap=c,now.rev=sz(path[b]);
15        path[a].pb(now);
16        now.to=a,now.cap=0,now.rev=sz(path[a])-1;
17        path[b].pb(now);
18    }
19    void bfs()
20    {
21        memset(level,-1,sizeof(level));
22        level[s]=0;
23        queue<int>q;q.push(s);
24        while(q.size())
25        {
26            int now=q.front();q.pop();
27            for(edge e:path[now])
28            {
29                if(e.cap>0&&level[e.to]==-1)
30                {
31                    level[e.to]=level[now]+1;
32                    q.push(e.to);
33                }
34            }
35        }
36    }
37    int dfs(int now,int flow)
38    {
39        if(now==t)return flow;
40        for(int &i=iter[now];i<sz(path[now]);i++)
41        {
42            edge &e=path[now][i];
43            if(e.cap>0&&level[e.to]==level[now]+1)
44            {
45                int res=dfs(e.to,min(flow,e.cap));
46                if(res>0)
47                {
48                    e.cap-=res;
49                    path[e.to][e.rev].cap+=res;
50                    return res;
51                }
52            }
53        }
54        return 0;
55    }
56    int dinic()
57    {
58        int res=0;
59        while(true)
60        {
61            bfs();
62            if(level[t]==-1)break;
63            memset(iter,0,sizeof(iter));
64            int now=0;
65            while((now=dfs(s,INF))>0)res+=now;
66        }
67        return res;
68    }
69 };

```

11.2 ISAP

```

1 #define SZ(c) ((int)(c).size())
2 struct Maxflow{
3     static const int MAXV=50010;
4     static const int INF =1000000;
5     struct Edge{

```

```

6   int v,c,r;
7   Edge(int _v,int _c,int _r):v(_v),c(_c),r(_r){}
8   };
9   int s,t; vector<Edge> G[MAXV];
10  int iter[MAXV],d[MAXV],gap[MAXV],tot;
11  void init(int n,int _s,int _t){
12      tot=n,s=_s,t=_t;
13      for(int i=0;i<=tot;i++){
14          G[i].clear(); iter[i]=d[i]=gap[i]=0;
15      }
16  }
17  void addEdge(int u,int v,int c){
18      G[u].push_back(Edge(v,c,SZ(G[v])));
19      G[v].push_back(Edge(u,0,SZ(G[u])-1));
20  }
21  int DFS(int p,int flow){
22      if(p==t) return flow;
23      for(int &i=iter[p];i<SZ(G[p]);i++){
24          Edge &e=G[p][i];
25          if(e.c>0&&d[p]==d[e.v]+1){
26              int f=DFS(e.v,min(flow,e.c));
27              if(f){ e.c-=f; G[e.v][e.r].c+=f; return f; }
28          }
29      }
30      if(--gap[d[p]]==0) d[s]=tot;
31      else{ d[p]++; iter[p]=0; ++gap[d[p]]; }
32      return 0;
33  }
34  int flow(){
35      int res=0;
36      for(res=0,gap[0]=tot;d[s]<tot;res+=DFS(s,INF));
37      return res;
38  } // reset: set iter,d,gap to 0
39  } flow;

```

11.3 MCMF

```

1  struct MCMF
2  {
3      int n,s,t,par[N+5],p_i[N+5],dis[N+5],vis[N+5];
4      struct edge{int to,cap,rev,cost;};
5      vector<edge>path[N];
6      void init(int _n,int _s,int _t)
7      {
8          n=_n,s=_s,t=_t;
9          FOR(i,0,2*n+5)par[i]=p_i[i]=vis[i]=0;
10     }
11     void add(int a,int b,int c,int d)
12     {
13         path[a].pb({b,c,sz(path[b]),d});
14         path[b].pb({a,0,sz(path[a])-1,-d});
15     }
16     void spfa()
17     {
18         FOR(i,0,n*2+5)dis[i]=INF,vis[i]=0;
19         dis[s]=0;
20         queue<int>q;q.push(s);
21         while(!q.empty())
22         {
23             int now=q.front();
24             q.pop();
25             vis[now]=0;
26             for(int i=0;i<sz(path[now]);i++)
27             {
28                 edge e=path[now][i];
29                 if(e.cap>0&&dis[e.to]>dis[now]+e.cost)
30                 {
31                     dis[e.to]=dis[now]+e.cost;
32                     par[e.to]=now;
33                     p_i[e.to]=i;
34                     if(vis[e.to]==0)
35                     {
36                         vis[e.to]=1;
37                         q.push(e.to);
38                     }
39                 }
40             }
41         }
42     }
43     pii flow()
44     {

```

```

45     int flow=0,cost=0;
46     while(true)
47     {
48         spfa();
49         if(dis[t]==INF)break;
50         int mn=INF;
51         for(int i=t;i!=s;i=par[i])
52             mn=min(mn,path[par[i]][p_i[i]].cap);
53         flow+=mn;cost+=dis[t]*mn;
54         for(int i=t;i!=s;i=par[i])
55         {
56             edge &now=path[par[i]][p_i[i]];
57             now.cap-=mn;
58             path[i][now.rev].cap+=mn;
59         }
60     }
61     return mp(flow,cost);
62 }
63 };

```

11.4 Hopcroft-Karp

```

1  struct HopcroftKarp {
2      // id: X = [1, nx], Y = [nx+1, nx+ny]
3      int n, nx, ny, m, MXCNT;
4      vector<vector<int>> g;
5      vector<int> mx, my, dis, vis;
6      void init(int nnx, int nny, int mm) {
7          nx = nnx, ny = nny, m = mm;
8          n = nx + ny + 1;
9          g.clear(); g.resize(n);
10     }
11     void add(int x, int y) {
12         g[x].emplace_back(y);
13         g[y].emplace_back(x);
14     }
15     bool dfs(int x) {
16         vis[x] = true;
17         Each(y, g[x]) {
18             int px = my[y];
19             if (px == -1 ||
20                 (dis[px] == dis[x]+1 &&
21                  !vis[px] && dfs(px))) {
22                 mx[x] = y;
23                 my[y] = x;
24                 return true;
25             }
26         }
27         return false;
28     }
29     void get() {
30         mx.clear(); mx.resize(n, -1);
31         my.clear(); my.resize(n, -1);
32     }
33     while (true) {
34         queue<int> q;
35         dis.clear(); dis.resize(n, -1);
36         for (int x = 1; x <= nx; x++){
37             if (mx[x] == -1) {
38                 dis[x] = 0;
39                 q.push(x);
40             }
41         }
42         while (!q.empty()) {
43             int x = q.front(); q.pop();
44             Each(y, g[x]) {
45                 if (my[y] != -1 && dis[my[y]] ==
46                     -1) {
47                     dis[my[y]] = dis[x] + 1;
48                     q.push(my[y]);
49                 }
50             }
51         }
52         bool brk = true;
53         vis.clear(); vis.resize(n, 0);
54         for (int x = 1; x <= nx; x++)
55             if (mx[x] == -1 && dfs(x))
56                 brk = false;
57     }
58     if (brk) break;

```

```

59     }
60     MXCNT = 0;
61     for (int x = 1; x <= nx; x++) if (mx[x] != -1)
62         MXCNT++;
63 } hk;

```

11.5 Cover / Independent Set

1 V(E) Cover: choose some V(E) to cover all E(V)
2 V(E) Independ: set of V(E) not adj to each other

3
4 M = Max Matching
5 Cv = Min V Cover
6 Ce = Min E Cover
7 Iv = Max V Ind
8 Ie = Max E Ind (equiv to M)

9
10 M = Cv (Konig Theorem)
11 Iv = V \ Cv
12 Ce = V - M

13 Construct Cv:
14 1. Run Dinic
15 2. Find s-t min cut
16 3. Cv = {X in T} + {Y in S}

11.6 KM

```

1 struct KM
2 {
3     int n,mx[1005],my[1005],pa[1005];
4     int g[1005][1005],lx[1005],ly[1005],sy[1005];
5     bool vx[1005],vy[1005];
6     void init(int _n)
7     {
8         n=_n;
9         FOR(i,1,n+1)fill(g[i],g[i]+1+n,0);
10    }
11    void add(int a,int b,int c){g[a][b]=c;}
12    void augment(int y)
13    {
14        for(int x,z;y;z=x,pa[y]=x,my[y]=x,mx[x]=y;
15            ]=y;
16    }
17    void bfs(int st)
18    {
19        FOR(i,1,n+1)sy[i]=INF,vx[i]=vy[i]=0;
20        queue<int>q;q.push(st);
21        for(;;)
22        {
23            while(!q.empty())
24            {
25                int x=q.front();q.pop();
26                vx[x]=1;
27                FOR(y,1,n+1)if(!vy[y])
28                {
29                    int t=lx[x]+ly[y]-g[x][y];
30                    if(t==0)
31                    {
32                        pa[y]=x;
33                        if(!my[y]){augment(y);return;}
34                        vy[y]=1, q.push(my[y]);
35                    }
36                    else if(sy[y]>t)pa[y]=x,sy[y]=t;
37                }
38            }
39            int cut=INF;
40            FOR(y,1,n+1)if(!vy[y]&&cut>sy[y])cut=sy[y];
41            FOR(j,1,n+1)
42            {
43                if(vx[j])lx[j]-=cut;
44                if(vy[j])ly[j]+=cut;
45                else sy[j]-=cut;
46            }
47            FOR(y,1,n+1)
48            {
49                if(!vy[y]&&sy[y]==0)
50                {

```

```

51         vy[y]=1;q.push(my[y]);
52     }
53 }
54 }
55 }
56 int solve()
57 {
58     fill(mx,mx+n+1,0);fill(my,my+n+1,0);
59     fill(ly,ly+n+1,0);fill(lx,lx+n+1,0);
60     FOR(x,1,n+1)FOR(y,1,n+1)lx[x]=max(lx[x],g[x][y]);
61     FOR(x,1,n+1)bfs(x);
62     int ans=0;
63     FOR(y,1,n+1)ans+=g[my[y]][y];
64     return ans;
65 }
66 };

```

12 Combinatorics

12.1 Catalan Number

$$C_0 = 1, C_n = \sum_{i=0}^{n-1} C_i C_{n-1-i}, C_n = C_n^{2n} - C_{n-1}^{2n}$$

0	1	1	2	5
4	14	42	132	429
8	1430	4862	16796	58786
12	208012	742900	2674440	9694845

12.2 Burnside's Lemma

Let X be the original set.
Let G be the group of operations acting on X .
Let X^g be the set of x not affected by g .
Let X/G be the set of orbits.
Then the following equation holds:

$$|X/G| = \frac{1}{|G|} \sum_{g \in G} |X^g|$$

13 Special Numbers

13.1 Fibonacci Series

1	1	1	2	3
5	5	8	13	21
9	34	55	89	144
13	233	377	610	987
17	1597	2584	4181	6765
21	10946	17711	28657	46368
25	75025	121393	196418	317811
29	514229	832040	1346269	2178309
33	3524578	5702887	9227465	14930352

$$f(45) \approx 10^9, f(88) \approx 10^{18}$$

13.2 Prime Numbers

• First 50 prime numbers:

1	2	3	5	7	11
6	13	17	19	23	29
11	31	37	41	43	47
16	53	59	61	67	71
21	73	79	83	89	97
26	101	103	107	109	113
31	127	131	137	139	149
36	151	157	163	167	173
41	179	181	191	193	197
46	199	211	223	227	229

- Very large prime numbers:
1000001333 1000500889 2500001909
2000000659 900004151 850001359
- $\pi(n) \equiv$ Number of primes $\leq n \approx n/((\ln n) - 1)$
 $\pi(100) = 25, \pi(200) = 46$
 $\pi(500) = 95, \pi(1000) = 168$
 $\pi(2000) = 303, \pi(4000) = 550$
 $\pi(10^4) = 1229, \pi(10^5) = 9592$
 $\pi(10^6) = 78498, \pi(10^7) = 664579$