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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

## 1.2 OwO

- Enjoy The Game!

# 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;

void init() {
    ;
}

void solve() {
    ;
}
```

```

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 syn on
2 se ai nu rnu ru cul mouse=a
3 se cin et ts=4 sw=4 sts=4
4 colo desert
5 set autochdir
6 no <F5> :!./a.out<CR>
7 no <F9> :!~/run.sh %:p:h %:p:t<CR>

```

## 2.3 Run.sh

```

1 clear
2 echo File Location: $1
3 echo File Name: $2
4 extension="${2##*}."
5 basename="${2%.*}"
6
7 if [ ! -f "$1/input" ]; then
8     echo "Input not exists, create an empty one."
9     echo "" >> $1/input
10 fi
11
12 echo =====
13 if [[ $extension == "cpp" || $extension == "c" ||
14     $extension == "ts" ]]; then
15     echo Start compiling \"$2\"...
16     echo -----
17     if [ $extension == "cpp" ]; then
18         g++ $1/$2 -I ~/Desktop/cpp/include -std=c++23 -fsanitize=address,undefined -Ofast -Wall -Wextra -o$1/a.out
19     fi
20     if [ $extension == "c" ]; then
21         gcc $1/$2 -std=c17 -g -fsanitize=address,undefined -Ofast -Wall -Wextra -o$1/a.out
22     fi
23     if [ $extension == "ts" ]; then
24         if [ ! -f "$1/tsconfig.json" ]; then
25             npx tsc -p $1 --init
26         fi
27         npx tsc -p $1
28     fi
29     if [ "$?" -ne 0 ]; then
30         exit 1
31     fi
32 fi
33
34 echo Start executing \"$2\"...
35 echo =====
36 echo Input file:
37 echo -----
38 cat $1/input
39 echo =====
40 declare startTime=`date +%s%N`
41 if [[ $extension == "cpp" || $extension == "c" ]]; then
42     $1/a.out < $1/input > $1/output
43 fi
44 if [ $extension == "py" ]; then

```

```

45     python $1/$2 < $1/input > $1/output
46 fi
47 if [[ $extension == "js" || $extension == "ts" ]]; then
48     if [ ! -f "$1/package.json" ]; then
49         echo "Remember to npm init"
50     fi
51     node $1/${basename}.js < $1/input > $1/output
52 fi
53 declare endTime=`date +%s%N`
54 delta=`expr $endTime - $startTime`
55 delta=`expr $delta / 1000000`
56 if [ "$?" -ne 0 ]; then
57     exit 1
58 fi
59 echo "Program ended in $delta ms with the return value $?"
60 cat $1/output

```

## 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; // Big First
18 __gnu_pbds::priority_queue<int, greater<int> > small_q; // Small First
19 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 constexpr int maxn=2e5+5;
2 int arr[(maxn+1)<<2];
3 #define m ((l+r)>>1)
4 void build(V<int>& v,int i=1,int l=0,int r=maxn){
5     if((int)v.size()<=l) return;
6     if(r-l==1){arr[i]=v[l];return;}
7     build(v,i<<1,l,m),build(v,i<<1|1,m,r);
8     arr[i]=max(arr[i<<1],arr[i<<1|1]);
9 }
10 void modify(int p,int k,int i=1,int l=0,int r=maxn){
11     if(p<1||r<=p) return;
12     if(r-l==1){arr[i]=k;return;}
13     if(p<m) modify(p,k,i<<1,l,m);
14     else modify(p,k,i<<1|1,m,r);
15     arr[i]=max(arr[i<<1],arr[i<<1|1]);
16 }
17 int query(int ql,int qr,int i=1,int l=0,int r=maxn){
18     if(qr<=l||r<=ql) return 0;
19     if(ql<=l&&r<=qr) return arr[i];
20     if(qr<=m) return query(ql,qr,i<<1,l,m);
21     if(m<=ql) return query(ql,qr,i<<1|1,m,r);
22     return max(query(ql,qr,i<<1,l,m),query(ql,qr,i
        <<1|1,m,r));
23 }
24 #undef m
25 inline void solve(){
26     int n,q;cin>>n>>q;
27     V<int> v(n);
28     for(auto& i:v)
29         cin>>i;
30     V<V<int>> e(n);
31     for(int i=1;i<n;i++){
32         int a,b;cin>>a>>b,a--,b--;
33         e[a].emplace_back(b);
34         e[b].emplace_back(a);
35     }
36     V<int> d(n,0),f(n,0),sz(n,1),son(n,-1);
37     F<void(int,int)> dfs1=
38     [&](int x,int pre){
39         for(auto i:e[x]) if(i!=pre){
40             d[i]=d[x]+1,f[i]=x;
41             dfs1(i,x),sz[x]+=sz[i];
42             if(!~son[x]||sz[son[x]]<sz[i])
43                 son[x]=i;
44         }
45     };dfs1(0,0);
46     V<int> top(n,0),dfn(n,-1),rnk(n,0);
47     F<void(int,int)> dfs2=
48     [&](int x,int t){
49         static int cnt=0;
50         dfn[x]=cnt++,rnk[dfn[x]]=x,top[x]=t;
51         if(!~son[x]) return;
52         dfs2(son[x],t);

```

```

53     for(auto i:e[x])
54         if(!~dfn[i]) dfs2(i,i);
55     };dfs2(0,0);
56     V<int> dfnv(n);
57     for(int i=0;i<n;i++)
58         dfnv[dfn[i]]=v[i];
59     build(dfnv);
60     while(q--){
61         int op,a,b;cin>>op>>a>>b;
62         switch(op){
63             case 1:{
64                 modify(dfn[a-1],b);
65             }break;
66             case 2:{
67                 a--,b--;
68                 int ans=0;
69                 while(top[a]!=top[b]){
70                     if(d[top[a]]>d[top[b]]) swap(a,b);
71                     ans=max(ans,query(dfn[top[b]],dfn[b]+1)
72                                     );
73                     b=f[top[b]];
74                 }
75                 if(dfn[a]>dfn[b]) swap(a,b);
76                 ans=max(ans,query(dfn[a],dfn[b]+1));
77                 cout<<ans<<endl;
78             }break;
79         }
80     }

```

## 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 : {1, 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>::max();
22     if (r - l == 1) return arr[i](x);
23     return max({arr[i](x), query(x, i << 1, l, m), query(
24         x, i << 1 | 1, m, r)});
25 }
26 #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);
69         switch (op) {
70             case 1:
71                 s[(((ll)a << 32) | b).push_back(i);
72                 break;
73             case 2:
74                 auto tmp = s[(((ll)a << 32) | b).back();
75                 s[(((ll)a << 32) | b).pop_back();
76                 insert(tmp, i, P<int> {a, b});
77         }
78     }
79     for (auto [p, v] : s) {
80         int a = p >> 32, b = p & -1;
81         while (v.size()) {
82             insert(v.back(), q, P<int> {a, b});
83             v.pop_back();
84         }
85     }
86     V<int> ans(q);
87     traversal(ans);
88     for (auto i : ans)
89         cout << i << ' ';
90     cout << endl;
91 }

```

## 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] - p) {
17             dp[0][i] = mp(dp[1][i-1].F + a[i] - p, dp[1][i-1].S+1);
18         } else {
19             dp[0][i] = mp(dp[0][i-1].F, min(dp[0][i-1].S, dp[1][i-1].S+1));
20         }
21         if (dp[0][i-1].F - a[i] > dp[1][i-1].F) {
22             dp[1][i] = mp(dp[0][i-1].F - a[i], dp[0][i-1].S);
23         } else if (dp[0][i-1].F - a[i] < dp[1][i-1].F) {
24             dp[1][i] = dp[1][i-1];
25         } else {
26             dp[1][i] = mp(dp[1][i-1].F, min(dp[0][i-1].S, dp[1][i-1].S));
27         }
28     }
29     return dp[0][n-1];
30 }
31 void solve() {
32     ll l = 0, r = 1e7;
33     pll res = calc(0);
34     if (res.S <= k) return cout << res.F << endl, void();
35     while (l < r) {
36         ll mid = (l+r)>>1;
37         res = calc(mid);
38         if (res.S <= k) r = mid;
39         else l = mid+1;
40     }
41     res = calc(l);
42     cout << res.F + k*1 << endl;
43 }

```

## 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         // Bellman-Ford
47         queue<int> q;
48         vector<int> pa;
49         void BellmanFord(vector<int>& src) {
50             dis.assign(n+1, LINF);
51             negCycle.assign(n+1, false);
52             pa.assign(n+1, -1);
53
54             for (auto& s : src) dis[s] = 0;
55
56             for (int rlx = 1; rlx <= n; rlx++) {
57                 for (int u = 1; u <= n; u++) {
58                     if (dis[u] == LINF) continue; // Important
59                     //
60                     for (auto& e : g[u]) {
61                         int v = e.first; ll w = e.second;
62                         if (dis[v] > dis[u] + w) {
63                             dis[v] = dis[u] + w;
64                             pa[v] = u;
65                             if (rlx == n) negCycle[v] = true;
66                         }
67                     }
68                 }
69             }
70
71             // Negative Cycle Detection
72             void NegCycleDetect() {
73                 /* No Neg Cycle: NO
74                 Exist Any Neg Cycle:
75                 YES
76                 v0 v1 v2 ... vk v0 */
77
78                 vector<int> src;
79                 for (int i = 1; i <= n; i++)
80                     src.emplace_back(i);
81
82                 SPFA(src);
83                 // BellmanFord(src);
84
85                 int ptr = -1;
86                 for (int i = 1; i <= n; i++) if (negCycle[i]) {
87                     ptr = i; break;
88                 }
89
90                 if (ptr == -1) { return cout << "NO" << endl, void(); }
91
92                 cout << "YES\n";
93                 vector<int> ans;
94                 vector<bool> vis(n+1, false);
95
96                 while (true) {
97                     ans.emplace_back(ptr);
98                     if (vis[ptr]) break;
99                     vis[ptr] = true;
100                     ptr = pa[ptr];
101                 }
102                 reverse(ans.begin(), ans.end());
103
104                 vis.assign(n+1, false);
105                 for (auto& x : ans) {
106                     cout << x << ' ';
107                     if (vis[x]) break;
108                     vis[x] = true;
109                 }
110             }
111         }
112     }

```

```

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 >> n >> m;
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.pb(no(u)^v);
31     g[no(u)].pb(ecnt++);
32     E.pb(no(v)^u);
33     g[no(v)].pb(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);

```

```

76         if (sv == '-') v = no(v);
77         clause(u, v);
78     }
79
80     FOR(i, 1, 2*n+1, 1) {
81         if (!in[i]) dfs(i);
82     }
83
84     FOR(u, 1, n+1, 1) {
85         int du = no(u);
86         if (sccid[u] == sccid[du]) {
87             return cout << "IMPOSSIBLE\n", 0;
88         }
89     }
90
91     FOR(u, 1, n+1, 1) {
92         int du = no(u);
93         cout << (sccid[u] < sccid[du] ? '+' : '-') << '
94         ';
95     }
96     cout << endl;
97
98     return 0;

```

## 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     }
26     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     } }

```

## 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 int main() {
24     WiWiHorz
25     init();
26
27     REP(i, m) {
28         int u, v;
29         cin >> u >> v;
30         if (u == v) continue;
31         adj[--u][--v]++;
32     }
33
34     dp[0][1] = 1;
35     FOR(i, 1, n, 1) {
36         dp[i][1] = 0;
37         dp[i][1|(1<<i)] = adj[0][i];
38     }
39     FOR(msk, 1, (1<<n), 1) {
40         if (msk == 1) continue;
41         dp[0][msk] = 0;
42     }
43
44     DP(n-1, (1<<n)-1);
45     cout << dp[n-1][(1<<n)-1] << endl;
46
47     return 0;
48 }

```

## 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
46     if(newNd->edge->d<curNd->edge->d){
47         root->edge=newNd->edge;
48         root->chd[2]=newNd->chd[2];
49         root->chd[3]=newNd->chd[3];
50         newNd->edge=curNd->edge;
51         newNd->chd[2]=curNd->chd[2];
52         newNd->chd[3]=curNd->chd[3];
53     }
54     if(root->chd[0]->dep<root->chd[1]->dep)
55         root->chd[0]=merge(root->chd[0],newNd);
56     else root->chd[1]=merge(root->chd[1],newNd);
57     root->dep=max(root->chd[0]->dep,
58                 root->chd[1]->dep)+1;
59     return root;
60 }
61 vector<heap*> V;
62 void build(){
63     nullNd=new heap; nullNd->dep=0; nullNd->edge=new nd;
64     fill(nullNd->chd,nullNd->chd+4,nullNd);
65     while(not dfsQ.empty()){
66         int u=dfsQ.front(); dfsQ.pop();
67         if(!nxt[u]) head[u]=nullNd;
68         else head[u]=head[nxt[u]->v];
69         V.clear();
70         for(auto&& e:g[u]){
71             int v=e->v;
72             if(dst[v]==-1) continue;
73             e->d+=dst[v]-dst[u];
74             if(nxt[u]!=e){
75                 heap* p=new heap;fill(p->chd,p->chd+4,nullNd);
76                 p->dep=1; p->edge=e; V.push_back(p);
77             }
78         }
79         if(V.empty()) continue;
80         make_heap(V.begin(),V.end(),cmp);
81         #define L(X) ((X<<1)+1)
82         #define R(X) ((X<<1)+2)
83         for(size_t i=0;i<V.size();i++){
84             if(L(i)<V.size()) V[i]->chd[2]=V[L(i)];
85             else V[i]->chd[2]=nullNd;
86             if(R(i)<V.size()) V[i]->chd[3]=V[R(i)];
87             else V[i]->chd[3]=nullNd;

```



```

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; 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  $x_i$  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    }

```

```

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            }
19            t[ptr].cnt++;
20        }
21    }
22 }; trie;

```

### 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-l], 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-i
11         );
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.F.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], rk[(i + (1<<k)) % n]), i);
39            radix_sort();
40            if (fill_suf()) return;
41        }
42    void LCP() { int k = 0;
43        for (int i = 0; i < n-1; i++) {
44            if (rk[i] == 0) continue;
45            int pi = rk[i];
46            int j = suf[pi-1];
47            while (i+k < n && j+k < n && s[i+k] == s[j+k]) k++;
48            lcp[pi] = k;

```

```

49         k = max(k-1, 0);
50     }
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,nmxz=-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); XD;\
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]]]=nmxz+=neq;
41        }
42        sais(ns,nsa,p+nn,q+n,t+n,c+z,nn,nmxz+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        for(int i=0;i<len;i++) RA[i]=sa.r[i]-1;
53        // resulting height, sa array \in [0,len)
54    }

```

## 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
27 Pt mv(Pt a, Pt b) { return b-a; }
28 T len2(Pt a) { return a*a; }
29 T dis2(Pt a, Pt b) { return len2(b-a); }

```

```

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.pb(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],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=0;
47             for(j=1;j<r;j++){
48                 w=min(max(c[j].first,0.0),1.0);
49                 if(!d) s+=w-z;
50                 d+=c[j].second; z=w;
51             }
52             sum+=(py[i][ii]^py[i][ii+1])*s;
53         }
54     }
55     return sum/2;
56 }

```

## 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]))!=0)
39             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]; }
65     rt[un]=pt[q];
66 }
67 inline int inConvex(Pt p){
68     int L,R,M;
69     if(p.X<Lx || p.X>Rx) return 0;
70     L=0;R=dn;
71     while(L<R-1){ M=(L+R)/2;
72         if(p.X<qt[M].X) R=M; else L=M; }
73     if(tri(qt[L],qt[R],p)<0) return 0;
74     L=0;R=un;
75     while(L<R-1){ M=(L+R)/2;
76         if(p.X<rt[M].X) R=M; else L=M; }
77     if(tri(rt[L],rt[R],p)>0) return 0;
78     return 1;
79 }
80 int main(){
81     int n,m,i;
82     Pt p;
83     scanf("%d",&n);
84     for(i=0;i<n;i++) scanf("%lld%lld",&pt[i].X,&pt[i].Y);
85     scanf("%d",&m);
86     for(i=0;i<m;i++) scanf("%lld%lld",&qt[i].X,&qt[i].Y);
87     n=minkowskiSum(n,m);
88     for(i=0;i<n;i++) pt[i]=rt[i];
89     scanf("%d",&m);
90     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=mypow(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:  
 $a^{\phi(n)} \equiv 1 \pmod{n}$  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:  
 $\sigma_x(n) = \sum_{d|n} d^x$ .  $n = \prod_{i=1}^r p_i^{a_i}$ .  
 $\sigma_x(n) = \prod_{i=1}^r \frac{p_i^{(a_i+1)x} - 1}{p_i^x - 1}$  if  $x \neq 0$ .  $\sigma_0(n) = \prod_{i=1}^r (a_i + 1)$ .
- Chinese remainder theorem (Coprime Moduli):  
 $x \equiv a_i \pmod{m_i}$ .  
 $M = \prod m_i$ .  $M_i = M/m_i$ .  $t_i = M_i^{-1}$ .  
 $x = kM + \sum a_i t_i M_i$ ,  $k \in \mathbb{Z}$ .
- 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:  $(f * g)(n) = \sum_{d|n} f(n)g(n/d)$
- 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 3958241859937 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 194555039024054273 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     {
62         if (siz(a) < siz(b)) a.resize(siz(b));
63         for (int i = 0; i < min(siz(a), siz(b)); i++) {
64             a[i] += b[i];
65             a[i] -= a[i] >= MOD ? MOD : 0;
66         }
67         return a;
68     }
69 template<typename T>
70 vector<T>& operator-=(vector<T>& a, const vector<T>& b){
71     {
72         if (siz(a) < siz(b)) a.resize(siz(b));
73         for (int i = 0; i < min(siz(a), siz(b)); i++) {
74             a[i] -= b[i];
75             a[i] += a[i] < 0 ? MOD : 0;
76         }
77         return a;
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 vector<ll> X, iX;
88 vector<int> rev;
89 void init_ntt() {
90     X.clear(); X.resize(maxn, 1); // x1 = g^((p-1)/n)
91     iX.clear(); iX.resize(maxn, 1);
92     ll u = pw(g, (MOD-1)/maxn);
93     ll iu = pw(u, MOD-2);
94     for (int i = 1; i < maxn; i++) {
95         X[i] = X[i-1] * u;
96         iX[i] = iX[i-1] * iu;
97         if (X[i] >= MOD) X[i] %= MOD;
98         if (iX[i] >= MOD) iX[i] %= MOD;
99     }
100     rev.clear(); rev.resize(maxn, 0);
101     for (int i = 1, hb = -1; i < maxn; i++) {
102         if (!(i & (i-1))) hb++;
103         rev[i] = rev[i ^ (1<<hb)] | (1<<(maxk-hb-1));
104     }
105 }
106 template<typename T>
107 void NTT(vector<T>& a, bool inv=false) {
108     int _n = (int)a.size();
109     int k = __lg(_n) + ((1<<__lg(_n)) != _n);
110     int n = 1<<k;
111     a.resize(n, 0);
112     short shift = maxk-k;
113     for (int i = 0; i < n; i++)
114         if (i > (rev[i]>>shift))
115             swap(a[i], a[rev[i]>>shift]);
116     for (int len = 2, half = 1, div = maxn>>1; len <= n; len<=1, half<=1, div>>=1) {
117         for (int i = 0; i < n; i += len) {
118             for (int j = 0; j < half; j++) {
119                 T u = a[i+j];
120                 T v = a[i+j+half] * (inv ? iX[j*div] : X[j*div]) % MOD;
121                 a[i+j] = (u+v >= MOD ? u+v-MOD : u+v);
122                 a[i+j+half] = (u-v < 0 ? u-v+MOD : u-v);
123             }
124         }
125     }
126     if (inv) {
127         T dn = pw(n, MOD-2);
128         for (auto& x : a) {
129             x *= dn;
130         }
131     }
132 }
133 if (x >= MOD) x %= MOD;
134 } } }
135 template<typename T>
136 inline void resize(vector<T>& a) {
137     int cnt = (int)a.size();
138     for (; cnt > 0; cnt--) if (a[cnt-1]) break;
139     a.resize(max(cnt, 1));
140 }
141 template<typename T>
142 vector<T>& operator*=(vector<T>& a, vector<T> b) {
143     int na = (int)a.size();
144     int nb = (int)b.size();
145     a.resize(na + nb - 1, 0);
146     b.resize(na + nb - 1, 0);
147     NTT(a); NTT(b);
148     for (int i = 0; i < (int)a.size(); i++) {
149         a[i] *= b[i];
150         if (a[i] >= MOD) a[i] %= MOD;
151     }
152     NTT(a, true);
153     resize(a);
154     return a;
155 }
156 template<typename T>
157 void inv(vector<T>& ia, int N) {
158     vector<T> _a(move(ia));
159     ia.resize(1, pw(_a[0], MOD-2));
160     vector<T> a(1, -_a[0] + (-_a[0] < 0 ? MOD : 0));
161     for (int n = 1; n < N; n<=1) {
162         // n -> 2*n
163         // ia' = ia(2-a*ia);
164         for (int i = n; i < min(siz(_a), (n<<1)); i++)
165             a.emplace_back(-_a[i] + (-_a[i] < 0 ? MOD : 0));
166         vector<T> tmp = ia;
167         ia *= a;
168         ia.resize(n<<1);
169         ia[0] = ia[0] + 2 >= MOD ? ia[0] + 2 - MOD : ia[0] + 2;
170         ia *= tmp;
171         ia.resize(n<<1);
172     }
173     ia.resize(N);
174 }
175 template<typename T>
176 void mod(vector<T>& a, vector<T>& b) {
177     int n = (int)a.size()-1, m = (int)b.size()-1;
178     if (n < m) return;
179     vector<T> ra = a, rb = b;
180     reverse(ra.begin(), ra.end()); ra.resize(min(n+1, n-m+1));
181     reverse(rb.begin(), rb.end()); rb.resize(min(m+1, n-m+1));
182     inv(rb, n-m+1);
183     vector<T> q = move(ra);
184     q *= rb;
185     q.resize(n-m+1);
186     reverse(q.begin(), q.end());
187     q *= b;
188     a -= q;
189     resize(a);
190 }
191 /* Kitamasa Method (Fast Linear Recurrence):
192 Find a[K] (Given a[j] = c[0]a[j-N] + ... + c[N-1]a[j-1])
193 Let B(x) = x^N - c[N-1]x^(N-1) - ... - c[1]x^1 - c[0]
194 Let R(x) = x^K mod B(x) (get x^K using fast pow and use poly mod to get R(x))

```

```

213 Let  $r[i]$  = the coefficient of  $x^i$  in  $R(x)$ 
214 =>  $a[K] = a[0]r[0] + a[1]r[1] + \dots + a[N-1]r[N-1] *$ 

```

## 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            r++;
25        }
26    }
27 }

```

### 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     struct Edge {
3         int t, c, r;
4         Edge() {}
5         Edge(int _t, int _c, int _r):
6             t(_t), c(_c), r(_r) {}
7     };
8     vector<vector<Edge>> G;
9     vector<int> dis, iter;
10    int s, t;
11    void init(int n) {
12        G.resize(n), dis.resize(n), iter.resize(n);
13        for (int i = 0; i < n; ++i)
14            G[i].clear();
15    }
16    void add(int a, int b, int c) {
17        G[a].eb(b, c, G[b].size());
18        G[b].eb(a, 0, G[a].size() - 1);
19    }
20    bool bfs() {
21        fill(ALL(dis), -1);
22        dis[s] = 0;
23        queue<int> que;
24        que.push(s);

```

```

25        while(!que.empty()) {
26            int u = que.front(); que.pop();
27            for(auto& e : G[u]) {
28                if(e.c > 0 && dis[e.t] == -1) {
29                    dis[e.t] = dis[u] + 1;
30                    que.push(e.t);
31                }
32            }
33        }
34        return dis[t] != -1;
35    }
36    int dfs(int u, int cur) {
37        if(u == t) return cur;
38        for(int &i = iter[u]; i < (int)G[u].size(); ++i) {
39            auto& e = G[u][i];
40            if(e.c > 0 && dis[u] + 1 == dis[e.t]) {
41                int ans = dfs(e.t, min(cur, e.c));
42                if(ans > 0) {
43                    G[e.t][e.r].c += ans;
44                    e.c -= ans;
45                    return ans;
46                }
47            }
48        }
49        return 0;
50    }
51    int flow(int a, int b) {
52        s = a, t = b;
53        int ans = 0;
54        while(bfs()) {
55            fill(ALL(iter), 0);
56            int tmp;
57            while((tmp = dfs(s, INF)) > 0)
58                ans += tmp;
59        }
60        return ans;
61    }
62 };
63

```

### 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;
```

```
73 }
74 };
```

## 11.3 MCMF

```
1 struct MCMF {
2     struct Edge {
3         int to, cap, rev;
4         ll cost;
5         Edge() {}
6         Edge(int _to, int _cap, int _rev, ll _cost) :
7             to(_to), cap(_cap), rev(_rev), cost(_cost) {}
8     };
9     static const int N = 2000;
10    vector<Edge> G[N];
11    int n, s, t;
12    void init(int _n, int _s, int _t) {
13        n = _n, s = _s, t = _t;
14        for(int i = 0; i <= n; ++i)
15            G[i].clear();
16    }
17    void add_edge(int from, int to, int cap, ll cost) {
18        G[from].eb(to, cap, (int)G[to].size(), cost);
19        G[to].eb(from, 0, (int)G[from].size() - 1, -cost);
20    }
21
22    bool vis[N];
23    int iter[N];
24    ll dis[N];
25    bool SPFA() {
26        for(int i = 0; i <= n; ++i)
27            vis[i] = 0, dis[i] = LINF;
28
29        dis[s] = 0; vis[s] = 1;
30        queue<int> que; que.push(s);
31        while(!que.empty()) {
32            int u = que.front(); que.pop();
33            vis[u] = 0;
34            for(auto& e : G[u]) if(e.cap > 0 && dis[e.to] > dis[u] + e.cost) {
35                dis[e.to] = dis[u] + e.cost;
36                if(!vis[e.to]) {
37                    que.push(e.to);
38                    vis[e.to] = 1;
39                }
40            }
41        }
42        return dis[t] != LINF;
43    }
44
45    int dfs(int u, int cur) {
46        if(u == t) return cur;
47        int ret = 0; vis[u] = 1;
48        for(int &i = iter[u]; i < (int)G[u].size(); ++i) {
49            auto &e = G[u][i];
50            if(e.cap > 0 && dis[e.to] == dis[u] + e.cost && !vis[e.to]) {
51                int tmp = dfs(e.to, min(cur, e.cap));
52                e.cap -= tmp;
53                G[e.to][e.rev].cap += tmp;
54                cur -= tmp;
55                ret += tmp;
56                if(cur == 0) {
57                    vis[u] = 0;
58                    return ret;
59                }
60            }
61        }
62        vis[u] = 0;
63        return ret;
64    }
65    pair<int, ll> flow() {
66        int flow = 0; ll cost = 0;
67        while(SPFA()) {
68            memset(iter, 0, sizeof(iter));
69            int tmp = dfs(s, INF);
70            flow += tmp, cost += tmp * dis[t];
71        }
72        return {flow, cost};
73    }
74 }
```

## 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]] == -1) {
46                        dis[my[y]] = dis[x] + 1;
47                        q.push(my[y]);
48                    }
49                }
50            }
51            bool brk = true;
52            vis.clear(); vis.resize(n, 0);
53            for (int x = 1; x <= nx; x++)
54                if (mx[x] == -1 && dfs(x))
55                    brk = false;
56            if (brk) break;
57        }
58        MXCNT = 0;
59        for (int x = 1; x <= nx; x++) if (mx[x] != -1)
60            MXCNT++;
61    }
62 } 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
14 Construct Cv:
15 1. Run Dinic
16 2. Find s-t min cut
17 3. Cv = {X in T} + {Y in S}

```

## 11.6 KM

```

1 #include <bits/stdc++.h>
2
3 using namespace std;
4 const int inf = 1e9;
5
6 struct KuhnMunkres {
7     int n;
8     vector<vector<int>> g;
9     vector<int> lx, ly, slack;
10    vector<int> match, visx, visy;
11    KuhnMunkres(int n) : n(n), g(n, vector<int>(n)),
12        lx(n), ly(n), slack(n), match(n), visx(n), visy(n) {}
13    vector<int> & operator[](int i) { return g[i]; }
14    bool dfs(int i, bool aug) { // aug = true 表示要更新 match
15        // 新 match
16        if(visx[i]) return false;
17        visx[i] = true;
18        for(int j = 0; j < n; j++) {
19            if(visy[j]) continue;
20            // 一邊擴增交錯樹、尋找增廣路徑
21            // 一邊更新 slack: 樹上的點跟樹外的點所造成的最小權重
22            int d = lx[i] + ly[j] - g[i][j];
23            if(d == 0) {
24                visy[j] = true;
25                if(match[j] == -1 || dfs(match[j], aug)) {
26                    if(aug) match[j] = i;
27                    return true;
28                }
29            } else {
30                slack[j] = min(slack[j], d);
31            }
32        }
33        return false;
34    }
35    bool augment() { // 回傳是否有增廣路
36        for(int j = 0; j < n; j++) if(!visy[j] && slack[j] == 0) {
37            visy[j] = true;
38            if(match[j] == -1 || dfs(match[j], false)) {
39                return true;
40            }
41        }
42        return false;
43    }
44    void relabel() {
45        int delta = inf;
46        for(int j = 0; j < n; j++) if(!visy[j]) delta = min(delta, slack[j]);
47        for(int i = 0; i < n; i++) if(visx[i]) lx[i] -= delta;
48        for(int j = 0; j < n; j++) {
49            if(visy[j]) ly[j] += delta;
50            else slack[j] -= delta;
51        }
52    }
53    int solve() {
54        for(int i = 0; i < n; i++) {
55            lx[i] = 0;
56            for(int j = 0; j < n; j++) lx[i] = max(lx[i], g[i][j]);
57        }
58        fill(ly.begin(), ly.end(), 0);

```

```

59        fill(match.begin(), match.end(), -1);
60        for(int i = 0; i < n; i++) {
61            // slack 在每一輪都要初始化
62            fill(slack.begin(), slack.end(), inf);
63            fill(visx.begin(), visx.end(), false);
64            fill(visy.begin(), visy.end(), false);
65            if(dfs(i, true)) continue;
66            // 重複調整頂標直到找到增廣路徑
67            while(!augment()) relabel();
68            fill(visx.begin(), visx.end(), false);
69            fill(visy.begin(), visy.end(), false);
70            dfs(i, true);
71        }
72        int ans = 0;
73        for(int j = 0; j < n; j++) if(match[j] != -1)
74            ans += g[match[j]][j];
75        return ans;
76    }
77    signed main() {
78        ios_base::sync_with_stdio(0), cin.tie(0);
79        int n;
80        while(cin >> n && n) {
81            KuhnMunkres KM(n);
82            for(int i = 0; i < n; i++) {
83                for(int j = 0; j < n; j++) {
84                    int c;
85                    cin >> c;
86                    if(c > 0)
87                        KM[i][j] = c;
88                }
89            }
90            cout << KM.solve() << '\n';
91        }
92    }

```

## 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  $\leq n \approx n/((\ln n) - 1)$   
 $\pi(100) = 25, \pi(200) = 46$   
 $\pi(500) = 95, \pi(1000) = 168$   
 $\pi(2000) = 303, \pi(4000) = 550$   
 $\pi(10^4) = 1229, \pi(10^5) = 9592$   
 $\pi(10^6) = 78498, \pi(10^7) = 664579$