Contents

1 Basic

1.1 compile

```
# preset before coding
echo "cd ~/Desktop" >> ~/.bashrc (optional)
gsettings set org.gnome.gedit.preferences.editor insert-
    spaces true
gsettings set org.gnome.gedit.preferences.editor tabs-
    size 4

# Editor
gedit a.cpp

# Compile
alias g++='g++ -std=c++20 -fsanitize=undefined -Wall -
    Wextra -Wshadow'

# Run
./a.out
./a.out < input.txt
./a.out < input.txt > output.txt

# Python Run
python3 a.py < input.txt > output.txt

# Copy Paste In Ubuntu
* copy: ctrl+insert
* paste: shift+insert
```

1.2 default code

```
#pragma GCC optimize("O3,unroll-loops")
#pragme GCC target("avx2,bmi,bmi2,lzcnt,popcnt")
#include <bits/stdc++.h>
using namespace std;
#define IOS ios::sync_with_stdio(0);cin.tie(0);cout.tie
    (0);
#define int long long
#define F first
#define S second
typedef pair<int,int> pii;

signed main(){
  IOS;
  int tc; cin >> tc;
  while(tc--){

  }
}
```

1.3 debug list

1. bits/std++.h 跟 global variable y1 衝突，不能用
2. 事先將把極端測資加入測試
3. 會不會爆 long long?
4. STL 容器要清空
5. 是否讀錯題目?
6. 注意公式有沒有推錯，codebook 輪流檢查有沒有抄錯
7. 除非還有題目明顯沒有跟到，否則火力集中寫剩下的題目

1.4 stress test note

```
# Save as test.bat, run it by "sudo ./test.bat"
set -e
g++ ac.cpp -o ac
g++ wa.cpp -o wa
for ((i=0; ; i++))
do
    echo "$i"
    python3 gen.py > input
    ./ac < input > ac.out 2> ac.err
    ./wa < input > wa.out 2> wa.err
    diff ac.out wa.out || break
done

# Save as gen.py
from ramdon import *
n = randint(0, 2**31-1)
print(n)

# Example different result of stress test
1c1
< 1 (ac.cpp, that run in brute-force)
---
> 0 (wa.cpp, that will be submitted in OJ)
```

2 Basic Syntax

2.1 Binary Search

```
int BinarySearch(vector<int>& nums, int target) {
    int l = 0, r = nums.size() - 1, m;
    while(l <= r){
        m = l + (r - l >> 1);
        if(nums[m] == target) return m;
        else if(target < nums[m]) r = m - 1;
        else l = m + 1;
    }
    return (target < nums[m] ? m: m + 1);
}
```

2.2 Bitset Usage

```
//declare
string s = "100101";
bitset<10>yee(s);//padding by 0

//usage
yee.set()        // all bitset set 1;
yee.set(current_bit);
yee.set(current_bit, [0, 1]);

yee.flip();       //flip all flip
yee.flip(current_bit);

yee.count() ;     //count how many bits of yee are 1
yee.size();       //return the length when string s to
    bitset yee

string s = yee.to_string();
unsigned long a = yee.to_ulong();
unsigned long long b = yee.to_ullong();
cout << s << endl;  //10011011
cout << a << endl;  //155
cout << b << endl;  //155
```

2.3 Container Usage

```
// map usage
map<char, int> mymap;
map<char, int>::iterator it = mymap.find('b');
if (it != mymap.end()) {
    mymap.erase(it);
```

```
    mymap.erase('b'); // erasing by key
    mymap.erase('e'); // erasing by range
}

// map advance insert
pair<map<char, int>::iterator, bool> ret;
ret = mymap.insert(pair<char, int>('z', 500));
if (ret.second == false) {
    cout << "element 'z' already existed";
    cout << " with a value of " << ret.first->second <<
        '\n';
}

// map swap
map<int, int> foo, bar;
foo.swap(bar);

// map find & contains
if (mymap.find('a') != mymap.end()) {
    return true;
}
if (mymap.count('a')) {
    return true; // support (ordered, unordered) x (map,
        multimap), return size_t
}
if (mymap.contains('a')) {
    return true; // support (ordered, unordered) x (map)
        , return bool
}

// set usage
set<int> myset;
myset.erase(myset.begin(), myset.end()); // erasing by
    range
myset.erase(5); // erasing by value

vector<int> vec = {1, 2, 3, 4, 5};
set<int> myset2(vec.begin(), vec.end());

// set intersection
vector<int> s1 = {1, 2, 3};
vector<int> s2 = {2, 3, 4};
vector<int> ans;
set_intersection(s1.begin(), s1.end(), s2.begin(), s2.
    end(), back_inserter(ans));

// vector usage
vector<int> name(10, 5); // vector with 10 elements,
    each of value 5
vector<int> third(name.begin(), name.end());

// vector insert
vector<int> myvector = {1, 2, 3, 4, 5};
myvector.insert(myvector.begin() + 2, 10); // insert
    value 10 at position 2
myvector.insert(myvector.begin() + 2, 3, 20); // insert
    value 20 three times at position 2
vector<int> anothervector = {6, 7, 8};
myvector.insert(myvector.end(), anothervector.begin(),
    anothervector.end());

// vector erase
myvector.erase(myvector.begin() + 1, myvector.begin() +
    3); // erase elements from position 1 to 3

// other
int arr[] = {1, 2, 3, 4, 5};
for (auto i : arr) {
    cout << i << " \n"[&i == &arr[4]];
}
```

2.4 Ranges Library Usage

```
// C++ ranges library (since C++20)
#include <ranges>

vector<int> vec = {1, 2, 3, 4, 5};
auto [min, max] = minmax_element(vec.begin(), vec.end())
    ;
ranges::sort(vec, greater<int>()); // sort in desc order
ranges::reverse(vec);

// iterate in reverse order
for(int i: vec | views:reverse) {
  cout << i << " ";
}

// lower_bound, upper_bound, binary_search in ranges
vector<int> vec = {1, 2, 3, 4, 5};
auto it = ranges::lower_bound(vec, 3);
auto it2 = ranges::upper_bound(vec, 3);
bool found = ranges::binary_search(vec, 3); // whether 3
    is in vec, require inc order
```

3 Dark Code

3.1 IO optimization

```
*if output to much, consider put all output in array
    first, then output the array.
getchar() -> getchar_unlocked()
fread() -> fread_unlocked()
-----------------------
inline char readchar() {
  const int S = 1<<20; // buffer size
  static char buf[S], *p = buf, *q = buf;
  if(p == q && (q = (p=buf)+fread(buf,1,S,stdin)) == buf
      ) return EOF;
  return *p++;
}
inline int nxtint() {
  // if readchar can't use, change readchar() to getchar
      ()
  int x = 0, neg = 0, c = readchar();
  if (c == EOF) return -1;
  while (('0' > c || c > '9') && c != '-' && c != EOF) c
      = readchar();
  if (c == '-')neg = true, c = readchar();
  while ('0' <= c && c <= '9') x = x * 10 + (c ^ '0'), c
      = readchar();
  return (neg? x: -x);
}
```

3.2 Black Magic

```
#include <ext/pb_ds/priority_queue.hpp>
#include <ext/pb_ds/assoc_container.hpp> // rb_tree
#include <ext/rope> // rope
using namespace __gnu_pbds;
using namespace __gnu_cxx; // rope
typedef __gnu_pbds::priority_queue<int> heap;
int main() {
  heap h1, h2; // max heap
  h1.push(1), h1.push(3), h2.push(2), h2.push(4);
  h1.join(h2); // h1 = {1, 2, 3, 4}, h2 = {};
  tree<ll, null_type, less<ll>, rb_tree_tag,
      tree_order_statistics_node_update> st;
  tree<ll, ll, less<ll>, rb_tree_tag,
      tree_order_statistics_node_update> mp;
  for (int x : {0, 2, 3, 4}) st.insert(x);
  cout << *st.find_by_order(2) << st.order_of_key(1) <<
      endl; //31
  rope<char> *root[10]; // nsqrt(n)
  root[0] = new rope<char>();
  root[1] = new rope<char>(*root[0]);
  // root[1]->insert(pos, 'a');
  // root[1]->at(pos); 0-base
  // root[1]->erase(pos, size);
}
// __int128_t,__float128_t
// for (int i = bs._Find_first(); i < bs.size(); i = bs.
    _Find_next(i));
```

4 Geometry

4.1 2D point

```
typedef double Double;
struct Point {
  Double x,y;

  bool operator < (const Point &b)const{
    //return tie(x,y) < tie(b.x,b.y);
    return atan2(y,x) < atan2(b.y,b.x);
  }
```

```
  Point operator + (const Point &b)const{
    return (Point){x+b.x,y+b.y};
  }
  Point operator - (const Point &b)const{
    return (Point){x-b.x,y-b.y};
  }
  Point operator * (const Double &d)const{
    return Point(d*x,d*y);
  }
  Double operator * (const Point &b)const{
    return x*b.x + y*b.y;
  }
  Double operator % (const Point &b)const{
    return x*b.y - y*b.x;
  }
  friend Double abs2(const Point &p){
    return p.x*p.x + p.y*p.y;
  }
  friend Double abs(const Point &p){
    return sqrt( abs2(p) );
  }
};
typedef Point Vector;

struct Line{
  Point P; Vector v;
  bool operator < (const Line &b)const{
    return atan2(v.y,v.x) < atan2(b.v.y,b.v.x);
  }
};
```

4.2 Convex Hull

```
#include "2Dpoint.cpp"

// return H, The first will occured TWICE in vector H!
void ConvexHull(vector<Point> &P, vector<Point> &H){
    int n = P.size(), m=0;
    sort(P.begin(),P.end());
    H.clear();

    for (int i=0; i<n; i++){
        while (m>=2 && (P[i]-H[m-2]) % (H[m-1]-H[m-2])
            <0)H.pop_back(), m--;
        H.push_back(P[i]), m++;
    }

    for (int i=n-2; i>=0; i--){
        while (m>=2 && (P[i]-H[m-2]) % (H[m-1]-H[m-2])
            <0)H.pop_back(), m--;
        H.push_back(P[i]), m++;
    }
}
```

5 Flow

5.1 Dinic

```
(a) Bounded Maxflow Construction:
1. add two node ss, tt
2. add_edge(ss, tt, INF)
3. for each edge u -> v with capacity [l, r]:
        add_edge(u, tt, l)
        add_edge(ss, v, l)
        add_edge(u, v, r-l)
4. see (b), check if it is possible.
5. answer is maxflow(ss, tt) + maxflow(s, t)
-------------------------------------------------------
(b) Bounded Possible Flow:
1. same construction method as (a)
2. run maxflow(ss, tt)
3. for every edge connected with ss or tt:
        rule: check if their rest flow is exactly 0
4. answer is possible if every edge do satisfy the rule;
5. otherwise, it is NOT possible.
-------------------------------------------------------
(c) Bounded Minimum Flow:
1. same construction method as (a)
2. answer is maxflow(ss, tt)
-------------------------------------------------------
(d) Bounded Minimum Cost Flow:
* the concept is somewhat like bounded possible flow.
1. same construction method as (a)
2. answer is maxflow(ss, tt) + (∑ l * cost for every
    edge)
-------------------------------------------------------
(e) Minimum Cut:
1. run maxflow(s, t)
2. run cut(s)
3. ss[i] = 1: node i is at the same side with s.
-------------------------------------------------------

const long long INF = 1LL<<60;
struct Dinic {  //O(VVE), with minimum cut
    static const int MAXN = 5003;
    struct Edge{
        int u, v;
        long long cap, rest;
    };

    int n, m, s, t, d[MAXN], cur[MAXN];
    vector<Edge> edges;
    vector<int> G[MAXN];

    void init(){
        edges.clear();
        for ( int i = 0 ; i < MAXN ; i++ ) G[i].clear();
    }

    // min cut start
    bool side[MAXN];
    void cut(int u) {
        side[u] = 1;
        for ( int i : G[u] ) {
            if ( !side[ edges[i].v ] && edges[i].rest )
                cut(edges[i].v);
        }
    }
    // min cut end

    void add_edge(int u, int v, long long cap){
        edges.push_back( {u, v, cap, cap} );
        edges.push_back( {v, u, 0, 0LL} );
        m = edges.size();
        G[u].push_back(m-2);
        G[v].push_back(m-1);
    }

    bool bfs(){
        memset(d, -1, sizeof(d));
        queue<int> que;
        que.push(s); d[s]=0;
        while (!que.empty()){
            int u = que.front(); que.pop();
            for (int ei : G[u]){
                Edge &e = edges[ei];
                if (d[e.v] < 0 && e.rest > 0){
                    d[e.v] = d[u] + 1;
                    que.push(e.v);
                }
            }
        }
        return d[t] >= 0;
    }

    long long dfs(int u, long long a){
        if ( u == t || a == 0 ) return a;
        long long flow = 0, f;
        for ( int &i=cur[u]; i < (int)G[u].size() ; i++
            ) {
            Edge &e = edges[ G[u][i] ];
            if ( d[u] + 1 != d[e.v] ) continue;
            f = dfs(e.v, min(a, e.rest) );
            if ( f > 0 ) {
                e.rest -= f;
                edges[ G[u][i]^1 ].rest += f;
                flow += f;
                a -= f;
                if ( a == 0 )break;
            }
        }
        return flow;
    }

    long long maxflow(int s, int t){
```

```
        this->s = s, this->t = t;
        long long flow = 0, mf;
        while ( bfs() ){
            memset(cur, 0, sizeof(cur));
            while ( (mf = dfs(s, INF)) ) flow += mf;
        }
        return flow;
    }
} dinic;
```

5.2 min cost flow

```
// long long version
typedef pair<long long, long long> pll;
struct CostFlow {
    static const int MAXN = 350;
    static const long long INF = 1LL<<60;
    struct Edge {
        int to, r;
        long long rest, c;
    };
    int n, pre[MAXN], preL[MAXN]; bool inq[MAXN];
    long long dis[MAXN], fl, cost;
    vector<Edge> G[MAXN];
    void init() {
        for ( int i = 0 ; i < MAXN ; i++) G[i].clear();
    }
    void add_edge(int u, int v, long long rest, long
        long c) {
        G[u].push_back({v, (int)G[v].size()  , rest,  c
            });
        G[v].push_back({u, (int)G[u].size()-1, 0, -c});
    }
    pll flow(int s, int t) {
        fl = cost = 0;
        while (true) {
            fill(dis, dis+MAXN, INF);
            fill(inq, inq+MAXN, 0);
            dis[s] = 0;
            queue<int> que;
            que.push(s);
            while ( !que.empty() ) {
                int u = que.front(); que.pop();
                inq[u] = 0;
                for ( int i = 0 ; i < (int)G[u].size() ;
                     i++) {
                    int v = G[u][i].to;
                    long long w = G[u][i].c;
                    if ( G[u][i].rest > 0 && dis[v] >
                        dis[u] + w) {
                        pre[v] = u; preL[v] = i;
                        dis[v] = dis[u] + w;
                        if (!inq[v]) {
                            inq[v] = 1;
                            que.push(v);
                        }
                    }
                }
            }

            if (dis[t] == INF) break;
            long long tf = INF;
            for (int v = t, u, l ; v != s ; v = u ) {
                u = pre[v]; l = preL[v];
                tf = min(tf, G[u][l].rest);
            }
            for (int v = t, u, l ; v != s ; v = u ) {
                u = pre[v]; l = preL[v];
                G[u][l].rest -= tf;
                G[v][G[u][l].r].rest += tf;
            }
            cost += tf * dis[t];
            fl += tf;
        }
        return {fl, cost};
    }
} flow;
```

6 Mathmatics

6.1 ax+by=gcd(a,b)

```
typedef pair<int, int> pii;
pii exgcd(int a, int b){
  if(b == 0) return make_pair(1, 0);
  else{
    int p = a / b;
    pii q = exgcd(b, a % b);
    int aa = q.second, bb = q.first - q.second * p;
    if(aa < 0) aa += b, bb -= a;
    return make_pair(aa, bb);
  }
}
```

6.2 BigInt

```
struct Bigint{
  static const int LEN = 60;
  static const int BIGMOD = 10000;
  int s;
  int vl, v[LEN];
  //  vector<int> v;
  Bigint() : s(1) { vl = 0; }
  Bigint(long long a) {
    s = 1; vl = 0;
    if (a < 0) { s = -1; a = -a; }
    while (a) {
      push_back(a % BIGMOD);
      a /= BIGMOD;
    }
  }
  Bigint(string str) {
    s = 1; vl = 0;
    int stPos = 0, num = 0;
    if (!str.empty() && str[0] == '-') {
      stPos = 1;
      s = -1;
    }
    for (int i=SZ(str)-1, q=1; i>=stPos; i--) {
      num += (str[i] - '0') * q;
      if ((q *= 10) >= BIGMOD) {
        push_back(num);
        num = 0; q = 1;
      }
    }
    if (num) push_back(num);
  }
  int len() const { return vl; /* return SZ(v); */ }
  bool empty() const { return len() == 0; }
  void push_back(int x) { v[vl++] = x; /* v.PB(x); */ }
  void pop_back() { vl--; /* v.pop_back(); */ }
  int back() const { return v[vl-1]; /* return v.back();
       */ }
  void n() { while (!empty() && !back()) pop_back(); }
  void resize(int nl) {
    vl = nl; fill(v, v+vl, 0);
    //    v.resize(nl); // fill(ALL(v), 0);
  }
  void print() const {
    if (empty()) { putchar('0'); return; }
    if (s == -1) putchar('-');
    printf("%d", back());
    for (int i=len()-2; i>=0; i--) printf("%.4d",v[i]);
  }
  friend std::ostream& operator << (std::ostream& out,
      const Bigint &a) {
    if (a.empty()) { out << "0"; return out; }
    if (a.s == -1) out << "-";
    out << a.back();
    for (int i=a.len()-2; i>=0; i--) {
      char str[10];
      snprintf(str, 5, "%.4d", a.v[i]);
      out << str;
    }
    return out;
  }
  int cp3(const Bigint &b)const {
    if (s != b.s) return s > b.s ? 1 : -1;
    if (s == -1) return -(-*this).cp3(-b);
    if (len() != b.len()) return len()>b.len()?1:-1;
    for (int i=len()-1; i>=0; i--)
      if (v[i]!=b.v[i]) return v[i]>b.v[i]?1:-1;
    return 0;
  }
```

```
  bool operator < (const Bigint &b)const{ return cp3(b)
      ==-1; }
  bool operator <= (const Bigint &b)const{ return cp3(b)
      <=0; }
  bool operator >= (const Bigint &b)const{ return cp3(b)
      >=0; }
  bool operator == (const Bigint &b)const{ return cp3(b)
      ==0; }
  bool operator != (const Bigint &b)const{ return cp3(b)
      !=0; }
  bool operator > (const Bigint &b)const{ return cp3(b)
      ==1; }
  Bigint operator - () const {
    Bigint r = (*this);
    r.s = -r.s;
    return r;
  }
  Bigint operator + (const Bigint &b) const {
    if (s == -1) return -(-(*this)+(-b));
    if (b.s == -1) return (*this)-(-b);
    Bigint r;
    int nl = max(len(), b.len());
    r.resize(nl + 1);
    for (int i=0; i<nl; i++) {
      if (i < len()) r.v[i] += v[i];
      if (i < b.len()) r.v[i] += b.v[i];
      if(r.v[i] >= BIGMOD) {
        r.v[i+1] += r.v[i] / BIGMOD;
        r.v[i] %= BIGMOD;
      }
    }
    r.n();
    return r;
  }
  Bigint operator - (const Bigint &b) const {
    if (s == -1) return -(-(*this)-(-b));
    if (b.s == -1) return (*this)+(-b);
    if ((*this) < b) return -(b-(*this));
    Bigint r;
    r.resize(len());
    for (int i=0; i<len(); i++) {
      r.v[i] += v[i];
      if (i < b.len()) r.v[i] -= b.v[i];
      if (r.v[i] < 0) {
        r.v[i] += BIGMOD;
        r.v[i+1]--;
      }
    }
    r.n();
    return r;
  }
  Bigint operator * (const Bigint &b) {
    Bigint r;
    r.resize(len() + b.len() + 1);
    r.s = s * b.s;
    for (int i=0; i<len(); i++) {
      for (int j=0; j<b.len(); j++) {
        r.v[i+j] += v[i] * b.v[j];
        if(r.v[i+j] >= BIGMOD) {
          r.v[i+j+1] += r.v[i+j] / BIGMOD;
          r.v[i+j] %= BIGMOD;
        }
      }
    }
    r.n();
    return r;
  }
  Bigint operator / (const Bigint &b) {
    Bigint r;
    r.resize(max(1, len()-b.len()+1));
    int oriS = s;
    Bigint b2 = b; // b2 = abs(b)
    s = b2.s = r.s = 1;
    for (int i=r.len()-1; i>=0; i--) {
      int d=0, u=BIGMOD-1;
      while(d<u) {
        int m = (d+u+1)>>1;
        r.v[i] = m;
        if((r*b2) > (*this)) u = m-1;
        else d = m;
      }
      r.v[i] = d;
    }
    s = oriS;
    r.s = s * b.s;
    r.n();
    return r;
  }
  Bigint operator % (const Bigint &b) {
    return (*this)-(*this)/b*b;
  }
};
```

6.3 GaussElimination

```
// by bcw_codebook

const int MAXN = 300;
const double EPS = 1e-8;

int n;
double A[MAXN][MAXN];

void Gauss() {
  for(int i = 0; i < n; i++) {
    bool ok = 0;
    for(int j = i; j < n; j++) {
      if(fabs(A[j][i]) > EPS) {
        swap(A[j], A[i]);
        ok = 1;
        break;
      }
    }
    if(!ok) continue;

    double fs = A[i][i];
    for(int j = i+1; j < n; j++) {
      double r = A[j][i] / fs;
      for(int k = i; k < n; k++) {
        A[j][k] -= A[i][k] * r;
      }
    }
  }
}
```

6.4 Inverse

```
int inverse[100000];
void invTable(int b, int p) {
  inverse[1] = 1;
  for( int i = 2; i <= b; i++ ) {
    inverse[i] = (long long)inverse[p%i] * (p-p/i) % p;
  }
}

int inv(int b, int p) {
  return b == 1 ? 1 : ((long long)inv(p % b, p) * (p-p/b
      ) % p);
}
```

6.5 LinearPrime

```
const int MAXP = 100; //max prime
vector<int> P;  // primes
void build_prime(){
  static bitset<MAXP> ok;
  int np=0;
  for (int i=2; i<MAXP; i++){
    if (ok[i]==0)P.push_back(i), np++;
    for (int j=0; j<np && i*P[j]<MAXP; j++){
      ok[ i*P[j] ] = 1;
      if ( i%P[j]==0 )break;
    }
  }
}
```

6.6 Miller Rabin

```
typedef long long LL;

inline LL modMul(LL a, LL b, LL m){
  return __int128{a} * b % m;
}

inline LL pow(LL a, LL b, LL m){LL ret = 1;
  for (; b; a = modMul(a, a, m), b >>= 1)
```

```
  if (b % 2) ret = modMul(ret, a, m);
  return ret;
}

bool is_prime(LL n){
  //LL sprp[3] = { 2LL, 7LL, 61LL};
  LL sprp[7] = {2, 325, 9375, 28178, 450775, 9780504,
      1795265022};
  if(n == 1 || (n & 1) == 0) return n == 2;
  LL u = n - 1, t = 0; for(; u % 2 == 0; t++) u >>= 1;
  //for(int i = 0; i < "sprp.size()"; i++)
  for(int i = 0; i < 7; i++){ LL a = sprp[i] % n;
    if(a == 0 || a == 1 || a == n - 1) continue;
    LL x = pow(a, u, n); if(x == 1 || x == n-1) continue
        ;
    for(int j = 1; j < t; j++){ x = modMul(x, x, n);
      if (x == 1) return 0; if (x == n - 1) break;
    }
    if(x == n - 1)continue; return 0;
  }
  return 1;
}
```

6.7 Pollard's rho

```
// does not work when n is prime
LL pollard_rho(LL n){
  //pre-define f = (x * x + 1) % mod
  if(!(n&1)) return 2;
  while(1){
    LL y = 2, x = rand()%(n-1) + 1, res = 1;
    for(int sz = 2; res == 1; sz *= 2){
      for(int i = 0; i < sz && res <= 1; i++){
        x = f(x, n);
        res = __gcd(abs(x - y), n);
      }
      y = x;
    }
    if(res != 0 && res != n) return res;
  }
}
```

6.8 數論基本工具

```
LL C(LL n, LL m){
  if (m<0 || m>n)return 0;
  return J[n] * inv(J[m]*J[n-m]%MOD) %MOD;
}

void factorize(LL n, vector<LL> &ans){
  if(is_prime(n)){
    ans.push_back(n);
  }else{
    LL p = pollard_rho(n);
    factorize(p, ans);
    factorize(n / p, ans);
  }
}
```

6.9 Mobius

```
void mobius() {
    fill(isPrime, isPrime + MAXN, 1);
    mu[1] = 1, num = 0;
    for (int i = 2; i < MAXN; ++i) {
        if (isPrime[i]) primes[num++] = i, mu[i] = -1;
        static int d;
        for (int j = 0; j < num && (d = i * primes[j]) <
             MAXN; ++j) {
            isPrime[d] = false;
            if (i % primes[j] == 0) {
                mu[d] = 0; break;
            } else mu[d] = -mu[i];
        }
    }
}
```

6.10 SG

```
Anti Nim (取走最後一個石子者敗)

先手必勝 if and only if
1. 「所有」堆的石子數都為 1 且遊戲的 SG 值為 0。
2. 「有些」堆的石子數大於 1 且遊戲的 SG 值不為 0。

-----------------------------------------------------
Anti-SG (決策集合為空的遊戲者贏)

定義 SG 值為 0 時，遊戲結束，
則先手必勝 if and only if
1. 遊戲中沒有單一遊戲的 SG 函數大於 1 且遊戲的 SG 函數為
    0。
2. 遊戲中某個單一遊戲的 SG 函數大於 1 且遊戲的 SG 函數不
    為 0。

-----------------------------------------------------
Sprague-Grundy

1. 雙人、回合制
2. 資訊完全公開
3. 無隨機因素
4. 可在有限步內結束
5. 沒有和局
6. 雙方可採取的行動相同

SG(S) 的值為 0：後手(P)必勝
不為 0：先手(N)必勝

int mex(set S) {
  // find the min number >= 0 that not in the S
  // e.g. S = {0, 1, 3, 4} mex(S) = 2
}

state = []
int SG(A) {
  if (A not in state) {
    S = sub_states(A)
    if( len(S) > 1 ) state[A] = reduce(operator.xor, [SG
        (B) for B in S])
    else state[A] = mex(set(SG(B) for B in next_states(A
        )))
  }
  return state[A]
}
```

6.11 Theorem

```
/*
Lucas's Theorem
  For non-negative integer n,m and prime P,
  C(m,n) mod P = C(m/M,n/M) * C(m%M,n%M) mod P
  = mult_i ( C(m_i,n_i) )
  where m_i is the i-th digit of m in base P.
-----------------------------------------------------
Pick's Theorem
  A = i + b/2 - 1
-----------------------------------------------------
Kirchhoff's theorem
  A_{ii} = deg(i), A_{ij} = (i,j) \in E ? -1 : 0
  Deleting any one row, one column, and cal the det(A)
-----------------------------------------------------
Nth Catalan recursive function:
C_0 = 1, C_{n+1} = C_n * 2(2n + 1)/(n+2)
-----------------------------------------------------
Mobius Formula
u(n) = 1        , if n = 1
       (-1)^m   , 若 n 無平方數因數，且 n = p1*p2*p3
           *...*pk
       0        , 若 n 有大於 1 的平方數因數
- Property
1. (積性函數) u(a)u(b) = u(ab)
2. Σ_{d|n} u(d) = [n == 1]
-----------------------------------------------------
Mobius Inversion Formula
if      f(n) = Σ_{d|n} g(d)
then    g(n) = Σ_{d|n} u(n/d)f(d)
             = Σ_{d|n} u(d)f(n/d)
- Application
the number/power of gcd(i, j) = k
- Trick
分塊, O(sqrt(n))
-----------------------------------------------------
Chinese Remainder Theorem (m_i 兩兩互質)
```

```
  x = a_1 (mod m_1)
  x = a_2 (mod m_2)
  ....
  x = a_i (mod m_i)

construct a solution:

  Let M = m_1 * m_2 * m_3 * ... * m_n
  Let M_i = M / m_i

  t_i = 1 / M_i
  t_i * M_i = 1 (mod m_i)

  solution x = a_1 * t_1 * M_1 + a_2 * t_2 * M_2 + ... +
       a_n * t_n * M_n + k * M
  = k*M + ∑ a_i * t_i * M_i, k is positive integer.

  under mod M, there is one solution x = ∑ a_i * t_i *
      M_i
-------------------------------------------------------
Burnside's Lemma
|G| * |X/G|  = sum( |X^g| ) where g in G
總方法數: 每一種旋轉下不動點的個數總和 除以 旋轉的方法數
*/
```

7 Graph

7.1 BCC

```
邊雙連通

任意兩點間至少有兩條不重疊的路徑連接，找法：
1. 標記出所有的橋
2. 對全圖進行 DFS，不走橋，每一次 DFS 就是一個新的邊雙連
    通

// from BCW

struct BccEdge {
  static const int MXN = 100005;
  struct Edge { int v,eid; };
  int n,m,step,par[MXN],dfn[MXN],low[MXN];
  vector<Edge> E[MXN];
  DisjointSet djs;
  void init(int _n) {
    n = _n; m = 0;
    for (int i=0; i<n; i++) E[i].clear();
    djs.init(n);
  }
  void add_edge(int u, int v) {
    E[u].PB({v, m});
    E[v].PB({u, m});
    m++;
  }
  void DFS(int u, int f, int f_eid) {
    par[u] = f;
    dfn[u] = low[u] = step++;
    for (auto it:E[u]) {
      if (it.eid == f_eid) continue;
      int v = it.v;
      if (dfn[v] == -1) {
        DFS(v, u, it.eid);
        low[u] = min(low[u], low[v]);
      } else {
        low[u] = min(low[u], dfn[v]);
      }
    }
  }
  void solve() {
    step = 0;
    memset(dfn, -1, sizeof(int)*n);
    for (int i=0; i<n; i++) {
      if (dfn[i] == -1) DFS(i, i, -1);
    }
    djs.init(n);
    for (int i=0; i<n; i++) {
      if (low[i] < dfn[i]) djs.uni(i, par[i]);
    }
  }
}graph;
```

7.2 Prim

```
// edge strucute
struct edge{
  int a, b;
  double data;
  bool operator <(const edge b)const{
    return data > b.data;
  }
};

// main prim algorithm
int n, m, root, aa, bb, cc;
while (cin >> n >> m){
  priority_queue<edge>yee;
  int visit[500] = {}, p[500] = {};
  double a[500][500] = {};
  //undirectional edge aa to bb is weighted cc
  for (int i = 0; i < m; i++){
    cin >> aa >> bb >> cc;
    a[aa][bb] = a[bb][aa] = cc;
  }
  cin >> root;
  yee.push({ 0, root, 0 });
  edge tmp;
  double total = 0;
  while (!yee.empty()){
    tmp = yee.top(); yee.pop();
    if (visit[tmp.b])continue;
    total += tmp.data; p[tmp.b] = tmp.a; visit[tmp.b] =
        1;
    for (int i = 1; i <= n; i++){
      if (a[tmp.b][i]!=.0&&(!visit[i])){
        yee.push({tmp.b,i,a[tmp.b][i]});
      }
    }
  }
  cout << total << endl;
}
```

7.3 Bellman Ford

```
int a[100][100], d[100], p[100];

void bellman_ford(int root, int n){
  for (int i = 1; i <= n; i++)d[i] = 1e9;
  d[root] = 0, p[root] = 0;
  for (int i = 0; i<n - 1; i++){
    for (int j = 1; j <= n; j++){
      for (int k = 1; k <= n; k++){
        if (d[j] != 1e9 && a[j][k] != 1e9){
          if (d[j] + a[j][k] < d[k]){
            d[k] = d[j] + a[j][k], p[k] = j;
          }
        }
      }
    }
  }
}

bool nega_cyc(int n){
  for (int i = 1; i <= n; i++){
    for (int j = 1; j <= n; j++){
      if (d[i] != 1e9 && a[i][j] != 1e9)
      if (d[i] + a[i][j] < d[j]){
        return 0;
      }
    }
  }
  return 1;
}

int main(){
  int n, m, aa, bb, dd;
  while (cin >> n >> m){
    for (int i = 0; i <= n; i++)for (int j = 0; j <= n;
        j++){
      a[i][j] = E9;
    }
    memset(p, 0, sizeof(p));
    for (int i = 0; i < m; i++){
      cin >> aa >> bb >> dd;
      a[aa][bb] = min(a[aa][bb], dd);
```

```
    }
    cin >> aa;
    bellman_ford(aa, n);
    int t = nega_cyc(n);
    if(t){
      for (int i = 1; i <= n; i++)cout << d[i] << " \n"[
          i==n];
      for (int i = 1; i <= n; i++)cout << p[i] << " \n"[
          i==n];
    }
    else cout << "There is a negative weight cycle in
        the graph\n";
  }
}
```

7.4 Kruskal

```
struct v {
  int a, b, c;
};

int p[200001];v a[200001];

bool sor(v a, v b) {
  return a.c < b.c;
}

int find(int x) {
  return(x != p[x] ? (p[x] = find(p[x])) : x);
}

int main() {
  int n, m, i, j, sum;
  while (cin >> n >> m) {
    sum = 0;
    for (i = 0; i < 200001; i++)p[i] = i;
    for (i = 0; i<m; i++)cin >> a[i].a >> a[i].b >> a[i
        ].c;
    sort(a, a + m, sor);
    for (i =0,j = 0;j<m; j++) {
      if(find(a[j].a) != find(a[j].b)){
        i++;
        p[find(a[j].a)] = find(a[j].b);
        sum += a[j].c;
      }
    }
    cout << ((i==n-1)?sum:-1) << endl;
  }
}
```

7.5 Dijkstra

```
int e[300][300], d[300], p[300];

struct node {
  int b, w;
  bool operator < (const node& bb)const {
    return w > bb.w;
  }
};

void dijkstra(int root, int n) {
  for (int i = 0; i <= n; i++)d[i] = (INT_MAX >> 1);
  memset(p, 0, sizeof(p));
  priority_queue<node>yee;
  d[root] = p[root] = 0;
  yee.push({ root, d[root] });

  while (!yee.empty()) {
    node tmp = yee.top(); yee.pop();
    for (int i = 1; i <= n; i++) {
      if (d[i]>d[tmp.b] + e[tmp.b][i]) {
        d[i] = d[tmp.b] + e[tmp.b][i];
        p[i] = tmp.b;
        yee.push( { i, d[tmp.b] });
      }
    }
  }
}

int main() {
  int n, m, aa, bb, root, cc;
  while (cin >> n >> m) {
    memset(e, 0, sizeof(e));
    for (int i = 0; i <= n; i++)for (int j = 0; j <= n;
        j++)e[i][j] = (INT_MAX >> 1);
    for (int i = 0; i < m; i++) {
      cin >> aa >> bb >> cc;
      e[aa][bb] = cc;
    }
    cin >> root;
    dijkstra(root, n);
    for (int i = 1; i <= n; i++)cout << d[i] << " \n"[i
        ==n];
    for (int i = 1; i <= n; i++)cout << p[i] << " \n"[i
        ==n];
  }
}
```

7.6 SCC

```
#define MXN 100005
#define PB push_back
#define FZ(s) memset(s,0,sizeof(s))

struct Scc{
int n, nScc, vst[MXN], bln[MXN];
vector<int> E[MXN], rE[MXN], vec;
void init(int _n){
  n = _n;
  for (int i=0; i<MXN; i++){
    E[i].clear();
    rE[i].clear();
  }
}
void add_edge(int u, int v){
  E[u].PB(v);
  rE[v].PB(u);
}
void DFS(int u){
  vst[u]=1;
  for (auto v : E[u])
    if (!vst[v]) DFS(v);
  vec.PB(u);
}
void rDFS(int u){
  vst[u] = 1;
  bln[u] = nScc;
  for (auto v : rE[u])
    if (!vst[v]) rDFS(v);
}
void solve(){
  nScc = 0;
  vec.clear();
  FZ(vst);
  for (int i=0; i<n; i++)
    if (!vst[i]) DFS(i);
  reverse(vec.begin(),vec.end());
  FZ(vst);
  for (auto v : vec){
    if (!vst[v]){
      rDFS(v);
      nScc++;
    }
  }
}
};
```

7.7 Hungarian

```
// Maximum Cardinality Bipartite Matching

struct Graph {
    static const int MAXN = 5005;
    vector<int> G[MAXN];
    int n;
    int match[MAXN]; // Matching Result
    int vis[MAXN];

    void init(int _n) {
        n = _n;
        for ( int i = 0 ; i < n ; i++ ) G[i].clear();
    }

    bool dfs(int u) {
        for ( auto v:G[u] ) {
```

```
            if (!vis[v]) {
                vis[v] = true;
                if (match[v] == -1 || dfs(match[v])) {
                    match[v] = u;
                    match[u] = v;
                    return true;
                }
            }
        }
        return false;
    }

    int solve() {
        int res = 0;
        memset(match, -1, sizeof(match));
        for (int i = 0; i < n; i++) {
            if (match[i] == -1) {
                memset(vis, 0, sizeof(vis));
                if (dfs(i)) res += 1;
            }
        }
        return res;
    }
} graph;
```

7.8 KM

```
Detect non-perfect-matching:
1. set all edge[i][j] as INF
2. if solve() >= INF, it is not perfectmatching.
-------------------------------------------------------
// Maximum Weight Perfect Bipartite Matching
// allow negative weight!

typedef long long Int;
struct KM {
    static const int MAXN = 1050;
    static const int INF = 1LL<<60;
    int n, match[MAXN], vx[MAXN], vy[MAXN];
    Int edge[MAXN][MAXN], lx[MAXN], ly[MAXN], slack[MAXN
        ];
    void init(int _n){
        n = _n;
        for ( int i = 0 ; i < n ; i++ )
            for ( int j = 0; j < n ; j++ )
                edge[i][j] = 0;
    }
    void add_edge(int x, int y, Int w){
        edge[x][y] = w;
    }
    bool DFS(int x){
        vx[x] = 1;
        for ( int y = 0 ; y < n ; y++ ) {
            if ( vy[y] ) continue;
            if ( lx[x] + ly[y] > edge[x][y] ) {
                slack[y] = min(slack[y], lx[x] + ly[y] -
                    edge[x][y]);
            } else {
                vy[y] = 1;
                if ( match[y] == -1 || DFS(match[y]) ){
                    match[y] = x;
                    return true;
                }
            }
        }
        return false;
    }
    Int solve() {
        fill(match, match + n, -1);
        fill(lx, lx + n, -INF);
        fill(ly, ly + n, 0);
        for ( int i = 0; i < n; i++ )
            for ( int j = 0; j < n; j++ )
                lx[i] = max(lx[i], edge[i][j]);
        for ( int i = 0 ; i < n; i++ ) {
            fill(slack, slack + n, INF);
            while (true){
                fill(vx, vx + n, 0);
                fill(vy, vy + n, 0);
                if ( DFS(i) ) break;
                Int d = INF;
                for ( int j = 0 ; j < n ; j++ )
                    if ( !vy[j] ) d = min(d, slack[j]);
                for ( int j = 0 ; j < n ; j++ ) {
                    if (vx[j]) lx[j] -= d;
                    if (vy[j]) ly[j] += d;
                    else slack[j] -= d;
                }
            }
        }
        Int res = 0;
        for ( int i = 0 ; i < n ; i++ ) {
            res += edge[ match[i] ][i];
        }
        return res;
    }
} graph;
```

7.9 最小平均環

```
// from BCW

/* minimum mean cycle */
const int MAXE = 1805;
const int MAXN = 35;
const double inf = 1029384756;
const double eps = 1e-6;
struct Edge {
  int v,u;
  double c;
};
int n,m,prv[MAXN][MAXN], prve[MAXN][MAXN], vst[MAXN];
Edge e[MAXE];
vector<int> edgeID, cycle, rho;
double d[MAXN][MAXN];
inline void bellman_ford() {
  for(int i=0; i<n; i++) d[0][i]=0;
  for(int i=0; i<n; i++) {
    fill(d[i+1], d[i+1]+n, inf);
    for(int j=0; j<m; j++) {
      int v = e[j].v, u = e[j].u;
      if(d[i][v]<inf && d[i+1][u]>d[i][v]+e[j].c) {
        d[i+1][u] = d[i][v]+e[j].c;
        prv[i+1][u] = v;
        prve[i+1][u] = j;
      }
    }
  }
}
double karp_mmc() {
  // returns inf if no cycle, mmc otherwise
  double mmc=inf;
  int st = -1;
  bellman_ford();
  for(int i=0; i<n; i++) {
    double avg=-inf;
    for(int k=0; k<n; k++) {
      if(d[n][i]<inf-eps) avg=max(avg,(d[n][i]-d[k][i])
          /(n-k));
      else avg=max(avg,inf);
    }
    if (avg < mmc) tie(mmc, st) = tie(avg, i);
  }
  for(int i=0; i<n; i++) vst[i] = 0;
  edgeID.clear(); cycle.clear(); rho.clear();
  for (int i=n; !vst[st]; st=prv[i--][st]) {
    vst[st]++;
    edgeID.PB(prve[i][st]);
    rho.PB(st);
  }
  while (vst[st] != 2) {
    int v = rho.back(); rho.pop_back();
    cycle.PB(v);
    vst[v]++;
  }
  reverse(ALL(edgeID));
  edgeID.resize(SZ(cycle));
  return mmc;
}
```

7.10 偵測負環

```
#include <bits/stdc++.h>
using namespace std;
```

```
const int INF = 1000000;
const int MAXN = 200;
int n, m, q;
int d[MAXN][MAXN];

int main () {
    while ( cin >> n >> m >> q && n) {

        for ( int i = 0 ; i <= n ; i++ ) {
            for ( int j = 0 ; j <= n ; j++ ) d[i][j] = (
                i==j ? 0 : INF);
        }

        for ( int i = 0 ; i < m ; i++ ) {
            int a, b, c;
            cin >> a >> b >> c;
            d[a][b] = min(d[a][b], c);
        }

        for ( int k = 0 ; k < n ; k++ ) {
            for ( int i = 0 ; i < n ; i++ ) {
                for ( int j = 0 ; j < n ; j++ ) {

                    if ( d[i][j] > d[i][k] + d[k][j] &&
                         d[i][k] < INF && d[k][j] < INF )
                         {
                        //printf("%d > %d + %d\n", d[i][
                            j], d[i][k], d[k][j]);
                        //if ( d[i][k] >= INF || d[k][j]
                             >= INF ) cout << "NO : " <<
                             i << " " << j << " " << k
                            << "--";
                        d[i][j] = min(d[i][j], d[i][k] +
                             d[k][j]);
                    }
                }
            }
        }

        for ( int i = 0 ; i < n ; i++ ) {
            for ( int j = 0 ; j < n ; j++ ) {
                for ( int k = 0 ; k < n && d[i][j] != -
                    INF ; k++ ) {
                    if ( d[k][k] < 0 && d[i][k] != INF
                         && d[k][j] != INF  )
                        d[i][j] = -INF;
                }
            }
        }
        int u, v;
        for (int i=0;i<q;i++){
            scanf("%d%d",&u,&v);

            if (d[u][v] == INF) printf("Impossible\n");
            else if (d[u][v] == -INF) printf("-Infinity\
                n");
            else printf("%d\n",d[u][v]);
        }
        puts("");
    }
    return 0;
}
```

7.11 Tarjan

```
割點
點 u 為割點 if and only if 滿足 1. or 2.
1. u 為樹根，且 u 有多於一個子樹。
2. u 不為樹根，且滿足存在 (u,v) 為樹枝邊 (或稱父子邊，即
     u 為 v 在搜索樹中的父親)，使得 DFN(u) <= Low(v)。

-------------------------------------------------------
橋
一條無向邊 (u,v) 是橋 if and only if (u,v) 為樹枝邊，且
    滿足 DFN(u) < Low(v)。

// 0 base
struct TarjanSCC{
  static const int MAXN = 1000006;
  int n, dfn[MAXN], low[MAXN], scc[MAXN], scn, count;
  vector<int> G[MAXN];
  stack<int> stk;
  bool ins[MAXN];

  void tarjan(int u){
    dfn[u] = low[u] = ++count;
    stk.push(u);
    ins[u] = true;

    for(auto v:G[u]){
      if(!dfn[v]){
        tarjan(v);
        low[u] = min(low[u], low[v]);
      }else if(ins[v]){
        low[u] = min(low[u], dfn[v]);
      }
    }

    if(dfn[u] == low[u]){
      int v;
      do {
      v = stk.top();
      stk.pop();
      scc[v] = scn;
      ins[v] = false;
      } while(v != u);
      scn++;
    }
  }

  void getSCC(){
    memset(dfn,0,sizeof(dfn));
    memset(low,0,sizeof(low));
    memset(ins,0,sizeof(ins));
    memset(scc,0,sizeof(scc));
    count = scn = 0;
    for(int i = 0 ; i < n ; i++ ){
      if(!dfn[i]) tarjan(i);
    }
  }

}SCC;
```

7.12 Topological Sort

```
#define N 87

bool adj[N][N];     // adjacency matrix
int visit[N];       // record visited coordinations in
    DFS
int order[N], n;    // save the order

bool cycle;         // detect the cycle

void DFS(int s)
{
    // back edge occured, detected the cycle
    if (visit[s] == 1) {cycle = true; return;}
    // forward edge and cross edge¡C
    if (visit[s] == 2) return;

    visit[s] = 1;
    for (int t=0; t<N; ++t){
        if (adj[s][t]) DFS(t);
    }
    visit[s] = 2;
    order[n--] = s;     // record the order
}

void topological_ordering()
{
    memset(visit, 0, sizeof(visit));
    cycle = false;
    n = N - 1;

    for (int s=0; s<9; ++s)
        if (!v[s])
            DFS(s);

    if (cycle) cout << "The graph has the cycle!";
    else{
        for (int i=0; i<N; ++i)
            cout << order[i];
        }
```

```
  }
}
```

8 Data Structure

8.1 2D Range Tree

```
// remember sort x !!!!!
typedef int T;
const int LGN = 20;
const int MAXN = 100005;

struct Point{
    T x, y;
    friend bool operator < (Point a, Point b){
        return tie(a.x,a.y) < tie(b.x,b.y);
    }
};
struct TREE{
    Point pt;
    int toleft;
}tree[LGN][MAXN];
struct SEG{
    T mx, Mx;
    int sz;
    TREE *st;
}seg[MAXN*4];

vector<Point> P;

void build(int l, int r, int o, int deep){
    seg[o].mx = P[l].x;
    seg[o].Mx = P[r].x;
    seg[o].sz = r-l+1;;

    if(l == r){
        tree[deep][r].pt = P[r];
        tree[deep][r].toleft = 0;
        seg[o].st = &tree[deep][r];
        return;
    }
    int mid = (l+r)>>1;
    build(l,mid,o+o,deep+1);
    build(mid+1,r,o+o+1,deep+1);

    TREE *ptr = &tree[deep][l];
    TREE *pl = &tree[deep+1][l], *nl = &tree[deep+1][mid
        +1];
    TREE *pr = &tree[deep+1][mid+1], *nr = &tree[deep
        +1][r+1];

    int cnt = 0;
    while(pl != nl && pr != nr) {
        *(ptr) = pl->pt.y <= pr->pt.y ? cnt++, *(pl++):
            *(pr++);
        ptr -> toleft = cnt; ptr++;
    }
    while(pl != nl) *(ptr) = *(pl++), ptr -> toleft = ++
        cnt, ptr++;
    while(pr != nr) *(ptr) = *(pr++), ptr -> toleft =
        cnt, ptr++;

}
int main(){
    int n; cin >> n;
    for(int i = 0 ;i < n; i++){
        T x,y; cin >> x >> y;
        P.push_back((Point){x,y});
    }
    sort(P.begin(),P.end());
    build(0,n-1,1,0);
}
```

8.2 Sparse Table

```
const int MAXN = 200005;
const int lgN = 20;

struct SP{ //sparse table
  int Sp[MAXN][lgN];
  function<int(int,int)> opt;
  void build(int n, int *a){ // 0 base
    for (int i=0 ;i<n; i++) Sp[i][0]=a[i];
    for (int h=1; h<lgN; h++){
      int len = 1<<(h-1), i=0;
      for (; i+len<n; i++)
        Sp[i][h] = opt( Sp[i][h-1] , Sp[i+len][h-1] );
      for (; i<n; i++)
        Sp[i][h] = Sp[i][h-1];
    }
  }
  int query(int l, int r){
    int h = __lg(r-l+1);
    int len = 1<<h;
    return opt( Sp[l][h] , Sp[r-len+1][h] );
  }
};
```

8.3 Segment Tree

```
// might have some problem
struct node{
  int val;
  node *l, *r;
  node(int v): val(v), l(0), r(0){}
  void pull(){val = min(l->val, r->val);}
};
int arr[N];
node* build(int l, int r, node *p){
  if(l == r) return new node(arr[l]);
  int m = l + r >> 1;
  p = new node(0);
  p->l = build(l, m, p->l), p->r = build(m+1, r, p->r);
  p->pull();
}
int query(int ql, int qr, int l, int r, node *p){
  if(ql <= l && r <= qr) return p->val;
  int m = l + r >> 1;
  if(qr <= m) return query(ql, qr, l, m, p->l);
  if(ql > m) return query(ql, qr, m+1, r, p->r);
  return min(query(ql, qr, l, m, p->l), query(ql, qr, m
      +1, r, p->r));
}
void modify(int x, int l, int r, node *p, int v){
  if(l == r)
  return p->val = v;
  int m = l + r >> 1;
  if(x <= m) modify(x, l, m, p->l, v);
  else modify(x, m+1, r, p->r, v);
  p->pull();
}
```

8.4 Lazy Tag

```
void modify(type value, int l, int r, int L, int R,
    vertex v){
    if(l == L && r == R){
        //打懶標在v上;
        return;
    }
    int M = (L + R) / 2;
    if(r <= M) modify(value, l, r, L, M, //v的左子節點);
    else if(l > M) modify(value, l, r, M + 1, R, //v的右
        子節點);
    else{
        modify(value, l, M, L, M, v的左子節點);
        modify(value, M + 1, r, M + 1, R, //v的右子節點)
            ;
    }
    //用兩個子節點的答案更新v的答案;
}
```

9 String

9.1 KMP

```
template<typename T>
void build_KMP(int n, T *s, int *f){ // 1 base
  f[0]=-1, f[1]=0;
  for (int i=2; i<=n; i++){
    int w = f[i-1];
    while (w>=0 && s[w+1]!=s[i])w = f[w];
    f[i]=w+1;
  }
```

```
}

template<typename T>
int KMP(int n, T *a, int m, T *b){
  build_KMP(m,b,f);
  int ans=0;

  for (int i=1, w=0; i<=n; i++){
    while ( w>=0 && b[w+1]!=a[i] )w = f[w];
    w++;
    if (w==m){
      ans++;
      w=f[w];
    }
  }
  return ans;
}
```

9.2 smallest rotation

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

9.3 Suffix Array

```
/*he[i]保存了在後綴數組中相鄰兩個後綴的最長公共前綴長度
 *sa[i]表示的是字典序排名為i的後綴是誰（字典序越小的排名
     越靠前）
 *rk[i]表示的是後綴我所對應的排名是多少  */

const int MAX = 1020304;
int ct[MAX], he[MAX], rk[MAX];
int sa[MAX], tsa[MAX], tp[MAX][2];
void suffix_array(char *ip){
  int len = strlen(ip);
  int alp = 256;
  memset(ct, 0, sizeof(ct));
  for(int i=0;i<len;i++) ct[ip[i]+1]++;
  for(int i=1;i<alp;i++) ct[i]+=ct[i-1];
  for(int i=0;i<len;i++) rk[i]=ct[ip[i]];
  for(int i=1;i<len;i*=2){
    for(int j=0;j<len;j++){
      if(j+i>=len) tp[j][1]=0;
      else tp[j][1]=rk[j+i]+1;
      tp[j][0]=rk[j];
    }
    memset(ct, 0, sizeof(ct));
    for(int j=0;j<len;j++) ct[tp[j][1]+1]++;
    for(int j=1;j<len+2;j++) ct[j]+=ct[j-1];
    for(int j=0;j<len;j++) tsa[ct[tp[j][1]]++]=j;
    memset(ct, 0, sizeof(ct));
    for(int j=0;j<len;j++) ct[tp[j][0]+1]++;
    for(int j=1;j<len+1;j++) ct[j]+=ct[j-1];
    for(int j=0;j<len;j++)
      sa[ct[tp[tsa[j]][0]]++]=tsa[j];
    rk[sa[0]]=0;
    for(int j=1;j<len;j++){
      if( tp[sa[j]][0] == tp[sa[j-1]][0] &&
        tp[sa[j]][1] == tp[sa[j-1]][1] )
        rk[sa[j]] = rk[sa[j-1]];
      else
        rk[sa[j]] = j;
    }
  }
  for(int i=0,h=0;i<len;i++){
    if(rk[i]==0) h=0;
    else{
      int j=sa[rk[i]-1];
      h=max(0,h-1);
      for(;ip[i+h]==ip[j+h];h++);
    }
    he[rk[i]]=h;
  }
}
```

9.4 Z-value

```
z[0] = 0;
for ( int bst = 0, i = 1; i < len ; i++ ) {
  if ( z[bst] + bst <= i ) z[i] = 0;
  else z[i] = min(z[i - bst], z[bst] + bst - i);
  while ( str[i + z[i]] == str[z[i]] ) z[i]++;
  if ( i + z[i] > bst + z[bst] ) bst = i;
}

// 回文版

void Zpal(const char *s, int len, int *z) {
    // Only odd palindrome len is considered
    // z[i] means that the longest odd palindrom
        centered at
    // i is [i-z[i] .. i+z[i]]
    z[0] = 0;
    for (int b=0, i=1; i<len; i++) {
        if (z[b] + b >= i) z[i] = min(z[2*b-i], b+z[b]-i
            );
        else z[i] = 0;
        while (i+z[i]+1 < len and i-z[i]-1 >= 0 and
               s[i+z[i]+1] == s[i-z[i]-1]) z[i] ++;
        if (z[i] + i > z[b] + b) b = i;
    }
}
```

10 Others

10.1 矩陣數定理

Matrix-Tree定理（Kirchhoff矩陣-樹定理）

Matrix-Tree定理是解決生成樹計數問題最有力的武器之一。它首先於1847年被Kirchhoff證明。在介紹定理之前，我們首先明確幾個概念：

1、G的度數矩陣D[G]是一個n*n的矩陣，並且滿足：當i≠j時，d_ij=0；當i=j時，d_ij等於v_i的度數。

2、G的鄰接矩陣A[G]也是一個n*n的矩陣，並且滿足：如果v_i、v_j之間有邊直接相連，則a_ij=1，否則為0。

我們定義G的Kirchhoff矩陣（也稱為拉普拉斯算子）C[G]為C[G]=D[G]-A[G]，

則Matrix-Tree定理可以描述為：G的所有不同的生成樹的個數等於其Kirchhoff矩陣C[G]任何一個n-1階主子式的行列式的絕對值。

所謂n-1階主子式，就是對於r(1≤r≤n)，將C[G]的第r行、第r列同時去掉後得到的新矩陣，用C_r[G]表示。

生成樹計數算法步驟：

1、 構建拉普拉斯矩陣

Matrix[i][j] = degree(i)，當 i==j -1，當 i 與 j 有邊相連 0，其他情況

2、 刪除第 r 行和第 r 列（r 可任選）

3、 計算矩陣的行列式

```
#include <stdio.h>
#include <string.h>
#include <algorithm>
#include <iostream>
#include <math.h>
using namespace std;
const double eps = 1e-8;
const int MAXN = 110;
int sgn(double x)
{
    if(fabs(x) < eps)return 0;
    if(x < 0)return -1;
    else return 1;
}
double b[MAXN][MAXN];
double det(double a[][MAXN],int n)
```

```
{
    int i, j, k, sign = 0;
    double ret = 1;
    for(i = 0;i < n;i++)
    for(j = 0;j < n;j++) b[i][j] = a[i][j];
    for(i = 0;i < n;i++)
    {
        if(sgn(b[i][i]) == 0)
        {
            for(j = i + 1; j < n;j++)
            if(sgn(b[j][i]) != 0) break;
            if(j == n)return 0;
            for(k = i;k < n;k++) swap(b[i][k],b[j][k]);
            sign++;
        }
        ret *= b[i][i];
        for(k = i + 1;k < n;k++) b[i][k]/=b[i][i];
        for(j = i+1;j < n;j++)
        for(k = i+1;k < n;k++) b[j][k] -= b[j][i]*b[i][k
            ];
    }
    if(sign & 1)ret = -ret;
    return ret;
}
double a[MAXN][MAXN];
int g[MAXN][MAXN];
int main()
{
    int T;
    int n,m;
    int u,v;
    scanf("%d",&T);
    while(T--)
    {
        scanf("%d%d",&n,&m);
        memset(g,0,sizeof(g));
        while(m--)
        {
            scanf("%d%d",&u,&v);
            u--;v--;
            g[u][v] = g[v][u] = 1;
        }
        memset(a,0,sizeof(a));
        for(int i = 0;i < n;i++)
        for(int j = 0;j < n;j++)
        if(i != j && g[i][j])
        {
            a[i][i]++;
            a[i][j] = -1;
        }
        double ans = det(a,n-1);
        printf("%.0lf\n",ans);
    }
    return 0;
}
```

10.2 1D/1D dp 優化

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

int t, n, L;
int p;
char s[MAXN][35];
ll sum[MAXN] = {0};
long double dp[MAXN] = {0};
int prevd[MAXN] = {0};

long double pw(long double a, int n) {
    if ( n == 1 ) return a;
    long double b = pw(a, n/2);
    if ( n & 1 ) return b*b*a;
    else return b*b;
}
long double f(int i, int j) {
//    cout << (sum[i] - sum[j]+i-j-1-L) << endl;
    return pw(abs(sum[i] - sum[j]+i-j-1-L), p) + dp[j];
}
struct INV {
    int L, R, pos;
};
INV stk[MAXN*10];
int top = 1, bot = 1;
void update(int i) {
    while ( top > bot && i < stk[top].L && f(stk[top].L,
         i) < f(stk[top].L, stk[top].pos) ) {
        stk[top - 1].R = stk[top].R;
        top--;
    }
    int lo = stk[top].L, hi = stk[top].R, mid, pos = stk
        [top].pos;
    //if ( i >= lo ) lo = i + 1;
    while ( lo != hi ) {
        mid = lo + (hi - lo) / 2;
        if ( f(mid, i) < f(mid, pos) ) hi = mid;
        else lo = mid + 1;
    }
    if ( hi < stk[top].R ) {
        stk[top + 1] = (INV) { hi, stk[top].R, i };
        stk[top++].R = hi;
    }
}

int main() {
    cin >> t;
    while ( t-- ) {
        cin >> n >> L >> p;
        dp[0] = sum[0] = 0;
        for ( int i = 1 ; i <= n ; i++ ) {
            cin >> s[i];
            sum[i] = sum[i-1] + strlen(s[i]);
            dp[i] = numeric_limits<long double>::max();
        }
        stk[top] = (INV) {1, n + 1, 0};
        for ( int i = 1 ; i <= n ; i++ ) {
            if ( i >= stk[bot].R ) bot++;
            dp[i] = f(i, stk[bot].pos);
            update(i);
//            cout << (ll) f(i, stk[bot].pos) << endl;
        }
        if ( dp[n] > 1e18 ) {
            cout << "Too hard to arrange" << endl;
        } else {
            vector<PI> as;
            cout << (ll)dp[n] << endl;
        }
    }
    return 0;
}
```

10.3 Theorm - DP optimization

```
Monotonicity & 1D/1D DP & 2D/1D DP
-----------------------------------------------------
Definition xD/yD
1D/1D DP[j] = min(0≤i<j) { DP[i] + w(i, j) }; DP[0] = k
2D/1D DP[i][j] = min(i<k≤j) { DP[i][k - 1] + DP[k][j] }
    + w(i, j); DP[i][i] = 0
-----------------------------------------------------
Monotonicity
       c       d
  -----------------
a | w(a, c) w(a, d)
b | w(b, c) w(b, d)

Monge Condition
Concave(凹四邊形不等式): w(a, c) + w(b, d) >= w(a, d) +
    w(b, c)
Convex (凸四邊形不等式): w(a, c) + w(b, d) <= w(a, d) +
    w(b, c)

Totally Monotone
Concave(凹單調): w(a, c) <= w(b, d) -----> w(a, d) <= w(
    b, c)
Convex (凸單調): w(a, c) >= w(b, d) -----> w(a, d) >= w(
    b, c)
-----------------------------------------------------
1D/1D DP O(n^2) -> O(nlgn)
**CONSIDER THE TRANSITION POINT**
Solve 1D/1D Concave by Stack
Solve 1D/1D Convex by Deque
-----------------------------------------------------
2D/1D Convex DP (Totally Monotone) O(n^3) -> O(n^2)
h(i, j - 1) ≤ h(i, j) ≤ h(i + 1, j)
```

10.4 Stable Marriage

```cpp
// normal stable marriage problem
// input:
//3
//Albert Laura Nancy Marcy
//Brad Marcy Nancy Laura
//Chuck Laura Marcy Nancy
//Laura Chuck Albert Brad
//Marcy Albert Chuck Brad
//Nancy Brad Albert Chuck

#include<bits/stdc++.h>
using namespace std;
const int MAXN = 505;

int n;
int favor[MAXN][MAXN]; // favor[boy_id][rank] = girl_id;
int order[MAXN][MAXN]; // order[girl_id][boy_id] = rank;
int current[MAXN]; // current[boy_id] = rank; boy_id
    will pursue current[boy_id] girl.
int girl_current[MAXN]; // girl[girl_id] = boy_id;

void initialize() {
  for ( int i = 0 ; i < n ; i++ ) {
    current[i] = 0;
    girl_current[i] = n;
    order[i][n] = n;
  }
}

map<string, int> male, female;
string bname[MAXN], gname[MAXN];
int fit = 0;

void stable_marriage() {

  queue<int> que;
  for ( int i = 0 ; i < n ; i++ ) que.push(i);
  while ( !que.empty() ) {
    int boy_id = que.front();
    que.pop();

    int girl_id = favor[boy_id][current[boy_id]];
    current[boy_id] ++;

    if ( order[girl_id][boy_id] < order[girl_id][
        girl_current[girl_id]] ) {
      if ( girl_current[girl_id] < n ) que.push(
          girl_current[girl_id]); // if not the first
          time
      girl_current[girl_id] = boy_id;
    } else {
      que.push(boy_id);
    }
  }

}

int main() {
  cin >> n;

  for ( int i = 0 ; i < n;  i++ ) {
    string p, t;
    cin >> p;
    male[p] = i;
    bname[i] = p;
    for ( int j = 0 ; j < n ; j++ ) {
      cin >> t;
      if ( !female.count(t) ) {
        gname[fit] = t;
        female[t] = fit++;
      }
      favor[i][j] = female[t];
    }
  }

  for ( int i = 0 ; i < n ; i++ ) {
    string p, t;
    cin >> p;
    for ( int j = 0 ; j < n ; j++ ) {
      cin >> t;
      order[female[p]][male[t]] = j;
    }
  }

  initialize();
  stable_marriage();

  for ( int i = 0 ; i < n ; i++ ) {
    cout << bname[i] << " " << gname[favor[i][current[i]
        - 1]] << endl;
  }

}
```

10.5 python 小抄

```python
#!/usr/bin/env python3

# 帕斯卡三角形
n = 10
dp = [ [1 for j in range(n)] for i in range(n) ]
for i in range(1,n):
    for j in range(1,n):
        dp[i][j] = dp[i][j-1] + dp[i-1][j]

for i in range(n):
    print( ' '.join( '{:5d}'.format(x) for x in dp[i] )
        )

# EOF1
while True:
    try:
        n, m = map(int, input().split())
    except:
        break
# EOF2
import sys
for s in sys.stdin:
    print(eval(s.replace("/", "//")))

# input a sequence of number
a = [ int(x) for x in input().split() ]
a.sort()
print( ''.join( str(x)+' ' for x in a ) )

# LCS
ncase = int( input() )
for _ in range(ncase):
    n, m = [int(x) for x in input().split()]
    a, b = "$"+input(), "$"+input()
    dp = [ [int(0) for j in range(m+1)] for i in range(n
        +1) ]
    for i in range(1,n+1):
        for j in range(1,m+1):
            dp[i][j] = max(dp[i-1][j],dp[i][j-1])
            if a[i]==b[j]:
                dp[i][j] = max(dp[i][j],dp[i-1][j-1]+1)

    for i in range(1,n+1):
        print(dp[i][1:])
    print('a={:s}, b={:s}, |LCS(a,b)|={:d}'.format(a
        [1:],b[1:],dp[n][m]))

# list, dict, string
a = [1, 3, 4, 65, 65]
b = list.copy() # b = [1, 3, 4, 65], list a 跟 llst b 互
    相獨立
cnt = list.count(65) # cnt == 2
loc = list.index(65) # loc == 3, find the leftmost
    element, if not found then return ERROR
list.sort(reverse = True|False, key = none|lambda x:x
    [1]) # list.sort has side effect but no reture value

# stack         # C++
stack = [3,4,5]
stack.append(6) # push()
stack.pop()     # pop()
stack[-1]       # top()
len(stack)      # size() O(1)

# queue         # C++
from collections import deque
```

```
queue = deque([3,4,5])
queue.append(6) # push()
queue.popleft() # pop()
queue[0]        # front()
len(queue)      # size() O(1)
```

11 Persistence