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1 Miscellaneous

1.1 Template

```
#include <bits/stdc++.h>
#define loop(i, a, n) for (int i = a; i < int(n); ++i)
#define loop_rev(i, b, a) for (ll i = b; i >= 1ll(a); --i)
using namespace std;
```

//optional:

```
#define int ll
```

```
typedef long long ll;
typedef long double ld;
typedef pair<int, int> ii;
typedef vector<int> vi;
typedef vector<vi> vvi;
```

```
void solve() {

}

int32_t main() {
    int t; cin >> t;
    while(t--)
        solve();
    return 0;
}
```

1.2 Input/Output c++

```
int main()
{
    // Ouput a specific number of digits past the decimal point,
    // in this case 5
    cout.setf(ios::fixed); cout << setprecision(5);
    cout << 100.0/7.0 << endl;
    cout.unsetf(ios::fixed);

    // Output the decimal point and trailing zeros
    cout.setf(ios::showpoint);
    cout << 100.0 << endl;
    cout.unsetf(ios::showpoint);

    // Output a '+' before positive values
    cout.setf(ios::showpos);
    cout << 100 << " " << -100 << endl;
    cout.unsetf(ios::showpos);

    // Output numerical values in hexadecimal
    cout << hex << 100 << " " << 1000 << " " << 10000 << dec << endl;

    //print 6 digits after the point
    printf("%.6f", (float)0.2426353);
    cout.setprecision(6);
    cout << fixed << 0.2426353 << endl;
}
```

1.3 Random STL stuff

// Example for using stringstream and next_permutation

```
int main(void) {
    vector<int> v;

    v.push_back(1);
    v.push_back(2);
    v.push_back(3);
    v.push_back(4);
}
```

```

// Expected output: 1 2 3 4
//                  1 2 4 3
//                  ...
//                  4 3 2 1
do {
    ostream oss;
    oss << v[0] << " " << v[1] << " " << v[2] << " " << v[3];

    // for input from a string s,
    // istream iss(s);
    // iss >> variable;

    cout << oss.str() << endl;
} while (next_permutation (v.begin(), v.end()));

v.clear();

v.push_back(1);
v.push_back(2);
v.push_back(1);
v.push_back(3);

// To use unique, first sort numbers. Then call
// unique to place all the unique elements at the beginning
// of the vector, and then use erase to remove the duplicate
// elements.

sort(v.begin(), v.end());
v.erase(unique(v.begin(), v.end()), v.end());

// Expected output: 1 2 3
for (size_t i = 0; i < v.size(); i++)
    cout << v[i] << " ";
cout << endl;
}

```

1.4 2-SAT Solver, SCC, T-Sort

```

void scc_dfs(const graph& G, int v, vector<int>& visit, vector<int>&
stack){
    if (visit[v]) return;

    visit[v] = true;
    for (auto& x : G[v]) scc_dfs(G, x, visit, stack);
    stack.push_back(v);
}

void scc_dfs(const graph& G, int v, int s, vector<int>& visit, vector<
int>& res){
    if (visit[v]) return;

    visit[v] = true;
    res[v] = s;
    for (auto& x : G[v]) scc_dfs(G, x, s, visit, res);
}

```

```

}

inline vector<int> scc_t_sort(const graph& G){
    graph G_rev(G.size());
    loop(i, 0, G.size()) for (auto& j : G[i]) G_rev[j].push_back(i);
    vector<int> visit(G.size(), false), stack;
    loop(i, 0, G.size()) scc_dfs(G, i, visit, stack);
    visit.assign(G.size(), false);
    vector<int> ret(G.size());
    int counter = 0;
    while (stack.size()) scc_dfs(G_rev, stack.back(), counter++, visit
, ret), stack.pop_back();
    return ret;
}

inline void add_or(graph& G, int a, int b, const vector<int>& not_v){
    G[not_v[a]].push_back(b);
    G[not_v[b]].push_back(a);
}

vector<int> sat_2(const vector<ii>& or_c, const vector<int>& not_v){
    graph G(not_v.size());
    for (auto& x : or_c) add_or(G, x.first, x.second, not_v);
    vector<int> arr = scc_t_sort(G);
    loop(i, 0, arr.size()) if (arr[i] == arr[not_v[i]]) return {};
    vector<int> val(G.size());
    loop(i, 0, arr.size()) if (arr[i] > arr[not_v[i]]) val[i] = true,
val[not_v[i]] = false;
    return val;
}

```

1.5 Knuth-Morris-Pratt

```

vector<int> kmp(string T, string P){
    int n = T.size();
    int m = P.size();
    vector<int> prefix(m, -1);
    int j = -1;
    for(int i = 1; i < m; i++){
        while(j != -1 && P[i] != P[j+1])
            j = prefix[j];
        if(P[i] == P[j+1])
            j++;
        prefix[i] = j;
    }
    j = -1;
    vector<int> pos;
    for(int i = 0; i < n; i++){
        while(j != -1 && T[i] != P[j+1])
            j = prefix[j];
        if(T[i] == P[j+1])
            j++;
        if(j == m-1)

```

```

        pos.push_back(i), j = prefix[j];
    }
    return pos;
}

```

1.6 Longest Increasing Subsequence

```

vector<int> LIS(vector<int> arr, bool strict = true){
    static const int inf = 2e9;
    vector<int> best(arr.size(), arr.size());
    arr.push_back(inf);
    vector<int> back(arr.size(), -1);

#define line(func) j = func(best.begin(), best.end(), i, [&arr](
    int a, int b){return arr[a] < arr[b];}) - best.begin()

    loop(i, 0, arr.size() - 1){
        int j;
        if (strict) line(lower_bound);
        else line(upper_bound);
        if (j != 0) back[i] = best[j - 1];
        best[j] = i;
    }

#undef line

    int pos = 0;
    while (pos < int(best.size()) - 1 && best[pos + 1] != int(arr.size()
        ()) - 1) ++pos;
    pos = best[pos];
    vector<int> ret;
    while (pos != -1) ret.push_back(pos), pos = back[pos];
    reverse(ret.begin(), ret.end());
    return ret;
}

```

1.7 Longest Common Subsequence

```

vector<char> LCS(string a, string b){
    int n = a.size(), m = b.size();
    vector<vector<int>> > dp(n, vector<int>(m));
    for(int i = 0; i < n; i++){
        for(int j = 0; j < m; j++){
            if(a[i] == b[j])
                dp[i][j] = (j && i)? dp[i-1][j-1]+1 : 1;
            else
                dp[i][j] = max(j? dp[i][j-1] : 0, i? dp[i-1][j] : 0);
        }
    }
    stack<char> ans;
    for(int i = n-1, j = m-1; i >= 0 && j >= 0;){
        if(a[i] == b[j]){
            ans.push(a[i]);

```

```

        i--; j--;
    }
    else{
        if((i? dp[i-1][j] : 0) < (j? dp[i][j-1] : 0))
            j--;
        else
            i--;
    }
}
vector<char> res;
while(!ans.empty())
    res.push_back(ans.top()), ans.pop();
return res;
}

```

1.8 Dates Python

```

import datetime

jdate = 17330
date = datetime.datetime.strptime(str(jdate), '%y%j').date()
# date is (date.day, date.month, date.year)

date = datetime.date(2017, 11, 26)

jdate = int( date.strftime('%y%j') )

```

1.9 Dates C++

// Routines for performing computations on dates. In these routines, months are expressed as integers from 1 to 12, days are expressed as integers from 1 to 31, and years are expressed as 4-digit integers.

```

#include <iostream>
#include <string>

using namespace std;

string dayOfWeek[] = {"Mon", "Tue", "Wed", "Thu", "Fri", "Sat", "Sun"};

// converts Gregorian date to integer (Julian day number)
int dateToInt (int m, int d, int y){
    return
        1461 * (y + 4800 + (m - 14) / 12) / 4 +
        367 * (m - 2 - (m - 14) / 12 * 12) / 12 -
        3 * ((y + 4900 + (m - 14) / 12) / 100) / 4 +
        d - 32075;
}

// converts integer (Julian day number) to Gregorian date: month/day/
year

```

```

void intToDate (int jd, int &m, int &d, int &y){
    int x, n, i, j;

    x = jd + 68569;
    n = 4 * x / 146097;
    x -= (146097 * n + 3) / 4;
    i = (4000 * (x + 1)) / 1461001;
    x -= 1461 * i / 4 - 31;
    j = 80 * x / 2447;
    d = x - 2447 * j / 80;
    x = j / 11;
    m = j + 2 - 12 * x;
    y = 100 * (n - 49) + i + x;
}

// converts integer (Julian day number) to day of week
string intToDay (int jd){
    return dayOfWeek[jd % 7];
}

int main (int argc, char **argv){
    int jd = dateToInt (3, 24, 2004);
    int m, d, y;
    intToDate (jd, m, d, y);
    string day = intToDay (jd);

    // expected output:
    // 2453089
    // 3/24/2004
    // Wed
    cout << jd << endl
         << m << "/" << d << "/" << y << endl
         << day << endl;
}

```

2 Geometry

2.1 Geometry Vectors

```

typedef double T;
typedef pair<T, T> ii;
typedef pair<ii, T> i3;
typedef pair<ii, ii> i4;

inline double cross(ii a, ii b){
    return a.first * b.y - a.y * b.first;
}

inline ii operator+(ii a, ii b){
    return ii(a.first + b.first, a.y + b.y);
}

inline ii operator-(ii a, ii b){

```

```

    return ii(a.first - b.first, a.y - b.y);
}

inline double operator*(ii a, ii b){
    return a.first * b.first + a.y * b.y;
}

inline ii operator/(ii a, double b){
    return ii(a.first / b, a.y / b);
}

inline T norm(ii x){
    return x * x;
}

inline int sig(double x){
    return x > 0 ? 1 : x == 0 ? 0 : -1;
}

inline double distance(ii a, ii b){
    return sqrt(norm(b - a));
}

bool inTriangle(ii a, ii b, ii c, ii p){
    int sign1 = sign(cross(a-p, b-a));
    int sign2 = sign(cross(b-p, c-b));
    int sign3 = sign(cross(c-p, a-c));
    if(max(sign1, max(sign2, sign3)) == 1 && min(sign1, min(sign2, sign3))
       == -1)
        return false;
    return true;
}

11 area(vector<ii> shape){ // counter-clockwise
    11 sum = 0;
    while (shape.size() > 2){
        sum += cross(shape[shape.size() - 2] - shape[0], shape[shape.
            size() - 1] - shape[0]);
        shape.pop_back();
    }
    return sum;
}

```

2.2 Convex Hull

```

inline int lowest_point(vector<ii> P){
    return min_element(P.begin(), P.end(), [](ii a, ii b){return
        ii(a.second, a.first) < ii(b.second, b.first);}) - P.begin
        ();
}

vector<ii> convex_hull(vector<ii> S){
    int first = lowest_point(S);
    ii origin = S[first];

```

```

S.erase(S.begin() + first);
//sort by angle
sort(S.begin(), S.end(), [&origin](ii p1, ii p2){return ii(-cross(
    p1 - origin, p2 - origin), norm(p1 - origin)) < ii(0, norm(p2
    - origin));});

vector<ii> hull = {origin};
for (auto& p : S){
    while(hull.size() >= 2 && cross(hull[hull.size() - 1] - hull[
        hull.size() - 2], p - hull[hull.size() - 1]) <= 0) hull.
        pop_back();
    hull.push_back(p);
}
return hull;
}

```

2.3 Minimal Bounding Circle

```

bool inside_circle(i3 circle, ii p){
    return distance(circle.first, p) <= circle.second;
}

i3 circle_from_2_points(ii a, ii b){
    return {(a+b)/2, distance(a, b)/2};
}

i3 circle_from_3_points(ii a, ii b, ii c){
    double d = 2.0*(a.x*(b.y - c.y) + b.x*(c.y - a.y) + c.x*(a.y - b.y
    ));
    double xc = ((a.x * a.x + a.y * a.y) * (b.y - c.y) + (b.first * b.
    first + b.y * b.y) * (c.y - a.y) + (c.first * c.first + c.y *
    c.y) * (a.y - b.y) ) / d;
    double yc = ((a.first * a.first + a.y * a.y) * (c.first - b.first)
    + (b.first * b.first + b.y * b.y) * (a.first - c.first) + (c.
    first * c.first + c.y * c.y) * (b.first - a.first) ) / d;
    cerr << xc << " " << yc << endl;
    ii center = {xc, yc};
    return {center, distance(center, a)};
}

i3 minimal_bounding_circle_3(vector<ii>& P, ii a, ii b){
    i3 circle = circle_from_2_points(a, b);
    for(ii p : P){
        if(!inside_circle(circle, p)){
            circle = circle_from_3_points(a, b, p);
        }
    }
    return circle;
}

i3 minimal_bounding_circle_2(vector<ii>& P, ii a){
    i3 circle = circle_from_2_points(a, P[0]);
    vector<ii> P2 = {P[0]};

```

```

for(int i = 1; i < (int)P.size(); ++i){
    ii p = P[i];
    if(!inside_circle(circle, p)){
        circle = minimal_bounding_circle_3(P2, a, p);
    }
    P2.push_back(P[i]);
}
return circle;
}

i3 minimal_bounding_circle(vector<ii>& P){
    if(P.size() < 2) return {{0,0}, -1}; // null!
    random_shuffle(P.begin(), P.end());

    i3 circle = circle_from_2_points(P[0], P[1]);
    vector<ii> P2 = {P[0], P[1]};
    for(int i = 2; i < (int)P.size(); ++i){
        ii p = P[i];
        if(!inside_circle(circle, p)){
            circle = minimal_bounding_circle_2(P2, p);
        }
        P2.push_back(P[i]);
    }
    return circle;
}

```

3 Numerical algorithms

3.1 Gauss Elimination

```

const int mod = 2;

inline int mul(int a, int b){
    return (ll(a) * ll(b)) % mod;
}

int power(int a, int b){
    if (b == 0) return 1;
    int c = power(a, b / 2);
    return mul(mul(c, c), (b % 2 == 0 ? 1 : a));
}

inline int inv(int x){
    return power(x, mod - 2);
}

vector<int> operator-(vector<int> arr1, const vector<int>& arr2){
    loop(i, 0, arr1.size()) arr1[i] = (ll(arr1[i]) - ll(arr2[i]) + mod
    ) % mod;
    return arr1;
}

vector<int> operator*(int k, vector<int> arr){

```

```

    for (auto& x : arr) x = (ll(x) * ll(k)) % mod;
    return arr;
}

#define N 2501
#define bool_array bitset<N>
const bool_array zero;

template<typename T>
void gauss(vector<T>& arr);

bool_array operator~(const bool_array& arr1, const bool_array& arr2){
    return arr1 ^ arr2;
}

bool_array operator*(int k, const bool_array& arr){
    return k == 1 ? arr : zero;
}

bool_array vector_int_to_bool_array(const vector<int>& arr){
    bool_array ret;
    loop(i, 0, arr.size()) ret[i] = arr[i];
    return ret;
}

vector<int> bool_array_to_vector_int(const bool_array& arr, int n){
    vector<int> ret(n);
    loop(i, 0, ret.size()) ret[i] = arr[i];
    return ret;
}

void gauss_com(vector<vector<int>>& arr){
    int m = arr.front().size();
    vector<bool_array> com(arr.size());
    loop(i, 0, com.size()) com[i] = vector_int_to_bool_array(arr[i]);
    gauss(com);
    arr.resize(com.size());
    loop(i, 0, com.size()) arr[i] = bool_array_to_vector_int(com[i], m);
}

template<typename T>
void gauss(vector<T>& arr){
    int row = 0;
    if (arr.size() == 0) return;
    loop(j, 0, arr[row].size()){
        int pos = -1;
        loop(k, row, arr.size()) if (arr[k][j] != 0){
            pos = k;
            break;
        }
        if (pos == -1) continue;
        swap(arr[pos], arr[row]);
        loop(k, row + 1, arr.size()) if (arr[k][j] != 0) arr[k] = arr[
            row][j] * arr[k] - arr[k][j] * arr[row];
    }
}

```

```

        if (++row == (int)arr.size()) break;
    }

    while (arr.size() != 0){
        int b = true;
        loop(j, 0, arr.back().size()) if (arr.back()[j] != 0){
            b = false;
            break;
        }
        if (!b) break;
        arr.pop_back();
    }

    int col = -1;
    loop(i, 0, arr.size()){
        while (arr[i][++col] == 0);
        loop(k, 0, i) if (arr[k][col] != 0) arr[k] = arr[i][col] * arr
            [k] - arr[k][col] * arr[i];
    }
}

```

3.2 Fast Fourier Transform

```

#define pi 3.14159265359

typedef complex<double> com;

void dft(vector<com>& p, com mult){
    if (p.size() == 1) return;

    vector<com> p1(p.size() / 2), p2(p.size() / 2);
    loop(i, 0, p.size()){
        if (i % 2 == 0) p1[i / 2] = p[i];
        else p2[i / 2] = p[i];

        com curr = 1, new_mult = mult * mult;
        dft(p1, new_mult), dft(p2, new_mult);
        loop(i, 0, p.size() / 2){
            com a = p1[i], b = curr * p2[i];
            p[i] = a + b, p[i + p.size() / 2] = a - b;
            curr *= mult;
        }
    }

    void dft(vector<com>& p, int k){
        dft(p, polar(1., k * 2 * pi / p.size()));
    }

    vector<double> mul(const vector<double>& _p1, const vector<double>&
        _p2){
        vector<com> p1(_p1.size()), p2(_p2.size());
        loop(i, 0, p1.size()) p1[i] = _p1[i];
        loop(i, 0, p2.size()) p2[i] = _p2[i];

        int k = 1;
    }
}

```

```

while (k < 2 * (int)p1.size() - 1 || k < 2 * (int)p2.size() - 1) k
    *= 2;
while ((int)p1.size() < k) p1.push_back(0);
while ((int)p2.size() < k) p2.push_back(0);

dft(p1, 1), dft(p2, 1);

vector<com> p(p1.size());
loop(i, 0, p1.size()) p[i] = p1[i] * p2[i];

dft(p, -1);

while (p.size() > 1 && norm(p.back()) < 0.001) p.pop_back();
vector<double> res(p.size());
loop(i, 0, res.size()) res[i] = real(p[i]) / p1.size();
return res;
}

```

3.3 Hadamard Transform

```

//
//Given A[], B[], find C[] such that
//  C[i] = sum_j A[j] B[i xor j]
//
const unsigned int mod = 1'000'000'007;

void trans(vi::iterator begin, vi::iterator end, int counter){
    if (counter == 0) return;
    int k = (end - begin) / 2;

    trans(begin, begin + k, counter - 1), trans(begin + k, end,
        counter - 1);
    loop(i, 0, k){
        unsigned int x = *(begin + i), y = *(begin + k + i);
        *(begin + i) = (x + y) % mod, *(begin + k + i) = (x + mod - y)
            % mod;
    }
}

vi mul(vi p1, vi p2, bool same = false){
    int k, counter;
    for (k = 1, counter = 0; k < (int)max(p1.size(), p2.size()); k *=
        2, ++counter);
    p1.resize(k), p2.resize(k);

    trans(p1.begin(), p1.end(), counter);
    if (!same) trans(p2.begin(), p2.end(), counter);
    else p2 = p1;
    loop(i, 0, p1.size()) p1[i] = (ll(p1[i]) * ll(p2[i])) % mod;
    trans(p1.begin(), p1.end(), counter);

    int curr = 1, mul = mod / 2 + 1;
    loop(i, 0, counter) curr = (ll(curr) * ll(mul)) % mod;
}

```

```

for (auto& x : p1) x = (ll(x) * ll(curr)) % mod;
return p1;
}

vi power(vi p, int k){
    vi m = p;
    p.assign(p.size(), 0); p[0] = 1;
    while (k){
        if (k % 2 == 1) mul(p, m);
        k /= 2;
        mul(m, m, true);
    }
    return p;
}

int32_t main(){
    ios::sync_with_stdio(false);
    int k, l; cin >> k >> l;
    vi p(l + 1, 1);
    p[0] = p[1] = 0;
    loop(i, 2, p.size()) for (int j = 2 * i; j < (int)p.size(); j += i
        ) p[j] = 0;

    p = power(p, k);
    cout << p[0] << endl;
    return 0;
}

```

3.4 Fast Subset Convolution

```

const unsigned int mod = 1'000'000'007;

void trans(vi& p){
    int n = p.size();
    for(int c = 1; c < n; c += c)
        loop(i, 0, n)
            if(i & c)
                p[i] += p[i-c];
}

void invtrans(vi& p){
    int n = p.size();
    for(int c = n/2; c; c /= 2)
        for(int i = n-1; i >= 0; i--)
            if(i & c)
                p[i] -= p[i-c];
}

vi mul(vi p1, vi p2){
    int n = p1.size();

    //loop(j, 0, n) cerr << p1[j]; cerr << endl;
    //loop(j, 0, n) cerr << p2[j]; cerr << endl;
    //cerr << endl;
}

```

```

trans(p1);
//loop(j, 0, n) cerr << p1[j]; cerr << endl;
trans(p2);
//loop(j, 0, n) cerr << p2[j]; cerr << endl;

loop(i, 0, n) p1[i] *= p2[i];

invtrans(p1);

//loop(j, 0, n) cerr << p1[j]; cerr << endl;
//cerr << endl;
return p1;
}

```

```

int32_t main(){
    ios::sync_with_stdio(false);

    int n, m, k; cin >> n >> m >> k;
    vvi A(m, vi(1 << n));
    loop(i, 0, m)
        loop(j, 0, (1 << n)){
            char c; cin >> c;
            A[i][j] = (c == '1');
        }
    loop(i, 0, k){
        int a, b; cin >> a >> b;
        vi ans = mul(A[a], A[b]);
        loop(j, 0, (1 << n))
            cout << (ans[j] ? 1 : 0);
        cout << endl;
    }

    return 0;
}

```

```

/*
3 5 3
11111010
11000000
11001000
11101000
11101000
0 1
1 2
3 4

*/

```

// Not Tested

// This is a collection of useful code for solving problems that
 // involve modular linear equations. Note that all of the
 // algorithms described here work on nonnegative integers.

// return a % b (positive value)
 int mod(int a, int b) {
 return ((a%b) + b) % b;
 }

// computes gcd(a,b)
 int gcd(int a, int b) {
 while (b) { int t = a%b; a = b; b = t; }
 return a;
 }

// computes lcm(a,b)
 int lcm(int a, int b) {
 return a / gcd(a, b) * b;
 }

// (a^b) mod m via successive squaring
 int powermod(int a, int b, int m)
 {
 int ret = 1;
 while (b)
 {
 if (b & 1) ret = mod(ret*a, m);
 a = mod(a*a, m);
 b >>= 1;
 }
 return ret;
 }

// returns g = gcd(a, b); finds x, y such that d = ax + by
 int extended_euclid(int a, int b, int &x, int &y) {
 int xx = y = 0;
 int yy = x = 1;
 while (b) {
 int q = a / b;
 int t = b; b = a%b; a = t;
 t = xx; xx = x - q*xx; x = t;
 t = yy; yy = y - q*yy; y = t;
 }
 return a;
 }

// finds all solutions to ax = b (mod n)
 vi modular_linear_equation_solver(int a, int b, int n) {
 int x, y;
 vi ret;
 int g = extended_euclid(a, n, x, y);
 if (!(b%g)) {
 x = mod(x*(b / g), n);
 }
 }


```

        for (int i = 0; i < g; i++)
            ret.push_back(mod(x + i*(n / g), n));
    }
    return ret;
}

// computes b such that ab = 1 (mod n), returns -1 on failure
int mod_inverse(int a, int n) {
    int x, y;
    int g = extended_euclid(a, n, x, y);
    if (g > 1) return -1;
    return mod(x, n);
}

// Chinese remainder theorem (special case): find z such that
// z % m1 = r1, z % m2 = r2. Here, z is unique modulo M = lcm(m1, m2)
.
// Return (z, M). On failure, M = -1.
ii chinese_remainder_theorem(int m1, int r1, int m2, int r2) {
    int s, t;
    int g = extended_euclid(m1, m2, s, t);
    if (r1%g != r2%g) return make_pair(0, -1);
    return make_pair(mod(s*r2*m1 + t*r1*m2, m1*m2) / g, m1*m2 / g);
}

// Chinese remainder theorem: find z such that
// z % m[i] = r[i] for all i. Note that the solution is
// unique modulo M = lcm_i (m[i]). Return (z, M). On
// failure, M = -1. Note that we do not require the a[i]'s
// to be relatively prime.
ii chinese_remainder_theorem(const vi &m, const vi &r) {
    ii ret = make_pair(r[0], m[0]);
    for (int i = 1; i < m.size(); i++) {
        ret = chinese_remainder_theorem(ret.second, ret.first,
            m[i], r[i]);
        if (ret.second == -1) break;
    }
    return ret;
}

// computes x and y such that ax + by = c
// returns whether the solution exists
bool linear_diophantine(int a, int b, int c, int &x, int &y) {
    if (!a && !b)
    {
        if (c) return false;
        x = 0; y = 0;
        return true;
    }
    if (!a)
    {
        if (c % b) return false;
        x = 0; y = c / b;
        return true;
    }

```

```

    }
    if (!b)
    {
        if (c % a) return false;
        x = c / a; y = 0;
        return true;
    }
    int g = gcd(a, b);
    if (c % g) return false;
    x = c / g * mod_inverse(a / g, b / g);
    y = (c - a*x) / b;
    return true;
}

int main() {
    // expected: 2
    cout << gcd(14, 30) << endl;

    // expected: 2 -2 1
    int x, y;
    int g = extended_euclid(14, 30, x, y);
    cout << g << " " << x << " " << y << endl;

    // expected: 95 451
    vi sols = modular_linear_equation_solver(14, 30, 100);
    for (int i = 0; i < sols.size(); i++) cout << sols[i] << " ";
    cout << endl;

    // expected: 8
    cout << mod_inverse(8, 9) << endl;

    // expected: 23 105
    //      11 12
    ii ret = chinese_remainder_theorem(vi({ 3, 5, 7 }), vi({ 2, 3,
        2 }));
    cout << ret.first << " " << ret.second << endl;
    ret = chinese_remainder_theorem(vi({ 4, 6 }), vi({ 3, 5 }));
    cout << ret.first << " " << ret.second << endl;

    // expected: 5 -15
    if (!linear_diophantine(7, 2, 5, x, y)) cout << "ERROR" <<
        endl;
    cout << x << " " << y << endl;
    return 0;
}

```

3.6 More Number Theory

```

// Not Tested

int max(int a, int b)
{
    return a>b ? a:b;
}

```

```

int min(int a, int b)
{
    return a<b ? a:b;
}

int gcd(int a, int b)
{
    if (b==0) return a;
    else return gcd(b, a%b);
}

int lcm(int a, int b)
{
    return a*b/gcd(a,b);
}

bool prime(int n)
{
    if (n<2) return false;
    for (int i=2;i*i<=n;i++)
        if (n%i==0) return false;
    return true;
}

bool isLeap(int n)
{
    if (n%100==0)
        if (n%400==0) return true;
        else return false;

    if (n%4==0) return true;
    else return false;
}

long powmod(long base, long exp, long modulus) {
    base %= modulus;
    long result = 1;
    while (exp > 0) {
        if (exp & 1) result = (result * base) % modulus;
        base = (base * base) % modulus;
        exp >>= 1;
    }
    return result;
}

int factmod (int n, int p) {
    long long res = 1;
    while (n > 1) {
        res = (res * powmod (p-1, n/p, p)) % p;
        for (int i=2; i<=n%p; ++i)
            res=(res*i) %p;
        n /= p;
    }
    return int (res % p);
}

```

```

}

void combination(int n, int m)
{
    if (n<m) return ;
    int a[50]={0};
    int k=0;

    for (int i=1;i<=m;i++) a[i]=i;
    while (true)
    {
        for (int i=1;i<=m;i++)
            cout << a[i] << " ";
        cout << endl;

        k=m;
        while ((k>0) && (n-a[k]==m-k)) k--;
        if (k==0) break;
        a[k]++;
        for (int i=k+1;i<=m;i++)
            a[i]=a[i-1]+1;
    }
}

int main(void)
{
    /***** Max or min *****/

    cout << "-----TEST FOR MAX OR MIN-----" << endl;
    // Max and min are implemented in library
    // the point for this is to show the syntax

    cout << "Max of (5,7): " << max(5,7) << endl;
    cout << "Min of (5,7): " << min(5,7) << endl;

    cout << "-----TEST FOR MAX OR MIN-----" << endl;
    cout << endl << endl;

    /***** GCD and LCM *****/

    cout << "-----TEST FOR GCD AND LCM-----" << endl;

    cout << "GCD of (12, 15): " << gcd(12,15) << endl;
    cout << "LCM of (12, 15): " << lcm(12,15) << endl;

    cout << "-----TEST FOR GCD AND LCM-----" << endl;
    cout << endl << endl;

    /***** prime number *****/

    cout << "-----TEST FOR PRIME NUMBER-----" << endl;

    cout << "Is 1251 prime?: " << prime(1251) << endl;
    cout << "Is 97 prime? : " << prime(97) << endl;
}

```

```

cout << "-----TEST FOR PRIME NUMBER-----" << endl;
cout << endl << endl;

/**** Leap year ****/

cout << "-----TEST FOR LEAP YEAR-----" << endl;

cout << "2012 is Leap? : " << isLeap(2012) << endl;
cout << "1900 is Leap? : " << isLeap(1900) << endl;
cout << "1903 is Leap? : " << isLeap(1903) << endl;

cout << "-----TEST FOR LEAP YEAR-----" << endl;
cout << endl << endl;

/**** a^b mod p and n! mod p ****/

cout << "-----TEST FOR (A^B MOD P) AND (N! MOD P)-----" <<
    endl;

cout << "5^6 mod 17: " << powmod(5, 6, 17) << endl;
cout << "17 mod 17 : " << factmod(17, 17) << endl;

cout << "-----TEST FOR (A^B MOD P) AND (N! MOD P)-----" <<
    endl;
cout << endl << endl;

/**** Generate combinations ****/

cout << "-----TEST FOR GENERATING COMBINATIONS-----" << endl
    ;

combination(6, 3); // pick 3 numbers from 6 numbers

cout << "-----TEST FOR GENERATING COMBINATIONS-----" << endl
    ;
cout << endl << endl;

return 0;
}

```

3.7 All Pairs Shortest Paths (Floyd Warshall)

```

const int inf = 1e9;
int main()
{
    int n,m; cin >> n >> m;
    vector<vector<int>> > D(n,vector<int>(n,inf));
    for(int i=0;i<m;i++){
        int a,b,d; cin >>a >> b >> d;
        D[a-1][b-1] = D[b-1][a-1] = d;
    }
    for(int i = 0;i<n;D[i][i]= 0);
    for(int k = 0;k<n;k++){

```

```

        for(int j = 0;j<n;j++){
            for(int i = 0;i<n;i++){
                D[i][j] = min(D[i][j],D[i][k]+D[k][j]);
            }
        }
    }

    return 0;
}

```

4 Graph algorithms

4.1 Dijkstra

```

vector<int> dijkstra(const graph_w& G, int s){
    int n = G.size();
    vector<int> dis(n, inf);
    set<ii> S;
    dis[s] = 0;
    S.insert({0, s});
    while(!S.empty()){
        int u = S.begin()->second;
        S.erase(S.begin());

        for(auto& e : G[u]){
            int v = e.first, w = e.second;
            if(dis[v] > dis[u] + w){
                S.erase({dis[v], v});
                dis[v] = dis[u] + w;
                S.insert({dis[v], v});
            }
        }
    }
    return dis;
}

```

4.2 Dinic Max Flow

```

//
// Dinic algorithm for maximum flow / minimum cut
// time: O(VVE), usually faster, no more than O(maxflow * E)
// space: O(V+E)
//
struct edge {
    int u, v;
    ll cap, flow;
    edge() {}
    edge(int u, int v, ll cap): u(u), v(v), cap(cap), flow(0) {}
};

struct Dinic {
    int N;

```

```
vector<edge> E;
vector<vector<int>> > g;
vector<int> d, pt;

Dinic(int N): N(N), E(0), g(N), d(N), pt(N) {}
```

```
void Addedge(int u, int v, ll cap) {
    if (u != v) {
        E.emplace_back(edge(u, v, cap));
        g[u].emplace_back(E.size() - 1);
        E.emplace_back(edge(v, u, 0));
        g[v].emplace_back(E.size() - 1);
    }
}

bool BFS(int S, int T) {
    queue<int> q({S});
    fill(d.begin(), d.end(), N + 1);
    d[S] = 0;
    while(!q.empty()) {
        int u = q.front(); q.pop();
        if (u == T) break;
        for (int k: g[u]) {
            edge &e = E[k];
            if (e.flow < e.cap && d[e.v] > d[e.u] + 1) {
                d[e.v] = d[e.u] + 1;
                q.emplace(e.v);
            }
        }
    }
    return d[T] != N + 1;
}
```

```
ll DFS(int u, int T, ll flow = -1) {
    if (u == T || flow == 0) return flow;
    for (int &i = pt[u]; i < g[u].size(); ++i) {
        edge &e = E[g[u][i]];
        edge &oe = E[g[u][i]^1];
        if (d[e.v] == d[e.u] + 1) {
            ll amt = e.cap - e.flow;
            if (flow != -1 && amt > flow) amt = flow;
            if (ll pushed = DFS(e.v, T, amt)) {
                e.flow += pushed;
                oe.flow -= pushed;
                return pushed;
            }
        }
    }
    return 0;
}
```

```
ll MaxFlow(int S, int T) {
    ll total = 0;
    while (BFS(S, T)) {
        fill(pt.begin(), pt.end(), 0);

```

```
        while (ll flow = DFS(S, T))
            total += flow;
    }
    return total;
};
```

4.3 Maximum Bipartite Matching

//Not Tested

// This code performs maximum bipartite matching.
//
// Running time: $O(|E| |V|)$ -- often much faster in practice
//
// INPUT: w[i][j] = edge between row node i and column node j
// OUTPUT: mr[i] = assignment for row node i, -1 if unassigned
// mc[j] = assignment for column node j, -1 if unassigned
// function returns number of matches made

```
bool find_match(int i, const vvi &w, vi &mr, vi &mc, vi &seen) {
    for (int j = 0; j < w[i].size(); j++) {
        if (w[i][j] && !seen[j]) {
            seen[j] = true;
            if (mc[j] < 0 || find_match(mc[j], w, mr, mc, seen)) {
                mr[i] = j;
                mc[j] = i;
                return true;
            }
        }
    }
    return false;
}
```

```
int bipartite_matching(const vvi &w, vi &mr, vi &mc) {
    mr = vi(w.size(), -1);
    mc = vi(w[0].size(), -1);

    int ct = 0;
    for (int i = 0; i < w.size(); i++) {
        vi seen(w[0].size());
        if (find_match(i, w, mr, mc, seen)) ct++;
    }
    return ct;
}
```

4.4 Dominators

```
namespace dominator{
    int T, n;
    vvi g, rg, bucket;
    vi sdom, par, dom, dsu, label, arr, rev;
```

4.5 Lowest Common Ancestor

//maybe remove

```
int LOGN;
vector<vector<int>> > LCA;
vector<int> depth;
vector<vector<int>> > tree;
void dfs(int u, int dep) {
    depth[u] = dep;
    for (int v : tree[u])
        dfs(v, dep + 1);
}

void init(int N, int fathers[]) {
    tree.assign(N, vector<int>());
    int root = -1;
    for (int i = 0; i < N; i++)
        if (fathers[i] == -1)
            root = i, fathers[i] = i;
        else
            tree[fathers[i]].push_back(i);
    depth.assign(N, 0);
    dfs(root, 0);
    LOGN = 3;
    for (int n = N; n /= 2; LOGN++);
    LCA.assign(LOGN, vector<int>(N));
    for (int i = 0; i < N; i++)
        LCA[0][i] = fathers[i];
    for (int d = 1; d < LOGN; d++)
        for (int i = 0; i < N; i++)
            LCA[d][i] = LCA[d-1][LCA[d-1][i]];
}

int query(int u, int v) {
    if (depth[u] < depth[v])
        swap(u, v);
    for (int d = LOGN - 1; d >= 0; d--)
        if (depth[LCA[d][u]] >= depth[v])
            u = LCA[d][u];
    if (u == v)
        return u;
    for (int d = LOGN - 1; d >= 0; d--)
        if (LCA[d][u] != LCA[d][v])
            u = LCA[d][u], v = LCA[d][v];
    return LCA[0][u];
}

int main()
{
    int t; cin >> t;
    for (int r = 0; r < t; r++) {
        int n; cin >> n;
        int *fathers = new int[n];
```

```
int find(int u, int x = 0) {
    if (u == dsu[u]) return x ? -1 : u;
    int v = find(dsu[u], x + 1);
    if (v < 0) return u;
    if (sdom[label[dsu[u]]] < sdom[label[u]]) label[u] = label[dsu[u]];
    dsu[u] = v;
    return x ? v : label[u];
}

void unite(int u, int v) {
    dsu[v] = u;
}

void dfs(int u) {
    T++; arr[u] = T; rev[T] = u;
    label[T] = T; sdom[T] = T; dsu[T] = T;
    loop(i, 0, g[u].size()) {
        int w = g[u][i];
        if (!arr[w]) dfs(w), par[arr[w]] = arr[u];
        rg[arr[w]].PB(arr[u]);
    }
}

static vi get(const graph& G, int root) {
    T = 0, n = G.size();
    int k = n + 1;
    g.assign(k, {}), rg.assign(k, {}), bucket.assign(k, {});
    sdom.assign(k, 0), par.assign(k, 0), dom.assign(k, 0), dsu.
        assign(k, 0), label.assign(k, 0), arr.assign(k, 0), rev.
        assign(k, 0);

    loop(i, 0, G.size()) for (auto& x : G[i]) g[i + 1].PB(x + 1);
    ++root;
    vector<int> res(n, -1);
    dfs(root); n = T;
    loop_rev(i, n, 1) {
        loop(j, 0, rg[i].size()) sdom[i] = min(sdom[i], sdom[find(
            rg[i][j])]);
        if (i > 1) bucket[sdom[i]].PB(i);
        loop(j, 0, bucket[i].size()) {
            int w = bucket[i][j], v = find(w);
            if (sdom[v] == sdom[w]) dom[w] = sdom[w];
            else dom[w] = v;
        }
        if (i > 1) unite(par[i], i);
    }
    loop(i, 2, n + 1) {
        if (dom[i] != sdom[i]) dom[i] = dom[dom[i]];
        res[rev[i] - 1] = rev[dom[i]] - 1;
    }
    return res;
}
}
```

```

for(int i = 0; i < n; i++) fathers[i] = -1;
for(int i = 0; i < n; i++) {
    int m; cin >> m;
    for(int j = 0; j < m; j++) {
        int x; cin >> x;
        fathers[x-1] = i;
    }
}
init(n, fathers);
cout << "Case " << r+1 << ":\n";
int q; cin >> q;
for(int a = 0; a < q; a++) {
    int u, v; cin >> u >> v;
    cout << query(u-1, v-1)+1 << endl;
}
}
return 0;
}

```

5 Data structures

5.1 Disjoint Sets (Union-Find)

```

vector<int> parent;

void init(int n) {
    parent.resize(n);
    for(int i = 0; i < n; i++) parent[i] = i;
}

int find(int u) {
    return u == parent[u] ? u : parent[u] = find(parent[u]);
}

void uni(int u, int v) {
    parent[find(u)] = find(v);
}

```

5.2 Fenwick Tree

```

//Not Tested
#define LOGSZ 17

int tree[(1<<LOGSZ)+1];
int N = (1<<LOGSZ);

// add v to value at x
void set(int x, int v) {
    while(x <= N) {
        tree[x] += v;
        x += (x & -x);
    }
}

```

```

}

// get cumulative sum up to and including x
int get(int x) {
    int res = 0;
    while(x) {
        res += tree[x];
        x -= (x & -x);
    }
    return res;
}

// get largest value with cumulative sum less than or equal to x;
// for smallest, pass x-1 and add 1 to result
int getind(int x) {
    int idx = 0, mask = N;
    while(mask && idx < N) {
        int t = idx + mask;
        if(x >= tree[t]) {
            idx = t;
            x -= tree[t];
        }
        mask >>= 1;
    }
    return idx;
}

```

5.3 Segment Tree

```

#define inf 1e9

struct segmentTree {
    vector<int> tree;
    int size;
    segmentTree(int n) {
        for(size = 2; n/=2; size+=size);
        tree.resize(size+size, inf);
    }
    void fix(int i) {
        tree[i] = min(tree[i+i], tree[i+i+1]);
    }
    void update(int x, int v) {
        for(tree[x+=size] = v; x/=2; fix(x));
    }
    int query(int a, int b) {
        int res = inf;
        for(a += size, b+=size; a<b; a/=2, b/=2) {
            if(a % 2 == 1) res = min(res, tree[a++]);
            if(b % 2 == 0) res = min(res, tree[b--]);
        }
        return (a==b? min(res, tree[a]) : res);
    }
};

```

5.4 Convex Hull Trick

```

typedef pair<ll, ll> llll;

enum line_type{
    normal,
    minus_infinity,
    infinity,
    value
};

ll gcd(ll a, ll b){
    if (a < b) swap(a, b);
    if (b == 0) return a;
    return gcd(b, a % b);
}

struct fraction{
    ll a, b;
    fraction(ll _a, ll _b = 1) : a(_a), b(_b){
        if (a == 0 && b == 0) return;
        if (b < 0) a = -a, b = -b;
        ll c = gcd(abs(a), b);
        a /= c, b /= c;
    }

    operator llll() const{
        return llll(a, b);
    }
};

inline bool operator<(const fraction& f1, const fraction& f2){
    if (llll(f1) == llll(f2)) return false;
    if (llll(f1) == llll(-1, 0) || llll(f2) == llll(1, 0)) return true;
    if (llll(f1) == llll(1, 0) || llll(f2) == llll(-1, 0)) return false;
    return ld(f1.a) * ld(f2.b) < ld(f2.a) * ld(f1.b);
}

struct line{
    ll a, b;
    line_type t = normal;
    set<line>::iterator* it = new set<line>::iterator;

    line(ll _a, ll _b) : a(_a), b(_b){}
    line(ll _x) : a(0), b(_x), t(value){}
    line(const line& other) : a(other.a), b(other.b), t(other.t){
        *it = *other.it;
    }
    line& operator=(const line& other){
        a = other.a;
        b = other.b;
        t = other.t;

        *it = *other.it;
        return *this;
    }

    ll operator()(ll x) const{
        return a * x + b;
    }

    static line left_edge(){
        line ret(0);
        ret.t = minus_infinity;
        return ret;
    }

    static line right_edge(){
        line ret(0);
        ret.t = infinity;
        return ret;
    }

    ~line(){
        delete it;
    }
};

inline fraction intersection(const line& l1, const line& l2){
    if (l1.t == infinity || l2.t == infinity) return fraction(1, 0);
    if (l1.t == minus_infinity || l2.t == minus_infinity) return fraction(-1, 0);
    return fraction(l1.b - l2.b, l2.a - l1.a);
}

inline bool operator<(const line& l1, const line& l2){
    if (l1.t == normal && l2.t == normal) return llll(-l1.a, l1.b) < llll(-l2.a, l2.b);
    if (l1.t == minus_infinity || l2.t == infinity) return true;
    if (l1.t == infinity || l2.t == minus_infinity) return false;
    if (l1.t == value) return fraction(l1.b) < intersection(*prev(*l2.it), l2);
    return !(fraction(l2.b) < intersection(l1, *next(*l1.it)));
}

struct cht{
    set<line> s = {line::left_edge(), line::right_edge()};

    cht(){
        *(s.begin()->it) = s.begin();
        *(next(s.begin()->it) = next(s.begin());
    }

    void insert_line(const line& l){
        set<line>::iterator it2 = s.upper_bound(l), it1 = prev(it2);
        if (it1 != s.begin() && (it1->a == l.a || !(intersection(*it1, l) < intersection(*it1, *it2)))) return;
        if (it2 != prev(s.end()) && l.a == it2->a) ++it2;
    }
};

```

```

    while (it1 != s.begin() && !(intersection(*prev(it1), *it1) <
        intersection(*it1, 1))) --it1;
    while (it2 != prev(s.end()) && !(intersection(*it2, 1) <
        intersection(*it2, *next(it2)))) ++it2;
    while (next(it1) != it2) s.erase(next(it1));
    set<line>::iterator it = s.insert(it1, 1);
    *(it->it) = it;
}

ll operator()(ll x){
    return (*prev(s.upper_bound(line(x))))(x);
}
};

```

5.5 Linear Convex Hull Trick

```

struct fraction{
    ll a, b;
    fraction(ll _a, ll _b = 1) : a(_a), b(_b){}
};

bool operator<(const fraction& f1, const fraction& f2){
    return f1.a * f2.b < f2.a * f1.b;
}

struct line{
    ll a, b;

    line(ll _a, ll _b) : a(_a), b(_b){}

    ll operator()(ll x) const{
        return a * x + b;
    }
};

```

```

    }
};

inline fraction intersection(const line& l1, const line& l2){
    return fraction(l1.b - l2.b, l2.a - l1.a);
}

struct cht{
    int pos = 0;
    vector<line> arr = {};

    cht(){}

    void insert_line_at_end(const line& l){
        if (arr.size() != 0 && !(l1ll(l.a, l.b) < l1ll(arr.back().a,
            arr.back().b))) return;
        if (arr.size() != 0 && l.a == arr.back().a) arr.pop_back();
        while (arr.size() >= 2 && !(intersection(arr[arr.size() - 2],
            arr.back()) < intersection(arr.back(), l))) arr.pop_back();
        ;
        arr.push_back(l);
    }

    ll operator()(ll x){
        pos = min(pos, int(arr.size()) - 1);
        while (pos != 0 && arr[pos - 1](x) < arr[pos](x)) --pos;
        while (pos != int(arr.size()) - 1 && arr[pos](x) >= arr[pos +
            1](x)) ++pos;
        return arr[pos](x);
    }
};

```