Contents

1 Setting

1.1 PS

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

using namespace std;

#define for1(s, e) for(int i = s; i < e; i++)
#define for1j(s, e) for(int j = s; j < e; j++)
#define forEach(k) for(auto i : k)
#define forEachj(k) for(auto j : k)
#define sz(vct) vct.size()
#define all(vct) vct.begin(), vct.end()
#define sortv(vct) sort(vct.begin(), vct.end())
#define uniq(vct) sort(all(vct));vct.erase(unique(all(vct)), vct.end())
#define fi first
#define se second
#define INF (1ll << 60ll)

typedef unsigned long long ull;
typedef long long ll;
typedef ll llint;
typedef unsigned int uint;
typedef unsigned long long int ull;
typedef ull ullint;

typedef pair<int, int> pii;
typedef pair<ll, ll> pll;
typedef pair<double, double> pdd;
typedef pair<double, int> pdi;
typedef pair<string, string> pss;

typedef vector<int> iv1;
typedef vector<iv1> iv2;
typedef vector<ll> llv1;
typedef vector<llv1> llv2;

typedef vector<pii> piiv1;
typedef vector<piiv1> piiv2;
typedef vector<pll> pllv1;
typedef vector<pllv1> pllv2;
typedef vector<pdd> pddv1;
typedef vector<pddv1> pddv2;

const double EPS = 1e-8;
const double PI = acos(-1);

template<typename T>
T sq(T x) { return x * x; }

int sign(ll x) { return x < 0 ? -1 : x > 0 ? 1 : 0; }
int sign(int x) { return x < 0 ? -1 : x > 0 ? 1 : 0; }
int sign(double x) { return abs(x) < EPS ? 0 : x < 0 ? -1 : 1; }
```

```
void solve() {

}

int main() {
  ios::sync_with_stdio(0);
  cin.tie(NULL);cout.tie(NULL);
  int tc = 1; // cin >> tc;
  while(tc--) solve();
}
```

2 Math

2.1 Basic Arithmetics

```
typedef long long ll;
typedef unsigned long long ull;

// calculate lg2(a)
inline int lg2(ll a) {
    return 63 - __builtin_clzll(a);
}

// calculate the number of 1-bits
inline int bitcount(ll a) {
    return __builtin_popcountll(a);
}

// calculate ceil(a/b)
// |a|, |b| <= (2^63)-1 (does not dover -2^63)
ll ceildiv(ll a, ll b) {
    if (b < 0) return ceildiv(-a, -b);
    if (a < 0) return (-a) / b;
    return ((ull)a + (ull)b - 1ull) / b;
}

// calculate floor(a/b)
// |a|, |b| <= (2^63)-1 (does not cover -2^63)
ll floordiv(ll a, ll b) {
    if (b < 0) return floordiv(-a, -b);
    if (a >= 0) return a / b;
    return -(ll)(((ull)(-a) + b - 1) / b);
}

// calculate a*b % m
// x86-64 only
ll large_mod_mul(ll a, ll b, ll m) {
    return ll((__int128)a*(__int128)b%m);
}

// calculate a*b % m
// |m| < 2^62, x86 available
// O(logb)
ll large_mod_mul(ll a, ll b, ll m) {
    a %= m; b %= m; ll r = 0, v = a;
    while (b) {
        if (b&1) r = (r + v) % m;
        b >>= 1;
        v = (v << 1) % m;
    }
    return r;
}

// calculate n^k % m
ll modpow(ll n, ll k, ll m) {
    ll ret = 1;
    n %= m;
    while (k) {
        if (k & 1) ret = large_mod_mul(ret, n, m);
        n = large_mod_mul(n, n, m);
        k /= 2;
    }
    return ret;
}

// calculate gcd(a, b)
ll gcd(ll a, ll b) {
    return b == 0 ? a : gcd(b, a % b);
}

// find a pair (c, d) s.t. ac + bd = gcd(a, b)
pair<ll, ll> extended_gcd(ll a, ll b) {
    if (b == 0) return { 1, 0 };
    auto t = extended_gcd(b, a % b);
    return { t.second, t.first - t.second * (a / b) };
}

// find x in [0,m) s.t. ax === gcd(a, m) (mod m)
ll modinverse(ll a, ll m) {
    return (extended_gcd(a, m).first % m + m) % m;
}

// calculate modular inverse for 1 ~ n
void calc_range_modinv(int n, int mod, int ret[]) {
    ret[1] = 1;
    for (int i = 2; i <= n; ++i)
        ret[i] = (ll)(mod - mod/i) * ret[mod%i] % mod;
}
```

2.2 FFT

```
void fft(int sign, int n, double *real, double *imag) {
    double theta = sign * 2 * pi / n;
    for (int m = n; m >= 2; m >>= 1, theta *= 2) {
        double wr = 1, wi = 0, c = cos(theta), s = sin(theta);
        for (int i = 0, mh = m >> 1; i < mh; ++i) {
            for (int j = i; j < n; j += m) {
                int k = j + mh;
                double xr = real[j] - real[k], xi = imag[j] - imag[k];
```

```
                real[j] += real[k], imag[j] += imag[k];
                real[k] = wr * xr - wi * xi, imag[k] = wr * xi + wi * xr;
            }
            double _wr = wr * c - wi * s, _wi = wr * s + wi * c;
            wr = _wr, wi = _wi;
        }
    }
    for (int i = 1, j = 0; i < n; ++i) {
        for (int k = n >> 1; k > (j ^= k); k >>= 1);
        if (j < i) swap(real[i], real[j]), swap(imag[i], imag[j]);
    }
}
// Compute Poly(a)*Poly(b), write to r; Indexed from 0
// O(n*logn)
int mult(int *a, int n, int *b, int m, int *r) {
    const int maxn = 100;
    static double ra[maxn], rb[maxn], ia[maxn], ib[maxn];
    int fn = 1;
    while (fn < n + m) fn <<= 1; // n + m: interested length
    for (int i = 0; i < n; ++i) ra[i] = a[i], ia[i] = 0;
    for (int i = n; i < fn; ++i) ra[i] = ia[i] = 0;
    for (int i = 0; i < m; ++i) rb[i] = b[i], ib[i] = 0;
    for (int i = m; i < fn; ++i) rb[i] = ib[i] = 0;
    fft(1, fn, ra, ia);
    fft(1, fn, rb, ib);
    for (int i = 0; i < fn; ++i) {
        double real = ra[i] * rb[i] - ia[i] * ib[i];
        double imag = ra[i] * ib[i] + rb[i] * ia[i];
        ra[i] = real, ia[i] = imag;
    }
    fft(-1, fn, ra, ia);
    for (int i = 0; i < fn; ++i) r[i] = (int)floor(ra[i] / fn + 0.5);
    return fn;
}
```

3 Data Structure

4 Geometry

4.1 Basic Operations

```
const double eps = 1e-9;

inline int diff(double lhs, double rhs) {
    if (lhs - eps < rhs && rhs < lhs + eps) return 0;
    return (lhs < rhs) ? -1 : 1;
}

inline bool is_between(double check, double a, double b) {
    if (a < b)
        return (a - eps < check && check < b + eps);
    else
        return (b - eps < check && check < a + eps);
}

struct Point {
    double x, y;
    bool operator==(const Point& rhs) const {
        return diff(x, rhs.x) == 0 && diff(y, rhs.y) == 0;
    }
    Point operator+(const Point& rhs) const {
        return Point{ x + rhs.x, y + rhs.y };
    }
    Point operator-(const Point& rhs) const {
        return Point{ x - rhs.x, y - rhs.y };
    }
    Point operator*(double t) const {
        return Point{ x * t, y * t };
    }
};

struct Circle {
    Point center;
    double r;
};

struct Line {
    Point pos, dir;
};

inline double inner(const Point& a, const Point& b) {
    return a.x * b.x + a.y * b.y;
}

inline double outer(const Point& a, const Point& b) {
    return a.x * b.y - a.y * b.x;
}

inline int ccw_line(const Line& line, const Point& point) {
    return diff(outer(line.dir, point - line.pos), 0);
}

inline int ccw(const Point& a, const Point& b, const Point& c) {
    return diff(outer(b - a, c - a), 0);
}

inline double dist(const Point& a, const Point& b) {
    return sqrt(inner(a - b, a - b));
}

inline double dist2(const Point &a, const Point &b) {
    return inner(a - b, a - b);
}

inline double dist(const Line& line, const Point& point, bool segment = false) {
    double c1 = inner(point - line.pos, line.dir);
    if (segment && diff(c1, 0) <= 0) return dist(line.pos, point);
    double c2 = inner(line.dir, line.dir);
```

```
    if (segment && diff(c2, c1) <= 0) return dist(line.pos + line.dir, point);
    return dist(line.pos + line.dir * (c1 / c2), point);
}

bool get_cross(const Line& a, const Line& b, Point& ret) {
    double mdet = outer(b.dir, a.dir);
    if (diff(mdet, 0) == 0) return false;
    double t2 = outer(a.dir, b.pos - a.pos) / mdet;
    ret = b.pos + b.dir * t2;
    return true;
}

bool get_segment_cross(const Line& a, const Line& b, Point& ret) {
    double mdet = outer(b.dir, a.dir);
    if (diff(mdet, 0) == 0) return false;
    double t1 = -outer(b.pos - a.pos, b.dir) / mdet;
    double t2 = outer(a.dir, b.pos - a.pos) / mdet;
    if (!is_between(t1, 0, 1) || !is_between(t2, 0, 1)) return false;
    ret = b.pos + b.dir * t2;
    return true;
}

Point inner_center(const Point &a, const Point &b, const Point &c) {
    double wa = dist(b, c), wb = dist(c, a), wc = dist(a, b);
    double w = wa + wb + wc;
    return Point{ (wa * a.x + wb * b.x + wc * c.x) / w, (wa * a.y + wb * b.y +
      wc * c.y) / w };
}

Point outer_center(const Point &a, const Point &b, const Point &c) {
    Point d1 = b - a, d2 = c - a;
    double area = outer(d1, d2);
    double dx = d1.x * d1.x * d2.y - d2.x * d2.x * d1.y
        + d1.y * d2.y * (d1.y - d2.y);
    double dy = d1.y * d1.y * d2.x - d2.y * d2.y * d1.x
        + d1.x * d2.x * (d1.x - d2.y);
    return Point{ a.x + dx / area / 2.0, a.y - dy / area / 2.0 };
}

vector<Point> circle_line(const Circle& circle, const Line& line) {
    vector<Point> result;
    double a = 2 * inner(line.dir, line.dir);
    double b = 2 * (line.dir.x * (line.pos.x - circle.center.x)
        + line.dir.y * (line.pos.y - circle.center.y));
    double c = inner(line.pos - circle.center, line.pos - circle.center)
        - circle.r * circle.r;
    double det = b * b - 2 * a * c;
    int pred = diff(det, 0);
    if (pred == 0)
        result.push_back(line.pos + line.dir * (-b / a));
    else if (pred > 0) {
        det = sqrt(det);
        result.push_back(line.pos + line.dir * ((-b + det) / a));
        result.push_back(line.pos + line.dir * ((-b - det) / a));
    }
    return result;
}

vector<Point> circle_circle(const Circle& a, const Circle& b) {
    vector<Point> result;
    int pred = diff(dist(a.center, b.center), a.r + b.r);
    if (pred > 0) return result;
    if (pred == 0) {
        result.push_back((a.center * b.r + b.center * a.r) * (1 / (a.r + b.r)));
        return result;
    }
    double aa = a.center.x * a.center.x + a.center.y * a.center.y - a.r * a.r;
    double bb = b.center.x * b.center.x + b.center.y * b.center.y - b.r * b.r;
    double tmp = (bb - aa) / 2.0;
    Point cdiff = b.center - a.center;
    if (diff(cdiff.x, 0) == 0) {
        if (diff(cdiff.y, 0) == 0)
            return result; // if (diff(a.r, b.r) == 0): same circle
        return circle_line(a, Line{ Point{ 0, tmp / cdiff.y }, Point{ 1, 0 } });
    }
    return circle_line(a,
        Line{ Point{ tmp / cdiff.x, 0 }, Point{ -cdiff.y, cdiff.x } });
}

Circle circle_from_3pts(const Point& a, const Point& b, const Point& c) {
    Point ba = b - a, cb = c - b;
    Line p{ (a + b) * 0.5, Point{ ba.y, -ba.x } };
    Line q{ (b + c) * 0.5, Point{ cb.y, -cb.x } };
    Circle circle;
    if (!get_cross(p, q, circle.center))
        circle.r = -1;
    else
        circle.r = dist(circle.center, a);
    return circle;
}

Circle circle_from_2pts_rad(const Point& a, const Point& b, double r) {
    double det = r * r / dist2(a, b) - 0.25;
    Circle circle;
    if (det < 0)
        circle.r = -1;
    else {
        double h = sqrt(det);
        // center is to the left of a->b
        circle.center = (a + b) * 0.5 + Point{ a.y - b.y, b.x - a.x } * h;
        circle.r = r;
    }
    return circle;
}
```

4.2 Convex Hull

```
// find convex hull
// O(n*logn)
vector<Point> convex_hull(vector<Point>& dat) {
```

```
    if (dat.size() <= 3) return dat;
    vector<Point> upper, lower;
    sort(dat.begin(), dat.end(), [](const Point& a, const Point& b) {
        return (a.x == b.x) ? a.y < b.y : a.x < b.x;
    });
    for (const auto& p : dat) {
        while (upper.size() >= 2 && ccw(*++upper.rbegin(), *upper.rbegin(), p)
          >= 0) upper.pop_back();
        while (lower.size() >= 2 && ccw(*++lower.rbegin(), *lower.rbegin(), p)
          <= 0) lower.pop_back();
        upper.emplace_back(p);
        lower.emplace_back(p);
    }
    upper.insert(upper.end(), ++lower.rbegin(), --lower.rend());
    return upper;
}
```

4.3 Poiont in Polygon

```
typedef double coord_t;

inline coord_t is_left(Point p0, Point p1, Point p2) {
    return (p1.x - p0.x) * (p2.y - p0.y) - (p2.x - p0.x) * (p1.y - p0.y);
}

// point in polygon test
// http://geomalgorithms.com/a03-_inclusion.html
bool is_in_polygon(Point p, vector<Point>& poly) {
    int wn = 0;
    for (int i = 0; i < poly.size(); ++i) {
        int ni = (i + 1 == poly.size()) ? 0 : i + 1;
        if (poly[i].y <= p.y) {
            if (poly[ni].y > p.y) {
                if (is_left(poly[i], poly[ni], p) > 0) {
                    ++wn;
                }
            }
        }
        else {
            if (poly[ni].y <= p.y) {
                if (is_left(poly[i], poly[ni], p) < 0) {
                    --wn;
                }
            }
        }
    }
    return wn != 0;
}
```

4.4 Polygon Cut

```
// left side of a->b
vector<Point> cut_polygon(const vector<Point>& polygon, Line line) {
    if (!polygon.size()) return polygon;
    typedef vector<Point>::const_iterator piter;
    piter la, lan, fi, fip, i, j;
    la = lan = fi = fip = polygon.end();
    i = polygon.end() - 1;
    bool lastin = diff(ccw_line(line, polygon[polygon.size() - 1]), 0) > 0;
    for (j = polygon.begin() ; j != polygon.end() ; j++) {
        bool thisin = diff(ccw_line(line, *j), 0) > 0;
        if (lastin && !thisin) {
            la = i;
            lan = j;
        }
        if (!lastin && thisin) {
            fi = j;
            fip = i;
        }
        i = j;
        lastin = thisin;
    }
    if (fi == polygon.end()) {
        if (!lastin) return vector<Point>();
        return polygon;
    }
    vector<Point> result;
    for (i = fi ; i != lan ; i++) {
        if (i == polygon.end()) {
            i = polygon.begin();
            if (i == lan) break;
        }
        result.push_back(*i);
    }
    Point lc, fc;
    get_cross(Line{ *la, *lan - *la }, line, lc);
    get_cross(Line{ *fip, *fi - *fip }, line, fc);
    result.push_back(lc);
    if (diff(dist2(lc, fc), 0) != 0) result.push_back(fc);
    return result;
}
```

4.5 Rotating Calipers

```
// get all antipodal pairs
// O(n)
void antipodal_pairs(vector<Point>& pt) {
    // calculate convex hull
    sort(pt.begin(), pt.end(), [](const Point& a, const Point& b) {
        return (a.x == b.x) ? a.y < b.y : a.x < b.x;
    });
    vector<Point> up, lo;
    for (const auto& p : pt) {
        while (up.size() >= 2 && ccw(*++up.rbegin(), *up.rbegin(), p) >= 0) up.
          pop_back();
        while (lo.size() >= 2 && ccw(*++lo.rbegin(), *lo.rbegin(), p) <= 0) lo.
          pop_back();
        up.emplace_back(p);
        lo.emplace_back(p);
```

```
    }

    for (int i = 0, j = (int)lo.size() - 1; i + 1 < up.size() || j > 0; ) {
        get_pair(up[i], lo[j]);  // DO WHAT YOU WANT
        if (i + 1 == up.size()) {
            --j;
        }
        else if (j == 0) {
            ++i;
        }
        else if ((long long)(up[i + 1].y - up[i].y) * (lo[j].x - lo[j - 1].x)
                > (long long)(up[i + 1].x - up[i].x) * (lo[j].y - lo[j - 1].y))
                  {
            ++i;
        }
        else {
            --j;
        }
    }
}
```

5 Graph

5.1 Dijkstra

```
template<typename T> struct Dijkstra {
  /*
    T: 간선가중치타입
  */
  struct Edge {
    ll node;
    T cost;
    bool operator<(const Edge &to) const {
      return cost > to.cost;
    }
  };

  ll n;
  vector<vector<Edge>> adj;
  vector<ll> prev;

  Dijkstra(ll n) : n{n}, adj(n+1) {}

  void addEdge(ll s, ll e, T cost) {
    adj[s].push_back(Edge(e, cost));
  }

  void addUndirectedEdge(ll s, ll e, T cost) {
    addEdge(s, e, cost);
    addEdge(e, s, cost);
  }

  vector <ll> dijkstra(ll s) {
    vector <ll> dist(n+1, INF);
    prev.resize(n+1, -1);
    priority_queue<edge> pq;
    pq.push({ s, 0ll });
    dist[s] = 0;
    while (!pq.empty()) {
      edge cur = pq.top();
      pq.pop();
      if (cur.cost > dist[cur.node]) continue;
      for (auto &nxt : adj[cur.node])
        if (dist[cur.node] + nxt.cost < dist[nxt.node]) {
          prev[nxt.node] = cur.node;
          dist[nxt.node] = dist[cur.node] + nxt.cost;
          pq.push({ nxt.node, dist[nxt.node] });
        }
    }
    return dist;
  }

  vector<ll> getPath(ll s, ll e) {
    vector<ll> ret;
    ll current = e;
    while(current != -1) {
      ret.push_back(current);
      current = prev[current];
    }
    reverse(ret.begin(), ret.end());
    return ret;
  }
};
```

5.2 Bellman-Ford

```
struct BellmanFord {
  struct BellmanEdge {
    ll to, cost;

    BellmanEdge(ll to, ll cost) : to(to), cost(cost) {}
  };

  ll N;
  vector<vector <BellmanEdge> > adj;
  llv1 D;
  vector<ll> prev;

  BellmanFord(ll N) : N(N) {
    adj.resize(N + 1);
  }

  void addEdge(ll s, ll e, ll cost) {
    adj[s].push_back(BellmanEdge(e, cost));
  }

  bool run(ll start_point) {
    // 음수간선 cycle 유무를반환합니다 .
    // 거리정보는 D 벡터에저장됩니다 .
```

```
    // O(V * E)

    D.resize(N + 1, INF);
    prev.resize(N + 1, -1);
    D[start_point] = 0;

    bool isCycle = false;

    for1(1, N + 1) {
      for1j(1, N + 1) {
        for(int k=0; k < sz(adj[j]); k++) {
          BellmanEdge p = adj[j][k];
          int end = p.to;
          ll dist = D[j] + p.cost;

          if (D[j] != INF && D[end] > dist) {
            D[end] = dist;
            if (i == N) isCycle = true;
          }
        }
      }
    }
    return isCycle;
  }

  llv1 getPath(ll s, ll e) {
    vector<ll> ret;
    ll current = e;
    while(current != -1) {
      ret.push_back(current);
      current = prev[current];
    }
    reverse(ret.begin(), ret.end());
    return ret;
  }
};
```

5.3 Floyd-Warshall

```
struct FloydWarshall{
  ll N;
  llv2 ar;

  FloydWarshall(ll N) : N(N) {
    ar.resize(N + 1, llv1(N + 1, INF));

    for1(1, N + 1) ar[i][i] = 0;
  }

  void addEdge(ll a, ll b, ll cost) {
    ar[a][b] = min(ar[a][b], cost);
    ar[b][a] = min(ar[b][a], cost);
  }

  void run() {
    for(int k = 1; k <= N; k++) {
      for(int i =  1; i <= N; i++) {
        for(int j = 1; j <= N; j++) {
          if(ar[i][j] > ar[i][k] + ar[k][j]) {
            ar[i][j] = ar[i][k] + ar[k][j];
          }
        }
      }
    }
  }
};
```

5.4 Spfa

```
// shortest path faster algorithm
// average for random graph : O(E) , worst : O(VE)

const int MAXN = 20001;
const int INF = 100000000;
int n, m;
vector<pii> graph[MAXN];

bool inqueue[MAXN];
int dist[MAXN];

void spfa(int start) {
    for (int i = 0; i < n; ++i) dist[i] = INF;
    dist[start] = 0;

    queue<int> q;
    q.push(start);
    inqueue[start] = true;

    while (!q.empty()) {
        int here = q.front();
        q.pop();

        inqueue[here] = false;
        for (auto& nxt : graph[here]) {
            if (dist[here] + nxt.second < dist[nxt.first]) {
                dist[nxt.first] = dist[here] + nxt.second;
                if (!inqueue[nxt.first]) {
                    q.push(nxt.first);
                    inqueue[nxt.first] = true;
                }
            }
        }
    }
}
```

5.5 Topological Sort

```
struct TopologicalSort {
  // 1-index
```

```
  int n;
  iv1 in_degree;
  iv2 graph;
  iv1 result;

  TopologicalSort(int n) : n(n) {
    in_degree.resize(n + 1, 0);
    graph.resize(n + 1);
  }

  void addEdge(int s, int e) {
    graph[s].push_back(e);
    in_degree[e]++;
  }

  void run() {
    queue<int> q;

    for1(1, n+1) {
      if(in_degree[i] == 0) q.push(i);
    }
    while(!q.empty()) {
      int here = q.front(); q.pop();
      result.push_back(here);

      for1(0, sz(graph[here])) {
        int there = graph[here][i];

        if(--in_degree[there]==0) q.push(there);
      }
    }
  }
};
```

5.6 Strongly Connected Component

```
struct SCC {
  // 1-index
  // run() 후에에 components 결과가담김 .

  ll V;
  llv2 edges, reversed_edges, components;
  vector<bool> visited;
  stack<ll> visit_log;

  SCC(ll V): V(V) {
    edges.resize(V + 1);
    reversed_edges.resize(V + 1);
  }

  void addEdge(int s, int e) {
    edges[s].push_back(e);
    reversed_edges[e].push_back(s);
  }

  void dfs(int node) {
    visited[node] = true;

    for (int next : edges[node])
      if (!visited[next]) dfs(next);
    visit_log.push(node);
  }
  void dfs2(int node) {
    visited[node] = true;
    for (int next:reversed_edges[node])
      if (!visited[next]) dfs2(next);
    components.back().push_back(node);
  }

  void run() {
    visited = vector<bool>(V + 1, false);
    for (int node = 1; node <= V; node++)
      if (!visited[node]) dfs(node);

    visited = vector<bool>(V + 1, false);
    while (!visit_log.empty()) {
      ll node = visit_log.top(); visit_log.pop();
      if (!visited[node]) {
        components.push_back(llv1());
        dfs2(node);
      }
    }
  }
};
```

5.7 Union Find

```
struct UnionFind {
  int n;
  vector<int> u;

  UnionFind(int n) : n(n) {
    u.resize(n + 1);
    for(int i = 1; i <= n; i++) {
      u[i] = i;
    }
  }

  int find(int k) {
    if(u[u[k]] == u[k]) return u[k];
    else return u[k]=find(u[k]);
  }

  void uni(int a, int b) {
    a = find(a);
    b = find(b);
    if(a < b) u[b] = a;
    else u[a] = b;
  }
```

```
};
```

5.8 MST Kruskal

```
template <class T>  struct MinimumSpanningTree {
  /*
    T: 가중치의타입

    n: 노드개수
    m: 간선개수
    result : MST 결과가중치 ( 합)
  */
  struct Edge {
    int u, v;
    T weight;

    Edge(int u, int v, T weight) : u(u), v(v), weight(weight) {}
    bool operator< (Edge other) const { return weight < other.weight; }
  };

  int n, m;
  vector<int> uf;
  vector<Edge> edges;
  vector<Edge> chosen_edges;

  T result; // 의MST 가중치합
  int cnt; // 뽑은간선수

  MinimumSpanningTree(int n, int m) : n(n), m(m) {
    uf.resize(n + 1);

    for1(0, n + 1) {
      uf[i] = i;
    }
    result = 0;
    cnt = 0;
  }

  int find(int a) {
    /*
      Union-Find: Find 연산
    */
    if(uf[a] == a) return a;
    return uf[a] = find(uf[a]);
  }

  int merge(int a, int b) {
    /*
      Union-Find: Union합쳐진경우
        true 반환
    */

    a = find(a);
    b = find(b);
    if(a == b) return false;

    uf[b] = a;
    return true;
  }

  void add_edge(int u, int v, T cost) {
    edges.push_back(Edge(u, v, cost));
  }

  void run() {
    sort(edges.begin(), edges.end());

    for(int i = 0; i < edges.size(); i++) {
      if(merge(edges[i].u,  edges[i].v)) {
        result += edges[i].weight;

        // chosen_edges.push_back(edges[i]);
        if(++cnt >= n - 1) break;
      }
    }
  }
};
```

5.9 Lowest Common Ancestor

```
#define MAX_DEGREE 20

struct LCA {
  // root: 트리의루트설정  , n: 트리의노드개수
  // addEdge -> init -> query(O(log(n))

  ll root, n;
  llv1 depth;
  llv2 adj;
  llv2 parent; // n X MAX_DEGREE

  LCA(ll root, ll n) : root(root), n(n) {
    depth.resize(n + 1);
    adj.resize(n + 1);
    parent.resize(n + 1, llv1(MAX_DEGREE, 0));
  }

  void addEdge(ll a, ll b) {
    adj[a].push_back(b);
    adj[b].push_back(a);
  }

  void init() {
    dfs(root, 0, 1);

    for(int i = 1; i < MAX_DEGREE; i++) {
      for(int j = 1; j <= n; j++) {
        parent[j][i] = parent[parent[j][i-1]][i-1];
      }
```

```
    }
  }

  void dfs(int here, int par, int d) {
    depth[here] = d;
    parent[here][0] = par;

    for(int there : adj[here]) {
      if(depth[there] > 0) continue;

      dfs(there, here, d + 1);
    }
  }

  int query(int a, int b) {
    if(depth[a] > depth[b]) {
      swap(a, b);
    }

    for(int i = MAX_DEGREE - 1; i >= 0; i--) {
      if (depth[b] - depth[a] >= (1 << i)) {
        b = parent[b][i];
      }
    }

    if(a == b) {
      return a;
    }

    for(int i = MAX_DEGREE - 1; i >= 0; i--) {
      if(parent[a][i] != parent[b][i]) {
        a = parent[a][i];
        b = parent[b][i];
      }
    }

    return parent[a][0];
  }
};
```

6 String

6.1 KMP

```
struct KMP {
  /*
    s 문자열에서문자열을 o 찾습니다.매칭이시작되는인덱스목록을반환합니다
        .
    Time: O(n + m)
  */
  vector<int> result;
  int MX;
  string s, o;
  int n, m; // n : s.length(), m :o.length();
  vector<int> fail;

  KMP(string s, string o) : s(s), o(o) {
    n = s.length();
    m = o.length();
    MX = max(n, m) + 1;
    fail.resize(MX, 0);

    run();
  }

  void run() {
    for(int i = 1, j = 0; i < m; i++){
      while(j > 0 && o[i] != o[j]) j = fail[j-1];
      if(o[i] == o[j]) fail[i] = ++j;
    }
    for(int i = 0, j = 0; i < n; i++) {
      while(j > 0 && s[i] != o[j]) {
        j = fail[j - 1];
      }
      if(s[i] == o[j]) {
        if(j == m - 1) {
          // matching OK;
          result.push_back(i - m + 1);
          j = fail[j];
        }
        else {
          j++;
        }
      }
    }
  }
};
```

6.2 Manacher

```
// Use space to insert space between each character
// To get even length palindromes!
// O(|str|)

vector<int> manacher(string &s) {
  int n = s.size(), R = -1, p = -1;
  vector<int> A(n);
  for (int i = 0; i < n; i++) {
    if (i <= R) A[i] = min(A[2 * p - i], R - i);
    while (i - A[i] - 1 >= 0 && i + A[i] + 1 < n && s[i - A[i] - 1] == s[i + A[i
      ] + 1])
      A[i]++;
    if (i + A[i] > R)
      R = i + A[i], p = i;
  }
  return A;
}

string space(string &s) {
```

```
  string t;
  for (char c : s) t += c, t += '␣';
  t.pop_back();
  return t;
}

int maxpalin(vector<int> &M, int i) {
  if (i % 2) return (M[i] + 1) / 2 * 2;
  return M[i] / 2 * 2 + 1;
}
```

6.3 Suffix Array

```
typedef char T;

// calculates suffix array.
// O(n*logn)
vector<int> suffix_array(const vector<T>& in) {
    int n = (int)in.size(), c = 0;
    vector<int> temp(n), pos2bckt(n), bckt(n), bpos(n), out(n);
    for (int i = 0; i < n; i++) out[i] = i;
    sort(out.begin(), out.end(), [&](int a, int b) { return in[a] < in[b]; });
    for (int i = 0; i < n; i++) {
        bckt[i] = c;
        if (i + 1 == n || in[out[i]] != in[out[i + 1]]) c++;
    }
    for (int h = 1; h < n && c < n; h <<= 1) {
        for (int i = 0; i < n; i++) pos2bckt[out[i]] = bckt[i];
        for (int i = n - 1; i >= 0; i--) bpos[bckt[i]] = i;
        for (int i = 0; i < n; i++)
            if (out[i] >= n - h) temp[bpos[bckt[i]]++] = out[i];
        for (int i = 0; i < n; i++)
            if (out[i] >= h) temp[bpos[pos2bckt[out[i] - h]]++] = out[i] - h;
        c = 0;
        for (int i = 0; i + 1 < n; i++) {
            int a = (bckt[i] != bckt[i + 1]) || (temp[i] >= n - h)
                    || (pos2bckt[temp[i + 1] + h] != pos2bckt[temp[i] + h]);
            bckt[i] = c;
            c += a;
        }
        bckt[n - 1] = c++;
        temp.swap(out);
    }
    return out;
}

// calculates lcp array. it needs suffix array & original sequence.
// O(n)
vector<int> lcp(const vector<T>& in, const vector<int>& sa) {
    int n = (int)in.size();
    if (n == 0) return vector<int>();
    vector<int> rank(n), height(n - 1);
    for (int i = 0; i < n; i++) rank[sa[i]] = i;
    for (int i = 0, h = 0; i < n; i++) {
        if (rank[i] == 0) continue;
        int j = sa[rank[i] - 1];
        while (i + h < n && j + h < n && in[i + h] == in[j + h]) h++;
        height[rank[i] - 1] = h;
        if (h > 0) h--;
    }
    return height;
}
```

6.4 2nd Suffix Array

```
struct SuffixComparator {
  const vector<int> &group;
  int t;

  SuffixComparator(const vector<int> &_group, int _t) : group(_group), t(_t) {}
  bool operator()(int a, int b) {
    if (group[a] != group[b]) return group[a] < group[b];
    return group[a + t] < group[b + t];
  }
};

vector<int> getSuffixArr(const string &s) {
  int n = s.size();
  int t = 1;

  vector<int> group(n + 1);

  for (int i = 0; i < n; i++) group[i] = s[i];
  group[n] = -1;

  vector<int> perm(n);
  for (int i = 0; i < n; i++) perm[i] = i;

  while (t < n) {
    SuffixComparator compare(group, t);
    sort(perm.begin(), perm.end(), compare);
    t *= 2;
    if (t >= n)
      break;

    vector<int> new_group(n + 1);
    new_group[n] = -1;
    new_group[perm[0]] = 0;
    for (int i = 1; i < n; i++)
      if (compare(perm[i - 1], perm[i]))
        new_group[perm[i]] = new_group[perm[i - 1]] + 1;
      else
        new_group[perm[i]] = new_group[perm[i - 1]];
    group = new_group;
  }
  return perm;
}

int getHeight(const string &s, vector<int> &pos) {
   // 최장중복부분문자열의길이
```

```
  const int n = pos.size();
  vector<int> rank(n);
  for (int i = 0; i < n; i++)
    rank[pos[i]] = i;
  int h = 0, ret = 0;
  for (int i = 0; i < n; i++) {
    if (rank[i] > 0) {
      int j = pos[rank[i] - 1];
      while (s[i + h] == s[j + h])
        h++;
      ret = max(ret, h);
      if (h > 0)
        h--;
    }
  }
  return ret;
}
```

7 Dynamic Programming

7.1 LIS

```
struct LIS {
  llv1 ar;

  llv1 v, buffer;
  llv1::iterator vv;
  vector<pair<ll, ll> > d;

  void perform() {
    v.pb(200000000011);

    ll n = sz(ar);

    for1(0, n){
      if (ar[i] > *v.rbegin()) {
        v.pb(ar[i]);
        d.push_back({ v.size() - 1, ar[i] });
      }
      else {
        vv = lower_bound(v.begin(), v.end(), ar[i]);
        *vv = ar[i];
        d.push_back({ vv - v.begin(), ar[i] });
      }
    }

    for(int i = sz(d) - 1; i > -1; i--){
      if(d[i].first == sz(v)-1){
        buffer.pb(d[i].second);
        v.pop_back();
      }
    }

    reverse(buffer.begin(), buffer.end());
  }

  ll length() {
    return buffer.size();
  }

  llv1 result() {
    return buffer;
  }
};
```

7.2 LIS only length

```
ll lis(llv1& ar) {
  llv1 v, buffer;
  llv1::iterator vv;
  v.pb(200000000011);

  ll n = sz(ar);

  for1(0, n){
    if(ar[i] > *v.rbegin()) {
      v.pb(ar[i]);
    }
    else{
      vv = lower_bound(v.begin(), v.end(), ar[i]);
      *vv = ar[i];
    }
  }
  return sz(v);
}
```

7.3 KnapSack

```
ll N, maxWeight, ans;
ll D[2][11000];
ll weight[110], cost[110];
void knapsack() {
  for (int x = 1; x <= N; x++) {
    for (int y = 0; y <= maxWeight; y++) {
      if (y >= weight[x]) {
        D[x % 2][y] = max(D[(x + 1) % 2][y], D[(x + 1) % 2][y - weight[x]] +
          cost[x]);
      } else {
        D[x % 2][y] = D[(x + 1) % 2][y];
      }
      ans = max(ans, D[x % 2][y]);
    }
  }
}
void input() {
  cin >> N >> maxWeight;
  for (int x = 1; x <= N; x++) {
    cin >> weight[x] >> cost[x];
```

```
  }
}
```

7.4 Coin Change

```
// 경우의수
ll CC(llv1 &coin, ll money, ll MX) {
  ll D[MX];
  fill(D, D + MX, 0);
  D[0] = 1;
  for (int i = coin.size() - 1; i >= 0; i--) {
    for (int j = coin[i]; j <= money; j++) {
      D[j] += D[j - coin[i]];
      D[j] %= MOD;
    }
  }
  return D[money] % MOD;
}
```

7.5 Bit Field DP

```
#define MOD 9901;

int dp[1 << 14 + 1][200];
int n, m;

int solve(int pos, int check, int dep) {
  if (dp[check][pos] != 0) return dp[check][pos];
  int &ret = dp[check][pos];
  if (dep == n * m) return ret = 1;
  if ((check & 1)) return ret = solve(pos - 1, check >> 1, dep) % MOD;

  int sum = 0;
  if (!(check & 1) && (pos - 1) / m > 0)
    sum += solve(pos - 1, (check >> 1) | (1 << (m - 1)), dep + 2) % MOD;
  if (!(check & 1) && pos % m != 1 && !(check & 2) && pos >= 2 && m > 1)
    sum += solve(pos - 2, check >> 2, dep + 2) % MOD;
  // cout<<pos<<" "<<check<<" "<<dep<<" "<<sum<<endl;

  return ret = sum % MOD;
}
int main() {
  cin >> n >> m;

  if (n * m % 2 == 1)
    cout << 0;
  else
    cout << solve(n * m, 0, 0) % MOD;

  return 0;
}
```