

Team Notebook

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Data Structure

1.1 BITRange

```
/**
 * Description: 1D range update, range sum query
 * Alternative to lazy segment tree
 * Source: GeeksForGeeks?
 * Verification: ?
 */

struct FenwickTree {
    vector<int> bit; // binary indexed tree
    int n;

    FenwickTree(int n) {
        this->n = n;
        bit.assign(n, 0);
    }

    FenwickTree(vector<int> a) : FenwickTree(a.size()) {
        for (size_t i = 0; i < a.size(); i++)
            add(i, a[i]);
    }

    int sum(int r) {
        int ret = 0;
        for (; r >= 0; r = (r & (r + 1)) - 1)
            ret += bit[r];
        return ret;
    }

    int sum(int l, int r) {
        return sum(r) - sum(l - 1);
    }

    void add(int idx, int delta) {
        for (; idx < n; idx = idx | (idx + 1))
            bit[idx] += delta;
    }
};
```

1.2 Binary Trie

```
//Binary Trie
//without deletion, comment all val change and trie.check
condition
//Don't forget to check maxval
```

```
struct node{
    node *kiri = NULL;
    node *kanan = NULL;
    int val = 0; //Can be deleted
};

struct btrie{
    node *head = new node;
    node *cur = head;
    void insert(int x){
        for(int i = 30; i >= 0; i--){
            if((x&(1<<i)) == 0){
                if(head->kanan == NULL)head->kanan = new node;
                head = head->kanan;
            } else{
                if(head->kiri == NULL)head->kiri = new node;
                head = head->kiri;
            }
            head->val += 1; // Can be deleted
        }
        head = cur;
    }
    void del(int x){
        for(int i = 30; i >= 0; i--){
            if((x&(1<<i)) == 0){
                head = head->kanan;
            } else{
                head = head->kiri;
            }
            head->val -= 1; //Can be deleted
        }
        head = cur;
    }
    int max(int x){
        int res = 0;
        for(int i = 30; i >= 0; i--){
            if((x&(1<<i)) == 0){
                if(check(head->kanan)){
                    res += (1<<i);
                    head = head->kiri;
                } else if(check(head->kanan)){
                    head = head->kanan;
                } //Break can be placed here
            } else {
                if(check(head->kanan)){
                    head = head->kanan;
                } else if(check(head->kiri)){
                    head = head->kiri;
                    res += (1<<i);
                }
            }
        }
    }
};
```

```
        } //Break can be placed here
    }
    head = cur;
    return (res^x);
}

private:
    bool check(node *x){
        if(x != NULL and x->val > 0) return true; //Condition
        may be changed
        else return false;
    }
};
```

1.3 LazyPropagation

```
#include <stdio.h>
#include <math.h>
#define MAX 1000
int tree[MAX] = {0};
int lazy[MAX] = {0};

/* si -> index of current node in segment tree
   ss and se -> Starting and ending indexes of elements for
   which current nodes stores sum.
   us and ue -> starting and ending indexes of update query
   diff -> which we need to add in the range us to ue */
void updateRangeUtil(int si, int ss, int se, int us,
                    int ue, int diff) {
    if (lazy[si] != 0) {
        tree[si] += (se-ss+1)*lazy[si];
        if (ss != se) {
            lazy[si*2 + 1] += lazy[si];
            lazy[si*2 + 2] += lazy[si];
        }
        lazy[si] = 0;
    }
    if (ss>se || ss>ue || se<us)
        return ;
    if (ss>=us && se<=ue) {
        tree[si] += (se-ss+1)*diff;
        if (ss != se) {
            lazy[si*2 + 1] += diff;
            lazy[si*2 + 2] += diff;
        }
        return;
    }
    int mid = (ss+se)/2;
    updateRangeUtil(si*2+1, ss, mid, us, ue, diff);
```

```

    updateRangeUtil(0, 0, n-1, us, ue, diff);
}

    updateRangeUtil(si*2+2, mid+1, se, us, ue, diff);
    tree[si] = tree[si*2+1] + tree[si*2+2];
}

void updateRange(int n, int us, int ue, int diff) {

/* A recursive function to get the sum of values in given
range of the array. The following are parameters for
this function.
si --> Index of current node in the segment tree.
Initially 0 is passed as root is always at'
index 0
ss & se --> Starting and ending indexes of the
segment represented by current node,
i.e., tree[si]
qs & qe --> Starting and ending indexes of query
range */
int getSumUtil(int ss, int se, int qs, int qe, int si) {
    if (lazy[si] != 0) {
        tree[si] += (se-ss+1)*lazy[si];
        if (ss != se) {
            // Since we are not yet updating children os si,
            // we need to set lazy values for the children
            lazy[si*2+1] += lazy[si];
            lazy[si*2+2] += lazy[si];
        }
        lazy[si] = 0;
    }
    // Out of range
    if (ss>se || ss>qe || se<qs)
        return 0;
    if (ss==qs && se==qe)
        return tree[si];
    int mid = (ss + se)/2;
    return getSumUtil(ss, mid, qs, qe, 2*si+1) +
        getSumUtil(mid+1, se, qs, qe, 2*si+2);
}

// Return sum of elements in range from index qs (quey
// start) to qe (query end). It mainly uses getSumUtil()
int getSum(int n, int qs, int qe) {
    // Check for erroneous input values
    if (qs < 0 || qe > n-1 || qs > qe) {
        printf("Invalid Input");
        return -1;
    }

    return getSumUtil(0, n-1, qs, qe, 0);
}

```

```

}

// A recursive function that constructs Segment Tree for
// array[ss..se]. si is index of current node in segment
// tree st.
void constructSTUtil(int arr[], int ss, int se, int si) {
    if (ss > se)
        return ;
    if (ss == se) {
        tree[si] = arr[ss];
        return;
    }
    int mid = (ss + se)/2;
    constructSTUtil(arr, ss, mid, si*2+1);
    constructSTUtil(arr, mid+1, se, si*2+2);

    tree[si] = tree[si*2 + 1] + tree[si*2 + 2];
}

void constructST(int arr[], int n) {
    // Fill the allocated memory st
    constructSTUtil(arr, 0, n-1, 0);
}

```

1.4 Trie

```

struct node2{
    node2 *children[26] = {NULL};
};

struct trie{
    node2 *head = new node2;
    node2 *cur = head;
    void insert(string x){
        head = cur;
        for(int i = 0; i < x.size(); i++){
            int val = x[i]-'a';
            if(head->children[val] == NULL){
                head->children[val] = new node2;
            }
            head = head->children[val];
        }
    }

    bool find(string x){
        head = cur;
        for(int i = 0; i < x.size(); i++){
            int val = x[i]-'a';
            if(head->children[val] == NULL)return false;

```

```

        head = head->children[val];
    }
    return true;
}
};

```

1.5 persistentSegmentTree

```

struct Node {
    int cnt;
    Node *left, *right;
    Node(int cnt, Node *left, Node *right) {
        this->cnt = cnt;
        this->left = left;
        this->right = right;
    }
    Node *insert(int l, int r, int k) {
        if (!(l <= k && k <= r)) r
            return this;
        Node *node = new
            Node(this->cnt + 1, this->left, this->right);
        if (l == r) return node;
        int m = (l + r) / 2;
        node->left = node->left->insert(l, m, k);
        node->right = node->right->insert(m + 1, r, k);
        return node;
    }

    static int query(Node *a, Node *b, int l, int r, int k) {
        if (l == r) return l;
        int m = (l + r) / 2;
        int cnt = b->left->cnt - a->left->cnt;
        if (cnt >= k + 1)
            return query(a->left, b->left, l, m, k);
        return query(a->right, b->right, m + 1, r, k - cnt);
    }
};

// MAIN
int n, m; scanf("%d %d", &n, &m);
map<int, int> M, RM;
int a[n];
for (int i = 0; i < n; i++) {
    scanf("%d", &a[i]);
    M[a[i]];
}
int cnt = 0;
for (auto it = M.begin(); it != M.end(); it++) {
    M[it->first] = cnt;

```

```

cntr--;
Node *null = new Node(0, NULL, NULL);
    RM[cntr] = it->first;
    cntr++;
}

null
->left = null, null->right = null;
Node *roots[n];
for (int i = 0; i < n; i++)
    roots[i] = (i == 0 ? null : roots[i - 1])->insert(0, cntr
        , M[a[i]]);
int u, v, k;
while (m--) {
    scanf("%d %d %d", &u, &v, &k); u--, v--, k--;
    Node *a = (u == 0 ? null : roots[u - 1]);
    Node *b = roots[v];
    int res = Node::query(a, b, 0, cntr, k);
    printf("%d\n", RM[res]);
}

```

1.6 treap

```

/**
 * Treap uses implicit key
 * This Implementation : maintain array, can insert and
 * delete in any
 * position, can reverse interval
 */
typedef struct item * pitem;

struct item{
    int cnt, value, prior;
    bool rev;
    pitem l, r;
    item(int prior, int value) : cnt(1), rev(false), prior(
        prior),
        value(value), l(NULL), r(NULL) {}
};

int cnt(pitem t) {
    return t ? t->cnt : 0;
}

void upd_cnt(pitem it) {
    if (it) it->cnt = cnt(it->l) + cnt(it->r) + 1;
}

void push(pitem it) {
    if (it && it->rev) {
        it->rev = false;
        swap(it->l, it->r);
    }
}

```

```

        if (it->l) it->l->rev ^= true;
        if (it->r) it->r->rev ^= true;
    }
}

void merge(pitem & t, pitem l, pitem r) {
    push(l);
    push(r);
    if (!l || !r) t = l ? l : r;
    else if (l->prior > r->prior)
        merge(l->r, l->r, r), t = l;
    else
        merge(r->l, l, r->l), t = r;
    upd_cnt(t);
}

void split(pitem t, pitem & l, pitem & r, int key, int add
    = 0) {
    if (!t) return void (l = r = 0);
    int cur_key = cnt(t->l) + add;
    if (key <= cur_key) {
        split(t->l, l, t->l, key, add);
        r = t;
    }
    else {
        split(t->r, t->r, r, key, add + cnt(t->l) + 1);
        l = t;
    }
    upd_cnt(t);
}

void reverse(pitem t, int l, int r) {
    pitem t1, t2, t3;
    split(t, t1, t2, l);
    split(t2, t2, t3, r-l+1);
    t2->rev ^= true;
    merge(t, t1, t2);
    merge(t, t, t3);
}

void output (pitem t) {
    if (!t) return;
    push (t);
    output (t->l);
    printf ("%d ", t->value);
    output (t->r);
}

// MAIN
int n; scanf("%d", &n);
srand(time(NULL));
pitem root = NULL;
for (int i = 0; i < n; i++) {

```

```

    int a; scanf("%d", &a);
    pitem cur = new item(rand(), a);
    if (root) merge(root, root, cur);
    else root = cur;
}

int m;
scanf("%d", &m);
for (int i = 0; i < m; i++) {
    int l, r;
    scanf("%d %d", &l, &r);
    reverse(root, l, r);
    output(root);
    printf("\n");
}

```

2 Dynamic Programming

2.1 Convex Hull Trick

```

//DP convex hull trick (Beware on overflow)
const ll is_query = -(1LL<<62);
struct Line {
    ll m, b;
    mutable function<const Line*> succ;
    bool operator<(const Line& rhs) const {
        if (rhs.b != is_query) return m < rhs.m;
        const Line* s = succ();
        if (!s) return 0;
        ll x = rhs.m;
        return b - s->b < (s->m - m) * x;
    }
};

struct HullDynamic : public multiset<Line> { // will
    maintain upper hull for maximum
    bool bad(iterator y) {
        auto z = next(y);
        if (y == begin()) {
            if (z == end()) return 0;
            return y->m == z->m && y->b <= z->b;
        }
        auto x = prev(y);
        if (z == end()) return y->m == x->m && y->b <= x->b;
        return (long double)(x->b - y->b)*(z->m - y->m) >= (
            long double)(y->b - z->b)*(y->m - x->m);
    }

    void insert_line(ll m, ll b) {
        auto y = insert({ m, b });
    }
}

```

```

    while (y != begin() && bad(prev(y))) erase(prev(y));
    y->succ = [=] { return next(y) == end() ? 0 : &*next(
        y); };
    if (bad(y)) { erase(y); return; }
    while (next(y) != end() && bad(next(y))) erase(next(y));
}

ll eval(ll x) {
    auto l = *lower_bound((Line) { x, is_query });
    return l.m * x + l.b;
}
};

```

3 Geometry

3.1 AreaPolygon

```

// Let a simple polygon (i.e. without self intersection, not
// necessarily convex) be given. It is required to
// calculate its area given its vertices.
double area(const vector<point>& fig) {
    double res = 0;
    for (unsigned i = 0; i < fig.size(); i++) {
        point p = i ? fig[i - 1] : fig.back();
        point q = fig[i];
        res += (p.x - q.x) * (p.y + q.y);
    }
    return fabs(res) / 2;
}

```

3.2 circleLineIntersect

```

// Given the coordinates of the center of a circle and its
// radius,
// and the equation of a line, you're required to find the
// points
// of intersection.
double r, a, b, c; // given as input
double x0 = -a*c/(a*a+b*b), y0 = -b*c/(a*a+b*b);
if (c*c > r*r*(a*a+b*b)+EPS)
    puts ("no points");
else if (abs (c*c - r*r*(a*a+b*b)) < EPS) {
    puts ("1 point");
    cout << x0 << ' ' << y0 << '\n';
}

```

```

}
else {
    double d = r*r - c*c/(a*a+b*b);
    double mult = sqrt (d / (a*a+b*b));
    double ax, ay, bx, by;
    ax = x0 + b * mult;
    bx = x0 - b * mult;
    ay = y0 - a * mult;
    by = y0 + a * mult;
    puts ("2 points");
    cout << ax << ' ' << ay << '\n' << bx << ' ' << by << '\n';
}
}

```

3.3 convexhull

```

/**
 * Description: Top-bottom convex hull
 * Source: Wikibooks
 * Verification:
 * https://open.kattis.com/problems/convexhull
 */

ll cross(pi O, pi A, pi B) {
    return (ll)(A.f-O.f)*(B.s-O.s) - (ll)(A.s-O.s)*(B.f-O.f);
}

vpi convex_hull(vpi P) {
    sort(all(P)); P.erase(unique(all(P)),P.end());
    int n = sz(P);
    if (n == 1) return P;

    vpi bot = {P[0]};
    FOR(i,1,n) {
        while (sz(bot) > 1 && cross(bot[sz(bot)-2],
            bot.back(), P[i]) <= 0) bot.pop_back();
        bot.pb(P[i]);
    }
    bot.pop_back();

    vpi up = {P[n-1]};
    FORd(i,n-1) {
        while (sz(up) > 1 && cross(up[sz(up)-2],
            up.back(), P[i]) <= 0) up.pop_back();
        up.pb(P[i]);
    }
    up.pop_back();

    bot.insert(bot.end(),all(up));
}

```

```

return bot;
}

```

3.4 convexhullGrahamScan

```

struct pt {
    double x, y;
};

bool cmp(pt a, pt b) {
    return a.x < b.x || (a.x == b.x && a.y < b.y);
}

bool cw(pt a, pt b, pt c) {
    return a.x*(b.y-c.y)+b.x*(c.y-a.y)+c.x*(a.y-b.y) < 0;
}

bool ccw(pt a, pt b, pt c) {
    return a.x*(b.y-c.y)+b.x*(c.y-a.y)+c.x*(a.y-b.y) > 0;
}

void convex_hull(vector<pt>& a) {
    if (a.size() == 1)
        return;

    sort(a.begin(), a.end(), &cmp);
    pt p1 = a[0], p2 = a.back();
    vector<pt> up, down;
    up.push_back(p1);
    down.push_back(p1);
    for (int i = 1; i < (int)a.size(); i++) {
        if (i == a.size() - 1 || cw(p1, a[i], p2)) {
            while (up.size() >= 2 && !cw(up[up.size()-2], up[
                up.size()-1], a[i]))
                up.pop_back();
            up.push_back(a[i]);
        }
        if (i == a.size() - 1 || ccw(p1, a[i], p2)) {
            while (down.size() >= 2 && !ccw(down[down.size()
                -2], down[down.size()-1], a[i]))
                down.pop_back();
            down.push_back(a[i]);
        }
    }

    a.clear();
    for (int i = 0; i < (int)up.size(); i++)
        a.push_back(up[i]);
    for (int i = down.size() - 2; i > 0; i--)

```

```

    a.push_back(down[i]);
}

```

3.5 findIntersectionTwoSegment

```

// You are given two segments AB and
// CD, described as pairs of their endpoints. Each segment
// can
// be a single point if its endpoints are the same. You have
// to
// find the intersection of these segments, which can be
// empty
// (if the segments don't intersect),
// a single point or a segment (if the given segments
// overlap).
const double EPS = 1E-9;
struct pt {
    double x, y;
    bool operator<(const pt& p) const{
        return x < p.x - EPS || (abs(x - p.x) < EPS && y < p.
            y - EPS);
    }
};
struct line {
    double a, b, c;
    line() {}
    line(pt p, pt q){
        a = p.y - q.y;
        b = q.x - p.x;
        c = -a * p.x - b * p.y;
        norm();
    }
    void norm(){
        double z = sqrt(a * a + b * b);
        if (abs(z) > EPS)
            a /= z, b /= z, c /= z;
    }
    double dist(pt p) const { return a * p.x + b * p.y + c; }
};
double det(double a, double b, double c, double d){
    return a * d - b * c;
}
inline bool betw(double l, double r, double x){
    return min(l, r) <= x + EPS && x <= max(l, r) + EPS;
}
inline bool intersect_1d(double a, double b, double c,
    double d){
    if (a > b)
        swap(a, b);

```

```

    if (c > d)
        swap(c, d);
    return max(a, c) <= min(b, d) + EPS;
}
bool intersect(pt a, pt b, pt c, pt d, pt& left, pt& right){
    if (!intersect_1d(a.x, b.x, c.x, d.x) || !intersect_1d(a.
        y, b.y, c.y, d.y))
        return false;
    line m(a, b);
    line n(c, d);
    double zn = det(m.a, m.b, n.a, n.b);
    if (abs(zn) < EPS) {
        if (abs(m.dist(c)) > EPS || abs(n.dist(a)) > EPS)
            return false;
        if (b < a)
            swap(a, b);
        if (d < c)
            swap(c, d);
        left = max(a, c);
        right = min(b, d);
        return true;
    } else {
        left.x = right.x = -det(m.c, m.b, n.c, n.b) / zn;
        left.y = right.y = -det(m.a, m.c, n.a, n.c) / zn;
        return betw(a.x, b.x, left.x) && betw(a.y, b.y, left.
            y) &&
            betw(c.x, d.x, left.x) && betw(c.y, d.y, left.y
            );
    }
}
}

```

3.6 geometry

Proyeksi segitiga: $BC^2 = AC^2 + AB^2 - 2AD \cdot AC$

```

#define EPS 1E-9
#define PI acos(-1)
// >>>> Constructor of point
struct point {
    double x,y;
    point() { x = y = 0.0; }
    point(double _x, double _y) : x(_x), y(_y) {}
    bool operator == (point other) const {
        return (fabs(x - other.x) < EPS && (fabs(y - other.y) <
            EPS));
    }
};
// >>>> Constructor of vector
struct vec {
    double x, y;

```

```

    vec(double _x, double _y) : x(_x), y(_y) {}
};
// >>>> Constructor of line (ax + by = c)
struct line {
    double a,b,c;
};
// Distance of two points
double dist(point p1, point p2) {
    return hypot(p1.x - p2.x, p1.y - p2.y);
}
double DEG_to_RAD(double theta) {
    return theta * PI / 180.0;
}
// Rotate a point THETA degrees
point rotate(point p, double theta) {
    double rad = DEG_to_RAD(theta);
    return point(p.x * cos(rad) - p.y * sin(rad),
        p.x * sin(rad) + p.y * cos(rad));
}
// Make a line l from 2 given points
void pointsToLine(point p1, point p2, line &l) {
    if (fabs(p1.x - p2.x) < EPS) {
        l.a = 1.0 ; l.b = 0.0 ; l.c = -p1.x;
    } else {
        l.a = -(double)(p1.y - p2.y) / (p1.x - p2.x);
        l.b = 1.0;
        l.c = -(double)(l.a * p1.x) - p1.y;
    }
}
// Check if two lines are parallel
bool areParallel(line l1, line l2) {
    return (fabs(l1.a-l2.a) < EPS) && (fabs(l1.b-l2.b) < EPS);
}
// Check if two lines are same
bool areSame(line l1, line l2) {
    return areParallel(l1, l2) && (fabs(l1.c - l2.c) < EPS);
}
// Check if two lines are intersect (at point P)
bool areIntersect(line l1, line l2, point &p) {
    if (areParallel(l1, l2)) return false;
    p.x = (l2.b * l1.c - l1.b * l2.c) / (l2.a * l1.b - l1.a *
        l2.b);
    if (fabs(l1.b) > EPS) p.y = -(l1.a * p.x + l1.c);
    else p.y = -(l2.a * p.x + l2.c); return true;
}
// Convert 2 points to vector A -> B
vec toVec(point a, point b) {
    return vec(b.x - a.x, b.y - a.y);
}
// Scale a vector

```

```

    return point(p.x + v.x, p.y + v.y);
vec scale(vec v, double s) {
    return vec(v.x * s, v.y * s);
}
// Translate P according to v
point translate(point p, vec v) {
}

// Dot product of two vectors
double dot(vec a, vec b) {
    return a.x * b.x + a.y * b.y;
}
// Cross product of two vectors
double cross(vec a, vec b) {
    return a.x * b.y - a.y * b.x;
}
double norm_sq(vec v) {
    return v.x * v.x + v.y * v.y;
}
// Get the minimum distance of point P and line AB
// Line PC is the minimum distance
double distToLine(point p, point a, point b, point &c) {
    vec ap = toVec(a, p), ab = toVec(a,b);
    double u = dot(ap, ab) / norm_sq(ab);
    c = translate(a, scale(ab, u));
    return dist(p,c);
}
// Get the minimum distance of point P and line segment AB
// Line PC is the minimum distance
double distToLineSegment(point p, point a, point b, point &c) {
}
vec ap = toVec(a, p), ab = toVec(a,b);
double u = dot(ap, ab) / norm_sq(ab);
if (u < 0.0) {
    c = point(a.x, a.y);
    return dist(p,a);
}
if (u > 1.0) {
    c = point(b.x, b.y);
    return dist(p, b);
}
return distToLine(p, a, b, c);
}
// Returns angle AOB in RADIANS
double angle(point a, point o, point b) {
    vec oa = toVec(o, a), ob = toVec(o, b);
    return acos(dot(oa,ob) / sqrt(norm_sq(oa) * norm_sq(ob)));
}
// Heron's Formula : Find the area of triangle double

```

```

heronsFormula(double a, double b, double c) {
    double s = perimeter(a, b, c) * 0.5;
    return sqrt(s * (s - a) * (s - b) * (s - c));
}
// Find the radius incircle of triangle ABC (lengths)
double rInCircle(double ab, double bc, double ca) {
    return heronsFormula(ab,bc,ca) / (0.5 * perimeter(ab, bc, ca));
}
// Find the radius incircle of triangle ABC (points)
double rInCircle(point a, point b, point c) {
    return rInCircle(dist(a, b), dist(b, c), dist(c, a));
}
// Returns 1 if there is an incircle center, return 0 otherwise
// ctr will be the incircle center
// r is the same as rInCircle
int inCircle(point p1, point p2, point p3, point &ctr, double &r) {
    r = rInCircle(p1, p2, p3);
    if (fabs(r) < EPS) return 0;

    line l1, l2;
    double ratio = dist(p1, p2) / dist(p1, p3);
    point p = translate(p2, scale(toVec(p2, p3), ratio / (1 + ratio)));
    pointsToLine(p1, p, l1);
    ratio = dist(p2, p1) / dist(p2, p3);
    p = translate(p1, scale(toVec(p1, p3), ratio / (1 + ratio)));
    pointsToLine(p2, p, l2);

    areIntersect(l1, l2, ctr);
    return 1;
}
// Find the radius circumcircle of triangle ABC (lengths)
double rCircumCircle(double ab, double bc, double ca) {
    return ab * bc * ca / (4.0 * heronsFormula(ab, bc, ca));
}
// Find the radius circumcircle of triangle ABC (points)
double rCircumCircle(point a, point b, point c) {
    return rCircumCircle(dist(a, b), dist(b, c), dist(c, a));
}
// Polygon Representation :
// 4 points, entered in counter clockwise order, 0-based indexing
// vector<point> P;
// P.push_back(point(1,1)); // P[0]
// P.push_back(point(3,3)); // P[1]
// P.push_back(point(9,7)); // P[2]

```

```

// P.push_back(point(1,7)); // P[3]
// P.push_back(P[0]); // P[n-1] = P[0]
// Checks if a polygon is convex or not
bool isConvex(const vector<point> &P) {
    int sz = (int)P.size();
    if (sz <= 3) return false;
    bool isLeft = ccw(P[0], P[1], P[2]);
    for (int i = 1; i > sz-1; i++)
        if (ccw(P[i], P[i+1], P[(i+2) % sz]) != isLeft)
            return false;
    return true;
}
// Line segment PQ intersect with line AB at this point
point lineIntersectSeg(point p, point q, point A, point B) {
    double a = B.y - A.y;
    double b = A.x - B.x;
    double c = B.x * A.y - A.x * B.y;
    double u = fabs(a * p.x + b * p.y + c);
    double v = fabs(a * q.x + b * q.y + c);
    return point((p.x * v + q.x * u) / (u + v),
        (p.y * v + q.y * u) / (u + v));
}
// Cuts polygon Q along the line AB
vector<point> cutPolygon(point a, point b, const vector<point> &Q) {
    vector<point> P;
    for (int i = 0; i < (int)Q.size(); i++) {
        double left1 = cross(toVec(a,b), toVec(a, Q[i])), left2 = 0;
        if (i != (int)Q.size()-1) left2 = cross(toVec(a, b), toVec(a, Q[i+1]));
        // Q[i] is on the left of AB
        // edge(Q[i], Q[i+1]) crosses line AB
        if (left1 > -EPS) P.push_back(Q[i]);
        if (left1 * left2 < -EPS)
            P.push_back(lineIntersectSeg(Q[i], Q[i+1], a, b));
    }
    if (!P.empty() && !(P.back() == P.front()))
        P.push_back(P.front());
    return P;
}
//-- Line Segment Intersection
int pyt(PII a, PII b){
    int dx=a.x-b.x;
    int dy=a.y-b.y;
    return (dx*dx + dy*dy);
}
int det(PII a, PII b, PII c){
    return ((a.x*b.y)+(b.x*c.y)+(c.x*a.y)

```

```

    h2=det(t1.F,t1.S, t2.S);
    -(a.x*c.y)-(b.x*a.y)-(c.x*b.y));
}
bool insec(pair<PII,PII> t1, pair<PII,PII> t2){
    bool hsl;
    h1=det(t1.F,t1.S, t2.F);

h3
    =det(t2.F,t2.S, t1.F);
    h4=det(t2.F,t2.S, t1.S);
    hsl=false;
    if ((h1*h2<=0) && (h3*h4<=0) && !((h1==0) && (h2==0) && (
        h3==0) && (h4==0))) {
        hsl=true;
    }
    return hasil;
}
...
//sg1 dan sg2 adalah pair<PII,PII>
if (insec(sg1,sg2)){
    le=sqrt((double)pyt(sg2.x, sg2.y));
    r1=fabs(crosp(MP(sg2.x, sg1.x),sg2)/le);
    r2=fabs(crosp(MP(sg2.x, sg1.y),sg2)/le);
    r2=r1+r2;
    dix=sg1.x.x + (r1/r2)*(sg1.y.x - sg1.x.x);
    diy=sg1.x.y + (r1/r2)*(sg1.y.y - sg1.x.y);
    //intersect here
    return MP(dix,diy);
}
// returns the area, which is half the determinant
// works for both convex and concave polygons
double area(vector<point> P) {
    double result = 0.0, x1, y1, x2, y2;
    for (int i = 0; i < P.size() - 1; i++) {
        x1 = P[i].x;
        x2 = P[i + 1].x;
        y1 = P[i].y;
        y2 = P[i + 1].y;
        result += (x1 * y2 - x2 * y1);
    }
    return fabs(result) / 2.0;
}
// returns true if point p is in either convex/concave
// polygon P
bool inPolygon(point p, const vector<point> &P) {
    if ((int) P.size() == 0) return false;
    double sum = 0; // assume first vertex = last vertex
    for (int i = 0; i < (int) P.size() - 1; i++) {
        if (ccw(p, P[i], P[i + 1]))
            sum += angle(P[i], p, P[i + 1]); // left turn/ccw

```

```

    else
        sum -= angle(P[i], p, P[i + 1]);
    } // right turn/ccw
    return fabs(fabs(sum) - 2 * PI) < EPS;
}
PT ComputeCentroid(const vector<PT> &p) {
    PT c(0,0);
    double scale = 6.0 * ComputeSignedArea(p);
    for (int i = 0; i < p.size(); i++){
        int j = (i+1) % p.size();
        c = c + (p[i]+p[j])*(p[i].x*p[j].y - p[j].x*p[i].y);
    }
    return c / scale;
} // compute distance between point (x,y,z) and plane ax+by+
    cz=d
double DistancePointPlane(double x, double y, double z,
    double a, double b, double c, double
        d)
{
    return fabs(a*x+b*y+c*z-d)/sqrt(a*a+b*b+c*c);
}
//circle-circle intersect
for(int i = 1; i < n; i++) {
    for(int j = i + 1; j <= n; j++) {
        double d = dist(P[i], P[j]);
        double r0 = P[i].r, x0 = P[i].x, y0 = P[i].y
        double r1 = P[j].r, x1 = P[j].x, y1 = P[j].y;
        point center;
        if (d > r0 + r1) continue;
        if (d < fabs(r0 - r1) || fabs(d) < EPS) {
            if (r0 < r1) center = P[i];
            else center = P[j];
        } else {
            double a = (r0*r0 - r1*r1 + d*d)/(2*d);
            double h = sqrt(r0*r0 - a*a);
            double x2 = x0 + a*(x1 - x0)/d;
            double y2 = y0 + a*(y1 - y0)/d;
            double translationY = h*(y1 - y0)/d;
            double translationX = h*(x1 - x0)/d;
            center.x = x2 + translationY;
            center.y = y2 - translationX;
            ans = max(ans, go(center));
            center.x = x2 - translationY;
            center.y = y2 + translationX;
        }
    }
    ans = max(ans, go(center));
}
// line segment with circle intersect
private int FindLineCircleIntersections(

```

```

    float cx, float cy, float radius,
    PointF point1, PointF point2,
    out PointF intersection1, out PointF intersection2)
{
    float dx, dy, A, B, C, det, t;
    dx = point2.X - point1.X;
    dy = point2.Y - point1.Y;
    A = dx * dx + dy * dy;
    B = 2 * (dx * (point1.X - cx) + dy * (point1.Y - cy));
    C = (point1.X - cx) * (point1.X - cx) +
        (point1.Y - cy) * (point1.Y - cy) -
        radius * radius;
    det = B * B - 4 * A * C;
    if ((A <= 0.0000001) || (det < 0)) {
        // No real solutions.
        intersection1 = new PointF(float.NaN, float.NaN);
        intersection2 = new PointF(float.NaN, float.NaN);
        return 0;
    } else if (det == 0) {
        // One solution.
        t = -B / (2 * A);
        intersection1 =
            new PointF(point1.X + t * dx, point1.Y + t * dy);
        intersection2 = new PointF(float.NaN, float.NaN);
        return 1;
    } else {
        // Two solutions.
        t = (float)((-B + Math.Sqrt(det)) / (2 * A));
        intersection1 = new PointF(point1.X + t * dx, point1.Y
            + t * dy);
        t = (float)((-B - Math.Sqrt(det)) / (2 * A));
        intersection2 = new PointF(point1.X + t * dx, point1.Y
            + t * dy);
        return 2;
    }
}
}

```

3.7 monotoneChain

```

// Implementation of Andrew's monotone chain 2D convex hull
// algorithm.
// Asymptotic complexity: O(n log n).
// Practical performance: 0.5-1.0 seconds for n=1000000 on a
// 1GHz machine.
#include <algorithm>
#include <vector>
using namespace std;
typedef double coord_t; // coordinate type

```



```

}
typedef double coord2_t; // must be big enough to hold 2*max
                           (|coordinate|)^2
struct Point {
    coord2_t x, y;
    bool operator <(const Point &p) const {
        return x < p.x || (x == p.x && y < p.y);
    }
};

// 2D cross product of OA and OB vectors, i.e. z-component
// of their 3D cross product.
// Returns a positive value, if OAB makes a counter-
// clockwise turn,
// negative for clockwise turn, and zero if the points are
// collinear.
coord2_t cross(const Point &O, const Point &A, const Point &B){
    return (A.x - O.x) * (B.y - O.y) - (A.y - O.y) * (B.x - O.x)
        );
}

// Returns a list of points on the convex hull in counter-
// clockwise order.
// Note: the last point in the returned list is the same as
// the first one.
vector<Point> convex_hull(vector<Point> P){
    int n = P.size(), k = 0;
    vector<Point> H(2*n);
    // Sort points lexicographically
    sort(P.begin(), P.end());
    // Build lower hull
    for (int i = 0; i < n; ++i) {
        while (k >= 2 && cross(H[k-2], H[k-1], P[i]) <= 0) k--;
        H[k++] = P[i];
    }
    // Build upper hull
    for (int i = n-2, t = k+1; i >= 0; i--) {
        while (k >= t && cross(H[k-2], H[k-1], P[i]) <= 0) k--;
        H[k++] = P[i];
    }
    H.resize(k-1);
    return H;
}

```

3.8 smallestEnclosingCircle

```

//declare variables here.
struct point {
    double x;

```

```

    double y;
};

struct circle {
    double x; double y; double r;
    circle() {}
    circle(double x, double y, double r): x(x), y(y), r(r) {}
};

circle f(vector<point> R) {
    if (R.size() == 0) {
        return circle(0, 0, -1);
    }
    else if (R.size() == 1) {
        return circle(R[0].x, R[0].y, 0);
    }
    else if (R.size() == 2) {
        return circle((R[0].x+R[1].x)/2.0, (R[0].y+R[1].y)/2.0,
            hypot(R[0].x-R[1].x, R[0].y-R[1].y)/2.0);
    } else {
        double D = (R[0].x - R[2].x)*(R[1].y - R[2].y) - (R[1].x
            - R[2].x)*(R[0].y - R[2].y);
        double p0 = (((R[0].x - R[2].x)*(R[0].x + R[2].x) + (R[0].
            y - R[2].y)*(R[0].y + R[2].y)) / 2 * (R[1].y - R[2].y)
            - ((R[1].x - R[2].x)*(R[1].x + R[2].x) + (R[1].y - R
            [2].y)*(R[1].y + R[2].y)) / 2 * (R[0].y - R[2].y))/D;
        double p1 = (((R[1].x - R[2].x)*(R[1].x + R[2].x) + (R[1].
            y - R[2].y)*(R[1].y + R[2].y)) / 2 * (R[0].x - R[2].x)
            - ((R[0].x - R[2].x)*(R[0].x + R[2].x) + (R[0].y - R
            [2].y)*(R[0].y + R[2].y)) / 2 * (R[1].x - R[2].x))/D;
        return circle(p0, p1, hypot(R[0].x - p0, R[0].y - p1));
    }
}

circle fmini(vector<point>& P, int i, vector<point> R) {
    if (i == P.size() || R.size() == 3) {
        return f(R);
    } else {
        circle D = fmini(P, i+1, R);
        if (hypot(P[i].x-D.x, P[i].y-D.y) > D.r) {
            R.push_back(P[i]);
            D = fmini(P, i+1, R);
        }
        return D;
    }
}

```

```

circle minidisk(vector<point> P) {
    random_shuffle(P.begin(), P.end());
    return fmini(P, 0, vector<point>());
}

```

```

}

```

3.9 twoSegmentIntersect

```

struct pt {
    long long x, y;
    pt() {}
    pt(long long _x, long long _y) : x(_x), y(_y) {}
    pt operator-(const pt& p) const { return pt(x - p.x, y -
        p.y); }
    long long cross(const pt& p) const { return x * p.y - y
        * p.x; }
    long long cross(const pt& a, const pt& b) const { return
        (a - *this).cross(b - *this); }
};

int sgn(const long long& x) { return x >= 0 ? x
    ? 1 : 0 : -1; }

bool inter1(long long a, long long b, long long c, long long
    d) {
    if (a > b)
        swap(a, b);
    if (c > d)
        swap(c, d);
    return max(a, c) <= min(b, d);
}

bool check_inter(const pt& a, const pt& b, const pt& c,
    const pt& d) {
    if (c.cross(a, d) == 0 && c.cross(b, d) == 0)
        return inter1(a.x, b.x, c.x, d.x) && inter1(a.y, b.y
            , c.y, d.y);
    return sgn(a.cross(b, c)) != sgn(a.cross(b, d)) &&
        sgn(c.cross(d, a)) != sgn(c.cross(d, b));
}

```

4 Graph

4.1 Flow

4.1.1 Bipartite Matching

```

//To handle some corner cases, don't forget to randomize the
//edge order
struct BipartiteMatcher {

```

```

G(n), L(n, -1), R(m, -1), Viz(n) {}
vector<vector<int>> G;
vector<int> L, R, Viz;

BipartiteMatcher(int n, int m) :

void AddEdge(int a, int b) {
    G[a].push_back(b);
}

bool Match(int node) {
    if (Viz[node])
        return false;
    Viz[node] = true;

    for (auto vec : G[node]) {
        if (R[vec] == -1) {
            L[node] = vec;
            R[vec] = node;
            return true;
        }
    }

    for (auto vec : G[node]) {
        if (Match(R[vec])) {
            L[node] = vec;
            R[vec] = node;
            return true;
        }
    }

    return false;
}

int Solve() {
    int ok = true;
    while (ok--) {
        fill(Viz.begin(), Viz.end(), 0);
        for (int i = 0; i < (int)L.size(); ++i)
            if (L[i] == -1)
                ok |= Match(i);
    }

    int ret = 0;
    for (int i = 0; i < L.size(); ++i)
        ret += (L[i] != -1);
    return ret;
}
};

```

4.1.2 Dinic

```

struct FlowEdge {
    int v, u;
    long long cap, flow = 0;
    FlowEdge(int v, int u, long long cap) : v(v), u(u), cap(
        cap) {}
};

struct Dinic {
    const long long flow_inf = 1e18;
    vector<FlowEdge> edges;
    vector<vector<int>> adj;
    int n, m = 0;
    int s, t;
    vector<int> level, ptr;
    queue<int> q;

    Dinic(int n, int s, int t) : n(n), s(s), t(t) {
        adj.resize(n);
        level.resize(n);
        ptr.resize(n);
    }

    void add_edge(int v, int u, long long cap) {
        edges.emplace_back(v, u, cap);
        edges.emplace_back(u, v, 0);
        adj[v].push_back(m);
        adj[u].push_back(m + 1);
        m += 2;
    }

    bool bfs() {
        while (!q.empty()) {
            int v = q.front();
            q.pop();
            for (int id : adj[v]) {
                if (edges[id].cap - edges[id].flow < 1)
                    continue;
                if (level[edges[id].u] != -1)
                    continue;
                level[edges[id].u] = level[v] + 1;
                q.push(edges[id].u);
            }
        }
        return level[t] != -1;
    }

    long long dfs(int v, long long pushed) {
        if (pushed == 0)

```

```

            return 0;
        if (v == t)
            return pushed;
        for (int& cid = ptr[v]; cid < (int)adj[v].size(); cid
            ++){
            int id = adj[v][cid];
            int u = edges[id].u;
            if (level[v] + 1 != level[u] || edges[id].cap -
                edges[id].flow < 1)
                continue;
            long long tr = dfs(u, min(pushed, edges[id].cap
                - edges[id].flow));
            if (tr == 0)
                continue;
            edges[id].flow += tr;
            edges[id ^ 1].flow -= tr;
            return tr;
        }
        return 0;
    }

    long long flow() {
        long long f = 0;
        while (true) {
            fill(level.begin(), level.end(), -1);
            level[s] = 0;
            q.push(s);
            if (!bfs())
                break;
            fill(ptr.begin(), ptr.end(), 0);
            while (long long pushed = dfs(s, flow_inf)) {
                f += pushed;
            }
        }
        return f;
    }
};

```

4.1.3 Edmond-Karp Max flow

```

#define MAXNODE 1000
#define INF 1000000007
int capacity[MAXNODE+5][MAXNODE+5];
vector<vector<int>> adj;

int bfs(int s, int t, vector<int>& parent) {
    fill(parent.begin(), parent.end(), -1);
    parent[s] = -2;
    queue<pair<int, int>> q;

```

```

    int cur = q.front().first;
    q.push({s, INF});

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

        for (int next : adj[cur]) {
            if (parent[next] == -1 && capacity[cur][next]) {
                parent[next] = cur;
                int new_flow = min(flow, capacity[cur][next]);
                if (next == t)
                    return new_flow;
                q.push({next, new_flow});
            }
        }

        return 0;
    }

int maxflow(int s, int t) {
    int flow = 0;
    vector<int> parent(MAXNODE);
    int new_flow;

    while (new_flow = bfs(s, t, parent)) {
        flow += new_flow;
        int cur = t;
        while (cur != s) {
            int prev = parent[cur];
            capacity[prev][cur] -= new_flow;
            capacity[cur][prev] += new_flow;
            cur = prev;
        }
    }

    return flow;
}

```

4.1.4 Min-cost flow

```

struct Edge
{
    int from, to, capacity, cost;
    Edge(int from, int to, int capacity, int cost){
        this->from = from;

```

```

        this->to = to;
        this->capacity = capacity;
        this->cost = cost;
    }
};

vector<vector<int>> adj, cost, capacity;

const int INF = 1e9;

void shortest_paths(int n, int v0, vector<int>& d, vector<
    int>& p) {
    d.assign(n, INF);
    d[v0] = 0;
    vector<int> m(n, 2);
    deque<int> q;
    q.push_back(v0);
    p.assign(n, -1);

    while (!q.empty()) {
        int u = q.front();
        q.pop_front();
        m[u] = 0;
        for (int v : adj[u]) {
            if (capacity[u][v] > 0 && d[v] > d[u] + cost[u][v]
                ) {
                d[v] = d[u] + cost[u][v];
                p[v] = u;
                if (m[v] == 2) {
                    m[v] = 1;
                    q.push_back(v);
                } else if (m[v] == 0) {
                    m[v] = 1;
                    q.push_front(v);
                }
            }
        }
    }
}

```

```

int min_cost_flow(int N, vector<Edge> edges, int K, int s,
    int t) {
    adj.assign(N, vector<int>());
    cost.assign(N, vector<int>(N, 0));
    capacity.assign(N, vector<int>(N, 0));
    for (Edge e : edges) {
        adj[e.from].push_back(e.to);
        adj[e.to].push_back(e.from);
        cost[e.from][e.to] = e.cost;
        cost[e.to][e.from] = -e.cost;
    }
}

```

```

        capacity[e.from][e.to] = e.capacity;
    }

    int flow = 0;
    int cost = 0;
    vector<int> d, p;
    while (flow < K) {
        shortest_paths(N, s, d, p);
        if (d[t] == INF)
            break;

        // find max flow on that path
        int f = K - flow;
        int cur = t;
        while (cur != s) {
            f = min(f, capacity[p[cur]][cur]);
            cur = p[cur];
        }

        // apply flow
        flow += f;
        cost += f * d[t];
        cur = t;
        while (cur != s) {
            capacity[p[cur]][cur] -= f;
            capacity[cur][p[cur]] += f;
            cur = p[cur];
        }

        if (flow < K)
            return 1;
        else
            return cost;
    }
}

```

4.1.5 hopcroft

```

// C++ implementation of Hopcroft Karp algorithm for
// maximum matching
#include <iostream>
#include <cstdlib>
#include <queue>
#include <list>
#include <climits>
#define NIL 0
#define INF INT_MAX

// A class to represent Bipartite graph for

```

```

    // and right sides of Bipartite Graph
// Hopcroft Karp implementation
class BGraph
{
    // m and n are number of vertices on left

int
    m, n;

    // adj[u] stores adjacents of left side
    // vertex 'u'. The value of u ranges from 1 to m.
    // 0 is used for dummy vertex
    std::list<int> *adj;

    // pointers for hopcroftKarp()
    int *pair_u, *pair_v, *dist;

public:
    BGraph(int m, int n); // Constructor
    void addEdge(int u, int v); // To add edge

    // Returns true if there is an augmenting path
    bool bfs();

    // Adds augmenting path if there is one beginning
    // with u
    bool dfs(int u);

    // Returns size of maximum matching
    int hopcroftKarpAlgorithm();
};

// Returns size of maximum matching
int BGraph::hopcroftKarpAlgorithm()
{
    // pair_u[u] stores pair of u in matching on left side of
    // Bipartite Graph.
    // If u doesn't have any pair, then pair_u[u] is NIL
    pair_u = new int[m + 1];

    // pair_v[v] stores pair of v in matching on right side
    // of Bipartite Graph.
    // If v doesn't have any pair, then pair_u[v] is NIL
    pair_v = new int[n + 1];

    // dist[u] stores distance of left side vertices
    dist = new int[m + 1];

    // Initialize NIL as pair of all vertices
    for (int u = 0; u <= m; u++)

```

```

        pair_u[u] = NIL;
    for (int v = 0; v <= n; v++)
        pair_v[v] = NIL;

    // Initialize result
    int result = 0;

    // Keep updating the result while there is an
    // augmenting path possible.
    while (bfs())
    {
        // Find a free vertex to check for a matching
        for (int u = 1; u <= m; u++)

            // If current vertex is free and there is
            // an augmenting path from current vertex
            // then increment the result
            if (pair_u[u] == NIL && dfs(u))
                result++;
    }
    return result;
}

// Returns true if there is an augmenting path available,
// else returns false
bool BGraph::bfs()
{
    std::queue<int> q; //an integer queue for bfs

    // First layer of vertices (set distance as 0)
    for (int u = 1; u <= m; u++)
    {
        // If this is a free vertex, add it to queue
        if (pair_u[u] == NIL)
        {
            // u is not matched so distance is 0
            dist[u] = 0;
            q.push(u);
        }

        // Else set distance as infinite so that this vertex
        // is considered next time for availability
        else
            dist[u] = INF;
    }

    // Initialize distance to NIL as infinite
    dist[NIL] = INF;

    // q is going to contain vertices of left side only.

```

```

while (!q.empty())
{
    // dequeue a vertex
    int u = q.front();
    q.pop();

    // If this node is not NIL and can provide a shorter
    // path to NIL then
    if (dist[u] < dist[NIL])
    {
        // Get all the adjacent vertices of the dequeued
        // vertex u
        std::list<int>::iterator it;
        for (it = adj[u].begin(); it != adj[u].end(); ++
            it)
        {
            int v = *it;

            // If pair of v is not considered so far
            // i.e. (v, pair_v[v]) is not yet explored
            // edge.
            if (dist[pair_v[v]] == INF)
            {
                // Consider the pair and push it to queue
                dist[pair_v[v]] = dist[u] + 1;
                q.push(pair_v[v]);
            }
        }
    }
}

// If we could come back to NIL using alternating path of
// distinct
// vertices then there is an augmenting path available
return (dist[NIL] != INF);
}

// Returns true if there is an augmenting path beginning
// with free vertex u
bool BGraph::dfs(int u)
{
    if (u != NIL)
    {
        std::list<int>::iterator it;
        for (it = adj[u].begin(); it != adj[u].end(); ++it)
        {
            // Adjacent vertex of u
            int v = *it;

            // Follow the distances set by BFS search

```

```

        { // new matching possible, store the
          matching
        }
        if (dist[pair_v[v]] == dist[u] + 1)
        {
            // If dfs for pair of v also returnn true then
            if (dfs(pair_v[v]) == true)

pair_v
[v] = u;

            pair_u[u] = v;
            return true;
        }
    }
}

// If there is no augmenting path beginning with u
then.
dist[u] = INF;
return false;
}
return true;
}

// Constructor for initialization
BGraph::BGraph(int m, int n)
{
    this->m = m;
    this->n = n;
    adj = new std::list<int>[m + 1];
}

// function to add edge from u to v
void BGraph::addEdge(int u, int v)
{
    adj[u].push_back(v); // Add v to 'us list.
}

int main()
{
    int v1, v2, e;
    std::cin >> v1 >> v2 >> e; // vertices of left side,
    right side and edges
    BGraph g(v1, v2); //
    int u, v;
    for (int i = 0; i < e; ++i)
    {
        std::cin >> u >> v;
        g.addEdge(u, v);
    }
    int res = g.hopcroftKarpAlgorithm();

```

```

    std::cout << "Maximum matching is " << res << "\n";

    return 0;
}

```

4.2 LCABinaryLifting

```

int n, l;
vector<vector<int>> adj;

int timer;
vector<int> tin, tout;
vector<vector<int>> up;

void dfs(int v, int p)
{
    tin[v] = ++timer;
    up[v][0] = p;
    for (int i = 1; i <= l; ++i)
        up[v][i] = up[up[v][i-1]][i-1];

    for (int u : adj[v]) {
        if (u != p)
            dfs(u, v);
    }

    tout[v] = ++timer;
}

bool is_ancestor(int u, int v)
{
    return tin[u] <= tin[v] && tout[u] >= tout[v];
}

int lca(int u, int v)
{
    if (is_ancestor(u, v))
        return u;
    if (is_ancestor(v, u))
        return v;
    for (int i = l; i >= 0; --i) {
        if (!is_ancestor(up[u][i], v))
            u = up[u][i];
    }
    return up[u][0];
}

void preprocess(int root) {
    tin.resize(n);

```

```

    tout.resize(n);
    timer = 0;
    l = ceil(log2(n));
    up.assign(n, vector<int>(l + 1));
    dfs(root, root);
}

```

4.3 LCARmq

```

/**
 * Description: Euler Tour LCA w/ O(1) query
 * Source: own
 * Verification: Debug the Bugs
 * Dependency: Range Minimum Query
 */

template<int SZ> struct LCA {
    vi adj[SZ];
    RMQ<pi, 2*SZ> r;
    vpi tmp;
    int depth[SZ], pos[SZ];
    int N, R = 1;

    void addEdge(int u, int v) {
        adj[u].pb(v), adj[v].pb(u);
    }

    void dfs(int u, int prev){
        pos[u] = sz(tmp); depth[u] = depth[prev]+1;
        tmp.pb({depth[u],u});
        for (int v: adj[u]) if (v != prev) {
            dfs(v, u);
            tmp.pb({depth[u],u});
        }
    }

    void init(int _N) {
        N = _N;
        dfs(R, 0);
        r.build(tmp);
    }

    int lca(int u, int v){
        u = pos[u], v = pos[v];
        if (u > v) swap(u,v);
        return r.query(u,v).s;
    }

    int dist(int u, int v) {

```

```

    return depth[u]+depth[v]-2*depth[lca(u,v)];
}
};

```

4.4 LCATarjan

```

vector<vector<int>> adj;
vector<vector<int>> queries;
vector<int> ancestor;
vector<bool> visited;

void dfs(int v)
{
    visited[v] = true;
    ancestor[v] = v;
    for (int u : adj[v]) {
        if (!visited[u]) {
            dfs(u);
            union_sets(v, u);
            ancestor[find_set(v)] = v;
        }
    }
    for (int other_node : queries[v]) {
        if (visited[other_node])
            cout << "LCA of " << v << " and " << other_node
                << " is " << ancestor[find_set(other_node)]
                << ".\n";
    }
}

void compute_LCAs() {
    // initialize n, adj and DSU
    // for (each query (u, v)) {
    //     queries[u].push_back(v);
    //     queries[v].push_back(u);
    // }

    ancestor.resize(n);
    visited.assign(n, false);
    dfs(0);
}

```

4.5 MST

4.5.1 secondBestMSTLCA

```

struct edge {

```

```

    int s, e, w, id;
    bool operator<(const struct edge& other) { return w <
        other.w; }
};
typedef struct edge Edge;

const int N = 2e5 + 5;
long long res = 0, ans = 1e18;
int n, m, a, b, w, id, l = 21;
vector<Edge> edges;
vector<int> h(N, 0), parent(N, -1), size(N, 0), present(N, 0);
vector<vector<pair<int, int>>> adj(N), dp(N, vector<pair<int, int>>(1));
vector<vector<int>> up(N, vector<int>(1, -1));

pair<int, int> combine(pair<int, int> a, pair<int, int> b) {
    vector<int> v = {a.first, a.second, b.first, b.second};
    int topTwo = -3, topOne = -2;
    for (int c : v) {
        if (c > topOne) {
            topTwo = topOne;
            topOne = c;
        } else if (c > topTwo && c < topOne) {
            topTwo = c;
        }
    }
    return {topOne, topTwo};
}

void dfs(int u, int par, int d) {
    h[u] = 1 + h[par];
    up[u][0] = par;
    dp[u][0] = {d, -1};
    for (auto v : adj[u]) {
        if (v.first != par) {
            dfs(v.first, u, v.second);
        }
    }
}

pair<int, int> lca(int u, int v) {
    pair<int, int> ans = {-2, -3};
    if (h[u] < h[v]) {
        swap(u, v);
    }
    for (int i = 1 - 1; i >= 0; i--) {
        if (h[u] - h[v] >= (1 << i)) {
            ans = combine(ans, dp[u][i]);
            u = up[u][i];

```

```

        }
    }
    if (u == v) {
        return ans;
    }
    for (int i = 1 - 1; i >= 0; i--) {
        if (up[u][i] != -1 && up[v][i] != -1 && up[u][i] !=
            up[v][i]) {
            ans = combine(ans, combine(dp[u][i], dp[v][i]));
            u = up[u][i];
            v = up[v][i];
        }
    }
    ans = combine(ans, combine(dp[u][0], dp[v][0]));
    return ans;
}

int main(void) {
    cin >> n >> m;
    for (int i = 1; i <= n; i++) {
        parent[i] = i;
        size[i] = 1;
    }
    for (int i = 1; i <= m; i++) {
        cin >> a >> b >> w; // 1-indexed
        edges.push_back({a, b, w, i - 1});
    }
    sort(edges.begin(), edges.end());
    for (int i = 0; i <= m - 1; i++) {
        a = edges[i].s;
        b = edges[i].e;
        w = edges[i].w;
        id = edges[i].id;
        if (unite_set(a, b)) {
            adj[a].emplace_back(b, w);
            adj[b].emplace_back(a, w);
            present[id] = 1;
            res += w;
        }
    }
    dfs(1, 0, 0);
    for (int i = 1; i <= 1 - 1; i++) {
        for (int j = 1; j <= n; ++j) {
            if (up[j][i - 1] != -1) {
                int v = up[j][i - 1];
                up[j][i] = up[v][i - 1];
                dp[j][i] = combine(dp[j][i - 1], dp[v][i - 1]);
            }
        }
    }
}

```

```

        if (rem.first != w) {
    }
    for (int i = 0; i <= m - 1; i++) {
        id = edges[i].id;
        w = edges[i].w;
        if (!present[id]) {
            auto rem = lca(edges[i].s, edges[i].e);
if
    (ans > res + w - rem.first) {
        ans = res + w - rem.first;
    }
    } else if (rem.second != -1) {
        if (ans > res + w - rem.second) {
            ans = res + w - rem.second;
        }
    }
    }
    }
    cout << ans << "\n";
    return 0;
}

```

4.6 SCC

4.6.1 2SAT

```

int n;
vector<vector<int>> g, gt;
vector<bool> used;
vector<int> order, comp;
vector<bool> assignment;

void dfs1(int v) {
    used[v] = true;
    for (int u : g[v]) {
        if (!used[u])
            dfs1(u);
    }
    order.push_back(v);
}

void dfs2(int v, int c1) {
    comp[v] = c1;
    for (int u : gt[v]) {
        if (comp[u] == -1)
            dfs2(u, c1);
    }
}

```

```

bool solve_2SAT() {
    used.assign(n, false);
    for (int i = 0; i < n; ++i) {
        if (!used[i])
            dfs1(i);
    }

    comp.assign(n, -1);
    for (int i = 0, j = 0; i < n; ++i) {
        int v = order[n - i - 1];
        if (comp[v] == -1)
            dfs2(v, j++);
    }

    assignment.assign(n / 2, false);
    for (int i = 0; i < n; i += 2) {
        if (comp[i] == comp[i + 1])
            return false;
        assignment[i / 2] = comp[i] > comp[i + 1];
    }
    return true;
}

```

4.6.2 Kosaraju

```

vector < vector<int> > g, gr;
vector<bool> used;
vector<int> order, component;

void dfs1 (int v) {
    used[v] = true;
    for (size_t i=0; i<g[v].size(); ++i)
        if (!used[ g[v][i] ])
            dfs1 (g[v][i]);
    order.push_back (v);
}

void dfs2 (int v) {
    used[v] = true;
    component.push_back (v);
    for (size_t i=0; i<gr[v].size(); ++i)
        if (!used[ gr[v][i] ])
            dfs2 (gr[v][i]);
}

int main() {
    int n;
    // ... reading n ...

```

```

for (;;) {
    int a, b;
    // ... reading next edge (a,b) ...
    g[a].push_back (b);
    gr[b].push_back (a);
}
used.assign (n, false);
for (int i=0; i<n; ++i)
    if (!used[i])
        dfs1 (i);
used.assign (n, false);
for (int i=0; i<n; ++i) {
    int v = order[n-1-i];
    if (!used[v]) {
        dfs2 (v);
        // ... printing next component ...
        component.clear();
    }
}
}

```

4.7 Shortest Path

4.7.1 BellmanFord

```

vi dist(V, INF); dist[s] = 0;

for (int i = 0; i < V - 1; i++) // relax all E edges V-1
    times
    for (int u = 0; u < V; u++) // these two loops = O(E),
        overall O(VE)
        for (int j = 0; j < (int)AdjList[u].size(); j++) {
            ii v = AdjList[u][j];
            // record SP spanning here if needed
            dist[v.first] = min(dist[v.first], dist[u] + v.second);
            // relax
        }

// after running the O(VE) Bellman 'Fords algorithm shown
// above
bool hasNegativeCycle = false;
for (int u = 0; u < V; u++) // one more pass to check
    for (int j = 0; j < (int)AdjList[u].size(); j++) {
        ii v = AdjList[u][j];
        if (dist[v.first] > dist[u] + v.second) // if this is
            still possible
            hasNegativeCycle = true;
        // then negative cycle exists!
    }
}

```

```
printf("Negative Cycle Exist? %s\n", hasNegativeCycle ? "Yes"
      : "No");
```

4.7.2 Dijkstra

```
/**
 * Description: shortest path!
 * Works with negative edge weights (aka SPFA?)
 */
```

```
template<class T> using pqg = priority_queue<T, vector<T>,
      greater<T>>;
```

```
template<class T> T poll(pqg<T>& x) {
    T y = x.top(); x.pop();
    return y;
}
```

```
template<int SZ> struct Dijkstra {
    ll dist[SZ];
    vpi adj[SZ];
    pqg<pl> q;
```

```
void addEdge(int A, int B, int C) {
    adj[A].pb({B,C}), adj[B].pb({A,C});
}
```

```
void gen(int st) {
    fill_n(dist, SZ, INF);
    q = pqg<pl>(); q.push({dist[st] = 0, st});
    while (sz(q)) {
        auto x = poll(q);
        if (dist[x.s] < x.f) continue;
        for (auto y: adj[x.s]) if (x.f+y.s < dist[y.f])
            q.push({dist[y.f] = x.f+y.s, y.f});
    }
};
```

4.8 centroidDecomposition

```
const int maxn = 1e5 + 5;
vector<vi> AdjList, centroid;
int id[maxn], sz[maxn];
```

```
void dfsSizeSubtree(int node, int p) {
    sz[node] = 1;
```

```
for(int i=0; i<AdjList[node].size(); i++){
    int v = AdjList[node][i];
    if(v!=p) {
        dfsSizeSubtree(v, node);
        sz[node] += sz[v];
    }
}

int findCentroid(int node, int ukuran, int label) {
    bool valid = true;
    for(int i=0; i<AdjList[node].size(); i++){
        int v = AdjList[node][i];
        if(sz[v] > ukuran/2 && id[v] == -1) {
            //pindah ke centroid itu
            valid = false;
            sz[node] = ukuran-sz[v];
            sz[v] = ukuran;
            int cen = findCentroid(v, ukuran, label);
            id[cen] = label;
            return cen;
        }
    }
    if(valid) {
        id[node] = label;
        return node;
    }
    return -1;
}

int dfsCentroid(int node, int label) {
    int root = findCentroid(node, sz[node], label);
    id[root] = label
    for(int i=0; i<AdjList[root].size(); i++){
        int v = AdjList[root][i];
        if(id[v] == -1){
            int cen = dfsCentroid(v, label+1);
            centroid[root].pb(cen); centroid[cen].pb(root);
        }
    }
    return root;
}
```

```
//MAIN
```

```
int n,i,j; scanf("%d", &n);
AdjList.assign(maxn, vi());
centroid.assign(maxn, vi());
for(i=0; i<n-1; i++){
    int a,b; scanf("%d %d", &a, &b);
    AdjList[a].pb(b); AdjList[b].pb(a);
```

```
}
dfsSizeSubtree(1, -1);
memset(id, -1, sizeof id);
int rootCentroid = dfsCentroid(1,0);
```

4.9 findBridge

```
int n; // number of nodes
vector<vector<int>> adj; // adjacency list of graph
```

```
vector<bool> visited;
vector<int> tin, low;
int timer;
```

```
void dfs(int v, int p = -1) {
    visited[v] = true;
    tin[v] = low[v] = timer++;
    for (int to : adj[v]) {
        if (to == p) continue;
        if (visited[to]) {
            low[v] = min(low[v], tin[to]);
        } else {
            dfs(to, v);
            low[v] = min(low[v], low[to]);
            if (low[to] > tin[v])
                IS_BRIDGE(v, to);
            //IS_BRIDGE(a, b) function that process fact
            //edge (a, b)
            //is a bridge
        }
    }
}
```

```
void find_bridges() {
    timer = 0;
    visited.assign(n, false);
    tin.assign(n, -1);
    low.assign(n, -1);
    for (int i = 0; i < n; ++i) {
        if (!visited[i])
            dfs(i);
    }
}
```

4.10 heavyLightDecomposition

```
const int maxn = 1e4 + 4;
vector<vii> AdjList;
```



```

    int maks = 0;
vi parent, depth, heavy, head, pos;
vector<vi> indexx;
int curPos, sz[maxn], w[maxn], tempW[maxn], akhir[maxn];

int dfs(int node, int p, int dalam) {
    sz[node] = 1;

    depth
    [node] = dalam;
    for(int i=0; i<AdjList[node].size(); i++){
        ii v = AdjList[node][i];
        int tetangga = v.first, berat = v.second;
        if(tetangga != p) {
            int idx = indexx[node][i];
            akhir[idx] = tetangga;
            parent[tetangga] = node;
            int ukuranTetangga = dfs(tetangga, node, dalam+1);
            ;
            sz[node] += ukuranTetangga;
            tempW[tetangga] = berat;
            if(maks < ukuranTetangga) {
                maks = ukuranTetangga;
                heavy[node] = tetangga;
            }
        }
    }
    return sz[node];
}

void decompose(int node, int h) {
    head[node] = h, pos[node] = curPos++;
    if(heavy[node] != -1)
        decompose(heavy[node], h);
    for(int i=0; i<AdjList[node].size(); i++){
        ii v = AdjList[node][i];
        int tetangga = v.first, berat = v.second;
        if(parent[node] != tetangga && heavy[node] !=
            tetangga)
            decompose(tetangga, tetangga);
    }
}

void assignWeight(int n) {
    for(int i=1; i<=n; i++){
        int posisi = pos[i];
        w[posisi] = tempW[i];
    }
}

```

```

int st[4*maxn];
int left(int n){return n<<1;}
int right(int n){return (n<<1) + 1;}

void build(int node, int l, int r) {
    if(l == r) {
        st[node] = w[l];
        return;
    }
    int mid = (l+r)/2;
    build(left(node), l, mid);
    build(right(node), mid+1, r);
    st[node] = max(st[left(node)], st[right(node)]);
}

int query(int node, int l, int r, int i, int j) {
    if(j < l || r < i) {return -inf;}
    if(i <= l && r <= j){return st[node];}
    int mid = (l+r)/2;
    int ans1 = query(left(node), l, mid, i, j);
    int ans2 = query(right(node), mid+1, r, i, j);
    return max(ans1, ans2);
}

void update(int node, int l, int r, int idx, int val) {
    if(r < idx || l > idx){return;}
    if(idx == r && idx == l){
        st[node] = val;
        return;
    }
    int mid = (l+r)/2;
    update(left(node), l, mid, idx, val);
    update(right(node), mid+1, r, idx, val);
    st[node] = max(st[left(node)], st[right(node)]);
}

void updateQuery(int idx, int val) {
    int nodeAkhir = akhir[idx];
    update(1,1,curPos,pos[nodeAkhir], val);
}

int jawabQuery(int a, int b) {
    if(a == b) return 0;
    int ans = -inf;
    for(; head[a] != head[b]; b = parent[head[b]]) {
        if(depth[head[a]] > depth[head[b]]) swap(a,b);
        int cur = query(1,1,curPos,pos[head[b]], pos[b]);
        ans = max(ans, cur);
    }
    if(depth[a] > depth[b]) swap(a,b);
}

```

```

int cur = query(1,1,curPos,pos[a]+1, pos[b]);
ans = max(ans, cur);
return ans;
}

void preprocess() {
    int n = AdjList.size();
    parent = vi(n+1);
    depth = vi(n+1);
    heavy = vi(n+1, -1);
    head = vi(n+1);
    pos = vi(n+1);
    curPos = 1;
    dfs(1, -1, 0);
    decompose(1,1);
    assignWeight(n);
    build(1,1,curPos);
}

// MAIN
// INPUT
preprocess()

```

5 Math

5.1 BigInt

```

const int BASE_LENGTH = 2;
const int BASE = (int) pow(10, BASE_LENGTH);
const int MAX_LENGTH = 500;

string int_to_string(int i, int width, bool zero) {
    string res = "";
    while (width-->0) {
        if (!zero && i == 0) return res;
        res = (char)(i%10 + '0') + res;
        i /= 10;
    }
    return res;
}

struct bigint {
    int len, s[MAX_LENGTH];

    bigint() {
        memset(s, 0, sizeof(s));
        len = 1;
    }
}

```

```

        s[len] = num % BASE;

bigint(unsigned long long num) {
    len = 0;
    while (num >= BASE) {
        num /= BASE;
        len++;
    }
    s[len++] = num;
}

bigint(const char* num) {
    int l = strlen(num);
    len = l/BASE_LENGTH;
    if (l % BASE_LENGTH) len++;
    int index = 0;
    for (int i = l - 1; i >= 0; i -= BASE_LENGTH) {
        int tmp = 0;
        int k = i - BASE_LENGTH + 1;
        if (k < 0) k = 0;
        for (int j = k; j <= i; j++) {
            tmp = tmp*10 + num[j] - '0';
        }
        s[index++] = tmp;
    }
}

void clean() {
    while(len > 1 && !s[len-1]) len--;
}

string str() const {
    string ret = "";
    if (len == 1 && !s[0]) return "0";
    for(int i = 0; i < len; i++) {
        if (i == 0) {
            ret += int_to_string(s[len - i - 1],
                                BASE_LENGTH, false);
        } else {
            ret += int_to_string(s[len - i - 1],
                                BASE_LENGTH, true);
        }
    }
    return ret;
}

unsigned long long ll() const {
    unsigned long long ret = 0;
    for(int i = len-1; i >= 0; i--) {

```

```

        ret *= BASE;
        ret += s[i];
    }
    return ret;
}

bigint operator + (const bigint& b) const {
    bigint c = b;
    while (c.len < len) c.s[c.len++] = 0;
    c.s[c.len++] = 0;
    bool r = 0;
    for (int i = 0; i < len || r; i++) {
        c.s[i] += (i < len) * s[i] + r;
        r = c.s[i] >= BASE;
        if (r) c.s[i] -= BASE;
    }
    c.clean();
    return c;
}

bigint operator - (const bigint& b) const {
    if (operator < (b)) throw "cannot do subtract";
    bigint c = *this;
    bool r = 0;
    for (int i = 0; i < b.len || r; i++) {
        c.s[i] -= b.s[i];
        r = c.s[i] < 0;
        if (r) c.s[i] += BASE;
    }
    c.clean();
    return c;
}

bigint operator * (const bigint& b) const {
    bigint c;
    c.len = len + b.len;
    for(int i = 0; i < len; i++)
        for(int j = 0; j < b.len; j++)
            c.s[i+j] += s[i] * b.s[j];
    for(int i = 0; i < c.len-1; i++){
        c.s[i+1] += c.s[i] / BASE;
        c.s[i] %= BASE;
    }
    c.clean();
    return c;
}

bigint operator / (const int b) const {
    bigint ret;
    int down = 0;

```

```

        for (int i = len - 1; i >= 0; i--) {
            ret.s[i] = (s[i] + down * BASE) / b;
            down = s[i] + down * BASE - ret.s[i] * b;
        }
        ret.len = len;
        ret.clean();
        return ret;
    }

    bool operator < (const bigint& b) const {
        if (len < b.len) return true;
        else if (len > b.len) return false;
        for (int i = 0; i < len; i++)
            if (s[i] < b.s[i]) return true;
            else if (s[i] > b.s[i]) return false;
        return false;
    }

    bool operator == (const bigint& b) const {
        return !(*this < b) && !(b < (*this));
    }

    bool operator > (const bigint& b) const {
        return b < *this;
    }
};

```

5.2 Number Theory

5.2.1 CRT

```

#include <bits/stdc++.h>
using namespace std;
// Returns modulo inverse of a with respect to m using
// extended
// Euclid Algorithm. Refer below post for details:
// https://www.geeksforgeeks.org/multiplicative-inverse-
// under-modulo-m/
int inv(int a, int m) {
    int m0 = m, t, q;
    int x0 = 0, x1 = 1;
    if (m == 1)
        return 0;
    // Apply extended Euclid Algorithm
    while (a > 1) {
        // q is quotient
        q = a / m;
        t = m;
        // m is remainder now, process same as

```

```

    x1 = t;
    // euclid's algo
    m = a % m, a = t;
    t = x0;
    x0 = x1 - q * x0;
}

// Make x1 positive
if (x1 < 0)
    x1 += m0;
return x1;
}

// k is size of num[] and rem[]. Returns the smallest
// number x such that:
// x % num[0] = rem[0],
// x % num[1] = rem[1],
// .....
// x % num[k-2] = rem[k-1]
// Assumption: Numbers in num[] are pairwise coprime
// (gcd for every pair is 1)
int findMinX(int num[], int rem[], int k) {
    // Compute product of all numbers
    int prod = 1;
    for (int i = 0; i < k; i++)
        prod *= num[i];
    // Initialize result
    int result = 0;
    // Apply above formula
    for (int i = 0; i < k; i++) {
        int pp = prod / num[i];
        result += rem[i] * inv(pp, num[i]) * pp;
    }
    return result % prod;
}

```

5.2.2 InverseModulo

```

/**
 * Description : find x such that ax = 1 mod m
 */
/* case 1 : when(gcd(a,m) = 1) */
/* use extended euclid : find x such that ax + my = 1 */
/* store x, y, and d as global variables */
/* d = gcd */
void extendedEuclid(int a, int b) {
    if (b == 0) { x = 1; y = 0; d = a; return; }
    /* base case */
    extendedEuclid(b, a % b);
}

```

```

/* similar as the original gcd */
int x1 = y;
int y1 = x - (a / b) * y;
x = x1;
y = y1;
}

/* compute the first case inverse modulo*/
int firstInverseModulo(int a, int m){
    /* produces x and y, such that ax + my = 1 */
    /* return a^-1 mod m */
    extendedEuclid(a, m);
    return (x + m)%m;
}

/* case 2 : m is prime */
/* a^(m-1) = 1 mod m */
/* a^(m-2) = a^-1 mod m */
int power(int a,int b){
    int res = 1;
    while (b > 0){
        if (b%2 == 1)
            res *= a;
        b /= 2;
        a *= a;
    }
    return res;
}

int secondInverseModulo(int a,int m){
    return power(a, m-2);
}

```

5.2.3 PrimeFactor

```

/**
 * Description : some function that have relation with prime
 * factor
 */
/* find prime factor */
vector<long long> primefactor(long long N){
    vector<long long> factors;
    long long idx = 0;
    long long PF = primes[idx];
    while (PF <= (long long)sqrt(N)){
        while (N%PF == 0){
            N /= PF;
            factors.push_back(PF);
        }
        PF = primes[++idx];
    }
}

```

```

if (N != 1) factors.push_back(N);
return factors;
}

/* number of divisor */
long long numDiv(long long N){
    long long ans = 1;
    long long idx = 0;
    long long PF = primes[idx];
    while (PF <= (long long)sqrt(N)){
        long long power = 0;
        while (N%PF == 0){
            power++;
            N /= PF;
        }
        ans *= (power + 1);
        PF = primes[++idx];
    }
    if (N != 1) ans *= 2;
    return ans;
}

/* sum of divisor */
long long sumDiv(long long N){
    long long ans = 1;
    long long idx = 0;
    long long PF = primes[idx];
    while (PF <= (long long)sqrt(N)){
        long long power = 0;
        while (N%PF == 0){
            power++;
            N /= PF;
        }
        /* 1 + PF + PF^2 + PF^3 + ... + PF^pow = (a.r^n - 1)
        / (r-1) */
        ans *= ((long long)pow((double)PF, power + 1.0) - 1)
            / (PF - 1);
        PF = primes[++idx];
    }
    if (N != 1) ans *= ((long long)pow((double)N, 2.0) - 1)
        / (N - 1);
    return ans;
}

/* Euler Phi */
long long eulerPhi(long long N){
    long long idx = 0;
    long long PF = primes[idx];
    long long ans = N;
    while (PF <= (long long)sqrt(N)){

```

```

    if (N != 1) ans -= ans / N;
    if (N%PF == 0) ans -= ans / PF;
    while (N%PF == 0) N /= PF;
    PF = primes[++idx];
}

return
    ans;
}

```

5.2.4 Sieve

```

/**
 * Description :Test Primality up to n in O(log(logn))
 */

```

```

const int SZ = 1e7;
bitset<SZ> bs;
vector<long long> primes;

void sieve(){
    bs.set();
    bs[0] = false; bs[1] = false;
    for (long long i = 2; i <= SZ; i++){
        if (bs[i]){
            primes.push_back(i);
            for (long long j = i * i; j <= SZ; j+=i)
                bs[j] = false;
        }
    }
}

```

5.2.5 millerRabin

```

def millerTest(d, n):
    lon = int(math.log(n))
    # b = min(n-2, 2*lon*lon)
    a = random.randrange(2, n-2)
    x = power(a, d, n)
    if (x == 1 or x == n-1):
        return True
    while (d != n-1):
        x = (x * x) % n
        d *= 2
    if (x == 1):
        return False
    if (x == n-1):
        return True

```

```

return False

def isPrime(n, k):
    if (n <= 1 or n == 4):
        return False
    if (n <= 3):
        return True

    d = n-1
    while (d % 2 == 0):
        d /= 2

    for i in range(0, k):
        if (not(millerTest(d, n))):
            return False
    return True

# factorization a number in O(n^1/3)
def fastFactorization(n):
    res = 1
    for pf in primes:
        if (pf * pf * pf > n):
            break
        cnt = 1
        while (n%pf == 0):
            n /= pf
            cnt+=1
        res *= (cnt)
        sqt = int(math.sqrt(n))
        if (isPrime(n, 10)):
            res *= 2
        elif (sqt * sqt == n and isPrime(sqt, 10)):
            res *= 3
        elif (n != 1):
            res *= 4
    return res

```

5.2.6 multiplicationOverflow

```

// calculate a * b % mod. mod may fit in 64-bit,
// but a*b might exceed. two ways, one using
// fast exponentiation style which is safe but
// slower, or using long double as written below (safe
// enough i guess)

long long mul(long long a, long long b, long long mod) {
    long double res = a;
    res *= b;
    long long c = (long long)(res / mod);
    a *= b;

```

```

    a -= c * mod;
    a %= mod;
    if (a < 0) a += mod;
    return a;
}

```

5.3 Polynomial

5.3.1 FFT mod

```

/*
Description: Allows multiplication of polynomials in
general moduli.
Verification:
http://codeforces.com/contest/960/submission/37085144
*/

```

```

namespace FFTmod {
int get(int s) {
    return s > 1 ? 32 - __builtin_clz(s - 1) : 0;
}

void fft(vcd& a, bool inv){
    int n = sz(a), j = 0;
    vcd roots(n/2);
    FOR(i,1,n) {
        int bit = (n >> 1);
        while (j >= bit){
            j -= bit;
            bit >>= 1;
        }
        j += bit;
        if(i < j) swap(a[i], a[j]);
    }

    ld ang = 2 * M_PI / n * (inv ? -1 : 1);
    FOR(i,n/2) roots[i] = cd(cos(ang * i), sin(ang * i));

    for (int i=2; i<=n; i<=1){
        int step = n / i;
        for(int j=0; j<n; j+=i){
            for(int k=0; k<i/2; k++){
                cd u = a[j+k], v = a[j+k+i/2] * roots[step * k];
                a[j+k] = u+v;
                a[j+k+i/2] = u-v;
            }
        }
    }
    if (inv) FOR(i,n) a[i] /= n;
}
}

```

```

vcd v1(n), v2(n), r1(n), r2(n);
FOR(i,sz(a)) v1[i] = cd(a[i] >> 15, a[i] & 32767);

v1 conv(v1 a, v1 b, ll mod){
    int s = sz(a)+sz(b)-1, L = get(s), n = 1<<L;

FOR
    (i,sz(b)) v2[i] = cd(b[i] >> 15, b[i] & 32767);
    fft(v1, 0); fft(v2, 0);

FOR(i,n) {
    int j = (i ? (n - i) : i);
    cd ans1 = (v1[i] + conj(v1[j])) * cd(0.5, 0);
    cd ans2 = (v1[i] - conj(v1[j])) * cd(0,-0.5);
    cd ans3 = (v2[i] + conj(v2[j])) * cd(0.5, 0);
    cd ans4 = (v2[i] - conj(v2[j])) * cd(0,-0.5);
    r1[i] = (ans1 * ans3) + (ans1 * ans4) * cd(0, 1);
    r2[i] = (ans2 * ans3) + (ans2 * ans4) * cd(0, 1);
}
fft(r1, 1); fft(r2, 1);
v1 ret(n);
FOR(i,n) {
    ll av = (ll)round(r1[i].real());
    ll bv = (ll)round(r1[i].imag()) + (ll)round(r2[i].real());
    ;
    ll cv = (ll)round(r2[i].imag());
    av %= mod, bv %= mod, cv %= mod;
    ret[i] = (av << 30) + (bv << 15) + cv;
    ret[i] %= mod; ret[i] += mod; ret[i] %= mod;
}
ret.resize(s);
return ret;
}
}

```

```
using namespace FFTmod;
```

5.3.2 FFT

```

#include <algorithm>
#include <cstdio>
#include <ctime>
#include <vector>
#include <complex>

using namespace std;

typedef complex<double> cd;
typedef vector<cd> vcd;

```

```

vcd fft(const vcd &as) {
    int n = as.size();
    int k = 0; // n
    while ((1 << k) < n) k++;
    vector<int> rev(n);
    rev[0] = 0;
    int high1 = -1;
    for (int i = 1; i < n; i++) {
        if ((i & (i - 1)) == 0) // . i , i-1 .
            high1++;
        rev[i] = rev[i ^ (1 << high1)]; //
        rev[i] |= (1 << (k - high1 - 1)); //
    }

    vcd roots(n);
    for (int i = 0; i < n; i++) {
        double alpha = 2 * M_PI * i / n;
        roots[i] = cd(cos(alpha), sin(alpha));
    }

    vcd cur(n);
    for (int i = 0; i < n; i++)
        cur[i] = as[rev[i]];

    for (int len = 1; len < n; len <= 1) {
        vcd ncur(n);
        int rstep = roots.size() / (len * 2);
        for (int pdest = 0; pdest < n; pdest++) {
            int p1 = pdest;
            for (int i = 0; i < len; i++) {
                cd val = roots[i * rstep] * cur[p1 + len];
                ncur[pdest] = cur[p1] + val;
                ncur[pdest + len] = cur[p1] - val;
                pdest++, p1++;
            }
            pdest += len;
        }
        cur.swap(ncur);
    }
    return cur;
}

vcd fft_rev(const vcd &as) {
    vcd res = fft(as);
    for (int i = 0; i < (int)res.size(); i++) res[i] /= as.
        size();
    reverse(res.begin() + 1, res.end());
    return res;
}

```

```

int main() {
    int n;
    scanf("%d", &n);
    vcd as(n);
    for (int i = 0; i < n; i++) {
        int x;
        scanf("%d", &x);
        as[i] = x;
    }

    clock_t stime = clock();
    vcd res = fft(as);
    fprintf(stderr, "%d\n", (int)(clock() - stime));
    for (int i = 0; i < n; i++)
        printf("%.4lf %.4lf\n", res[i].real(), res[i].imag());

    stime = clock();
    vcd as2 = fft_rev(res);
    fprintf(stderr, "%d\n", (int)(clock() - stime));
    for (int i = 0; i < n; i++)
        printf("%.4lf %.4lf\n", as2[i].real(), as2[i].imag());
    return 0;
}

```

5.3.3 FFT2

```

**
* Description:
* Source: KACTL, https://pastebin.com/3Tnj5mRu
* Verification: SPOJ polymul, CSA manhattan
*/

```

```

namespace FFT {
    int get(int s) {
        return s > 1 ? 32 - __builtin_clz(s - 1) : 0;
    }

    vcd fft(vcd& a) {
        int n = sz(a), x = get(n);
        vcd res, RES(n), roots(n);
        FOR(i,n) roots[i] = cd(cos(2*M_PI1*i/n),sin(2*M_PI1*i/n));

        res = a;
        FOR(i,1,x+1) {
            int inc = n>>i;
            FOR(j,inc) for (int k = 0; k < n; k += inc){
                int t = 2*k%n+j;
                RES[k+j] = res[t]+roots[k]*res[t+inc];
            }
        }
    }
}

```

```

    return res;
}
swap(res, RES);
}

}

vcd fft_rev(vcd& a) {
    vcd res = fft(a);
    FOR(i, sz(res)) res[i] /= sz(a);
    reverse(res.begin() + 1, res.end());
    return res;
}

vcd brute(vcd& a, vcd& b) {
    vcd c(sz(a)+sz(b)-1);
    FOR(i, sz(a)) FOR(j, sz(b)) c[i+j] += a[i]*b[j];
    return c;
}

vcd conv(vcd a, vcd b) {
    int s = sz(a)+sz(b)-1, L = get(s), n = 1<<L;
    if (s <= 0) return {};
    if (s <= 200) return brute(a, b);
    a.resize(n); a = fft(a);
    b.resize(n); b = fft(b);
    FOR(i, n) a[i] *= b[i];
    a = fft_rev(a);

    a.resize(s);

    return a;
}

v1 convl1(v1 a, v1 b) {
    vcd A(sz(a)); FOR(i, sz(a)) A[i] = a[i];
    vcd B(sz(b)); FOR(i, sz(b)) B[i] = b[i];
    vcd X = conv(A, B);
    v1 x(sz(X)); FOR(i, sz(X)) x[i] =
    round(X[i].real());
    return x;
}
}

```

6 Misc

6.1 Mo

```

bool comp(query a, query b){
    if (a.L / block == b.L/block)
        return a.R < b.R;
    return a.L/block < b.L/block;
}

void add(int x){
    cnt[x]++;
    if (cnt[x] == 1) distinct++;
}

void del(int x){
    cnt[x]--;
    if (cnt[x] == 0) distinct--;
}

int main(){
    OPTIMATION
    cin >> N;
    for (int i = 0; i < N; i++){
        cin >> arr[i];
        block = (int)sqrt(N) + 1;
        cin >> Q;
        for (int i = 0; i < Q; i++){
            int tl, tr;
            cin >> tl >> tr;
            tl--; tr--;
            q[i].L = tl;
            q[i].R = tr;
            q[i].no = i;
        }
        sort(q, q+Q, comp);
        currL = 0;
        currR = 0;
        for (int i = 0; i < Q; i++){
            int L = q[i].L;
            int R = q[i].R;
            while (currL < L) {
                del(arr[currL]);
                currL++;
            }
            while (currL > L){
                add(arr[currL-1]);
                currL--;
            }
            while (currR <= R) {

```

```

                add(arr[currR]);
                currR++;
            }
            while (currR > R+1){
                del(arr[currR-1]);
                currR--;
            }
            ans[q[i].no] = distinct;
        }
        for (int i = 0; i < Q; i++){
            cout << ans[i] << '\n';
        }
        return 0;
    }
}

```

6.2 josephus

```

int josephus(int n, int k) {
    if (n == 1)
        return 0;
    if (k == 1)
        return n-1;
    if (k > n)
        return (josephus(n-1, k) + k) % n;
    int cnt = n / k;
    int res = josephus(n - cnt, k);
    res -= n % k;
    if (res < 0)
        res += n;
    else
        res += res / (k - 1);
    return res;
}

```

6.3 mt19937

```

#include <bits/stdc++.h>
using namespace std;
//Application of mt199937

const int N = 3000000;

double average_distance(const vector<int> &permutation) {
    double distance_sum = 0;

    for (int i = 0; i < N; i++)
        distance_sum += abs(permutation[i] - i);
}

```

```

mt19937 rng(chrono::steady_clock::now().time_since_epoch
().count());

return distance_sum / N;
}

int main() {
vector
<int> permutation(N);

for (int i = 0; i < N; i++)
    permutation[i] = i;

shuffle(permutation.begin(), permutation.end(), rng);
cout << average_distance(permutation) << '\n';

for (int i = 0; i < N; i++)
    permutation[i] = i;

for (int i = 1; i < N; i++)
    swap(permutation[i], permutation[
        uniform_int_distribution<int>(0, i)(rng)]);

cout << average_distance(permutation) << '\n';
}

```

6.4 pbds

```

#include <ext/pb_ds/assoc_container.hpp> // Common file
#include <ext/pb_ds/tree_policy.hpp>
#include <functional> // for less
#include <iostream>
using namespace __gnu_pbds;
using namespace std;

// a new data structure defined. Please refer below
// GNU link : https://goo.gl/WVDL6g
typedef tree<int, null_type, less<int>, rb_tree_tag,
    tree_order_statistics_node_update>
    new_data_set;

// Driver code
int main()
{
    new_data_set p;
    p.insert(5);
    p.insert(2);
    p.insert(6);

```

```

p.insert(4);

// value at 3rd index in sorted array.
cout << "The value at 3rd index ::"
    << *p.find_by_order(3) << endl;

// index of number 6
cout << "The index of number 6::"
    << p.order_of_key(6) << endl;

// number 7 not in the set but it will show the
// index number if it was there in sorted array.
cout << "The index of number seven ::"
    << p.order_of_key(7) << endl;

return 0;
}

```

7 Setup

7.1 C++Template

```

#pragma GCC optimize ("O3")
#pragma GCC target ("sse4")

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

#define fi first
#define se second
#define pb push_back

typedef long long LL;
typedef vector<int> vi;
typedef pair<int,int> ii;

const int MOD = 1e9 + 7;
const LL INF = 1e18;

void fastscan(int &number) {
    //variable to indicate sign of input number
    bool negative = false;
    register int c;
    number = 0;
    c = getchar();
    if (c=='-') {
        negative = true;
        c = getchar();
    }

```

```

}
for (; (c>47 && c<58); c=getchar())
    number = number *10 + c - 48;
if (negative)
    number *= -1;
}

/**
 * Description: Custom comparator for map / set
 * Source: StackOverflow
 * Verification: ?
 */
struct cmp {
    bool operator()(const int& l, const int& r) const {
        return l > r;
    }
};
set<int,cmp> s;

int main(){
    //ios_base::sync_with_stdio(0); cin.tie(0); cout.tie(0)

    return 0;
}

```

7.2 FastScanner

```

class FastScanner {
private:
    Inputstream stream;
    private byte[] buf = new byte[1024];
    private int curChar;
    private int numChars;

public:
    FastScanner(Inputstream stream) {
        this.stream = stream;
    }

    int read() {
        if (numChars == -1)
            throw new InputMismatchException();
        if (curChar >= numChars) {
            curChar = 0;
            try {
                numChars = stream.read(buf);
            } catch (IOException e) {
                throw new InputMismatchException();
            }
            if (numChars <= 0) return -1;
        }
    }
}

```

```

boolean isSpaceChar(int c) {
    return buf[curChar++];
}

return c' == ' || c' == '\n || c' == '\r || c' == '\t || c
    == -1;
}

public int nextInt() {
    return Integer.parseInt(next());
}

public long nextLong() {
    return Long.parseLong(next());
}

public double nextDouble() {
    return Double.parseDouble(next());
}

public String next() {
    int c = read();
    while (isSpaceChar(c)) c = read();
    StringBuilder res = new StringBuilder();
    do {
        res.appendCodePoint(c);
        c = read();
    } while (!isSpaceChar(c));
    return res.toString();
}

public String nextLine() {
    int c = read();
    while (isEndline(c))
        c = read();
    StringBuilder res = new StringBuilder();
    do {
        res.appendCodePoint(c);
        c = read();
    } while (!isEndline(c));
    return res.toString();
}
}

```

7.3 sublimesetup

```
{
```

```

"cmd": ["g++", "-std=c++11", "$file_name", "-o", "${
    file_base_name}.exe", "&&", "start", "cmd", "/k" , "
    $file_base_name"],
"selector": "source.cpp",
"file_regex": "^(..[^:]*):([0-9]+)?(?:[0-9]+)?(?:.*)$",
"working_dir": "${file_path}",
"shell": true
}

```

8 String

8.1 Hashing

```

/*use double hashing */

long long compute_hash(string const& s) {
    const int p = 31; //another good option : p = 53
    const int m = 1e9 + 9;
    long long hash_value = 0;
    long long p_pow = 1;
    for (char c : s) {
        hash_value = (hash_value + (c - 'a' + 1) * p_pow) % m
        ;
        p_pow = (p_pow * p) % m;
    }
    return hash_value;
}

```

8.2 KMP

```

#define HHH 10003

int ne[HHH]; // next[], if par[i] not matched, jump to i =
    ne[i]
int kmp(string& par, string& ori) {
    ne[0] = -1;
    for (int p = ne[0], i = 1; i < par.length(); i++) {
        while (p >= 0 && par[p+1] != par[i])
            p = ne[p];
        if (par[p+1] == par[i])
            p++;
        ne[i] = p;
    }

    int match = 0;
    for (int p = -1, q = 0; q < ori.length(); q++) {

```

```

        while (p >= 0 && par[p+1] != ori[q])
            p = ne[p];
        if (par[p+1] == ori[q])
            p++;
        if (p + 1 == par.length()) { // match!
            p = ne[p];
            match++;
        }
    }

    return match; // return number of occurrence
}

```

```

int main () {
    int n; cin >> n;
    string par, ori;
    while (cin >> par >> ori)
        cout << kmp(par, ori) << endl;
    return 0;
}

```

8.3 Manacher

```

int dp[HHH];
int lengthLongestPalindromSubstring(string& s) {
    memset(dp, 0, sizeof(dp));
    int ans = 0;
    int pivot = 1;
    int len = s.length() * 2; // _s0_s1_s2 = 2 * length
    for (int i = 1; i < len; i++) {
        int pBorder = pivot + dp[pivot];
        int iBorder = i;
        if (iBorder < pBorder && 2 * pivot - i > 0) {
            dp[i] = dp[2*pivot-i];
            iBorder = min(pBorder, i + dp[i]);
        }

        if (iBorder >= pBorder) {
            int j = iBorder + (iBorder % 2 ? 2 : 1);
            for (; j < len && 2*i-j > 0 && s[j/2] == s[(2*i-j)
                ]/2; j += 2)
                ;
            iBorder = j - 2;
            dp[i] = iBorder - i;
            pivot = i;
        }
        ans = max(ans, dp[i] + 1);
    }
}

```



```

    int n; cin >> n;
    return ans;
}

int main () {
    string
        s;
    while (cin >> s)
        cout << lengthLongestPalindromSubstring(s) << endl;
    return 0;
}

```

8.4 rabinkarp

/* Problem: Given two strings - a pattern s and a text t, determine if the pattern appears in the text and if it does, enumerate all its occurrences in $O(|s|+|t|)$ time.*/

```

vector<int> rabin_karp(string const& s, string const& t) {
    const int p = 31;
    const int m = 1e9 + 9;

```

```

    int S = s.size(), T = t.size();

    vector<long long> p_pow(max(S, T));
    p_pow[0] = 1;
    for (int i = 1; i < (int)p_pow.size(); i++)
        p_pow[i] = (p_pow[i-1] * p) % m;

    vector<long long> h(T + 1, 0);
    for (int i = 0; i < T; i++)
        h[i+1] = (h[i] + (t[i] - 'a' + 1) * p_pow[i]) % m;
    long long h_s = 0;
    for (int i = 0; i < S; i++)
        h_s = (h_s + (s[i] - 'a' + 1) * p_pow[i]) % m;

    vector<int> occurrences;
    for (int i = 0; i + S - 1 < T; i++) {
        long long cur_h = (h[i+S] + m - h[i]) % m;
        if (cur_h == h_s * p_pow[i] % m)
            occurrences.push_back(i);
    }
    return occurrences;
}

```

8.5 zAlgorithm

```

string s; cin >> s;
int L = 0, R = 0;
int n = s.size();
for (int i = 1; i < n; ++i) {
    if (i > R) {
        L = R = i;
        while (R < n && s[R] == s[R-L]) ++R;
        Z[i] = R-L; --R;
    }
    else {
        int k = i-L;
        if (Z[k] < R-i+1) Z[i] = Z[k];
        else {
            L = i;
            while (R < n && s[R] == s[R-L]) ++R;
            Z[i] = R-L; --R;
        }
    }
}
}

```